Exposure Assessment Modelling Approach to Off-Target Soil and Plants through Runoff from Agricultural Fields

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ABSTRACT

The objective of this study was to investigate the magnitude and likelihood of exposure of off-target plants to pesticide residues through runoff and drift from an agricultural field to an adjacent Plant Exposure Zone (PEZ). Screening level models will be compared to two vegetative filter models: PRZM-Buffer and VFSMOD. PRZM-Buffer is a modified version of the Pesticide Root Zone Model (PRZM), a rainfall-runoff simulation model, to simulate pesticide fate and transport in a PEZ. VFSMOD is a vegetative filter strip (VFS) model designed to simulate VFS processes to remove sediment and pesticides from field runoff/erosion. Current regulatory scenarios for PRZM were used to represent main field simulations. Movement of pesticide through the PEZ and the concentrations for the segments were modeled with the PRZM-Buffer model and VFSMOD. Results from these two models will be compared to each other and to screening level models. Multiple widths of buffers were assessed to determine distance required for soil concentrations to drop below level of concern for off-target terrestrial species.

Vegetated Filter Strip Models

The fate of a pesticide applied in the environment is governed by the complex interaction of numerous factors, including: the physicochemical characteristics of the pesticide, the agronomic practices related to the production of the crop and the use of the pesticide, the soil and hydrogeological conditions where the pesticide is used, and climatological conditions at the time of and following its use. Under label uses, residues have the potential to appear in areas adjacent to the treated field as the result of runoff, erosion, and/or spray drift. To estimate environmental concentrations of these residues to non-target crops and plants, simulation models were required that account for as many of these governing processes as possible.

TERRPLANT

TerrPlant was created by the Plant Technical Team and is used by the U.S. EPA Environmental Fate and Effects Division (EFED) as a Tier 1 model for screening level assessments of pesticides. The model is implemented in Microsoft Excel. The purpose of TerrPlant is to provide screening level estimates of exposure to terrestrial plants from single pesticide applications. The model does not consider exposures to plants from multiple pesticide applications. TerrPlant derives pesticide EECs in runoff and in drift. RQs are developed for non-listed and listed species of monocots and dicots inhabiting dry and semi-aquatic areas which are adjacent to treatment sites.TerrPlant incorporates two similar conceptual models for depicting dry and semi-aquatic areas of terrestrial habitats. For both models, a non-target area is adjacent to the target area. Pesticide exposures to plants in the non-target area are estimated to receive runoff and spray drift from the target area. For a dry area adjacent to the treatment area, runoff exposure is estimated as sheet runoff. Sheet runoff is the amount of pesticide in water that runs off of the soil surface of a target area of land which is equal in size to the non-target area (1:1 ratio of areas). For semi-aquatic areas, runoff exposure is estimated as channel runoff. Channel runoff is the amount of pesticide that runs off of a target area 10 times the size of the non-target area (10:1 ratio of areas). Exposures through runoff and spray drift are then compared to measures of survival and growth (e.g. effects to seedling emergence and vegetative vigor) to develop RQ values.

Provisional AUDREY III

Audrey III is based on a new conceptual model and uses PRZM 5 to estimate runoff of a treated onto a Plant Exposure Zone (PEZ) where it is combined with loading from spray drift. Loading from runoff is limited by the capacity of the PEZ to retain water and the width of the PEZ is limited to the area that can reasonably be assumed to maintain distributed overland flow. For this assessment, this width was assumed to be 30 m The current, U.S. EPA provisional version of Audrey III is run in a spreadsheet. The runoff volume, and the mass of pesticide carried with the runoff, and on eroded sediment are taken from the 'ZTS' file which is output from PRZM. PRZM version 5.0+ is run in the Pesticide Water Calculator (version 1.52), a shell that is used to manage input and output and run PRZM and Variable Volume Waterbody Model (VVWM). The VVWM component of PWC is not used by Audrey III. Spray drift curves are the same as those in the AgDRIFT model and have been imbedded in the Audrey III spreadsheet. These curves assume that the wind was blowing at 10 mph directly towards the PEZ during application of the pesticide.

WINPRZM BUFFER (WPB II)

The down gradient compartment in WinPRZM (buffer) was originally added to evaluate the effectiveness of vegetative filter strips in reducing runoff, pesticide runoff flux, and pesticide erosion flux. Pesticide deposition and transport across the effective area of a filter strip is a function of the width of the buffer; vegetation cover (e.g., untreated crop, trees with underbrush, or grasses); slope; and storm intensity. The filter strip is essentially represented as another PRZM simulation(s) that receives time-series boundary condition file of chemical and water loadings generated by the simulation of the treated field.

VFSMOD

VFSMOD (v4.2.4 04/2014), a vegetative filter strip (VFS) model designed to simulate VFS processes to remove sediment and other pollutants from surface water runoff (Muñoz-Carpena and Parsons 2010; Muñoz-Carpena et al. 2007; Sabbagh et al. 2009). It is a field scale, mechanistic, storm-based model that was designed to route the incoming runoff volume and sediment from an adjacent field through a VFS (Muñoz-Carpena and Parsons 2010). The model has been successfully validated to field experiments with the Nash-Sutcliffe coefficient of efficiency ranging from 0.7 to 0.9 between the model prediction and the measured data for infiltration, outflow and trapping of particles and pesticides (Abu-Zreig 2001; Fox et al. 2010; Pérez-Ovilla 2010; Poletika et al. 2009; Sabbagh et al. 2009). Also, the effectiveness of a properly maintained VFS has been published and has demonstrated a reduction in runoff and erosion loading into nearby water bodies (Abu-Zreig 2001; Fox et al. 2010; Sabbagh et al. 2009).

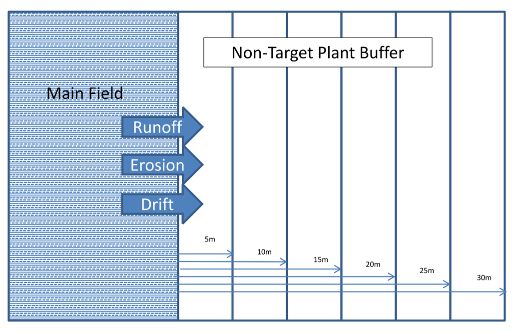
Table 1. Audrey III, WPB, and VFSMOD Input Parameters		
PRZM Kansas Corn Scenario, Generic Chemical		
Soil degration half-life	216	d
Foliar dissipation half-life	35	d
Foliar washoff coefficient	0.5	cm^{-1}
Kd	0.609	L/kg
Application Method	Aerial, Very Fine to Fine	
Buffer setback	0	m
Hydrology Parameters		
Field capacity	0.086	cm^3/cm^3
Wilting point	0.036	cm^3/cm^3
Available water capacity	0.05	cm^3/cm^3
SCS Curve Number	86	
SCS S value	1.63	
Bulk density	1.44	kg/L
Soil mass	2049155.92	kg
Geometry Parameters		
Sheetflow zone width	30	m
Side length of field	316.23	m
Exposure zone depth	15	cm
PEZ area	9486.83	m^2
PEZ volume	1423.02	m^3
PEZ water capacity	71.15	m^3

Drift Fractions

Buffer Section	Fraction	Buffer Section	Fraction
1	0.486	16	0.299
2	0.458	17	0.292
3	0.434	18	0.286
4	0.415	19	0.281
5	0.398	20	0.276
6	0.384	21	0.272
7	0.373	22	0.268
8	0.362	23	0.265
9	0.353	24	0.26
10	0.345	25	0.256
11	0.337	26	0.25
12	0.33	27	0.245
13	0.322	28	0.239
14	0.314	29	0.234
15	0.307	30	0.229

Model Setup

INPUTS: The inputs required for Terrplant are minimal and are shown in F1. Inputs required for Audrey, WPB, and VFSMOD are quite similar (Table 1) with the exception of hydrology in VFSMOD. Audrey and WPB are based on Curve Number hydrology whereas VFSMOD is based on Richards Eq Infiltration. Additionally, they all are using the same main field loadings from PRZM 5+(time series output).
OUTPUTS: TerrPlant produces a single event output based on assumed drift and runoff masses into the buffer area. The other three models produce daily results for drift loads and runoff/erosion loads onto the buffer (below).The drift loads are derived from agdrift (Table 1).
ENDPOINTS: The endpoints necessary to produce non-target EECs are the combined foliar mass loadings from drift and the soil concentration in the top 15 cm. At this time VFSMOD only produces total soil mass rather than top 15 cm.



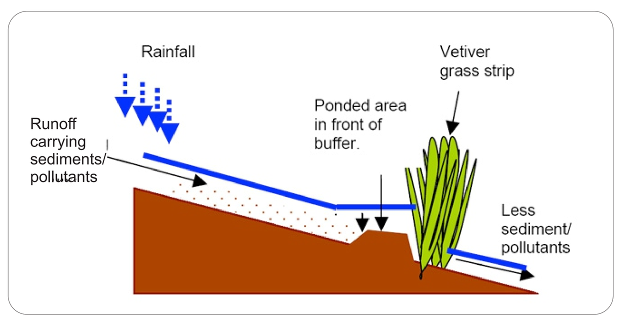
(F1)

TerrPlant Tier I Assessment

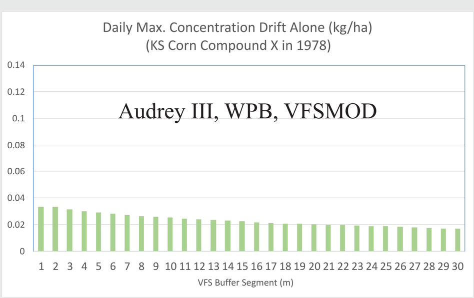
Table 2. Input parameters used to derive EECs.			
Input Parameter	**Symbol**	**Value (user inputs)**	**Units**
Application Rate	A	0.079	lb ai/a
Incorporation	I	1	none
Runoff Fraction	R	0.05	none
Drift Fraction	D	0.05	none

Table 3. EECs for Compound X. Units in lb ai/a.		
Description	**Equation**	**EEC**
Runoff to dry areas	(A/I)*R	0.00395
Runoff to semi-aquatic areas	(A/I)*R*10	0.0395
Spray drift	**A*D**	**0.00395**
Total for dry areas	**((A/I)*R)+(A*D)**	**0.0079**
Total for semi-aquatic areas	**((A/I)*R*10)+(A*D)**	**0.04345**

(F2)



(F3)



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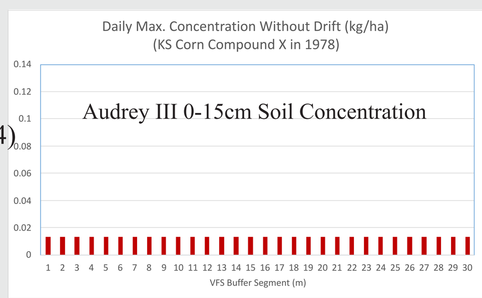

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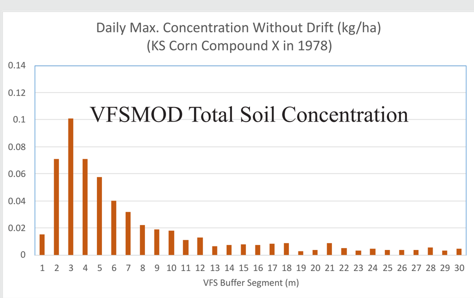

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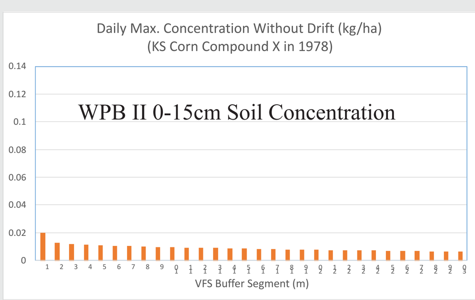

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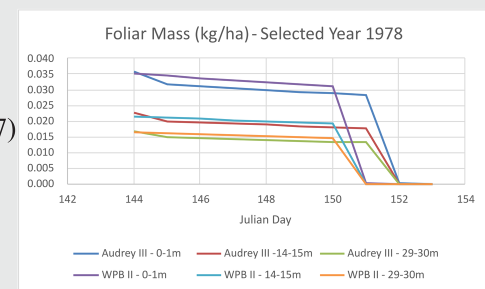
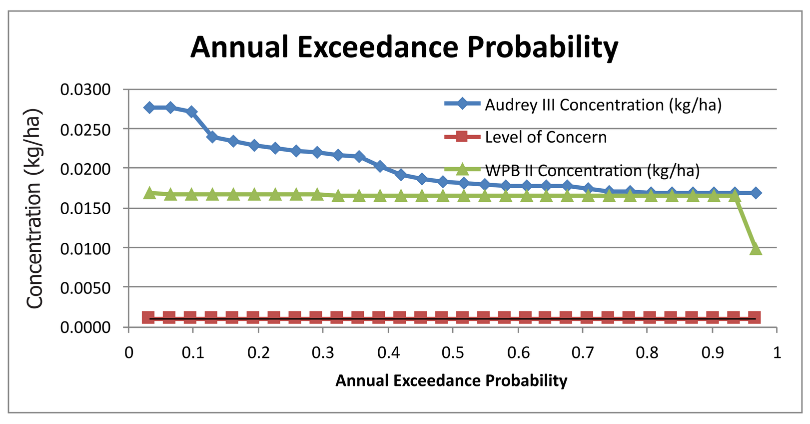
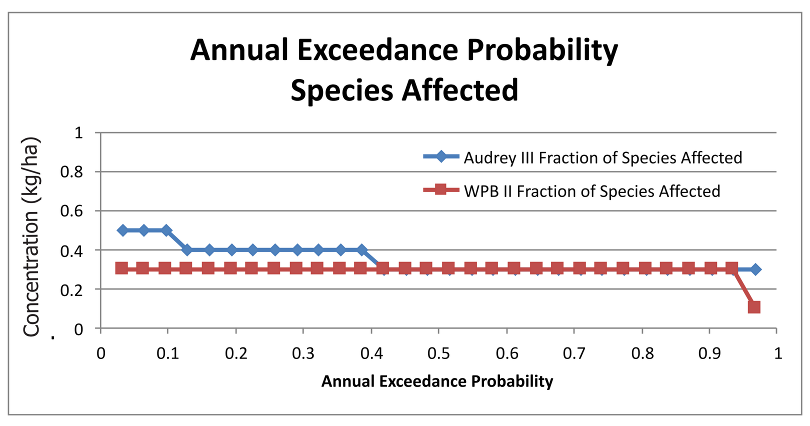


(F8)

Species	Affected	EEC Level (kg/ha)
corn	biomass	0.05943
cucumber	biomass	0.01177
oat	height	0.03689
oilseed rape	height	0.00998
onion	height	0.05999
pea	none	0.05831
sorghum	biomass	0.00107
soybean	biomass	0.04687
sugar beet	biomass	0.02523
tomato	biomass	0.02007





Results and Discussion

The drift onto foliage for all 3 models are the same as shown in F3. However, infiltrated mass are quite different between the 3 models (F4-F6). Audrey uniformly distributes the infiltrated mass across the buffer. WPB and VFSMOD attempt to add pseudo 2 dimensionality of runoff infiltration as it travels across the buffer. Logically this makes sense since more mass from drift is loaded onto foliage nearer to the main field and runoff as it travels along the buffer may not reach the far end of the buffer thus lowering the soil concentration. However, it is a bit tricky to convert 1-dimensional models to pseudo 2- dimensional with mathematical veracity. WPB II and Audrey soil concentration patterns are quite similar (F4 vs. F6) with WPB 0-1 meter higher and 29-30m about about half of Audrey. As mentioned previously it is a bit difficult to directly compare VSFMOD soil concentrations as it only provides total soil concentration. But the pattern is still distinctly different. VFSMOD's consideration of a retarding barrier (F2) of water entering buffer leads to greatly enhanced infiltration at the boundary area between the main field and buffer. One thing to note about the about the drift load onto foliage is that the foliage only experiences the load for a short period of time, 8 days (F7), due to washoff and foliar degradation. Audrey III and WPB II do show some differences in EECs and affected species probabilities (F9-F10). WPB II did not show increased exposure above spray drift loads since the maximum soil concentrations did not co-occur with maximum drift events. Further investigation is needed to fully understand the differences between the two models but is most likely related to how foliar washoff is handled relative to infiltration into soil and addition to the runoff water. VFSMOD was not compared due to te difference in how soil concentration is currently predicted.

Conclusions and Recommendations

Testing different models and their approaches provides a useful comparison on how sensitive certain model assumptions are to the predicted endpoints. In this case soil concentration differences from how runoff water and foliar washoff within the buffer are modelled. VFSMOD would need to be reconfigured to output 15 cm soil concentrations so further comparisons between all 3 models can be confirmed.