

Landscape scale aquatic exposure and effect modelling considering spot application

Sebastian Multsch¹, Mike Fuchs², Dirk Nickisch³, Khaled Brimo³, Joachim Kleinmann¹, Sebastian Gebler¹, Andreas Lorke² | Contact: sebastian.multsch@basf.com



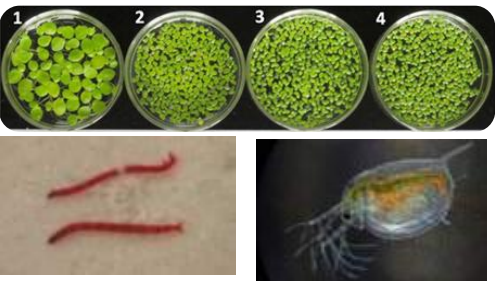
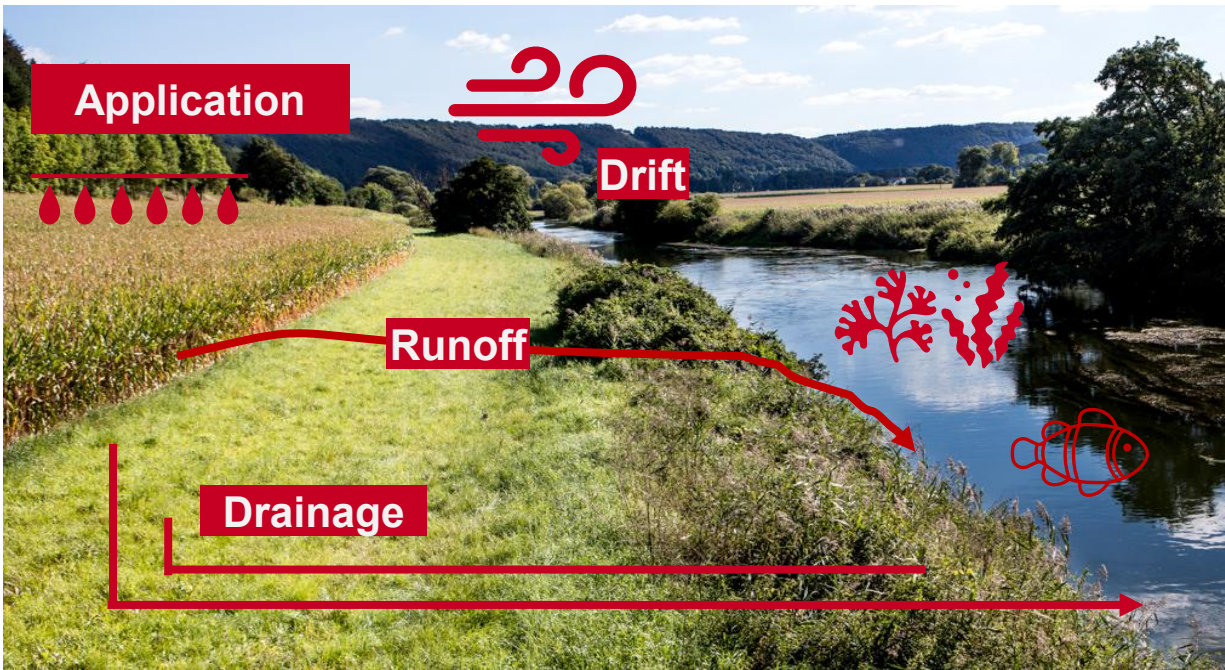
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3rd Sep. 2026

Agricultural Solutions | Regulatory Science

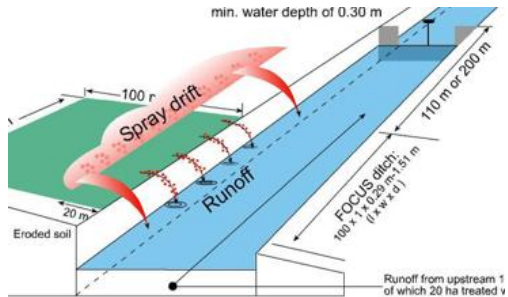


Background

- Aquatic risk assessments rely on conservative assumptions for runoff, drainage, and spray drift, driving risk outcomes and mitigation requirements across many active substances.



Experimental effects



Modelled exposure
Single river

$$\frac{\text{Toxicity (EC}_{50})}{\text{Exposure (PEC}_{\text{sw}})} = \text{TER}$$

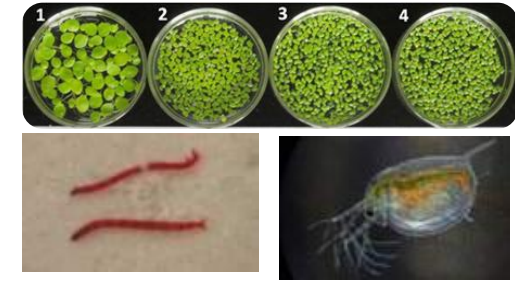
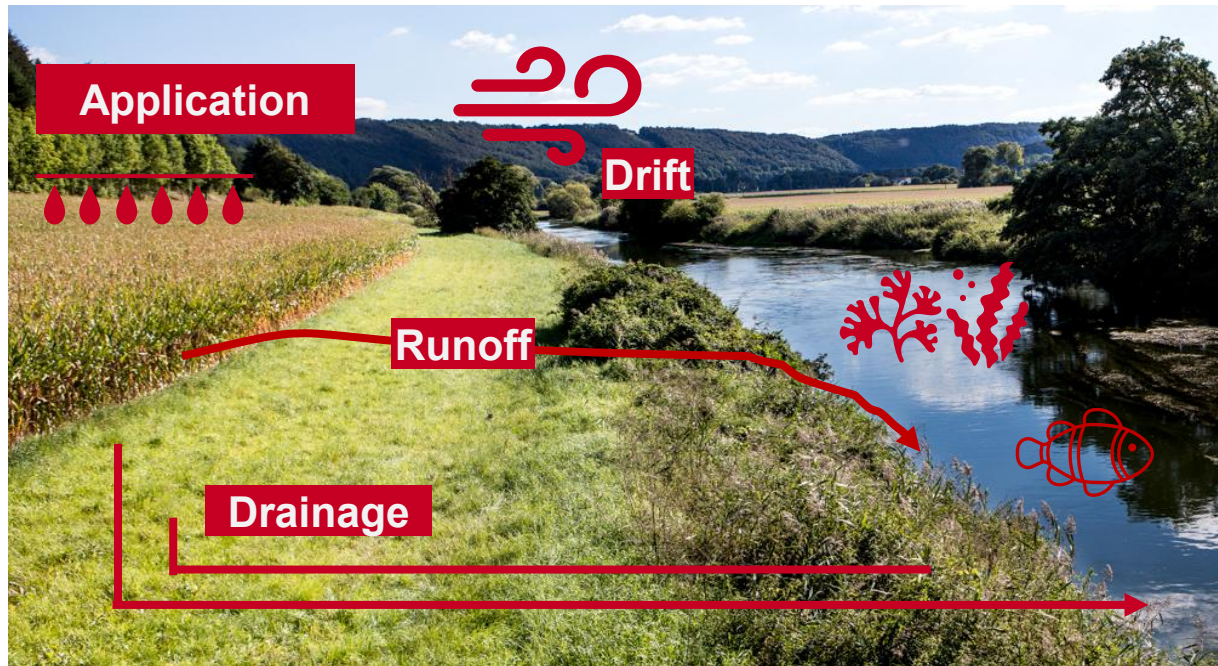
Acceptable:

$\text{TER}_{\text{acute}} > 100$

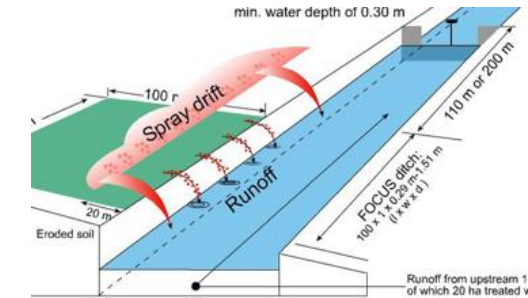
$\text{TER}_{\text{long-term}} > 10$

Background

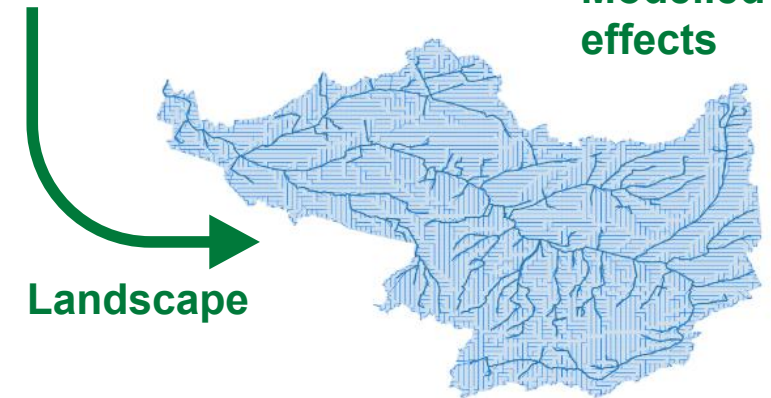
- Aquatic risk assessments rely on conservative assumptions for runoff, drainage, and spray drift, driving risk outcomes and mitigation requirements across many active substances.
- GIS-based modelling provides a scientifically robust pathway to contextualise this conservatism through spatial realism, enabling differentiated risk interpretation while maintaining protection goals.



Experimental effects



**Modelled exposure
Single river**

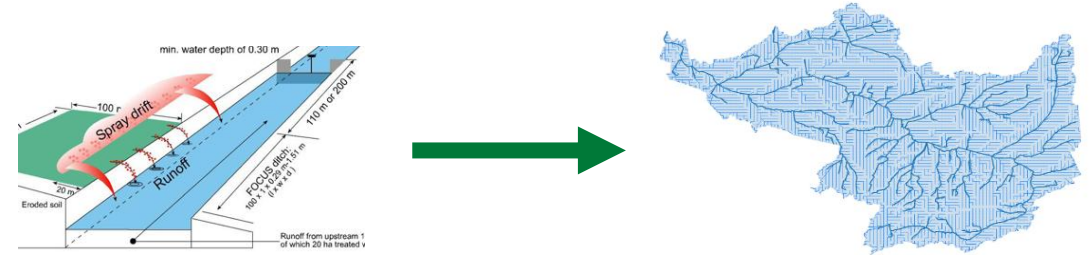


Landscape

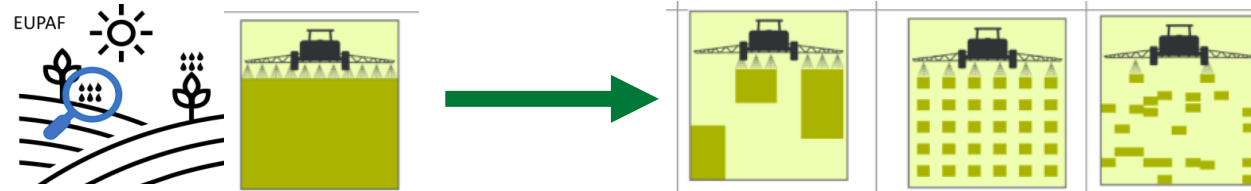
Modelled effects

Objective

- Highest-tier refinement: Integrated landscape modelling links hydrology, exposure, fate, and effects [1].



- Rising relevance: Digital farming and precision application increasingly shape regulatory risk assessment [2,3].



- Current gap: No harmonised guidance; further work needed on reliability and applicability.

- **This study:**

- ▶ Links exposure and effect models to assess precision application impacts on aquatic risk.
- ▶ Provide technical proof-of-concept integrating a landscape model with real-world data.

[1] Aquatic GD. *EFSA Journal* 2013;11(7):3290.

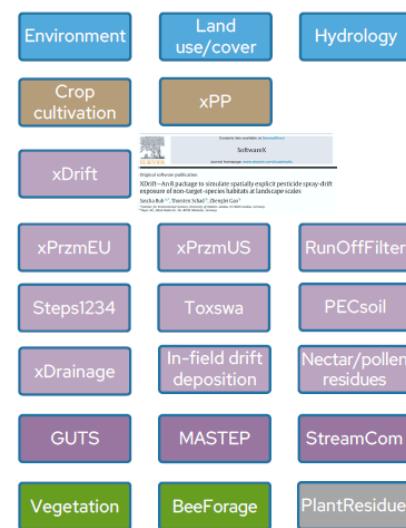
[2] EUPAF [url: [BVL - EUPAF](#)].

[3] EC (2024). [url: [cdd9b6c4-29dc-4077-a118-3e51c0abeb80_en](#)].

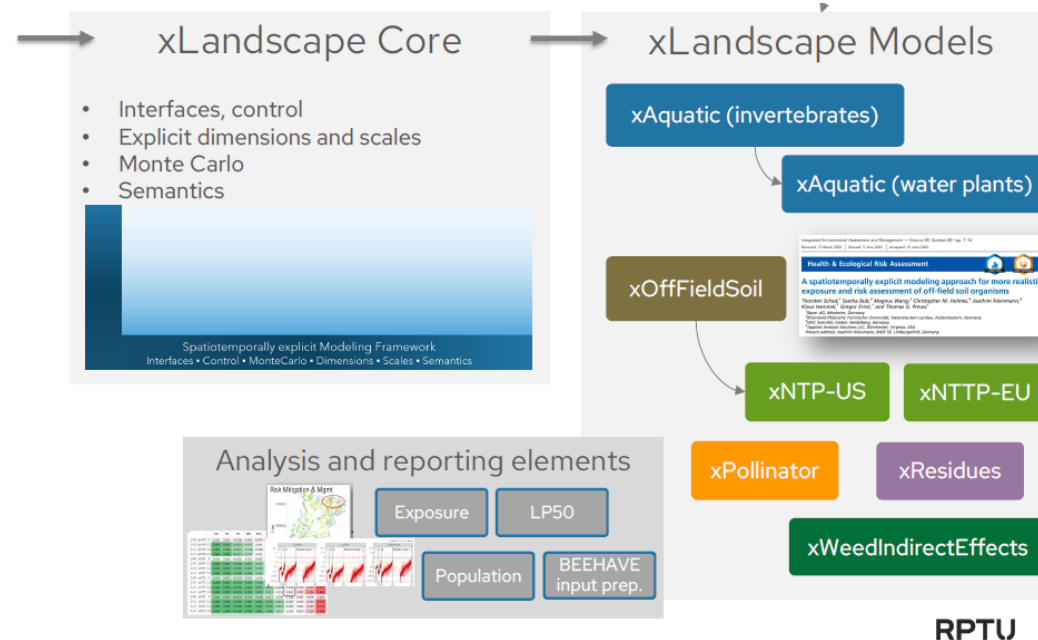
Model & Scenario

- **xLandscape:** Open-source Python framework for scenario-based coupling of exposure, fate, and effect models. [1,2]

- **Key objective:** Enable transparent, reproducible landscape-scale modelling.



14 xLandscape, 26.09.2023, 11thEMW, Montpellier



- The xLandscape model “xAquaticRisk” [2] was extended: **xaquatic-funne**

- ▶ Integration of further modules:
 - Drainage: FOCUS MACRO [3]
 - Runoff: FOCUS PRMZ (taken from xOffFieldSoil)
 - Drift: The droplet and atmospheric dispersion drift (DAD-drift) model [4]
 - Spray Path Generator tool
- ▶ Setup of a new landscape scenario: Funne catchment, DE.

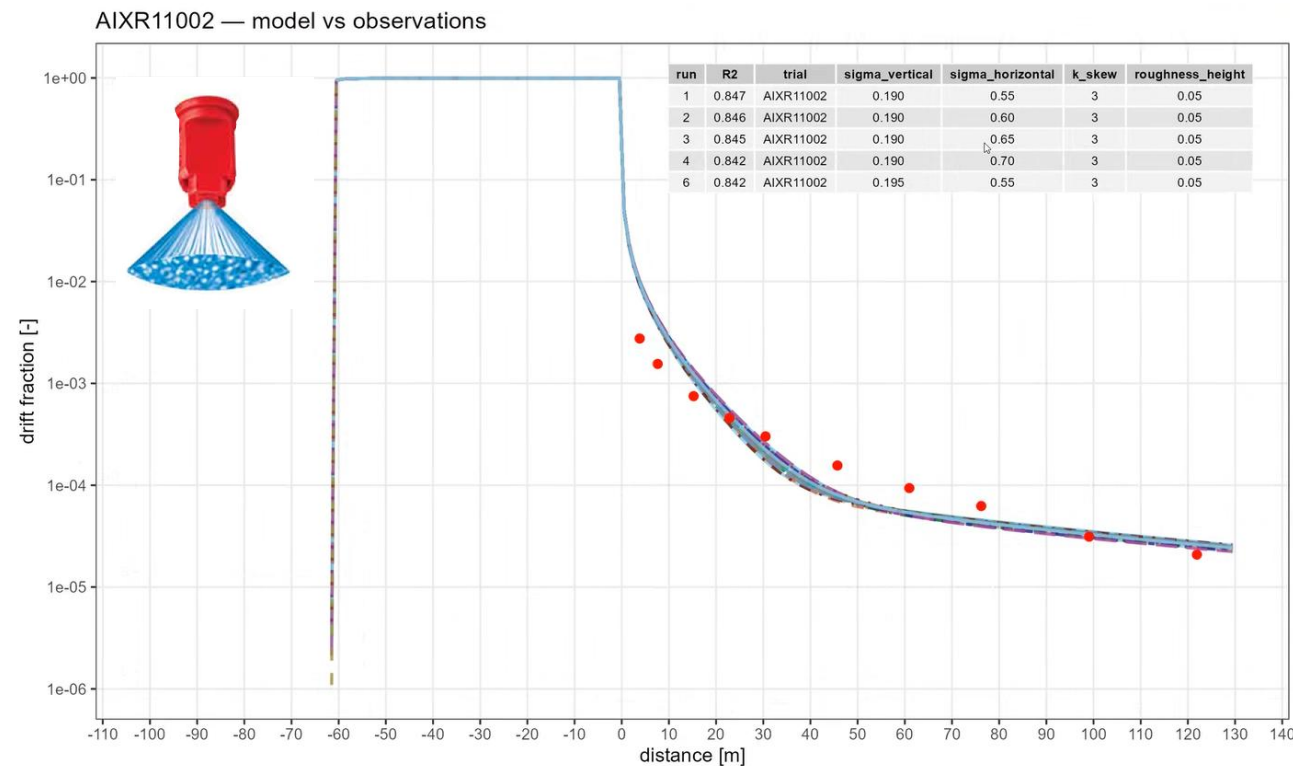
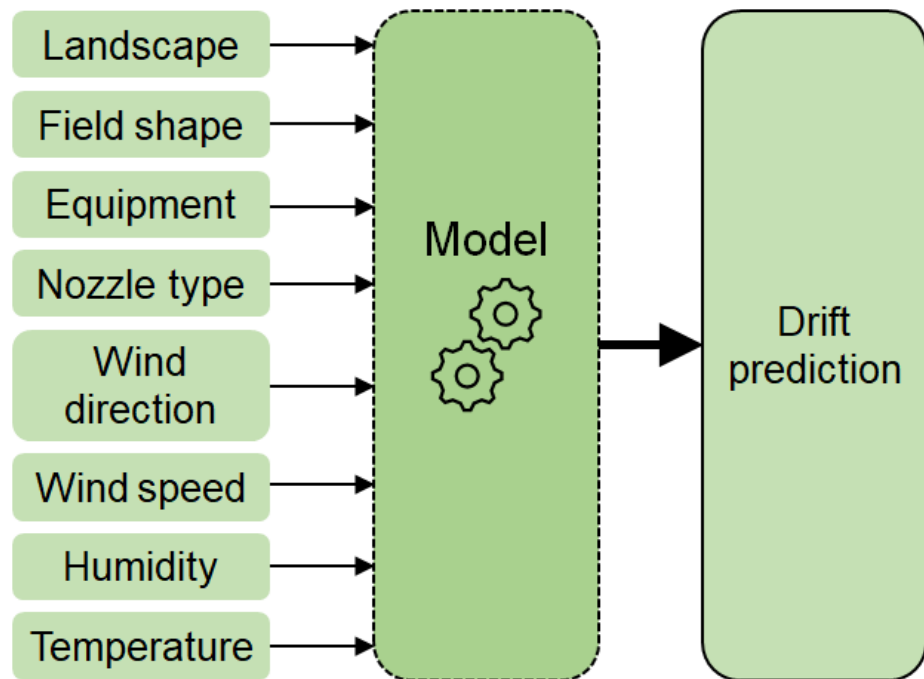
[1] Bub (2026): <https://github.com/xlandscape/>.

[2] Buddendorf et al. (2023)

[3] Multsch et al. (2024)

[4] Fuchs et al. (2025)

The droplet and atmospheric dispersion drift (DAD-drift) model



- DAD is a physically based spray-drift model calibrated for a range of commonly used nozzle types. [1]
- Consideration of weather conditions driving droplet transport and deposition across landscapes.
- Refinement of **droplet-size distributions** possible using formulation-specific measurements.

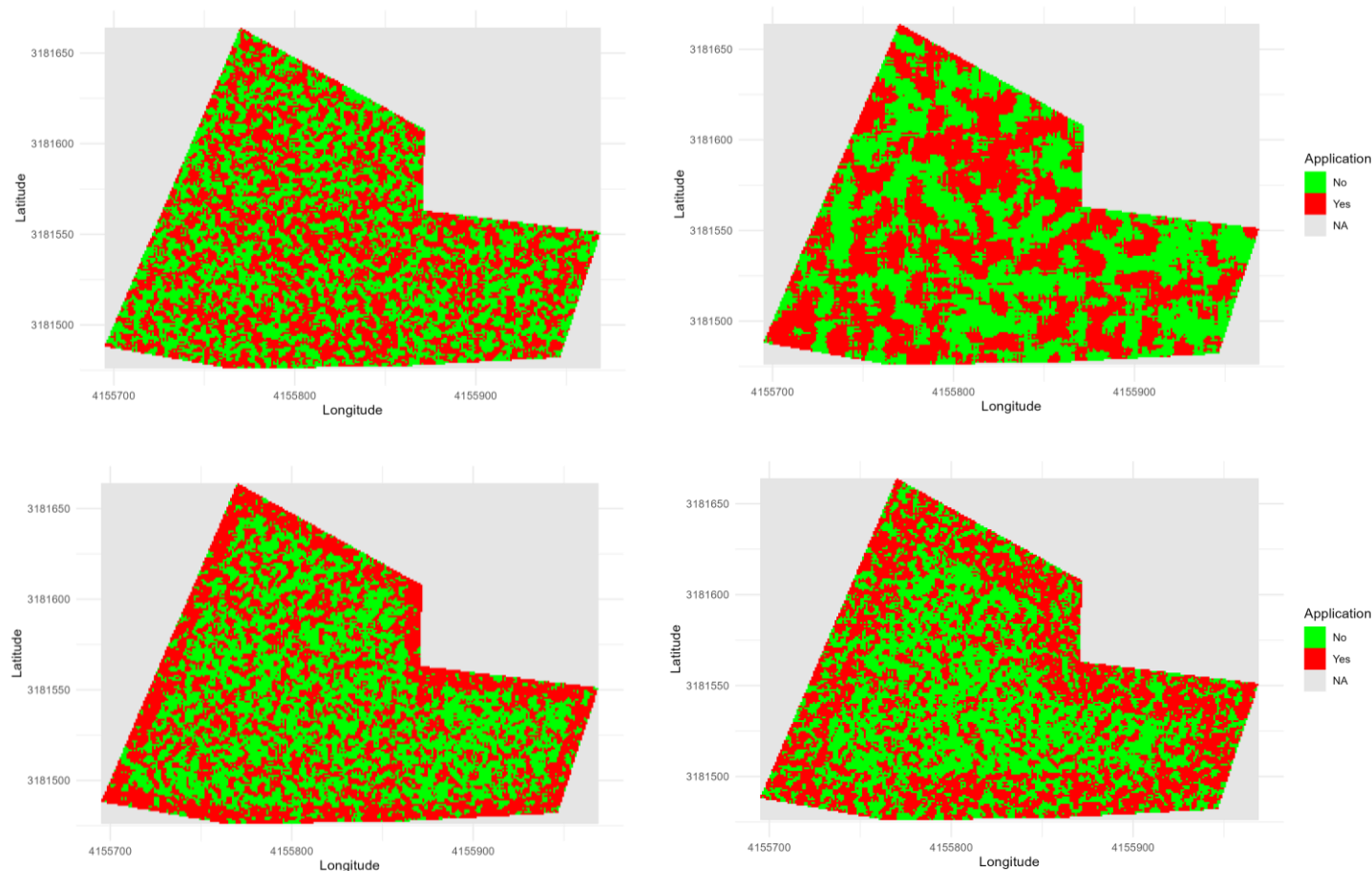
[1] Fuchs et al. (2025)

Spray Patch Generator Tool

- Generates artificial spot application maps for scenario development and sensitivity analysis based on the following parameter:

- Infection Rate
- Micro-Macro-Ratio
- Smoothing Radius Micro
- Smoothing Radius Macro
- Edge Bias
- Edge Width

- Ability to represent real-world herbicide spray pattern.

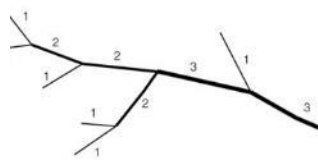


Funne catchment (Germany)

Hydrography

River: 117.90km
Elevation: 46 – 109 m
Slope : 0.01m/m (max: 0.18m/m)

Strahler 1: 65 km
Strahler 2: 33 km
Strahler 3: 9 km
Strahler 4: 10 km

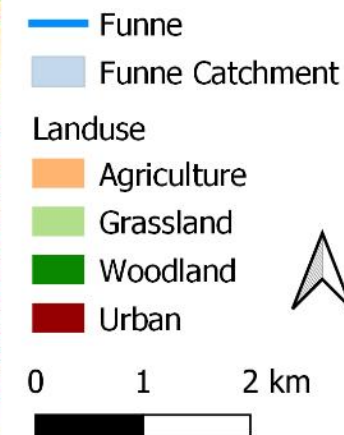
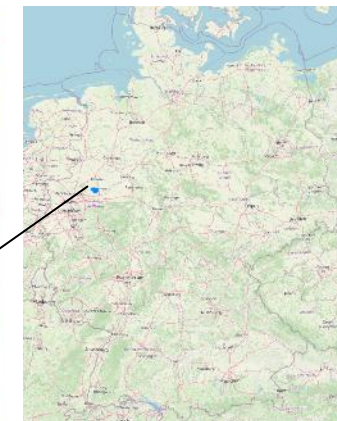
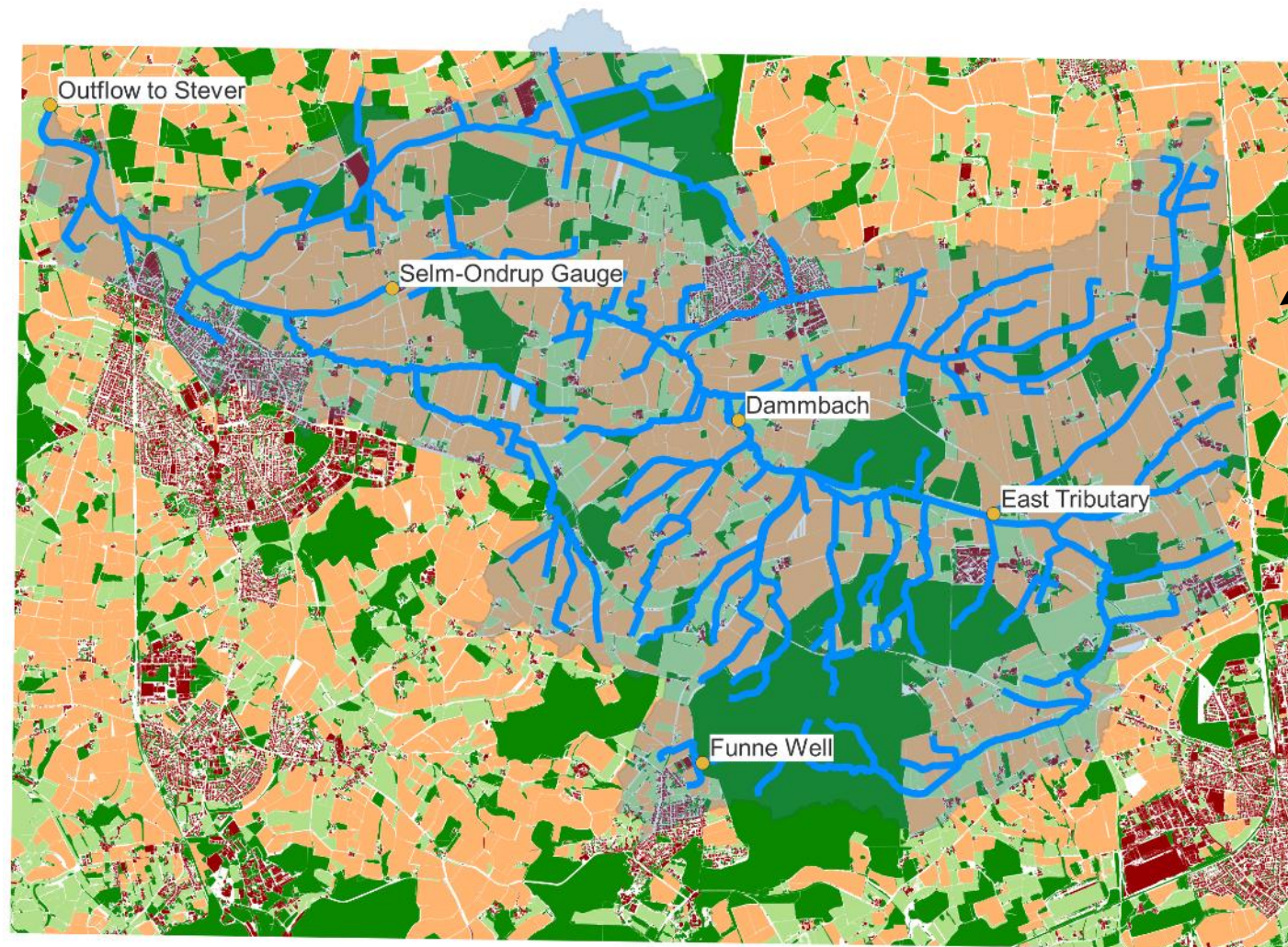


Land use

Agriculture 2489 ha (53 %)
Grassland 894 ha (19 %)
Woodland 1329 ha (28%)

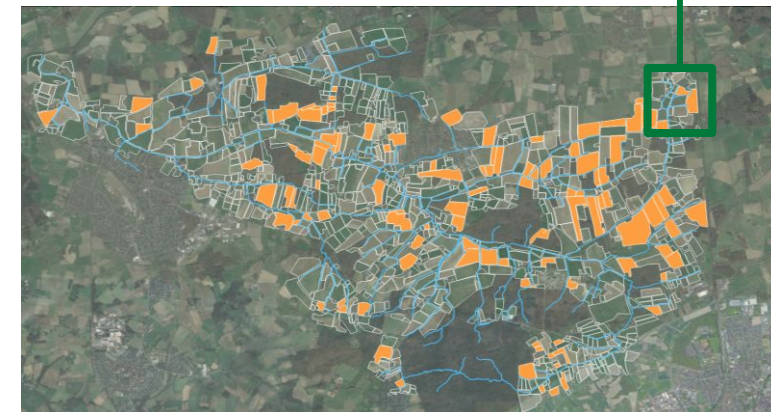
Climate (2000-2022)

Rainfall: 493 – 990 mm/year
ET0: 691 – 886 mm/year
Windspeed: 3.6 m/s

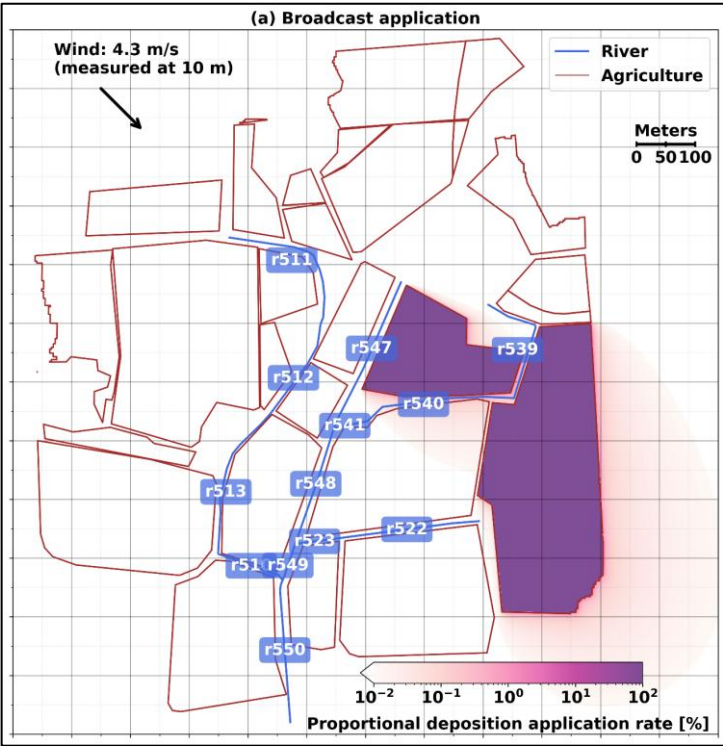


Case study – Small headwater Funne

- **Herbicide:** Mobile, medium degrading
- **Spring (BBCH 30)** application in winter cereals
- **Nozzle type:** AIXR11004 (JKI class: 50% nozzle reduction)
- Comparison of drift assessment approach:
 - ▶ FOCUS Rautmann curves.
 - ▶ DAD-Drift broadcast application
 - ▶ DAD-Drift Spot application
- **Efate water:** Steps river network
 - ▶ Based on Steps1-2-3-4 [M. Klein, Fraunhofer IME]
 - ▶ One water layer, two sediment layer, hourly time step
 - ▶ Degradation, Adsorption & desorption sediment
- **Effects**
 - ▶ Duckweed - *Lemna gibba*
 - ▶ TKTD model based on Schmitt et al. (2013)



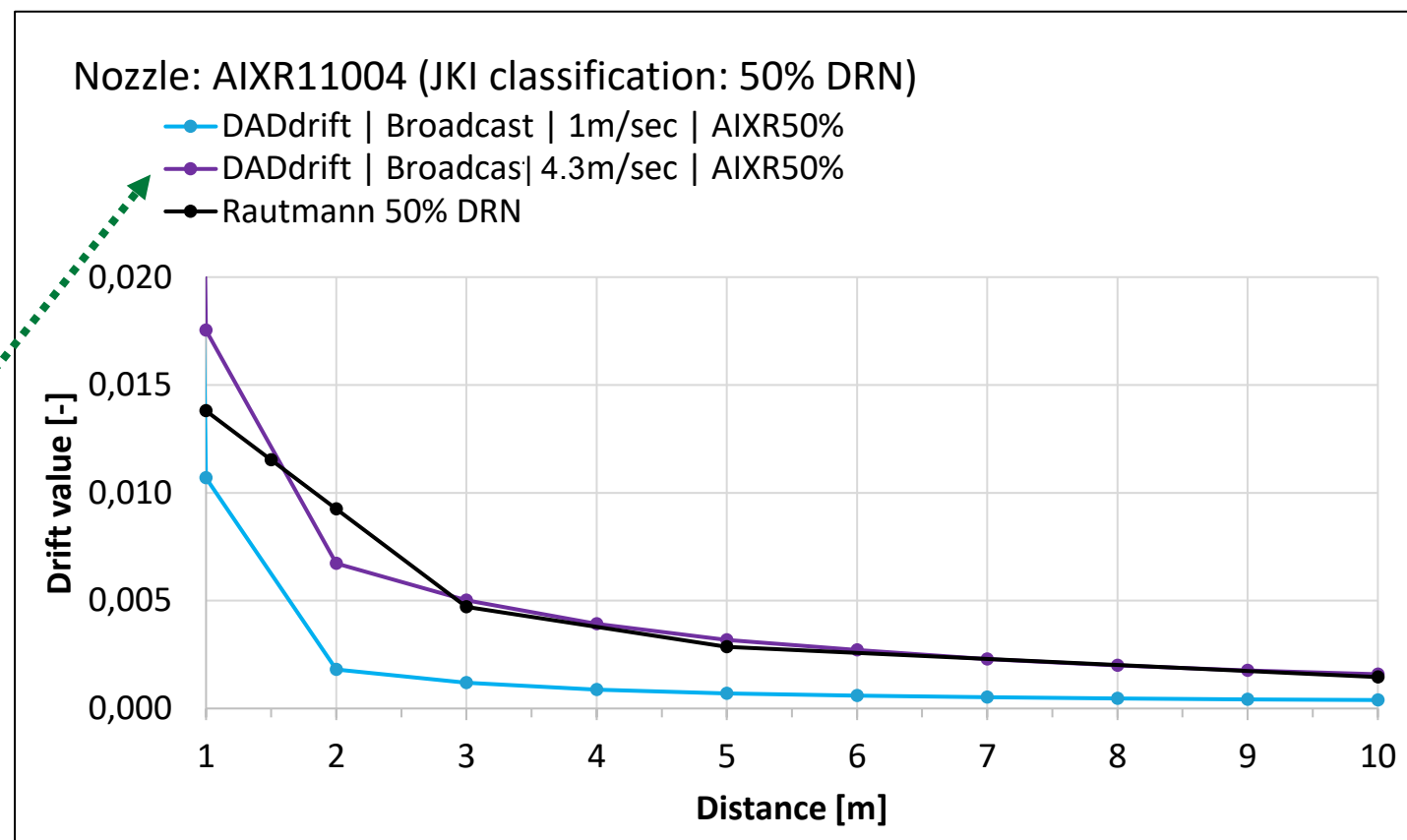
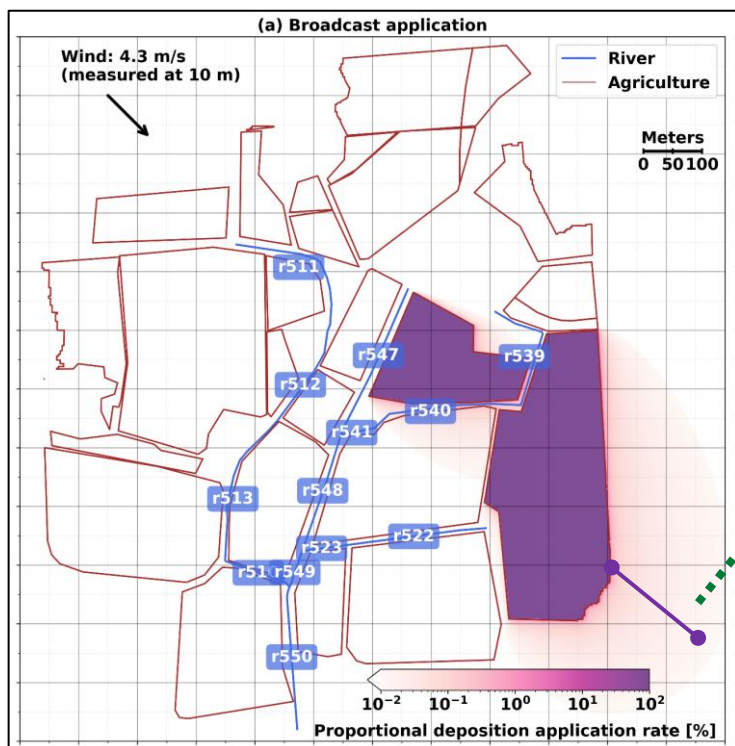
Exposure: Broadcast application



- ❖ FOCUS standard values yield the highest PEC_{sw,max} (e.g. up to ~2 µg/L).
- ❖ Physically based DAD drift modelling reduces PECs by up to one to two orders of magnitude.

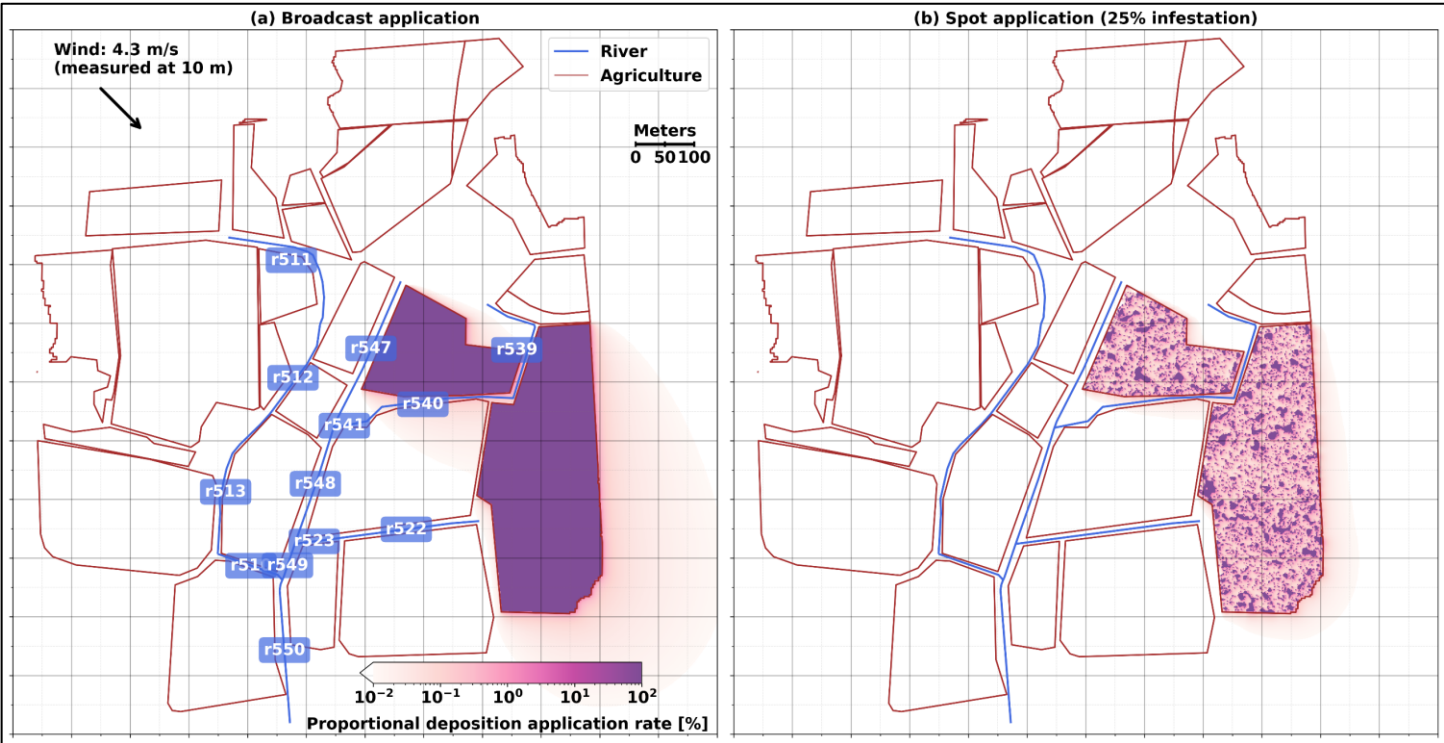
Scenario	PEC _{sw, max} [µg/L]					
	r539	r540	r541	r548	r549	r550
FOCUS value	1.78	2.13	1.71	0.37	0.36	0.11
DAD Broadcast	0.05	0.10	0.08	0.02	0.02	<0.01

Exposure: Broadcast application



- ❖ DAD drift simulations using a conservative wind speed (4.3 m/s) reproduce the regulatory standard Rautmann drift curves, confirming their protective character.
- ❖ In practice, PPP applications are often performed under lower wind speeds, indicating potential for contextualised refinement under clearly defined conditions.

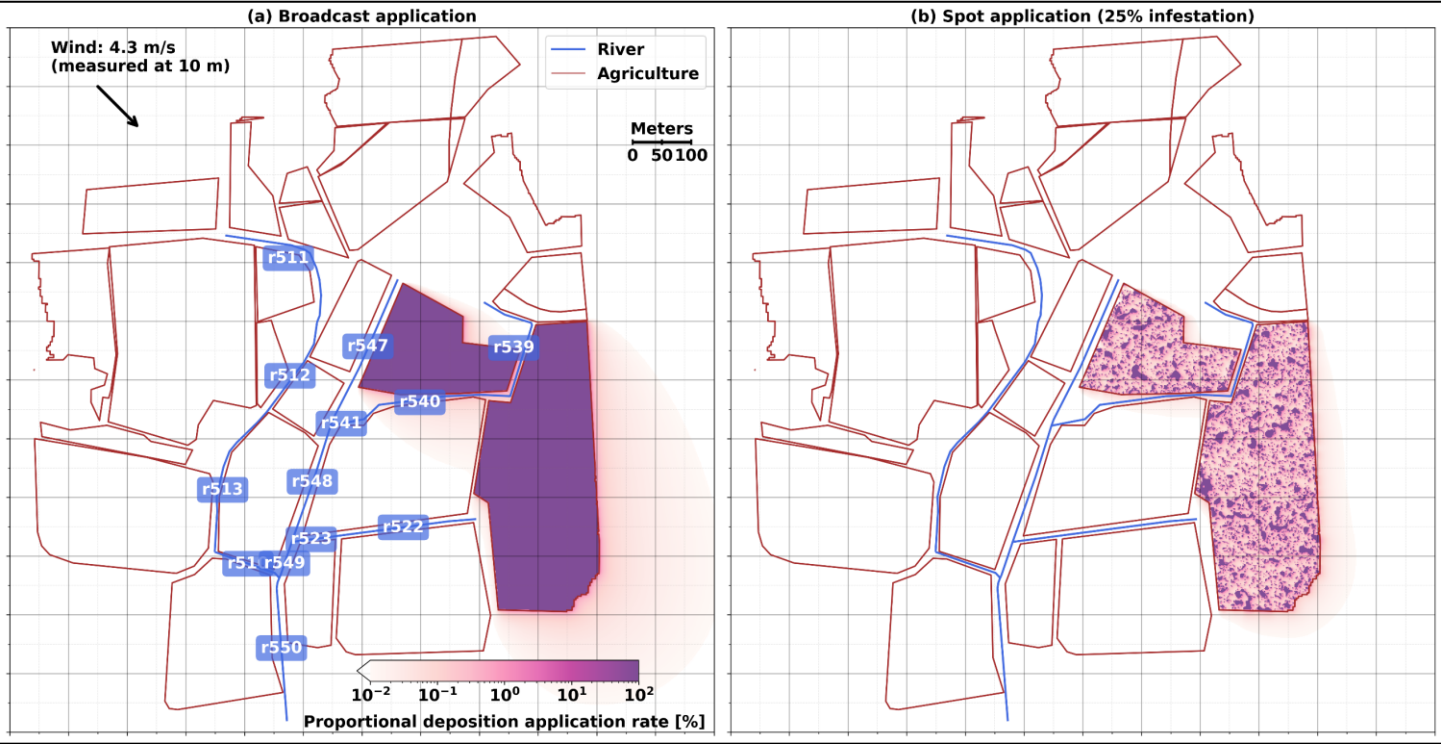
Exposure: Broadcast application versus Precision Application



- ❖ FOCUS standard values yield the highest PEC_{sw,max} (e.g. up to ~2 µg/L).
- ❖ Physically based DAD drift modelling reduces PECs by up to one to two orders of magnitude.
- ❖ Precision spot application leads to a further reduction across all reaches (mostly <0.03 µg/L).

Scenario	PEC _{sw, max} [µg/L]					
	r539	r540	r541	r548	r549	r550
FOCUS value	1.78	2.13	1.71	0.37	0.36	0.11
DAD Broadcast	0.05	0.10	0.08	0.02	0.02	<0.01
DAD Spot	0.01	0.03	0.02	<0.01	<0.01	<0.01

Effects



The **minimum EP₅₀ value for Lemna** (the factor by which the exposure profile must be multiplied to achieve a 50% growth reduction) was calculated for river segments.

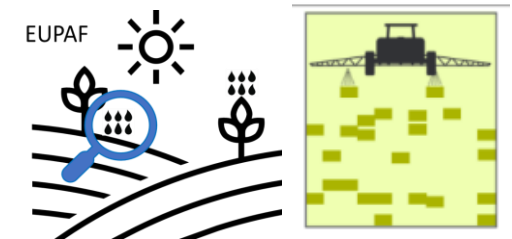
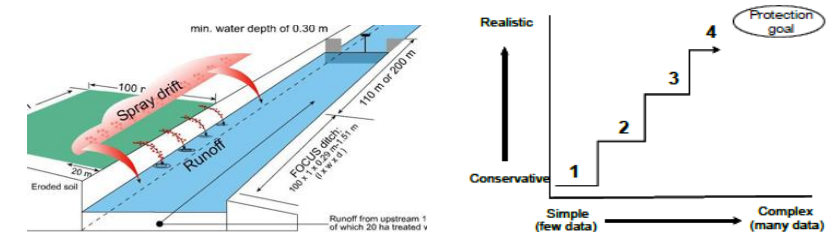
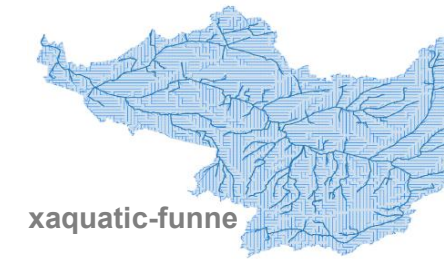
Regulatory threshold to pass:

EP₅₀ > 10

Scenario	PEC _{sw, max} [µg/L]						EP ₅₀ [-]					
	r539	r540	r541	r548	r549	r550	r539	r540	r541	r548	r549	r550
FOCUS value	1.78	2.13	1.71	0.37	0.36	0.11	4	2	2	6	6	18
DAD Broadcast	0.05	0.10	0.08	0.02	0.02	<0.01	151	47	51	156	160	459
DAD Spot	0.01	0.03	0.02	<0.01	<0.01	<0.01	539	172	186	592	613	>1000

Conclusions and outlook

- **New xLandscape model** implemented with additional features:
 - ▶ Drainage (FOCUS MACRO) & physically-based drift calculation (DAD-Drift)
 - ▶ Generation of spot application pattern
- **Funne scenario (DE):** Meso-scale catchment with intensive agriculture, drained soils and highly variable hydrological conditions.
- GIS-based modelling (Tier-4 landscape scale [1]) provides a scientifically robust pathway to contextualise conservatism of lower tiers through spatial realism, enabling differentiated risk interpretation while maintaining protection goals.
- Still many limitations, e.g. no consideration of local vegetation.
- Nozzle selection greater influence on drift than formulation composition.
- The physical drift model, using conservative wind speed assumptions, reproduces regulatory-accepted drift curves, indicating potential for refinement under well-defined application conditions.



[1] Aquatic GD. *EFSA Journal* 2013;11(7):3290.

[2] EUPAF [url: [BVL - EUPAF](#)].

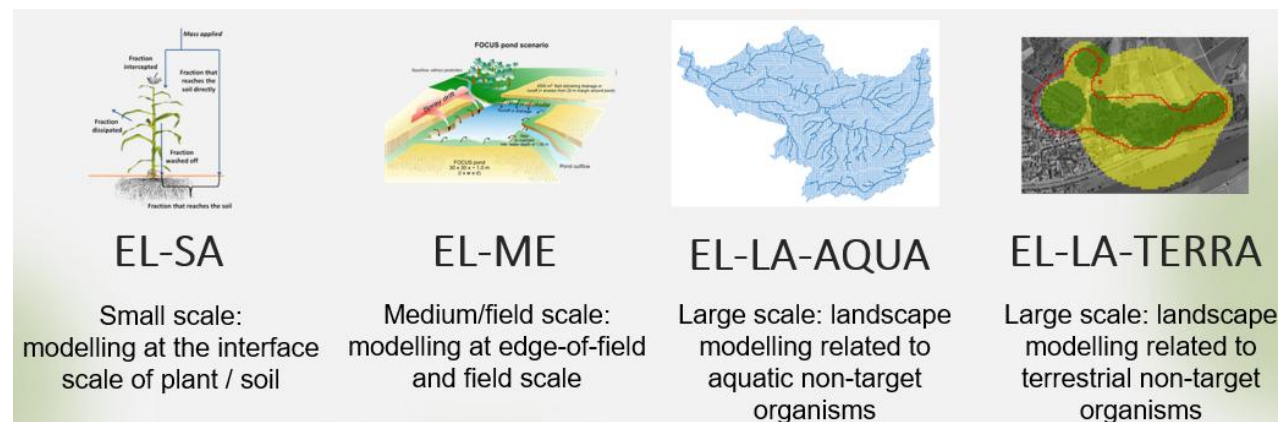
Outlook: ELINK2 – Linking Exposure and Effects across scales

- SETAC working group launched 2026
- >50 participants from industry, academia and authorities.
- Explicit linking of exposure and effects across spatial scales:
 - ▶ Scenarios towards **spatially explicit** exposure patterns and ecologically relevant effect metrics
 - ▶ Joint **case-study driven approach** involving exposure and effect modelers as well as GIS experts



- **EL-LA-AQUA: xLandscape Funne setup basis for technical proof-of-concept**

- ▶ **Macrophytes | Lemna sp. | Herbicide**
- ▶ **Invertebrates | Asellus Aquaticus | Insecticide**
- ▶ **Fish | Stickleback | Fungicide.**





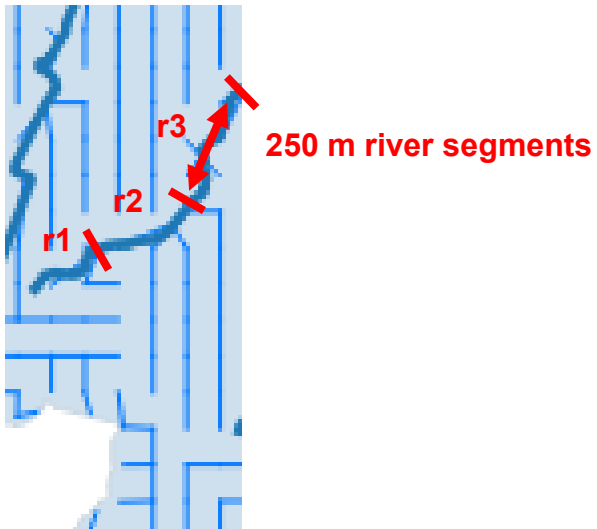
We create chemistry

Hydrography

(1) Inputs:

- 1m digital elevation model
- Stream network local authorities
- Catchment boundary

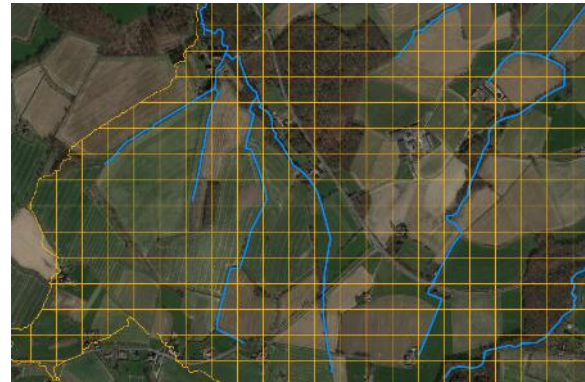
(2) River separated into 250 m segments.



(3) Harmonisation of river segment slopes by averaging altitudes of neighbouring reaches.

$\text{altitude_r1} = (\text{altitude_r1} + \text{altitude_r2}) / 2$
 $\text{altitude_r2} = (\text{altitude_r2} + \text{altitude_r3}) / 2$
...

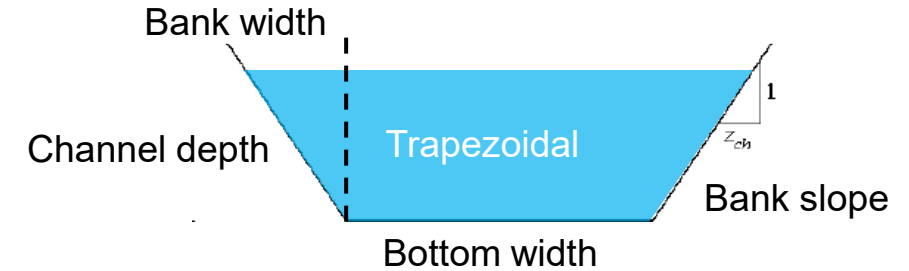
(4) Catchment separated into grid cells (100m x 100m)



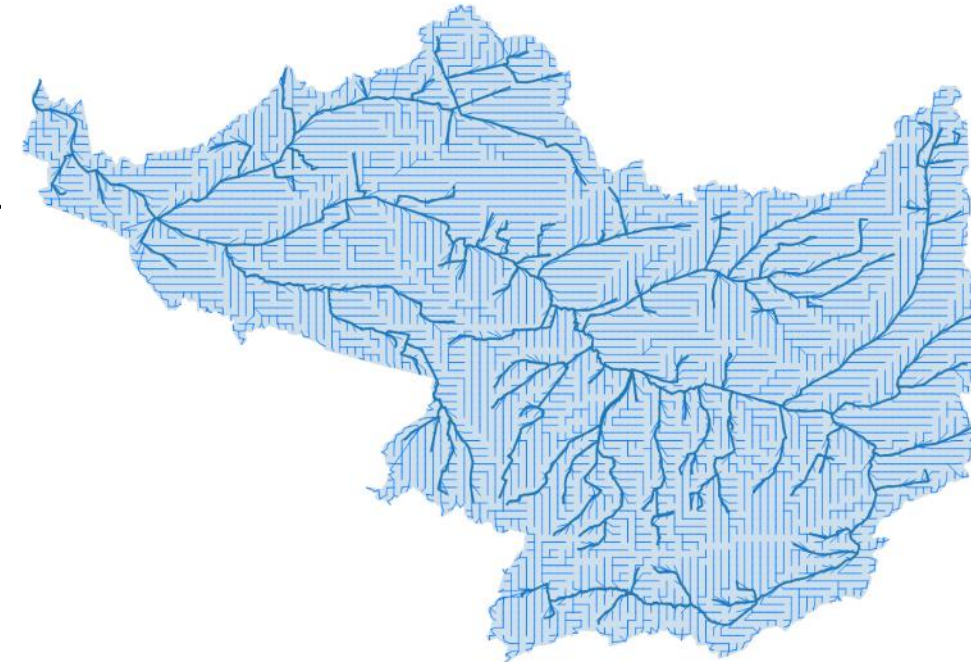
(5) Cells are connected to next downstream cell or next river segment



(6) Definition of cross-sectional shapes



→ Funne hydrography

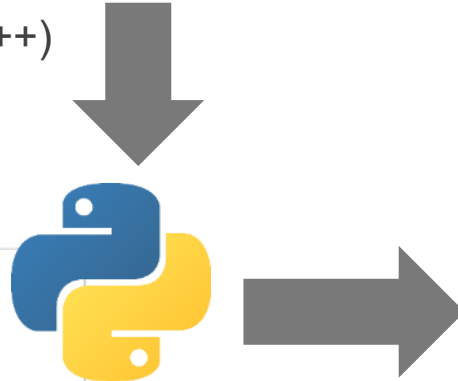
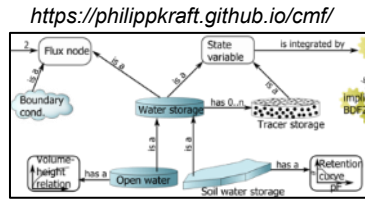


Hydrology

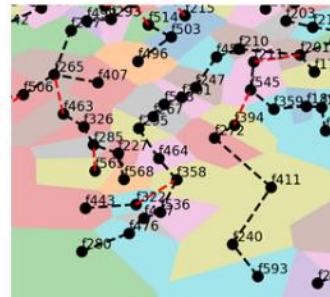
CMF (Kraft et al., 2011)

Catchment Modelling Framework

- Hydrological programming library (C++)
- Written in C++, interface Python
- Free software under GPLv3



```
import LandscapeModel as LM
from scipy.spatial import Voronoi
import shapely.geometry
if __name__ == "__main__":
    # connect fields and river segments
    fieldcon = LM.FieldConnector(fpath="c:/ExampleCatchment/",
                                simplify_connections=4, connection_type="RO_GW")
    fieldcon.makePlot("ExampleCatchment.png", resX=100, resY=100,
                     plotVoronoi=False, plotElevation=True, plot_simplified=True)
```



A. Empirical Area Yield



$$q_{outlet} = \frac{Q_{measured}}{A}$$

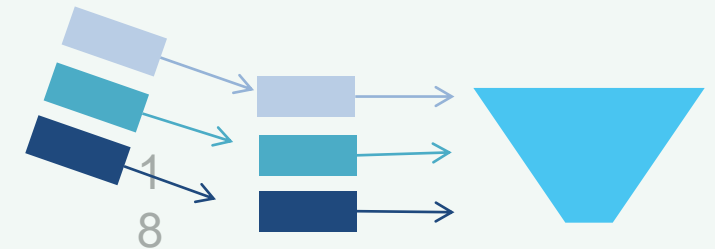
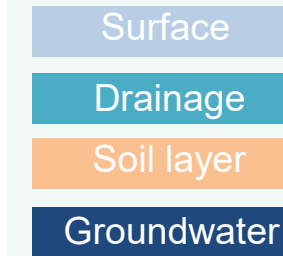
q_{outlet} – discharge per unit area ($\text{m}^3 \text{sec}^{-1} \text{m}^{-2}$)

$Q_{measured}$ - discharge ($\text{m}^3 / \text{sec}^{-1}$)

A - catchment area (m^2)

Water inflows into reaches are calculated by multiplying the specific discharge (water flow normalised by catchment area) measured at the outlet by the specific land area which drains into the reach.

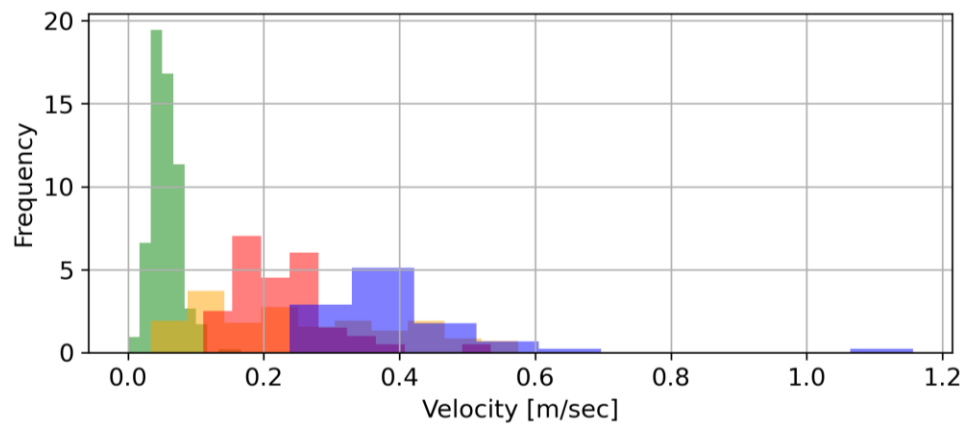
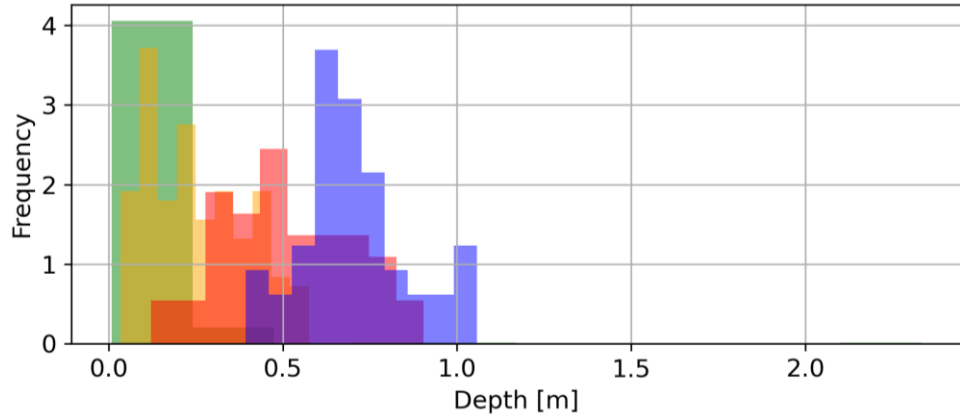
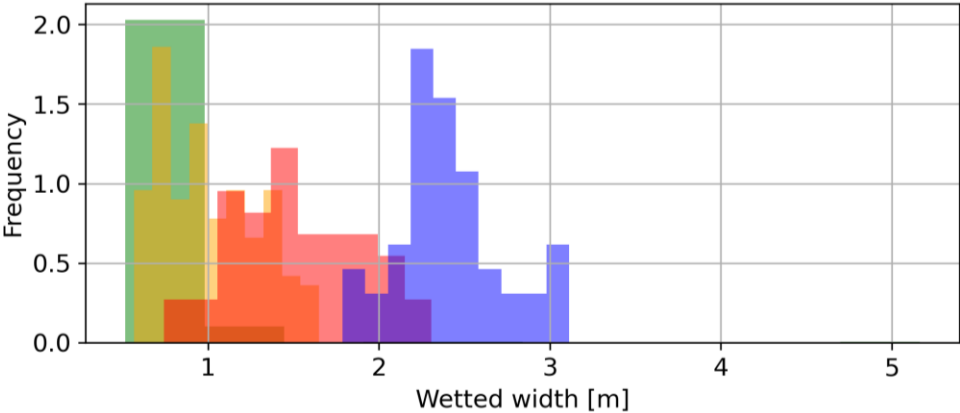
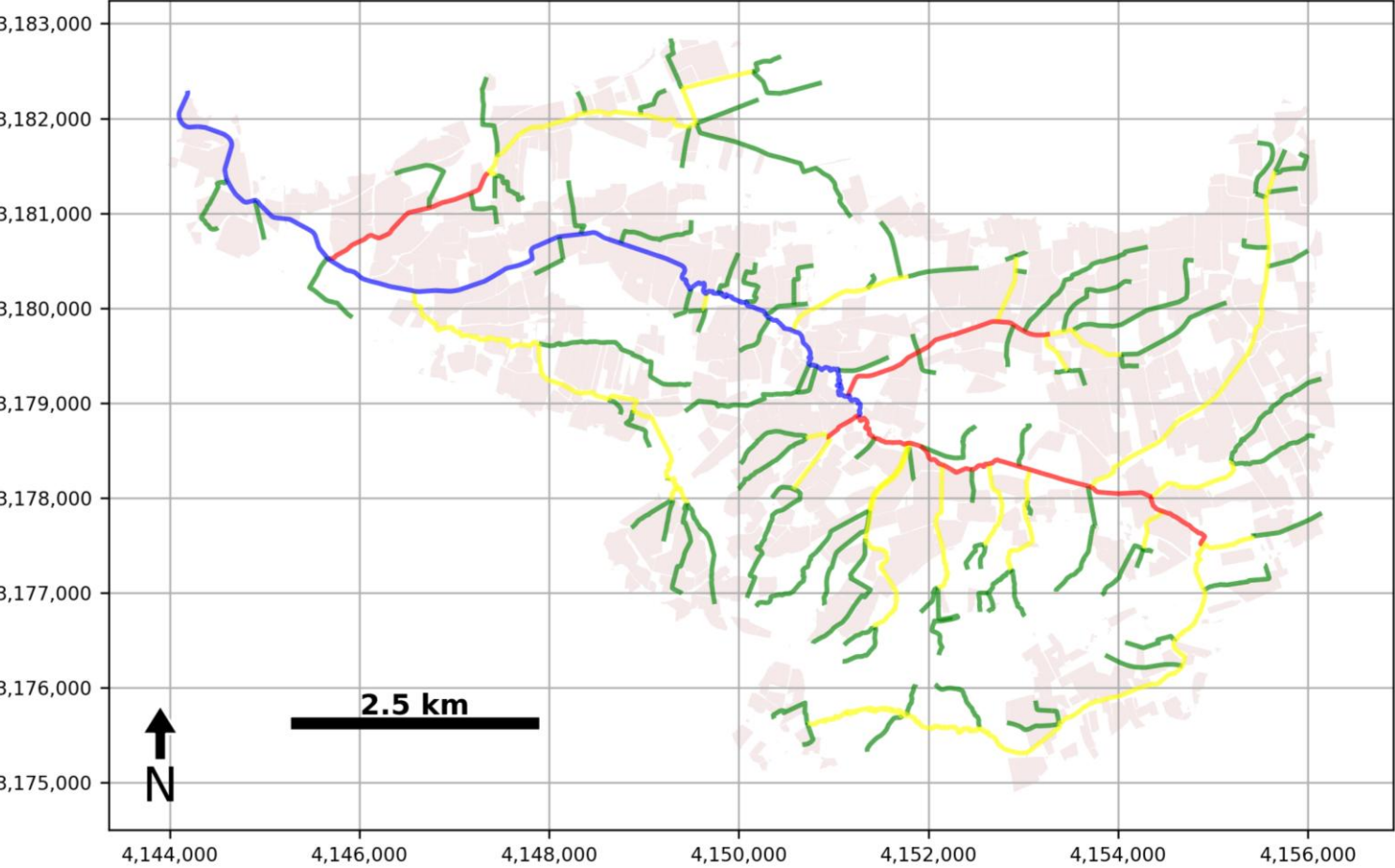
B. Mechanistic rainfall-runoff



Field scale water balance calculated with 1D approach based on local environmental data. Water flows from field to field and field to reach by kinematic wave approach.

Kraft, P., Vaché, K. B., Frede, H. G., & Breuer, L. (2011). CMF: a hydrological programming language extension for integrated catchment models. *Environmental Modelling & Software*, 26(6), 828-830.

Hydrological scenario

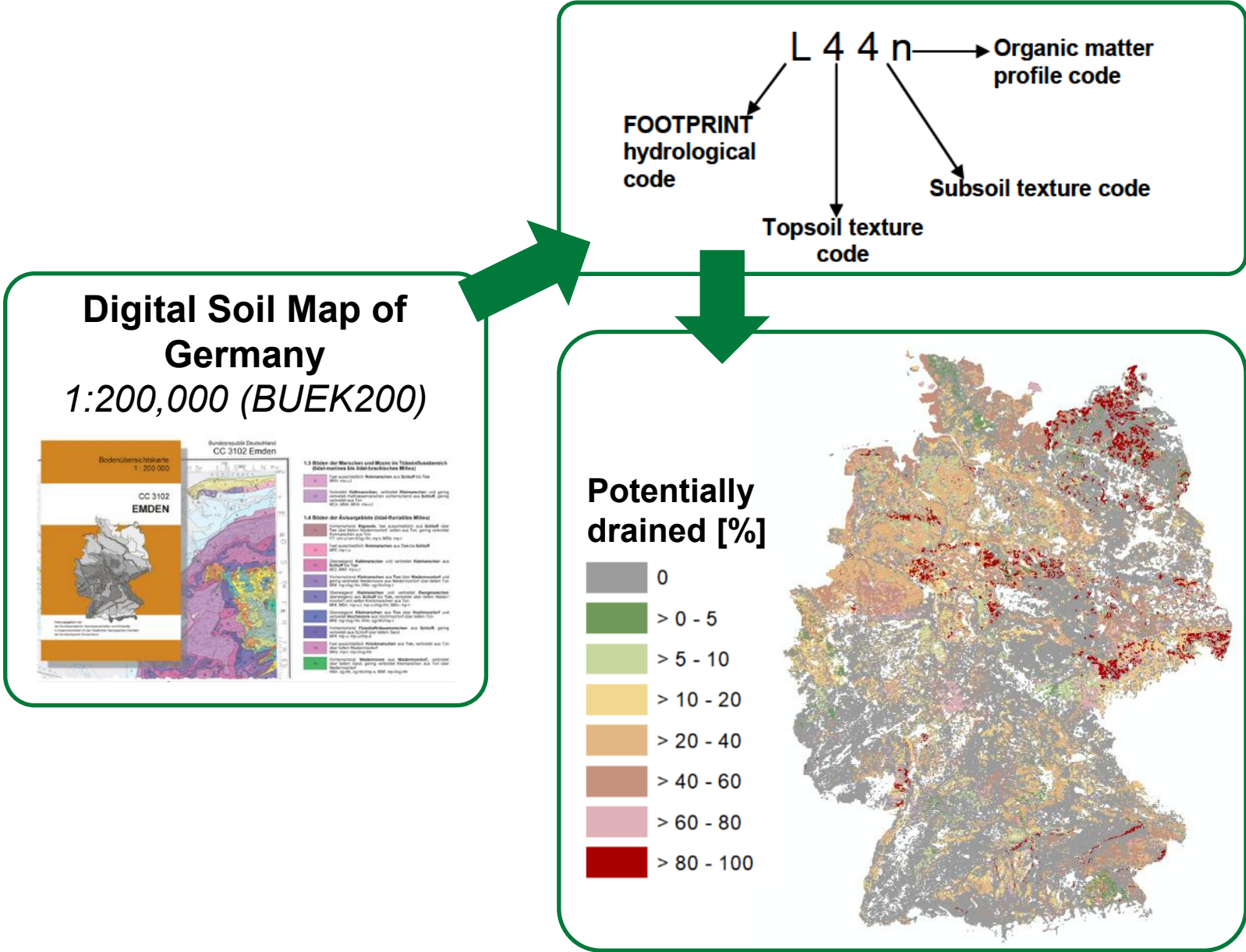


Strahler 1	Strahler 3
Strahler 2	Strahler 4

Strahler	1	2	3	4
Bank slope	1	1	0.5	0.5
Bottom with	0.5	1	2	4
Channel depth	1.25	1.5	2	2
Bank width	1.25	1.5	2	2

Footprint soil types

- The system of FOOTPRINT Soil Types (FSTs) has been derived during the EU project FOOTPRINT (2006-2009), mainly by John Hollis (UK).
- The FST system is model-independent, but complete parameterization methodologies for MACRO and PRZM exist (Dubus et al., 2010)
- 17 different FST soil types identified for Funne catchment based on BUEK200.
- FOCUS MACRO lower boundary conditions were derived based on FST



Dubus, I. G. & Reichenberger, S. (2010). FOOTPRINT—Functional tools for pesticide risk assessment and management. Final report EU project FOOTPRINT (SSPI-CT-2005-022704), 221 p.
Reichenberger S. et al. (2023). Automated classification of the German soil map (BUEK200) into FOOTPRINT soil types and parameterization in MACRO. Poster presentation. SETAC 2023.

FOCUS PRZM

- Parametrization based on FOCUS R1 scenario.

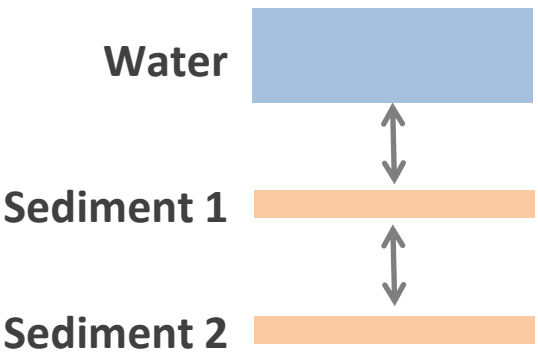


ALVID	LULCTypeID	key	PARF	METF	RAINF	DRAINCON	ROFFCON
8	603	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	r431	r431
9	575	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
10	574	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
11	574	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	r431	r431
12	634	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
57	115	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
58	575	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
59	574	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	None	None
181	171	0	y12i_WOSR	Funne_ET.bin	Funne_P.bin	r450	r450

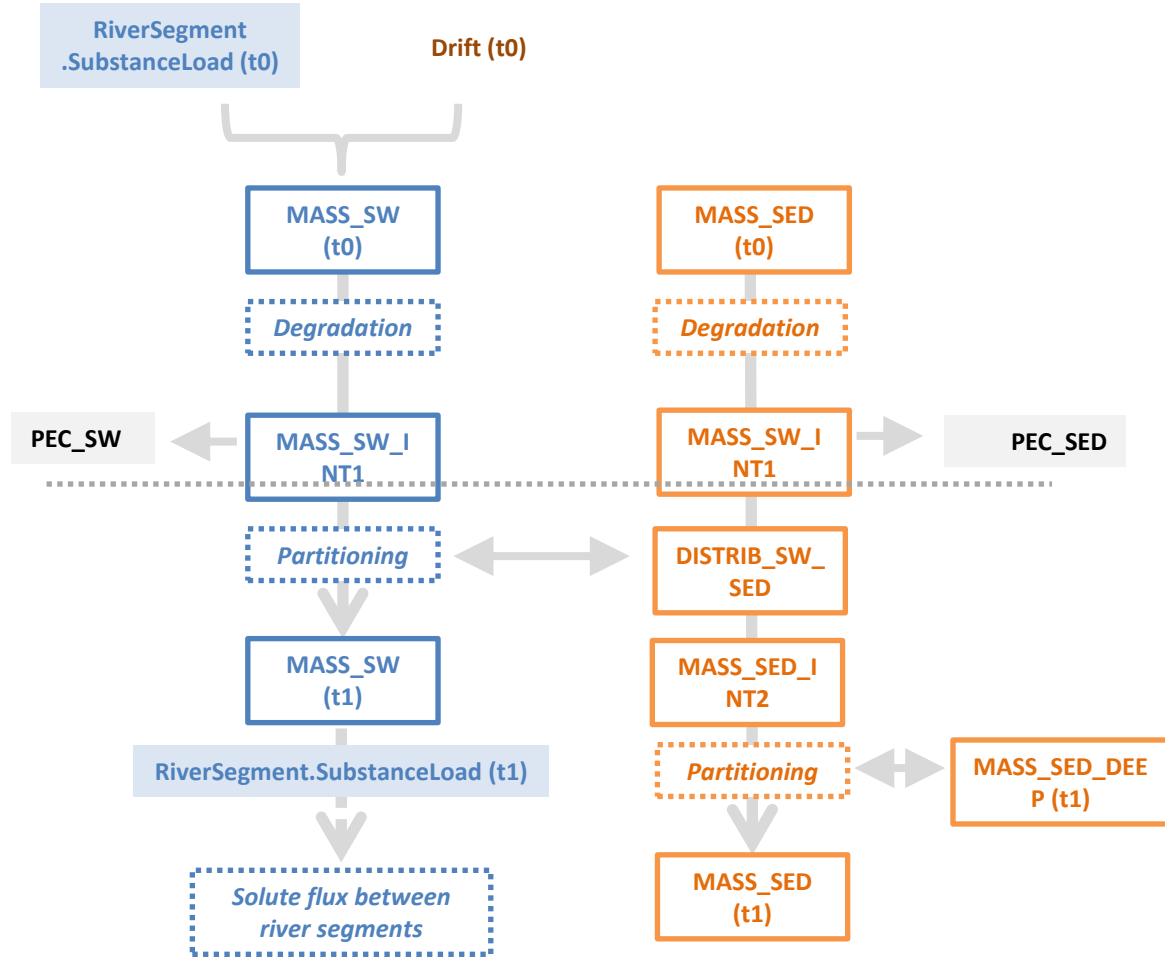
ROFFCON	SLOPE	THICKN1	THICKN2	THICKN3	BD1	BD2	BD3	OC1	OC2	OC3	SAF
r431	1.130145378667...	30.000000000000...	30.000000000000...	40.000000000000...	1.836548000000...	1.836548000000...	1.836548000000...	1.480000000000...	1.480000000000...	1.480000000000...	55.89999
None	1.960469531250...	30.000000000000...	30.000000000000...	40.000000000000...	1.836548000000...	1.836548000000...	1.836548000000...	1.480000000000...	1.480000000000...	1.480000000000...	55.89999
None	1.841950905120...	30.000000000000...	30.000000000000...	40.000000000000...	1.836548000000...	1.836548000000...	1.836548000000...	1.480000000000...	1.480000000000...	1.480000000000...	55.89999
r431	1.859761627952...	30.000000000000...	30.000000000000...	40.000000000000...	1.836548000000...	1.836548000000...	1.836548000000...	1.480000000000...	1.480000000000...	1.480000000000...	55.89999
None	1.510255371623...	30.000000000000...	30.000000000000...	40.000000000000...	1.836548000000...	1.836548000000...	1.836548000000...	1.480000000000...	1.480000000000...	1.480000000000...	55.89999

Steps 1-2-3-4

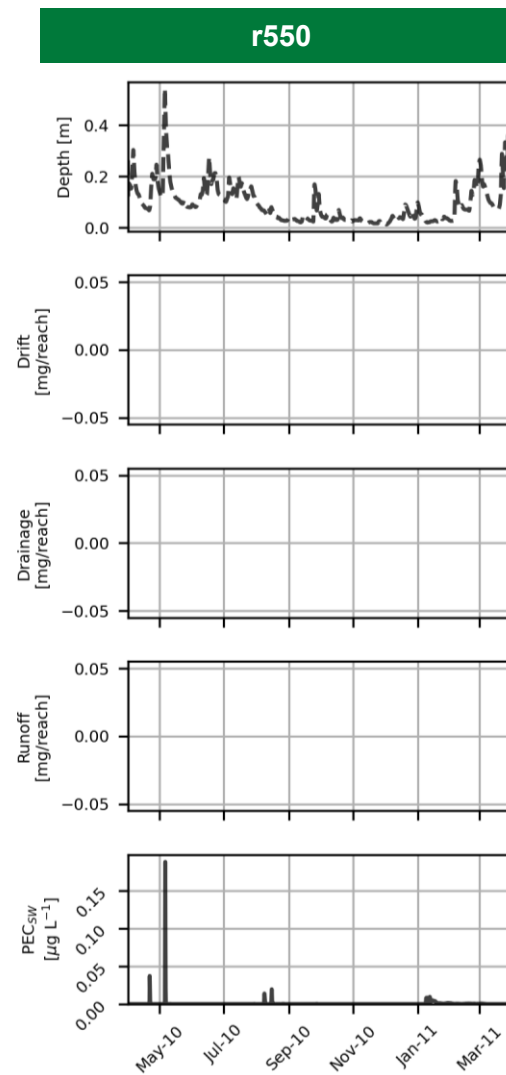
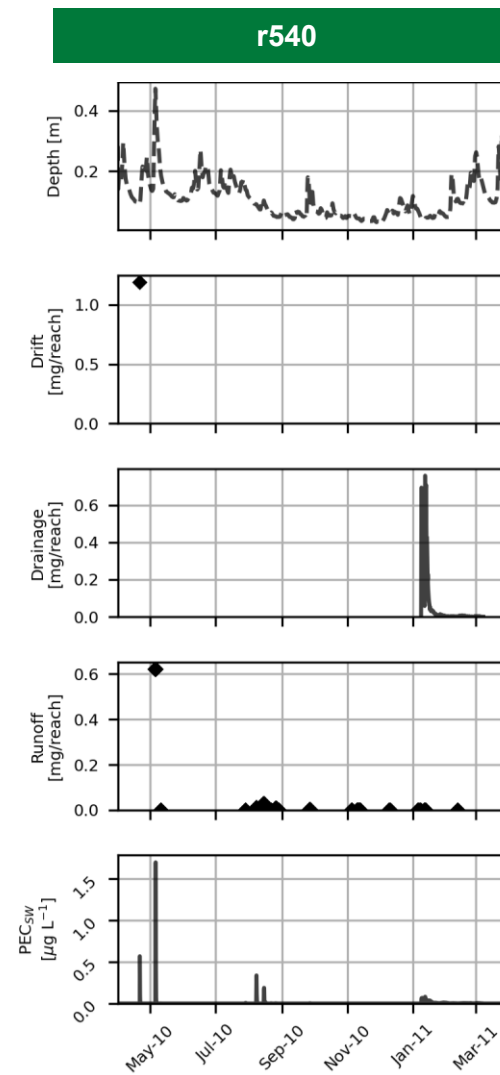
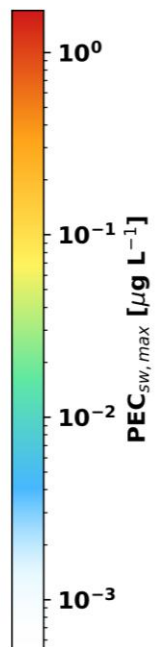
(a) Compartments



(b) Procedures



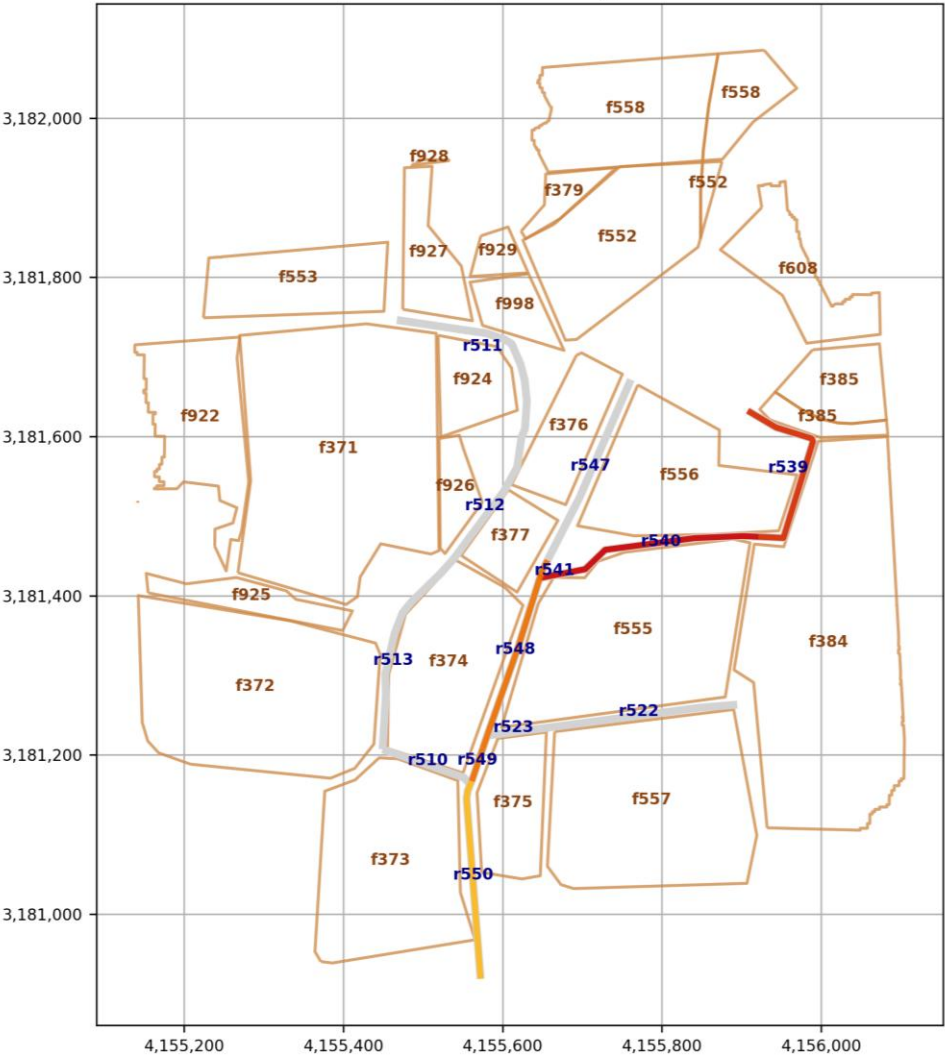
BBCH 30 (Apr)



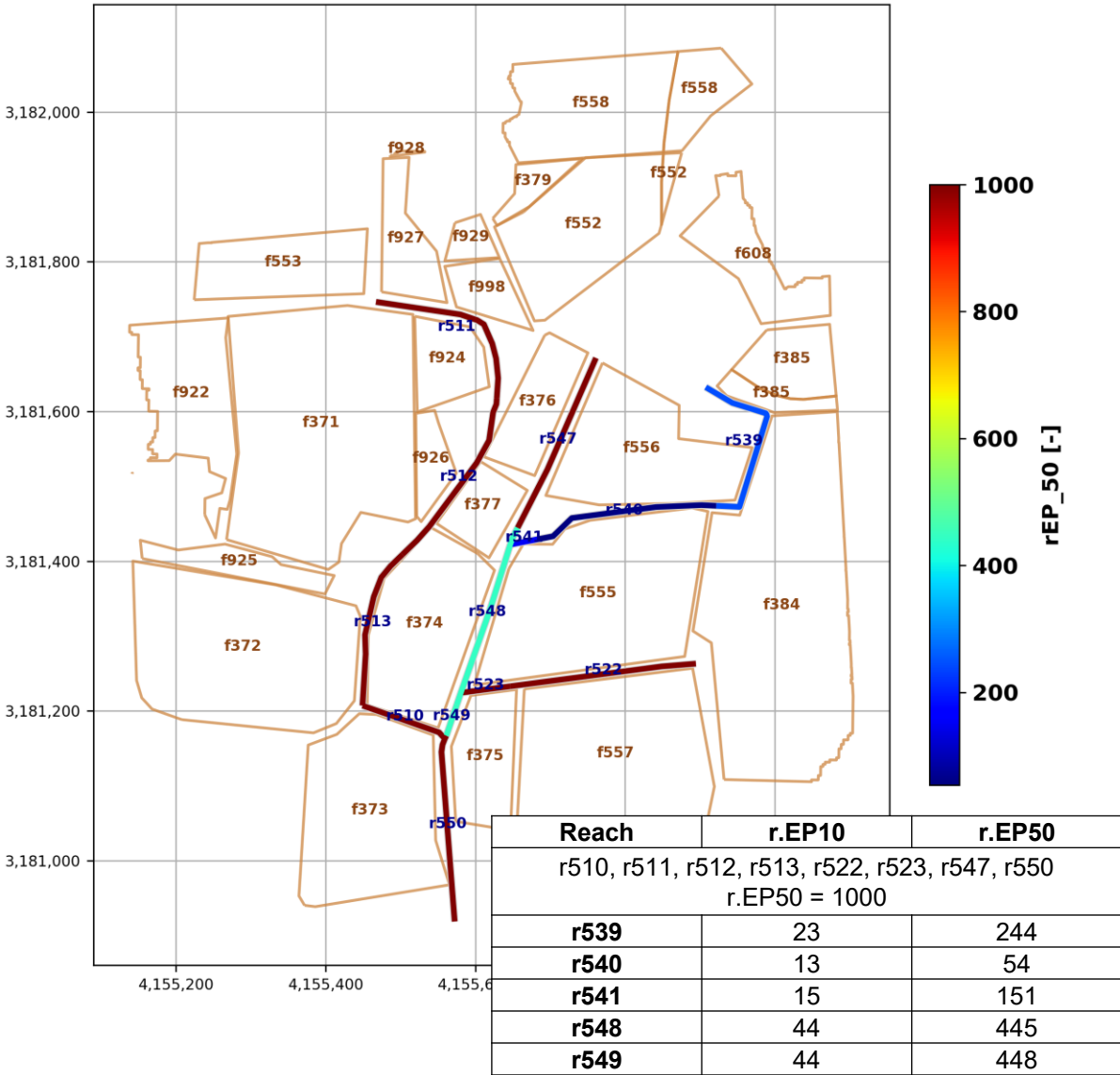
Effects

BBCH 30 (Apr)

X3553QVR117XBJ0TSM



X3553QVR117XBJ0TSM



Reach	r.EP10	r.EP50
r510, r511, r512, r513, r522, r523, r547, r550		
r.EP50 = 1000		
r539	23	244
r540	13	54
r541	15	151
r548	44	445
r549	44	448