

SPOTMOD - Case studies for refining edge-of-field exposure following precision application using real application maps

Rafael Muñoz-Carpena¹, Jorge Olivares-Rivas², Stefan Reichenberger³, Tyler J. Schultz¹, Robin Sur⁴

¹ University of Florida, Gainesville, FL, USA

² knoell Germany GmbH, Mannheim, Germany

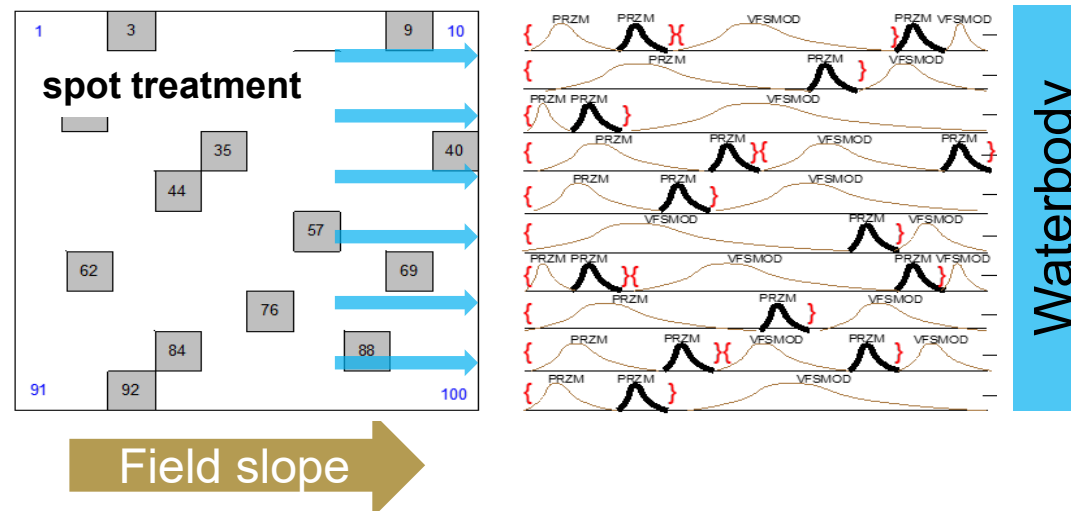
³ knoell France SAS, Lyon, France

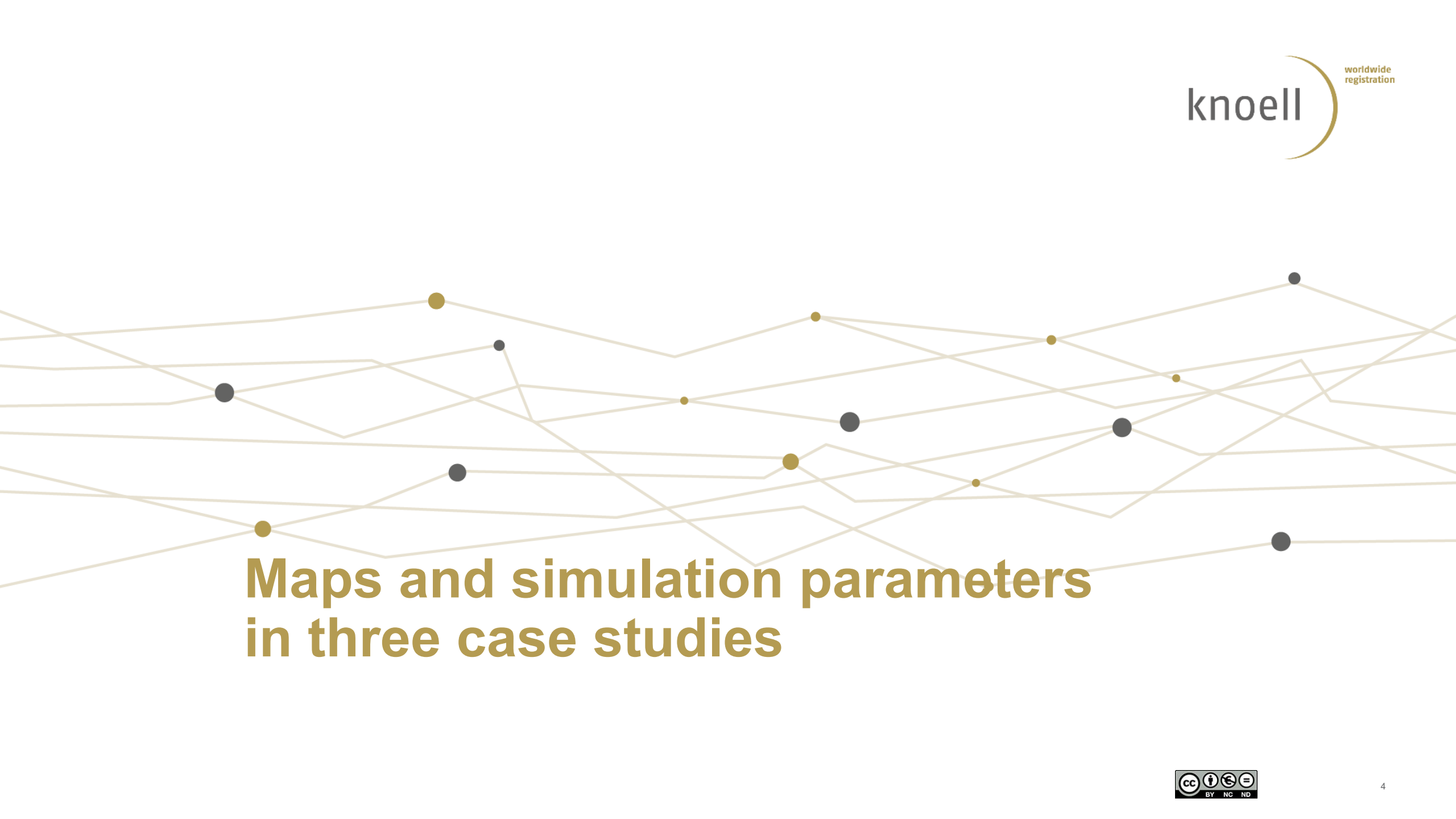
⁴ Bayer AG, Monheim, Germany

Session III - XVIII Symposium in Pesticide Chemistry,
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Introduction and objectives

- The technical development of SPOTMOD was explained in the previous talk
- This talk asks the question: **how could regulatory processes consider spot application as a mitigation strategy for pesticide runoff?**
- Three distinct case studies quantifying pesticide runoff input into field-adjacent waterbodies following precision application on three maps were conducted

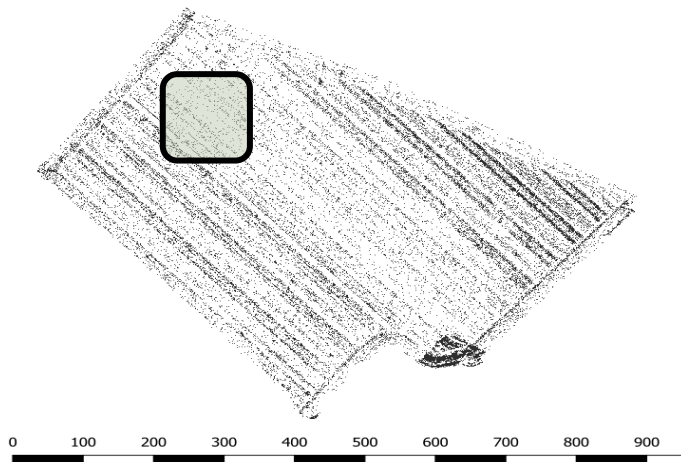




Maps and simulation parameters in three case studies

- The main difference between the three case studies is the field infestation and weed distribution used for each simulation

1-hectare maps of thistles from sugar beet fields in France



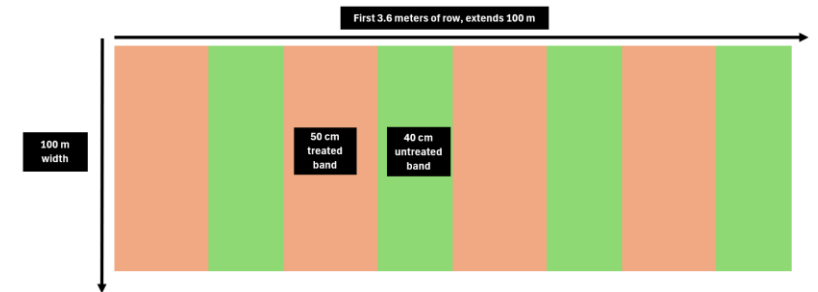
Thistles in sugar beets in France (source: Corteva Agriscience; de Cirugeda Helle and Guth, 2024)

12-hectare map of weeds from soybean fields in Ohio



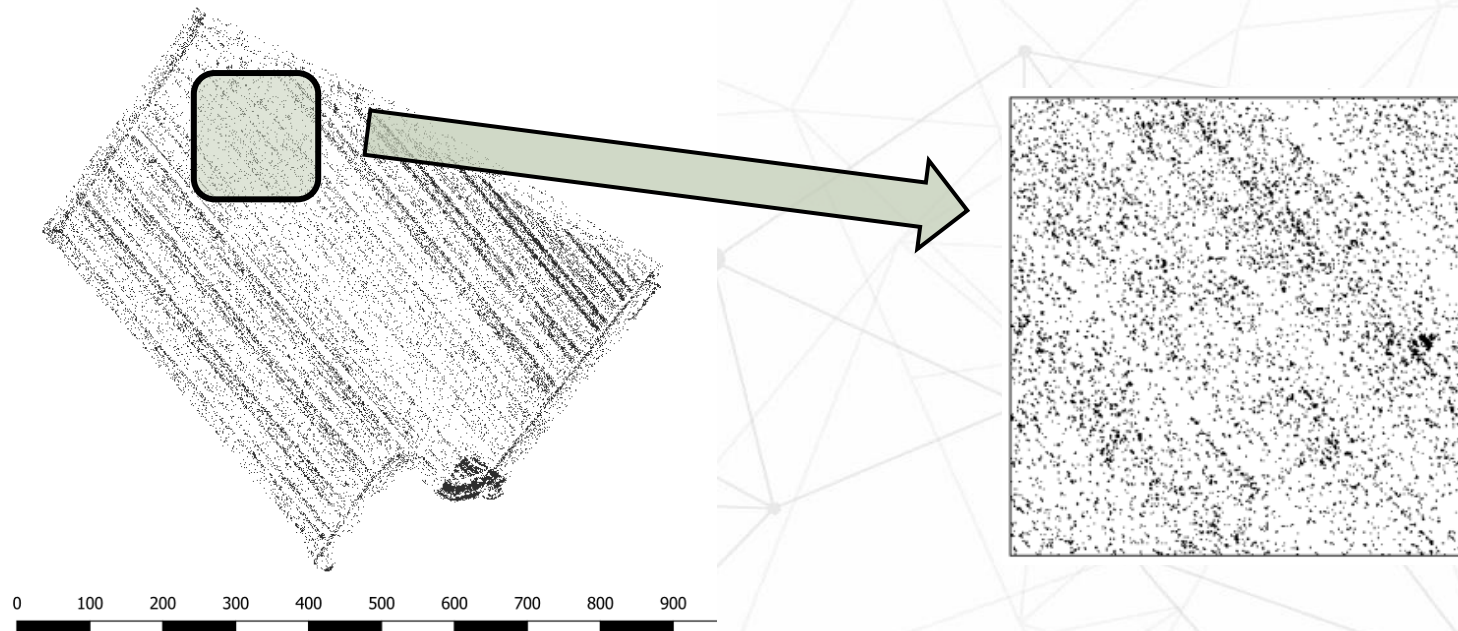
Herbicide application in soybean fields in Ohio (source: Oklahoma State University, 2025)

1-hectare map of an artificial band application pattern



Map generation - Case Study 1

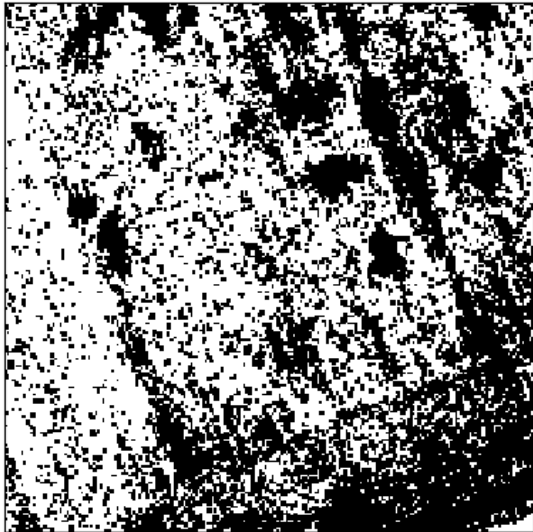
- A total of 2057 one-hectare tiles were extracted from 26 of the 38 provided field maps with GIS



Example of real weed maps (thistles in sugar beet) obtained with tractor-mounted cameras from field sites in France (source: Corteva Agriscience; de Cirugeda Helle and Guth, 2024)

- To investigate the effect of weed distribution on the PEC_{SW} , the following three tiles were selected for Case Study 1 (waterbody is to the right of each tile)

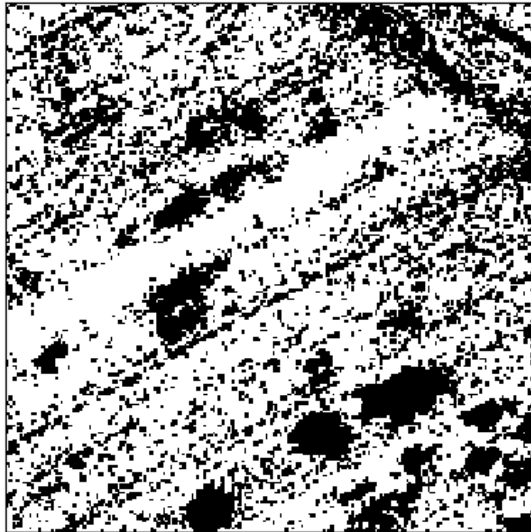
45 cm spot size. Treated rate: 46%



Waterbody

Treated field edge

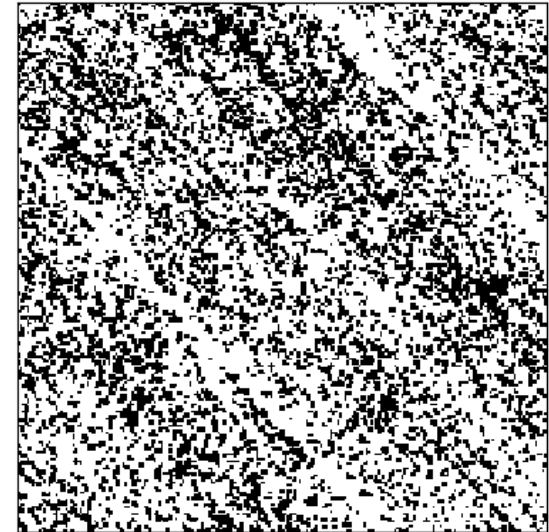
45 cm spot size. Treated rate: 34%



Waterbody

Patchy distribution

45 cm spot size. Treated rate: 36%

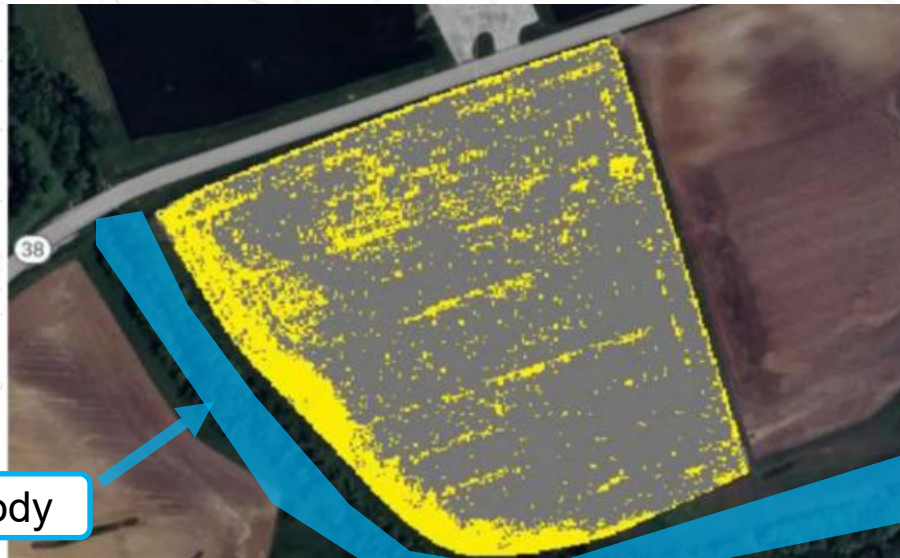


Waterbody

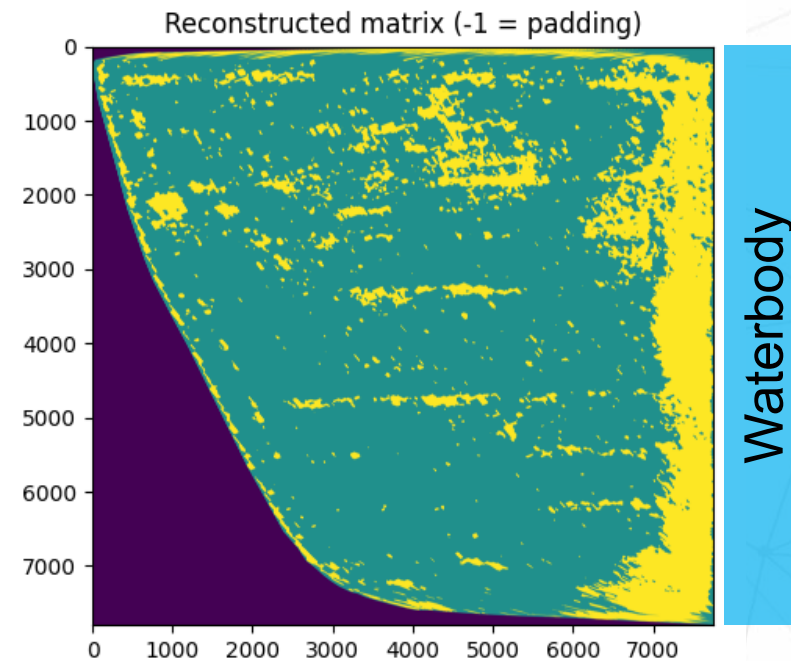
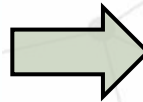
Random / scattered
distribution

Map generation - Case Study 2

- The 12-hectare map of herbicide application on weeds in soybean fields in Ohio (shared by Oklahoma State University) was converted into a matrix and rotated to match the requirements for a SPOTMOD simulation (flow from left to right)



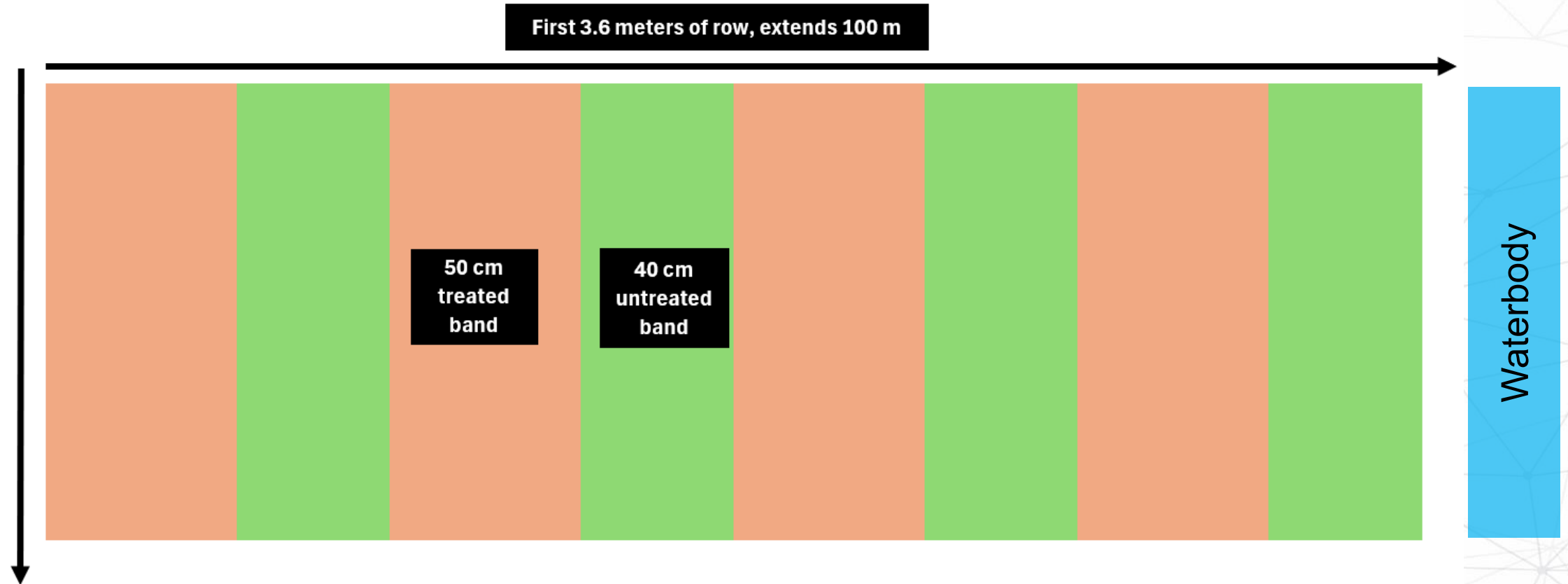
Spray application map on soybean fields in Ohio (source: Oklahoma State University, 2025)



Row-based map derived from the field data, considering both treated (yellow) and untreated (blue) areas

Map generation - Case Study 3

- An abstract row was created for this simulation assuming an intercalating pattern of 50 cm treated bands and 40 cm untreated bands over 100 meters (waterbody is to the right of the field)



- The following settings were used in each simulation

Remark	Case study 1 – Thistles	Case study 2 – Weeds	Case study 3 – Band application
Substance	Two dummy substances: 1: 10 d soil DT ₅₀ , 10 L/kg K _{Foc} 2: 100 d soil DT ₅₀ , 1000 L/kg K _{Foc}	Existing approved herbicide: 12 d soil DT ₅₀ , 70 L/kg K _{Foc}	Existing approved herbicide: 12 d soil DT ₅₀ , 70 L/kg K _{Foc}
Crop	Sugar beets	Sugar beets	Sugar beets
FOCUS Scenario	R1	R1	R1
Application timing	1 day after emergence	1 day after emergence	1 day after emergence
Number of maps	3	1	1
Spot size [cm]	45 × 45 65 × 65 85 × 85	25 × 25	5 × 5

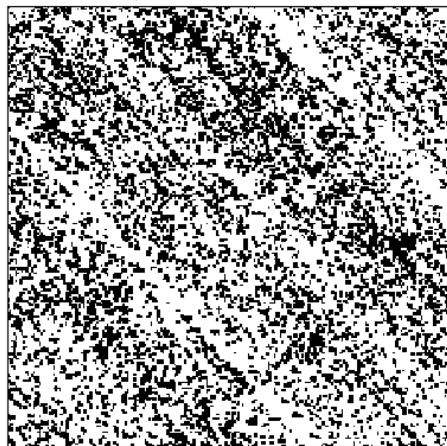
- The results of all SPOTMOD simulations were normalized to a 1-hectare field (in alignment with FOCUS SW)
- A standard FOCUS PRZM SW simulation was performed assuming broadcast application with the same soil / scenario / substance properties for each case study
- The runoff and pesticide outflow calculated by FOCUS PRZM and SPOTMOD were passed on to a TOXSWA stream metamodel (Adriaanse et al., 2017)
- 20 years are simulated by PRZM in FOCUS, but only the 50th percentile year is used for evaluation
 - The year selected for evaluation in FOCUS was selected in SPOTMOD too (unless otherwise specified)
- The PEC_{sw} obtained by SPOTMOD is compared to the PEC_{sw} obtained by PRZM after being linearly reduced by the treated area

$$PRZM_{scaled} = PRZM_{broadcast} * Treated Area (\%)$$

Results

Case Study 1 – Random distribution

45 cm spot size. Treated rate: 36%



Spot size [cm]	Treated area [%]	PEC _{sw} [µg/L] - Substance 1			PEC _{sw} [µg/L] – Substance 2		
		PRZM _{scaled}	SPOTMOD	Reduction eff. [%]	PRZM _{scaled}	SPOTMOD	Reduction eff. [%]
45	36	4.51	1.38	69	0.425	0.157	63
65	49	6.18	2.11	66	0.582	0.239	59
85	62	7.75	3.04	61	0.730	0.343	53

Substances

S1: 10 d DT_{50,soil},
10 L/kg K_{Foc}

S2: 100 d DT_{50,soil},
1000 L/kg K_{Foc}

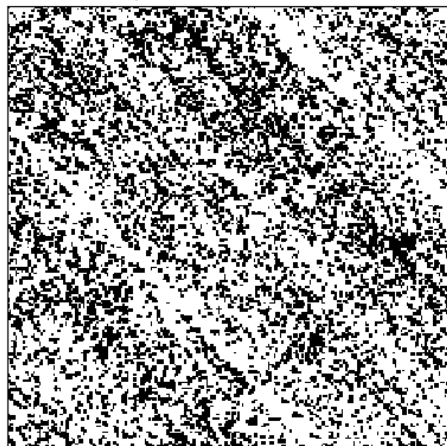
$$\text{Reduction efficiency (\%)} = \frac{\text{PRZM}_{\text{scaled}} - \text{SPOT}}{\text{PRZM}_{\text{scaled}}} * 100$$

Case Study 1 – Random distribution

knoell

worldwide
registration

45 cm spot size. Treated rate: 36%



Spot size [cm]	Treated area [%]	PEC _{sw} [µg/L] - Substance 1			PEC _{sw} [µg/L] - Substance 2		
		PRZM _{scaled}	SPOTMOD	Reduction eff. [%]	PRZM _{scaled}	SPOTMOD	Reduction eff. [%]
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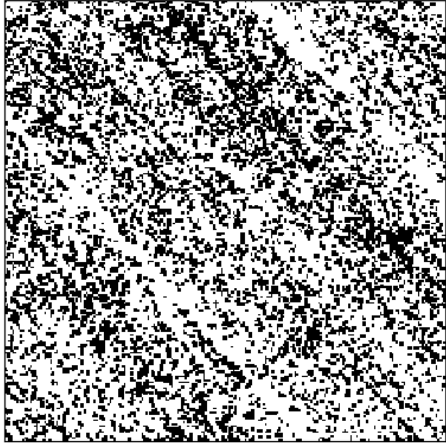
S2: 100 d DT_{50,soil},
1000 L/kg K_{Foc}

Trend 1

In all simulations and models, PEC_{sw} is roughly 10 times higher for Substance 1 than Substance 2 (mainly due to lower sorption)

Case Study 1 – Random distribution

45 cm spot size. Treated rate: 36%



Substances

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Trend 2

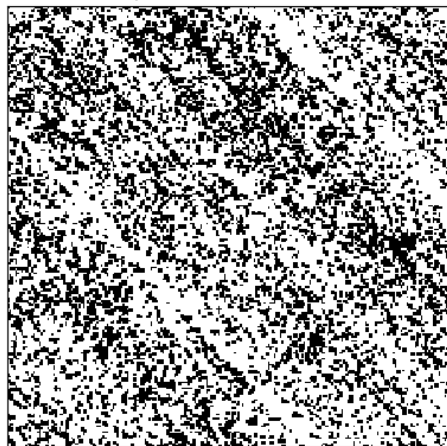
Treated rate increases with spot size.

In PRZM, the PEC is scaled considering the treated area, so the change is linear.

In SPOTMOD, the change is almost linear at this range...

Case Study 1 – Random distribution

45 cm spot size. Treated rate: 36%



Substances

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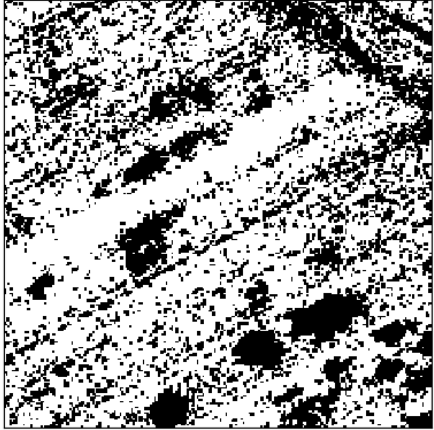
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45	36	4.51	1.38	69			
65	49	6.18	2.11	66			
85	62	7.75	3.04	61			

Trend 2

However, at a treated rate of 100%,
the reduction factor would become
0%.

Case Study 1 – Patchy distribution

45 cm spot size. Treated rate: 34%



Substances

S1: 10 d $DT_{50,soil}$,
10 L/kg K_{Foc}

S2: 100 d $DT_{50,soil}$,
1000 L/kg K_{Foc}

Spot size [cm]	Treated area [%]	PEC _{sw} [µg/L] - Substance 1			PEC _{sw} [µg/L] – Substance 2		
		PRZM _{scaled}	SPOTMOD	Reduction eff. [%]	PRZM _{scaled}	SPOTMOD	Reduction eff. [%]
45	34	4.34	1.66	62	0.409	0.187	54
65	45	5.65	2.32	59	0.532	0.260	51
85	55	6.87	3.04	56	0.647	0.340	47

$$Reduction\ efficiency\ (\%) = \frac{PRZM_{scaled} - SPOT}{PRZM_{scaled}} * 100$$

Case Study 1 – Treated field edge

45 cm spot size. Treated rate: 46%



Spot size [cm]	Treated area [%]	PEC _{sw} [µg/L] - Substance 1			PEC _{sw} [µg/L] – Substance 2		
		PRZM _{scaled}	SPOTMOD	Reduction eff. [%]	PRZM _{scaled}	SPOTMOD	Reduction eff. [%]
45	46	5.81	2.90	50	0.547	0.325	41
65	57	7.13	3.86	46	0.671	0.430	36
85	66	8.28	4.86	41	0.780	0.540	31

Substances

S1: 10 d DT_{50,soil},
10 L/kg K_{Foc}

S2: 100 d DT_{50,soil},
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$$\text{Reduction efficiency (\%)} = \frac{\text{PRZM}_{\text{scaled}} - \text{SPOT}}{\text{PRZM}_{\text{scaled}}} * 100$$

Case Study 1 – Impact of weed distribution

Results from Substance 1	Random distribution		Patchy distribution		Treated field edge		
	Spot size [cm]	Treated area [%]	Reduction efficiency [%]	Treated area [%]	Reduction factor [%]	Treated area [%]	Reduction efficiency [%]
	45	36	69	34	62	46	50
	65	49	66	45	59	57	46
	85	62	61	55	56	66	41
Trend 3 The different treated rates make it tricky to distinguish the effect							

Trend 3

The different treated rates make it tricky to distinguish the effect of the map on the results; but the reduction factors are consistently higher for more random maps.

Case Study 1 – Impact of map

Results from Substance 1	Random distribution		Patchy distribution		Treated field edge	
Spot size [cm]	Treated area [%]	Reduction efficiency [%]	Treated area [%]	Reduction factor [%]	Treated area [%]	Reduction efficiency [%]
45	36	69	34	62	46	50
65	Trend 3 This is most evident at the largest spot size. Despite similar treatment rates for the random distribution and treated field edge, the random distribution has a much higher reduction factor due to the distribution of the herbicide.					
85	62	61	55	56	66	41

Trend 3

This is most evident at the largest spot size. Despite similar treatment rates for the random distribution and treated field edge, the random distribution has a much higher reduction factor due to the distribution of the herbicide.

Case Study 2

Year	PRZM _{scaled} PEC _{sw} [µg/L]	SPOTMOD PEC _{sw} [µg/L]	Reduction eff. [%]
1975	0.012	0.003	72.5
1976	0.365	0.114	68.7
1977	0.001	0.001	42.2
1978	0.152	0.069	54.4
1979	0.001	0.001	54.9
1980	0.322	0.153	52.5
1981	0.346	0.178	48.5
1982	0.170	0.072	57.6
1983	0.032	0.011	66.0
1984	0.048	0.023	51.4
1985	0.023	0.006	72.8
1986	0.148	0.046	69.0
1987	0.099	0.036	64.0
1988	0.005	0.002	66.5
1989	0.012	0.003	76.6
1990	0.001	<0.001	46.0
1991	0.001	<0.001	54.5
1992	0.007	0.005	33.5
1993	0.120	0.043	64.5
1994	0.037	0.019	49.3
Minimum	0.001	<0.001	33.5
Maximum	0.365	0.178	76.6
90th percentile	0.324	0.118	45.6 *
Average	0.095	0.039	58.3

Reduction eff. (%) =

$$\frac{PRZM_{scaled} - SPOT}{PRZM_{scaled}} * 100$$

FOCUS evaluation year

* 10th percentile reduction factor covers 90th percentile of cases

Case Study 2

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FOCUS evaluation year

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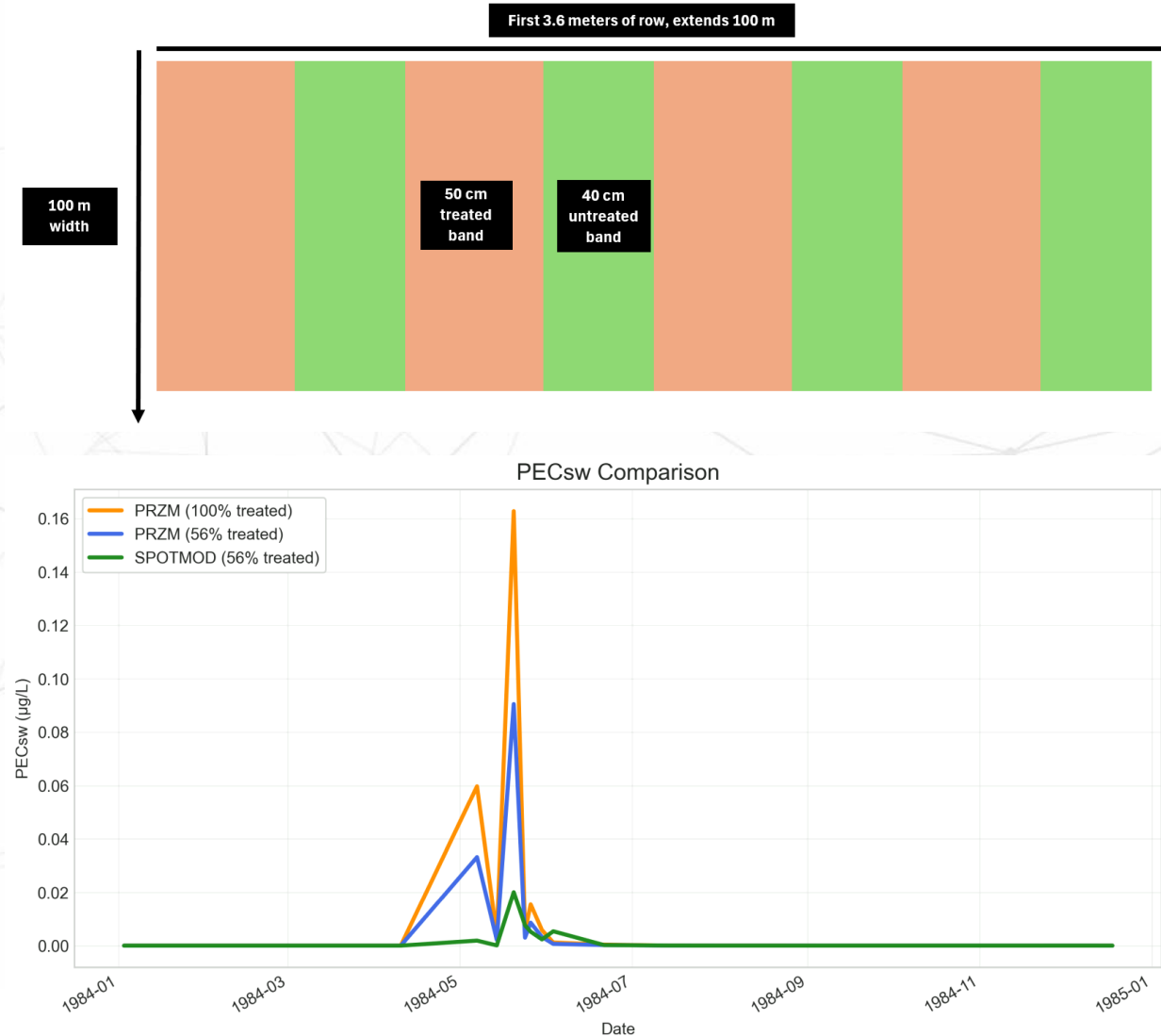
Case Study 2

- Reduction factors range from 33.5% to 76.6%
- The average and the evaluation year reduction factors are very close (56.3% vs 51.4%)
- On the year selected by FOCUS for evaluation (1984), a reduction factor of 51.4% is obtained by SPOTMOD
- However, a percentile of the reduction factor from the 20 years could be used to conservatively cover most years



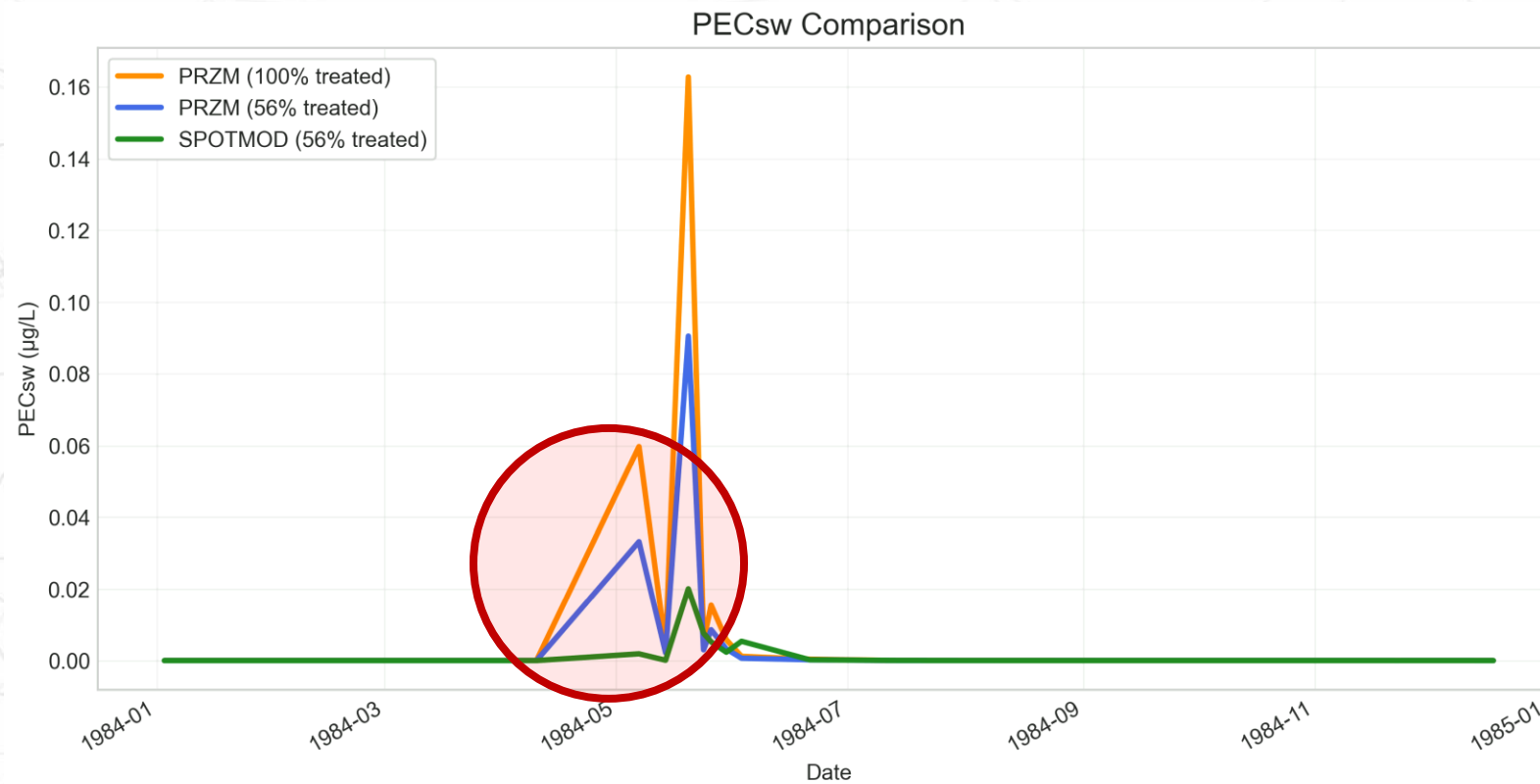
Case Study 3

- The treated rate in the field is 55.6%
- A reduction factor of 78% is obtained for this simulation in the FOCUS evaluation year
- As desired, the PRZM and SPOTMOD hydrology proved to be very consistent for this simulation
 - $R^2 = 0.948$
 - $NSE = 0.944$
 - $PBIAS = -4\%$ runoff volume



Case Study 3

- The time series shows that SPOTMOD does not yield pesticide flux in one of the PEC peaks simulated by PRZM



Case Study 3

- This occurs even though there is a good hydrological match between the models

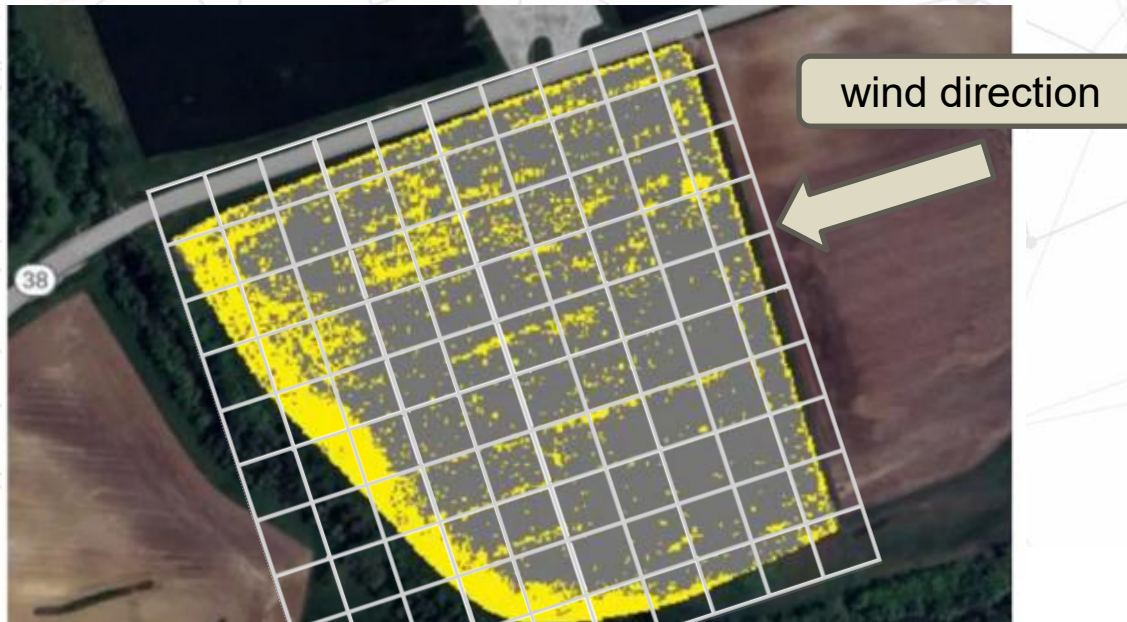


- VFSSMOD is a mechanistic model and PRZM is an empirical model, so while the runoff is simulated exceptionally well over the 20-year period, there may be differences in transport, degradation and remobilization processes in some important events that are simulated in a more physically consistent way by SPOTMOD
- Although this peak does not result in the max PEC of that year, it highlights the danger of bias when considering individual years
- To account for this, the SPOTMOD metamodel will use multiple maps and 20-year simulations for each set of parameters.
 - A given percentile of the resulting values will reduce the influence of any individual year/event.

Discussion

- **Standard TOXSWA assessment using a reduction factor based on a set of representative simulation parameters**
 - Reduction factors are used straightforwardly in FOCUS Step 4 simulations
 - For example, a 10-meter VFS corresponds to a runoff/erosion reduction of 60/80%
 - To consider the mitigation of spot applications, a reduction factor could be taken from the SPOTMOD metamodel to cover the intended simulation parameters
 - The calculated reduction factor could be used to mitigate runoff / erosion flux entries into TOXSWA while keeping the runoff / erosion volumes unchanged
- **Refined TOXSWA assessment using a time series calculated with SPOTMOD**
 - Instead of using a constant reduction factor over the entire simulation period, the time series calculated by SPOTMOD could be used as an input to TOXSWA to have event-specific mitigations
- **Metamodel calculations**
 - SPOTMOD has a built-in TOXSWA metamodel (Adriaanse et al., 2017) that calculates PEC_{sw}

- A FOCUS surface water assessment for a runoff scenario considers both drift and runoff entries
- This presentation has focused on runoff; however, other working groups* are developing methods to estimate drift entries from precision application methods
- Drift and runoff entries could either be considered together in the TOXSWA metamodel (Adriaanse et al., 2017) or used as inputs for a FOCUS TOXSWA simulation



*For example, “Spray Drift from Banded and Regular Spot Application” talk by Michael Bird at 9:00 am

Many thanks to Olivier de Cirugeda Helle, Vincent Guth and Anne Alix from Corteva Agriscience, and to Amanda Douridas and Nathan Douridas from Oklahoma State University for providing the observed weed maps!

Rafael Muñoz-Carpena acknowledges support from USDA National Institute of Food and Agriculture (NIFA) Hatch projects 1028045 and 1024706, and the UF High-Performance computer (HiperGator).

- Hunze, E., Beneke, F., FARMERSPACE
- Corteva Agriscience; de Cirugeda Helle and Guth, 2024
- Adriaanse, Paulien I., Van Leerdam, Robert C., and Boesten, Jos JTI. The effect of the runoff size on the pesticide concentration in runoff water and in FOCUS streams simulated by PRZM and TOXSWA. *Science of the Total Environment* 584 (2017). doi: 10.1016/j.scitotenv.2016.12.001
- Muñoz-Carpena, R., Parsons, J.E., and Gilliam, J.W. 1999. Modeling hydrology and sediment transport in vegetative filter strips. *Journal of Hydrology* 214(1-4):111-129. doi: 10.1016/S0022-1694(98)00272
- Muñoz-Carpena, R., Ritter, A., Fox, G. 2019. Comparison of empirical and mechanistic equations for vegetative filter strip pesticide mitigation in long-term environmental exposure assessments. *Water Research* 165:1149833. doi:10.1016/j.watres.2019.114983

Many thanks for your attention!

Supplementary slides

	Case study 1	Case study 2	Case study 3
Map	Distribution of <u>thistles in sugar beet fields in France</u> obtained with tractor-mounted cameras	Distribution of <u>weeds in a soybean field in Ohio</u> obtained by a tractor with precision application technology	Abstract map based on <u>band patterns used in real fields</u> and existing regulatory processes (sugar beets)
Source	Corteva Agriscience; de Cirugeda Helle and Guth, 2024	Oklahoma State University, 2025	Not applicable
Map size	1 hectare (the original maps are of varying sizes, 1-hectare tiles were selected with GIS in alignment with FOCUS SW calculations)	12.4 hectares	1 hectare
Number of maps	3 (out of 2057 created tiles)	1	1

Case Study 1 – Impact of map

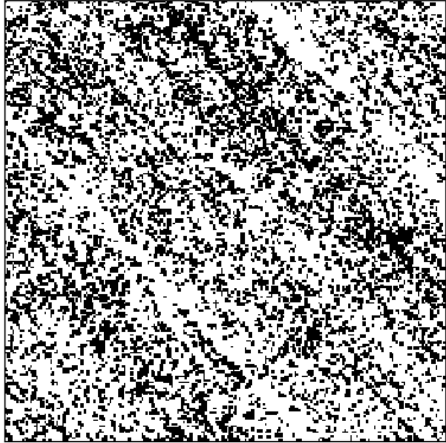
Results from Substance 1

Spot Size [cm]	Treated Rate [%]	Random map			Patchy map			Outflow loaded map		
		PRZM	SPOTMOD	Reduction factor (%)	PRZM	SPOTMOD	Reduction factor (%)	PRZM	SPOTMOD	Reduction factor (%)
45	36 / 34 / 46	4.51	1.38	69	4.34	1.66	62	5.81	2.90	50
65	49 / 45 / 57	6.18	2.11	66	5.65	2.32	59	7.13	3.86	46
85	62 / 55 / 66	7.75	3.04	61	6.87	3.04	56	8.28	4.86	41

Case Study 1 – Random distribution

knoell

45 cm spot size. Treated rate: 36%

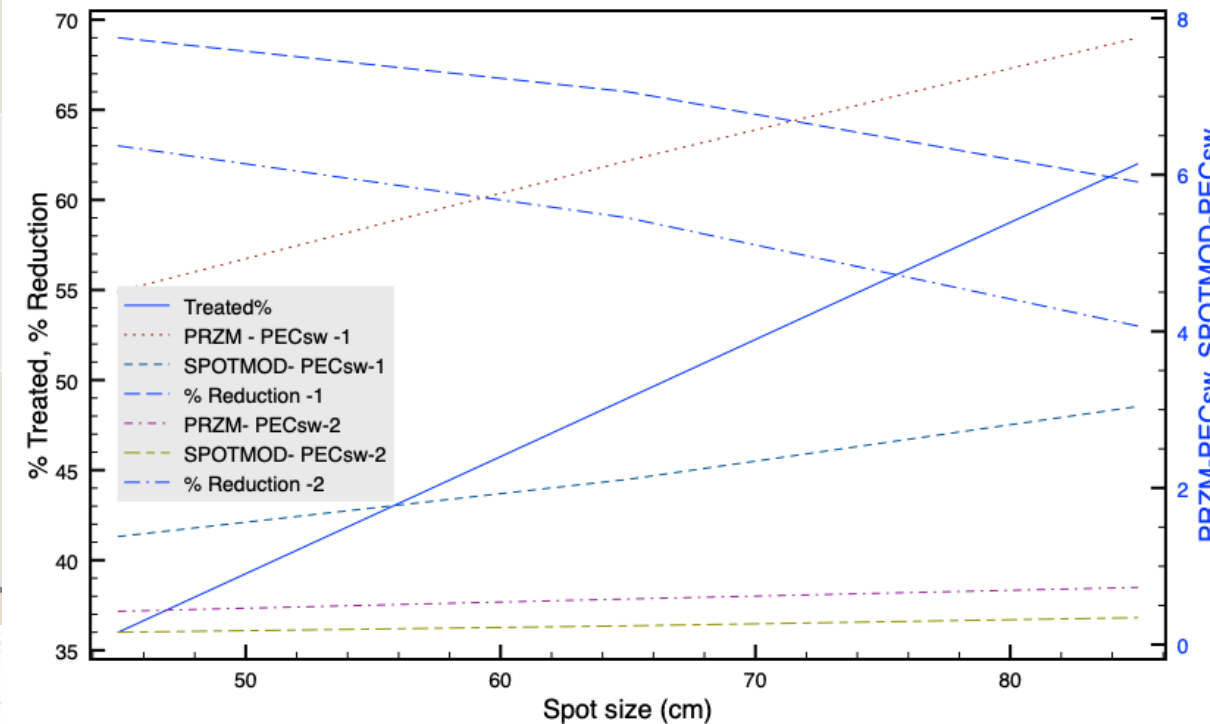


Substances

S1: 10 d $DT_{50,soil}$,
10 L/kg K_{Foc}

S2: 100 d $DT_{50,soil}$,
1000 L/kg K_{Foc}

Spot size [cm]	Treated area [%]	PEC _{sw} [µg/L] - Substance 1			PEC _{sw} [µg/L] - Substance 2		
		PRZM	SPOTMOD	Reduction factor [%]	PRZM	SPOTMOD	Reduction factor [%]
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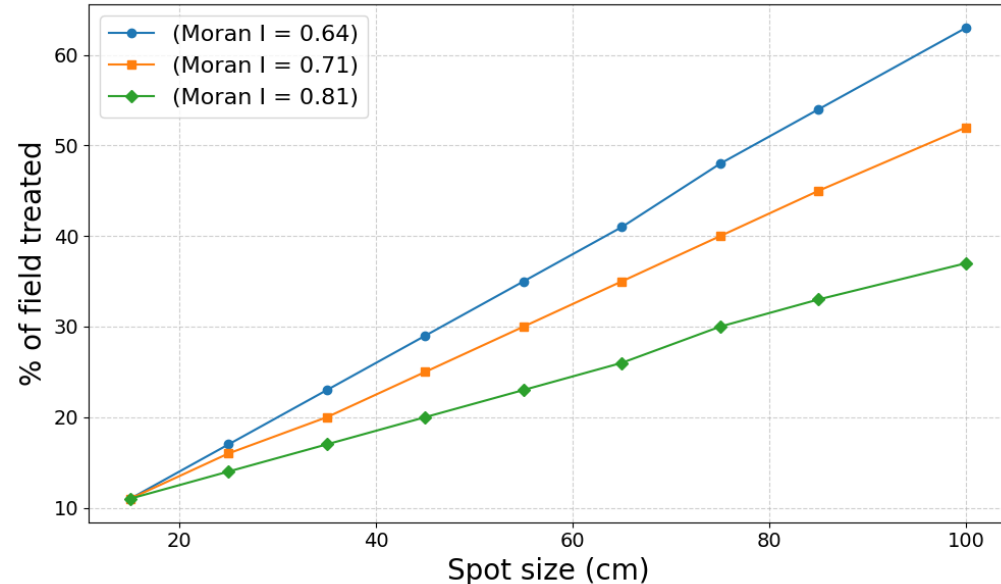
Trend 2

Treated rate increases with spot size.

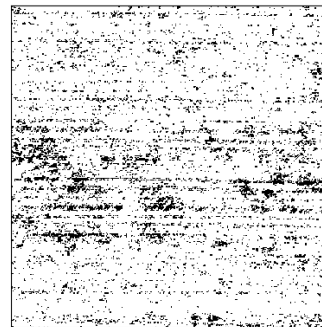
PRZM, the PEC is scaled considering the treated area, so the change is linear.

SPOTMOD, the change does not follow a linear trend since the map changes with spot size, affecting the reduction in PEC.

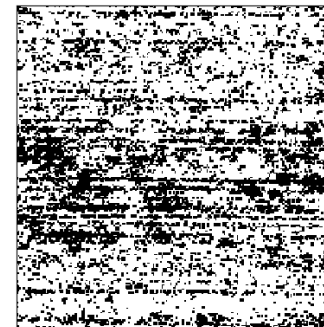
- To create tiles for larger application spot sizes, the 5 cm x 5 cm grid is upsampled again
 - As a conservative rule, if any original pixel within a new grid cell is infested with weeds, the new cell is marked as infested.
- The treated area fraction increases with spot size and sparseness of infestation is also included
 - Moran's I is used as an estimate of spatial autocorrelation (low I values, more random distribution; high I , more clustered)
 - Lower I values (more random distribution) result in a quicker increase in treated area fraction



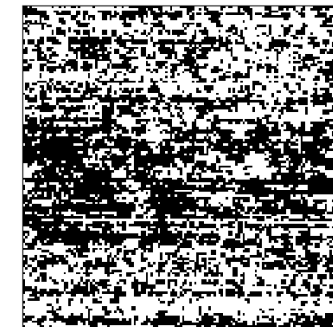
Resampling of an extracted tile



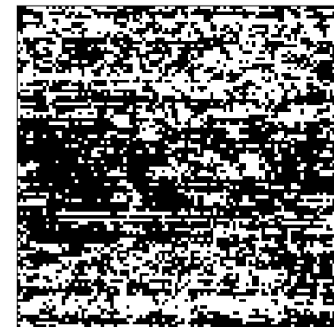
15 x 15 cm spot size
11% infestation rate
0.71 Moran I



45 x 45 cm spot size
33% infestation rate



75 x 75 cm spot size
49% infestation rate



100 x 100 cm spot size
56% infestation rate

- To handle large-scale simulation workloads, SPOTMOD is further optimized for High-Performance Computing (HPC) environments:
 - Utilizes advanced multiprocessing libraries
 - Implements MPI (Message Passing Interface) for multi-node parallelization
 - Leverages SCRATCH directories to boost read/write performance
- Simulations are configured using a JSON file that defines multiple parameter combinations, enabling millions of simulations to be set up and managed efficiently in a single batch

- By accounting for spatial heterogeneity, varying spot sizes, infestation rates, and spatial autocorrelation, the metamodel provides a realistic representation of weed distributions
- For specific cases, users can run SPOTMOD with custom maps to model different weed distributions
- Based on our judgment, we limited the map selection to infestation rates of up to 30%, as higher rates are unlikely to benefit from spot treatments and would typically be addressed with full-field applications
- The selected combinations of spot sizes and infestation rates aim to cover the range of realistic scenarios for spot treatments in the field

- Potential nomograph for PECsw compared with broadcast application as a function of infestation rate and treated spot size
- Curves are speculative, but treated area fractions are from a real example tile

