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Findings from spatially distributed leaching modelling of pesticides in Germany with GeoPELMO DE

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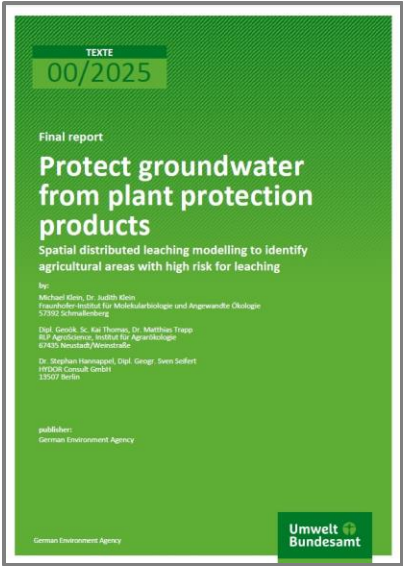
Final report was published in February 2026

PROJECT ARC • 2016–2025

Title: *Protect groundwater from PPPs – SDLM to identify agricultural areas with high risk for leaching*



FINAL REPORT



Published by the German Environment Agency

<https://www.uba.de/n306929de>

Matrix flow is the core of GeoPELMO DE

MODEL BASIS

1 m soil depth for leaching
precautionary principle

New German soil data

GeoPELMO updated with current
geodata

- Subsoil sorption is considered

PROCESS LOGIC

DOMINANT PATHWAY

MATRIX FLOW

chromatographic transport

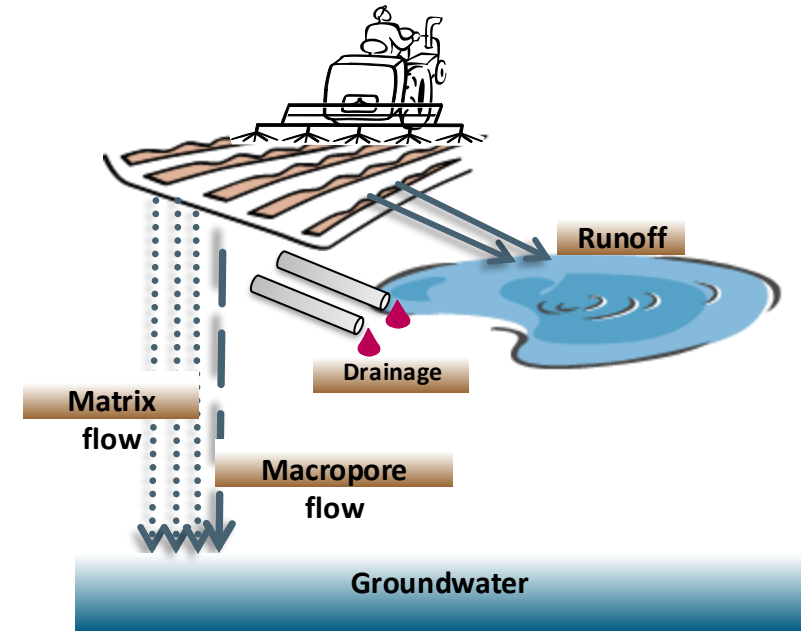
EXTENDED MODEL ADDS

Surface runoff

Macropore flow

Drainage from tile drains

Interflow excluded



TWO MODEL VERSIONS

GeoPELMO DE L

matrix flow

or

GeoPELMO DE L+R+M+D

matrix + runoff + macropore + drainage

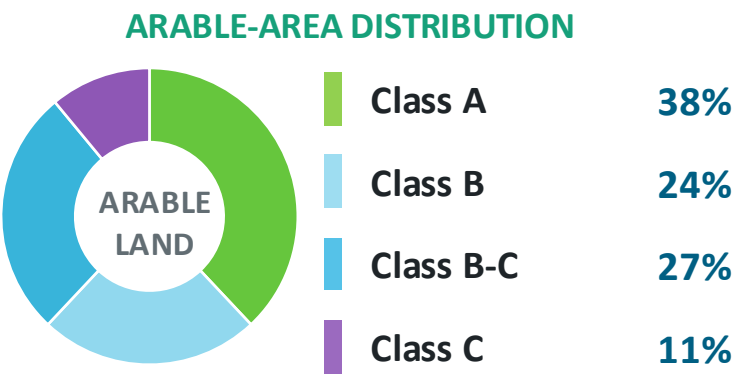
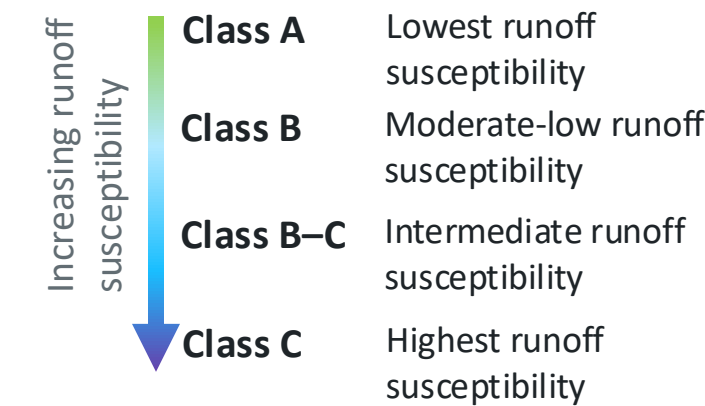
Run-off is modelled based on RCN

Runoff Curve Number (RCN)

Estimated based on:

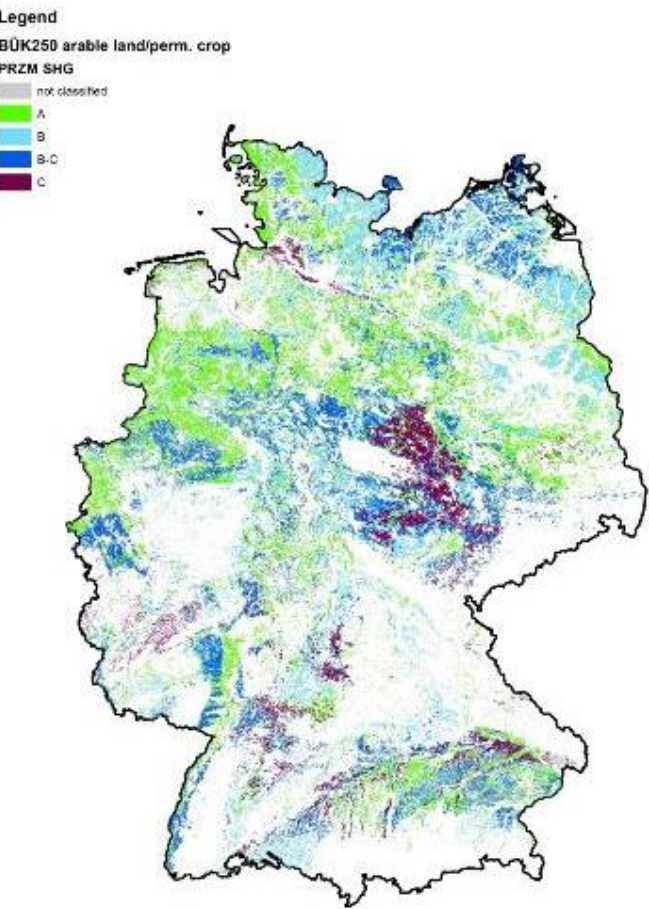
- 01 Soil hydrology** Hydrological properties of the soil
- 02 Crop type** Land use and crop-specific conditions
- 03 Soil moisture** Moisture conditions at the time of rainfall

BÜK250 soil profiles were assigned to four hydrologic soil groups using the FOOTPRINT classification.



Share of German arable land by hydrologic soil group (FOOTPRINT classification).

Spatial distribution of hydrological soil groups



Spatial distribution of hydrological soil groups for arable land and permanent crops in Germany (FOOTPRINT)

Drainage in GeoPELMO DE based on soil types

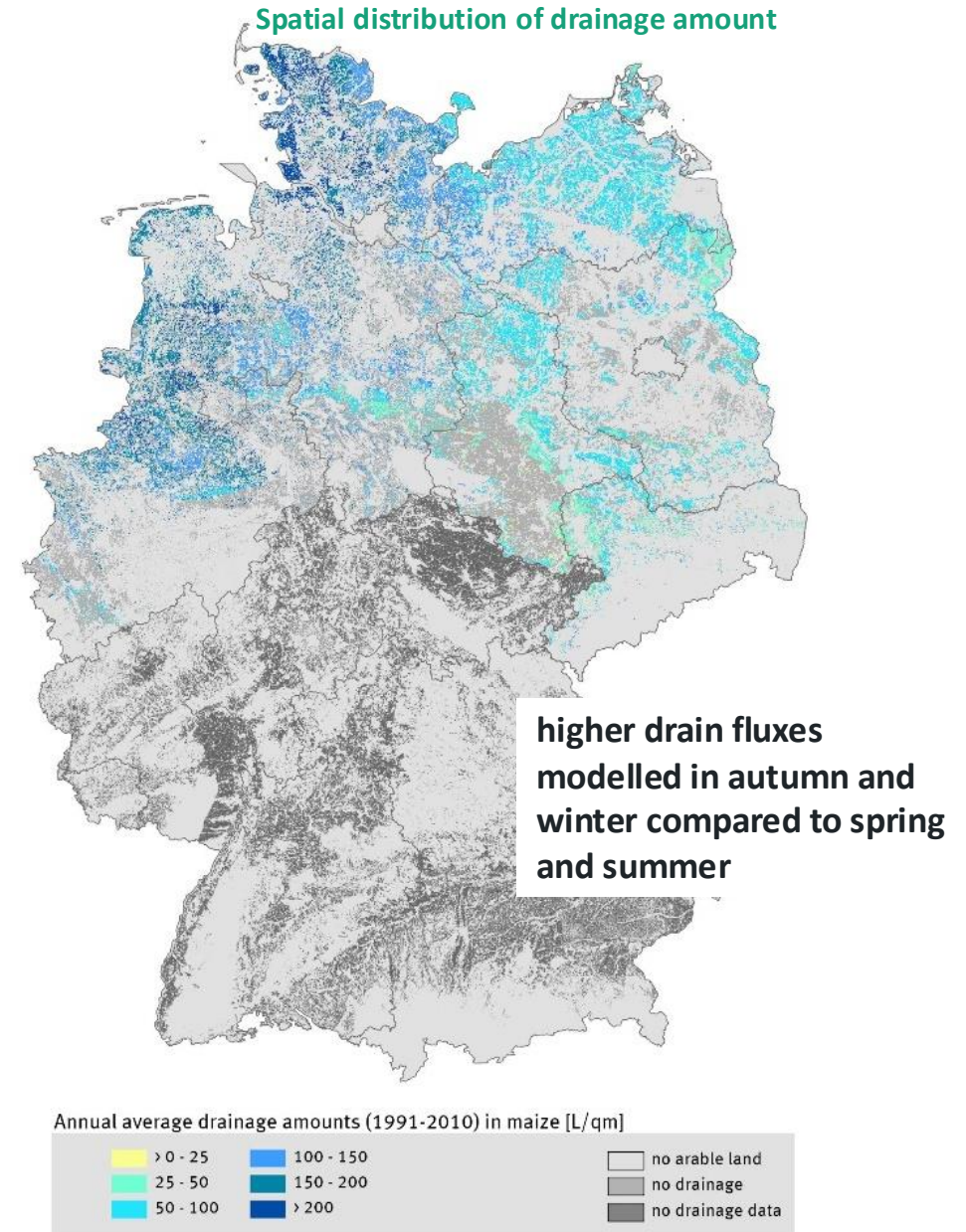
Drainage

- information about drained fields not available
- maps of potentially drained areas for 6 Federal states in Northern Germany
- drainage rates for soils in 3 Federal states

Drainage defined in GeoPELMO DE:

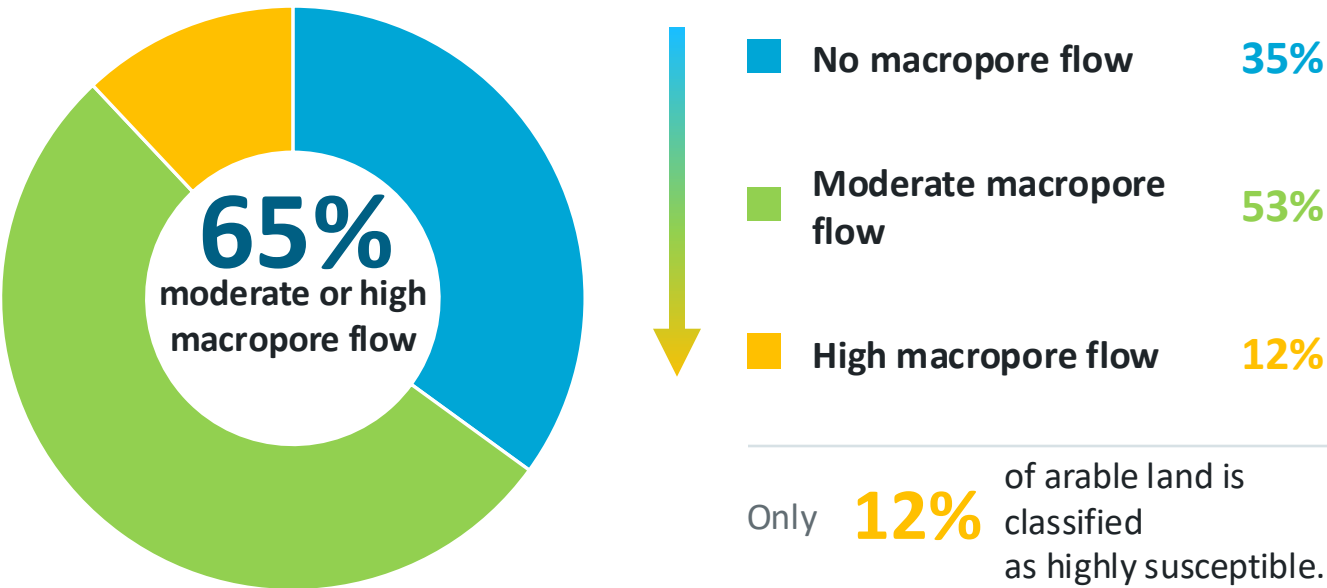
- for 7 Federal states in Northern Germany
- drainage efficiency factor (f_{eff}) reduces percolate rates in 80cm soil depth

Spatial distribution of drainage amount



Macropore flow affects 65% of arable land – but high susceptibility is limited to 12%

ARABLE-AREA DISTRIBUTION

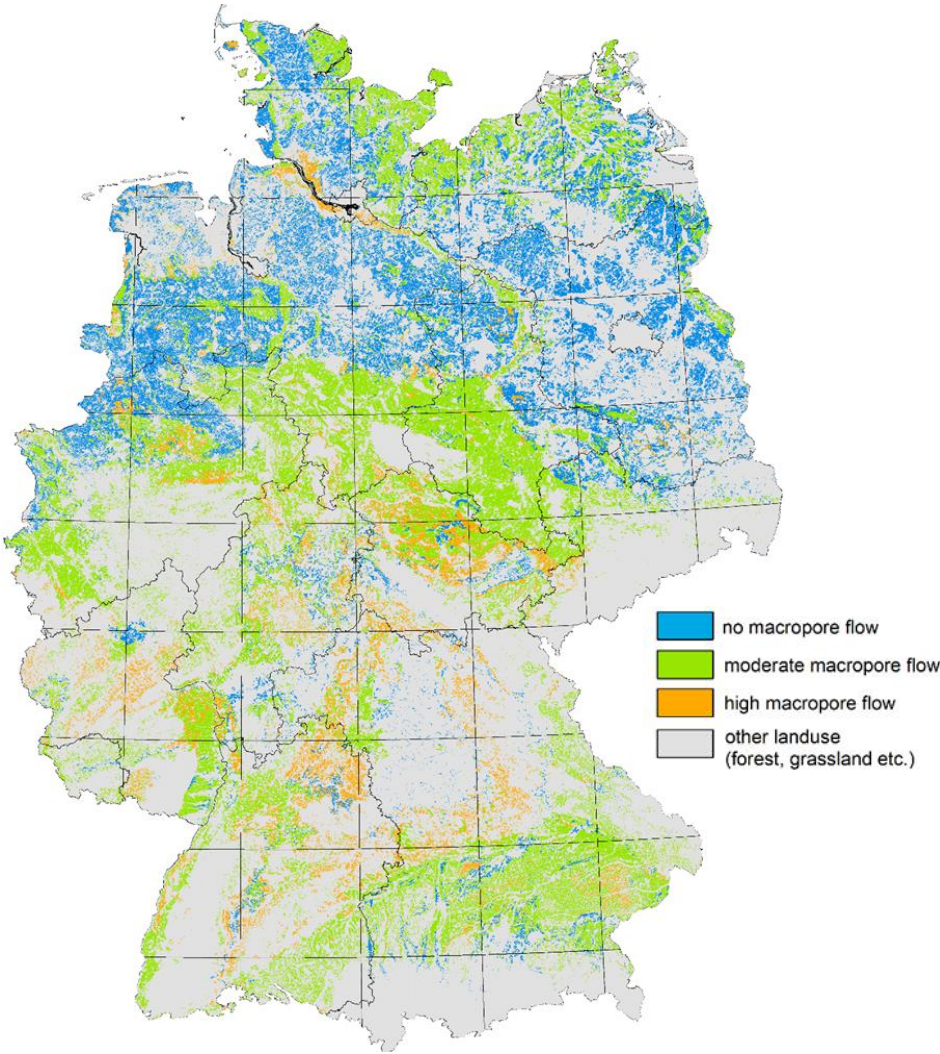


MODEL LOGIC

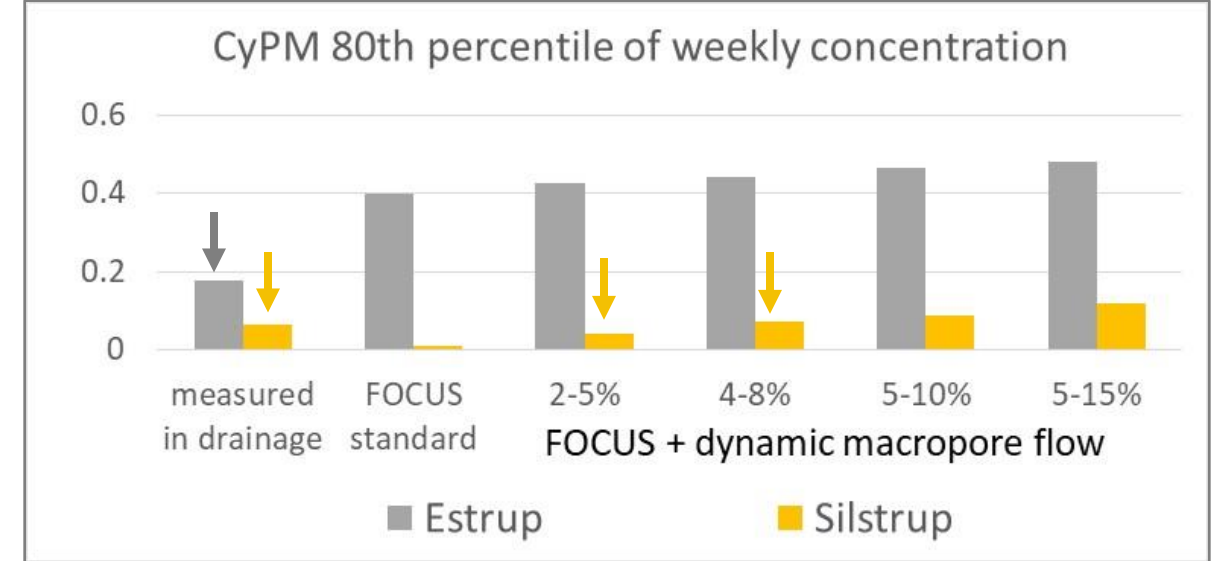
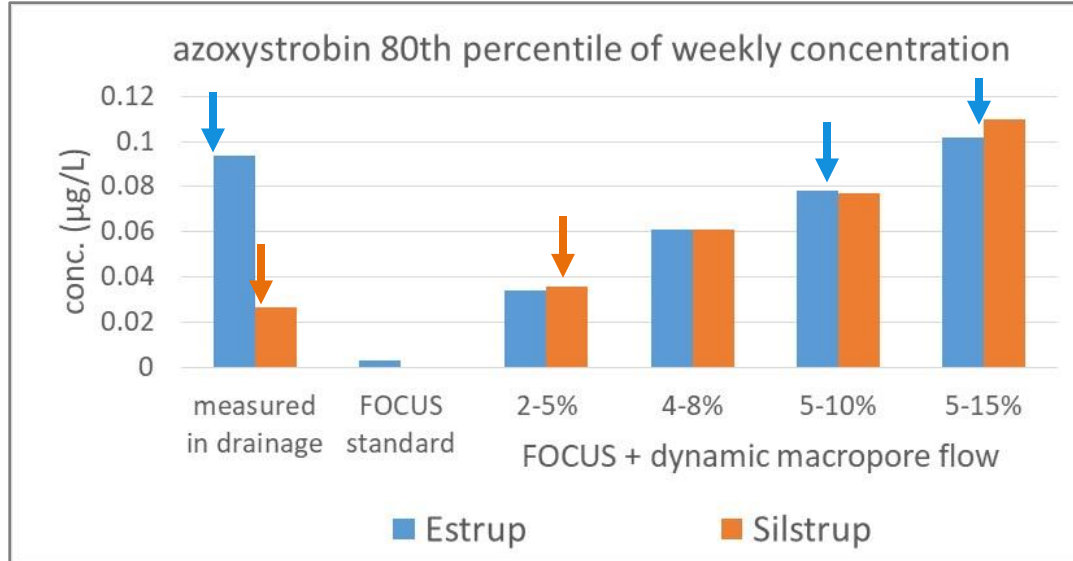
A combination of static and dynamic approach is used depending on periods of dry weather before heavy rain events.

Up to 8% of daily rainfall above 10 mm is routed through macropores at 80 cm depth for soils with high macropore flow.

Spatial distribution of macropore flow

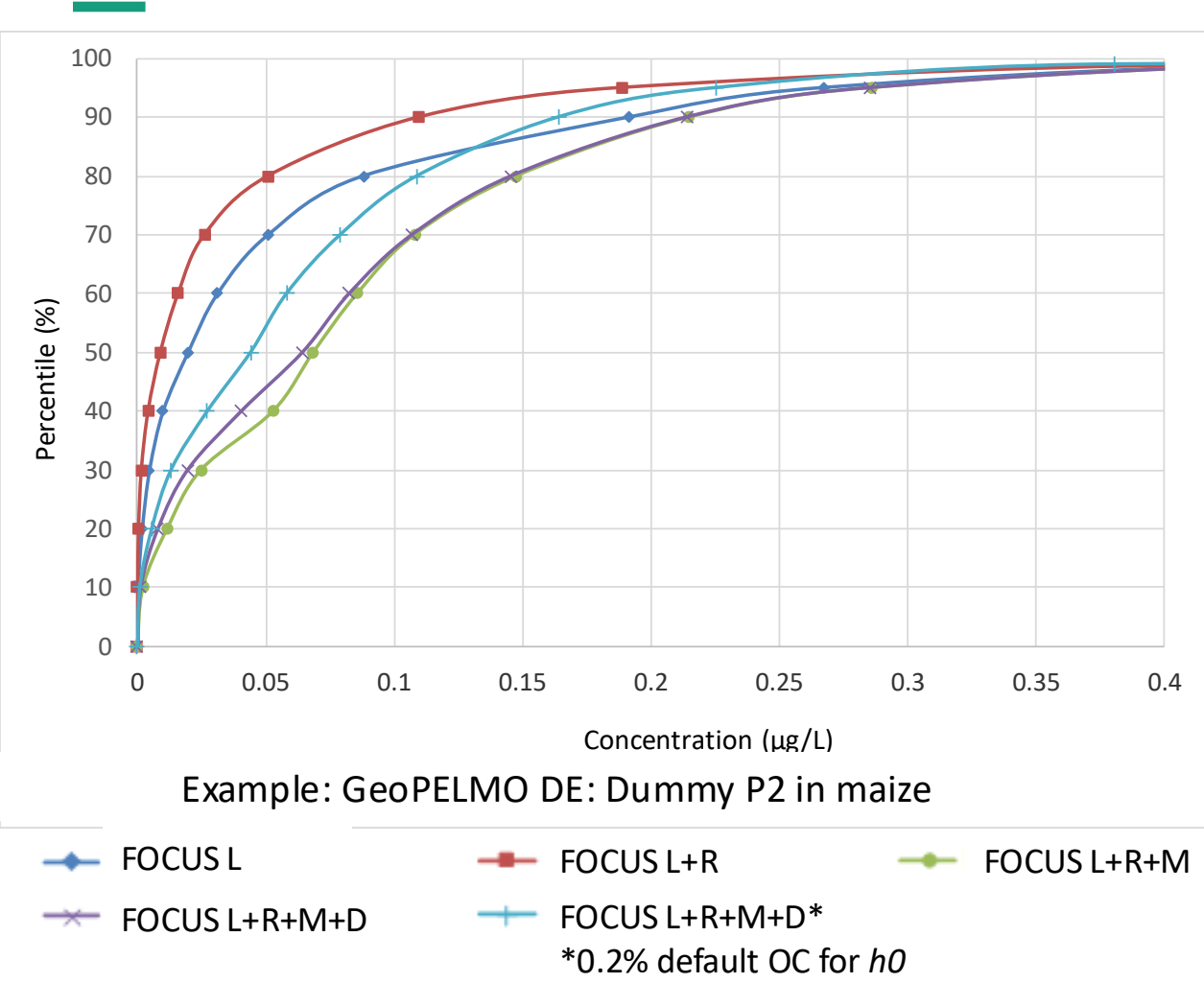


Macropore flow calibration based on Danish PLAP monitoring data and lysimeter studies



- A low to medium parameterization of static + dynamic macropore flow of 4-8% was finally defined in GeoPELMO DE for soils with high potential for macropore flow,
- and 2-4% (half) for soils with moderate macropore flow

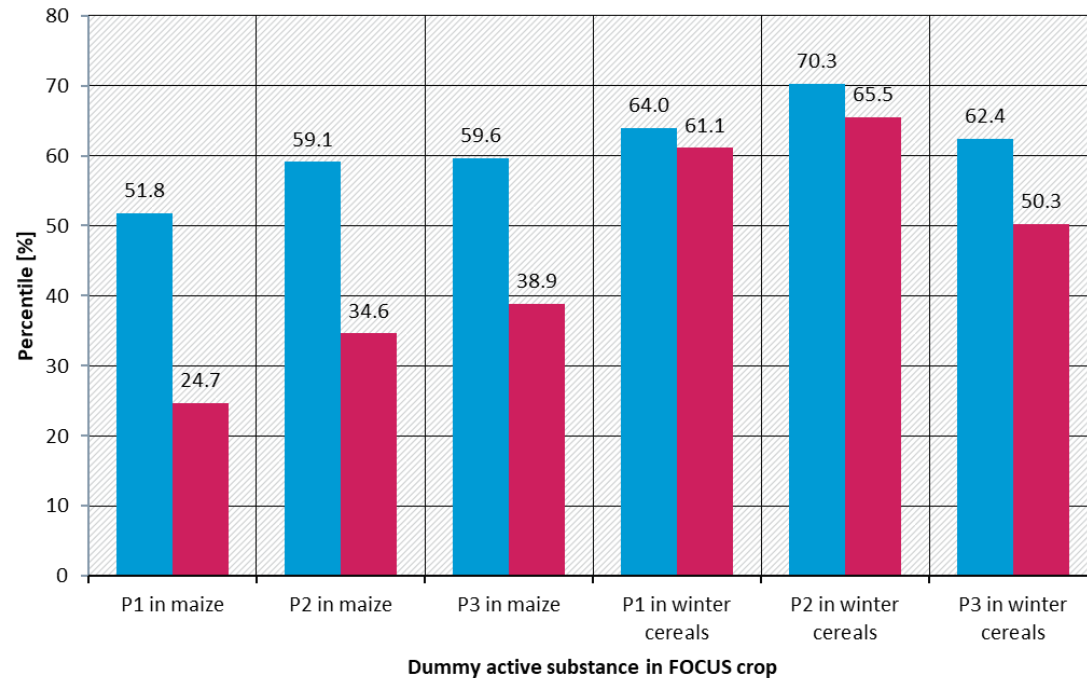
Macropore flow drives the strongest upward concentration shift



PROCESS EFFECTS	ACTIVE SUBSTANCES	METABOLITES
RUNOFF	↓ Mainly lowers concentrations	↕ May lower or raise concentrations
MACROPORE FLOW	↑ ↑ Strongest upward shift	↕ May lower or raise concentrations
DRAINAGE	↓ Small downward shift	↕ May lower or raise concentrations
COMBINED EFFECT	Together, the processes reshape the full concentration distribution; subsoil organic carbon <i>h0</i> adds another shift.	

Additional processes reduce protection levels

3 parent compounds in maize and in winter cereals

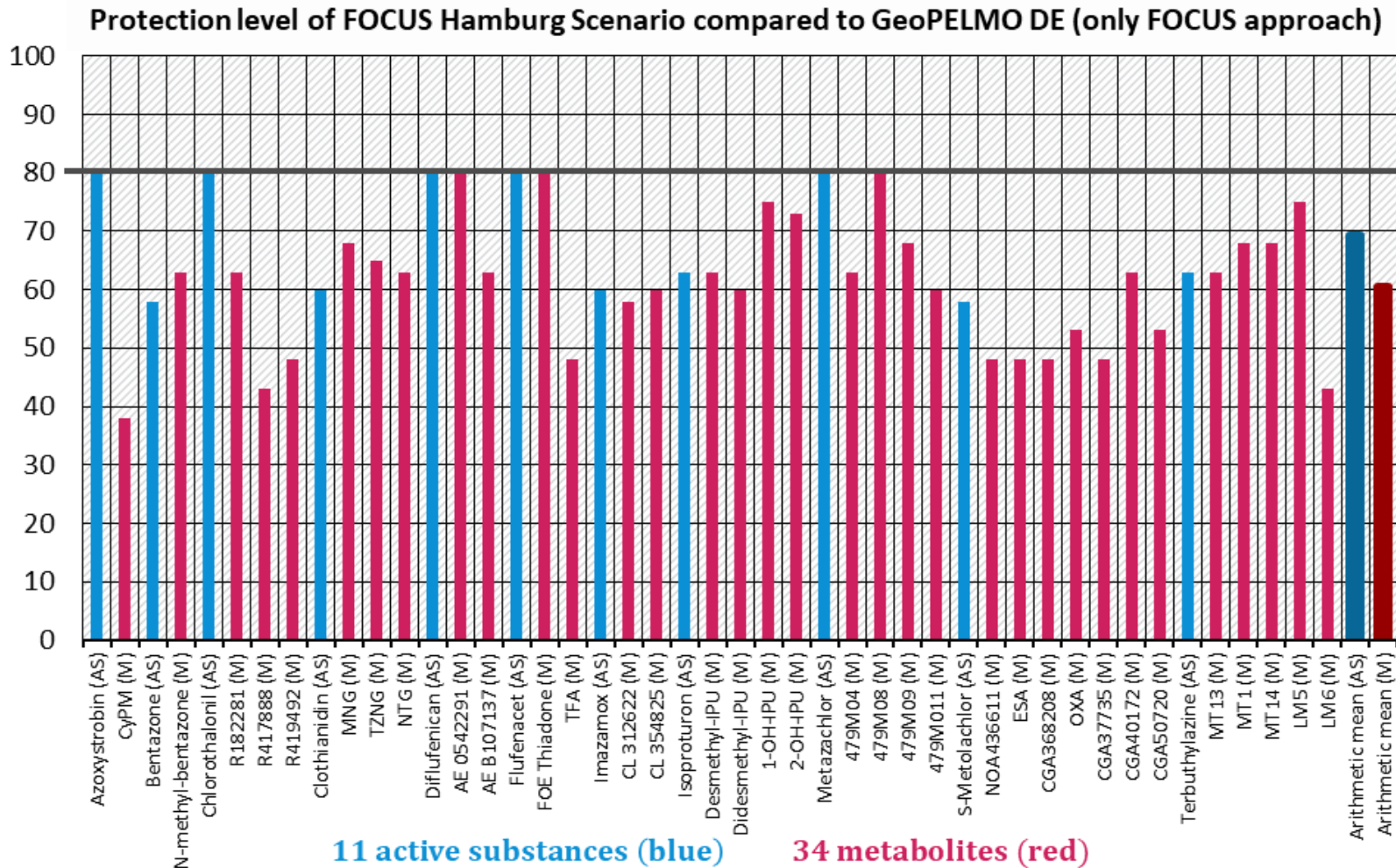


Hamburg compared to GeoPELMO DE L (matrix flow)

Hamburg compared to GeoPELMO DE L+R+M+D

- Hamburg does not cover the expected 80th spatial percentile of nationwide modelled percolate concentrations
- Percentile (level of protection) is lower for active substances if additional processes are considered
- mainly macropore flow results in a lower level of protection, particularly in spring applications (maize)

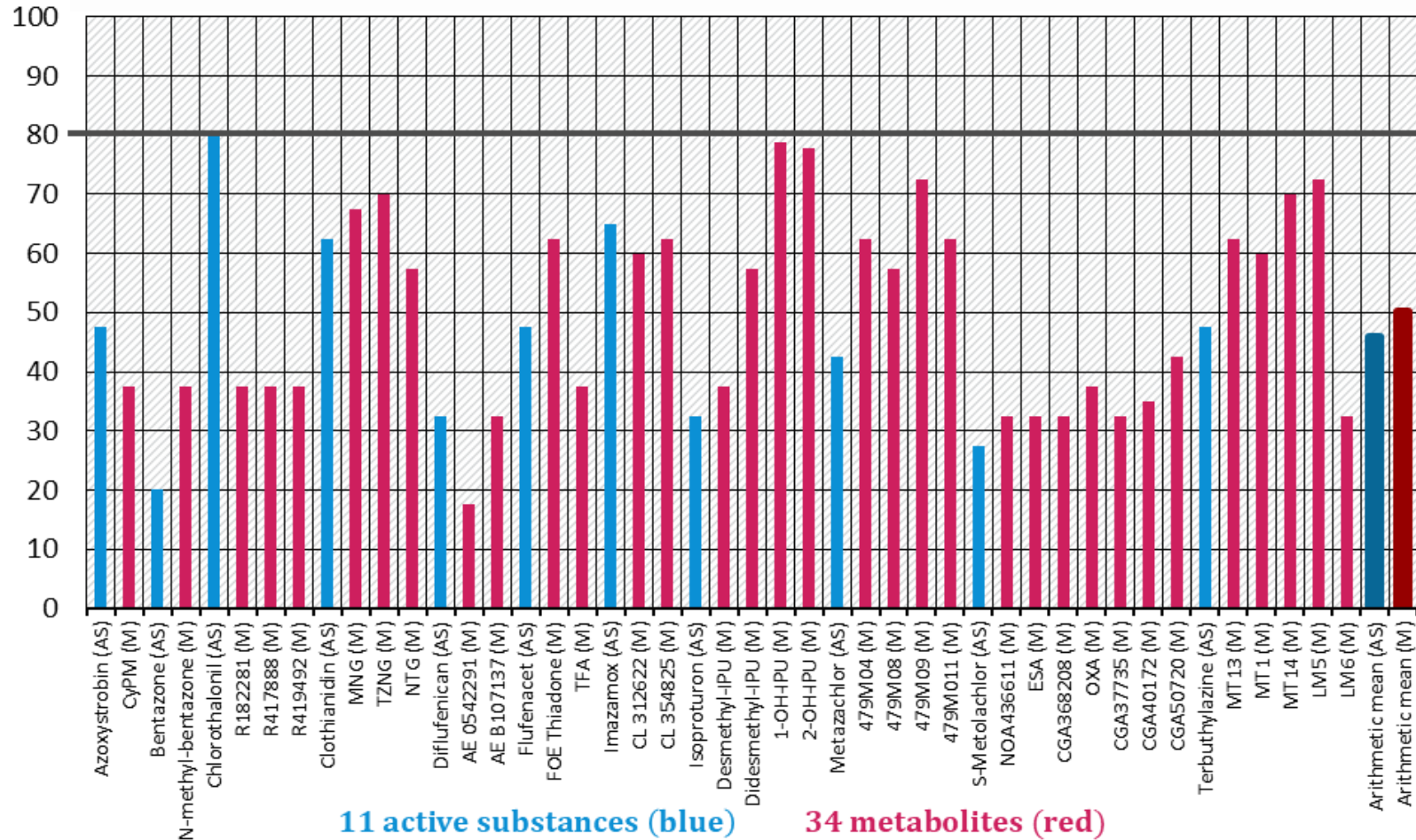
Many active substances & metabolites analysed



- Evaluation of a large number of active substances and metabolites using **GeoPELMO DE L (matrix flow)**
- Protection levels vary strongly between substances

Additional processes reduce protection levels

Protection goal of FOCUS Hamburg Scenario compared to GeoPELMO DE (+ additional processes)



- Evaluation of a large number of active substances and metabolites using **GeoPELMO DE L+R+M+D**
- Protection levels vary strongly between substances

GeoPELMO DE provides a prototype for nationwide leaching assessment

FRAMEWORK

A new GeoPELMO DE version adds runoff, macropore flow and drainage.

Nationwide climate, soil and groundwater datasets were reviewed and adapted.

CALIBRATION

Lysimeter results and Danish PLAP monitoring data supported macropore-flow calibration in PELMO.

Evidence connects the nationwide framework to observed behaviour.

MAIN EFFECTS

- Water balance** Runoff and drainage had the strongest influence.
- Concentrations** Macropore flow and subsoil organic-carbon parametrisation had the strongest effects.
- Conservatism** Nationwide leachate estimates were often more conservative than FOCUS Hamburg.

MORE INFORMATION Visit poster S2P01 for further information on scenario selection.

Reference: Klein et al. (2026), TEXTE 33/2026, doi:10.60810/openumwelt-8431

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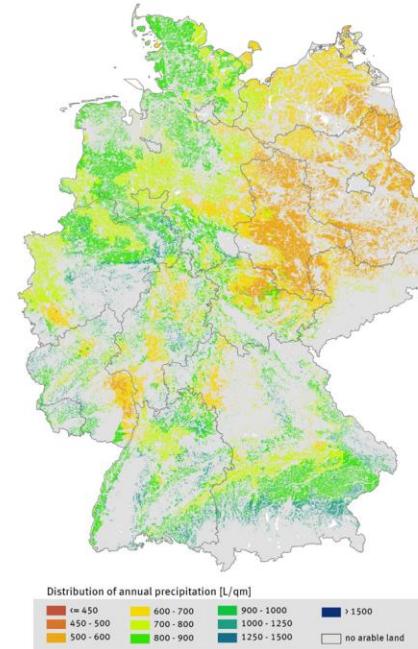
Nationwide weather and soil data adapted

Weather data

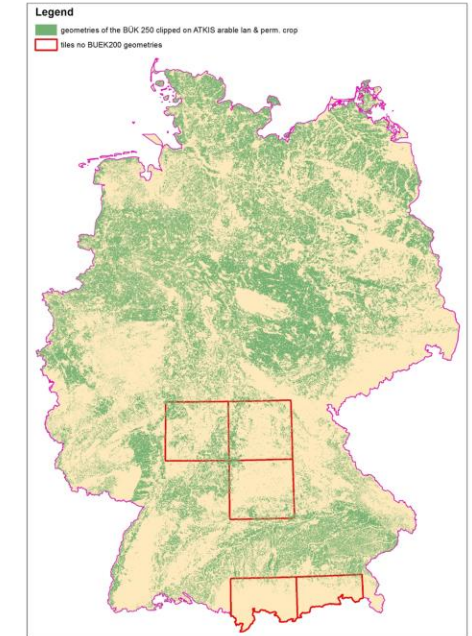
- 299 German Weather Service stations; daily records, 1985–2010
- Precipitation, temperature and relative humidity; west–east rainfall gradient
- Stations assigned spatially using seasonal temperature and precipitation

Soil data (BÜK 250)

- 3,400 profiles for arable land and permanent crops
- Effective field capacity and field capacity derived from soil texture
- Subsoil organic-carbon data become less reliable with depth



Mean annual precipitation
1985–2010 (Klein et al. 2026)



BÜK 250 soil profiles
for agricultural land

Hamburg has a higher OC content than average soils

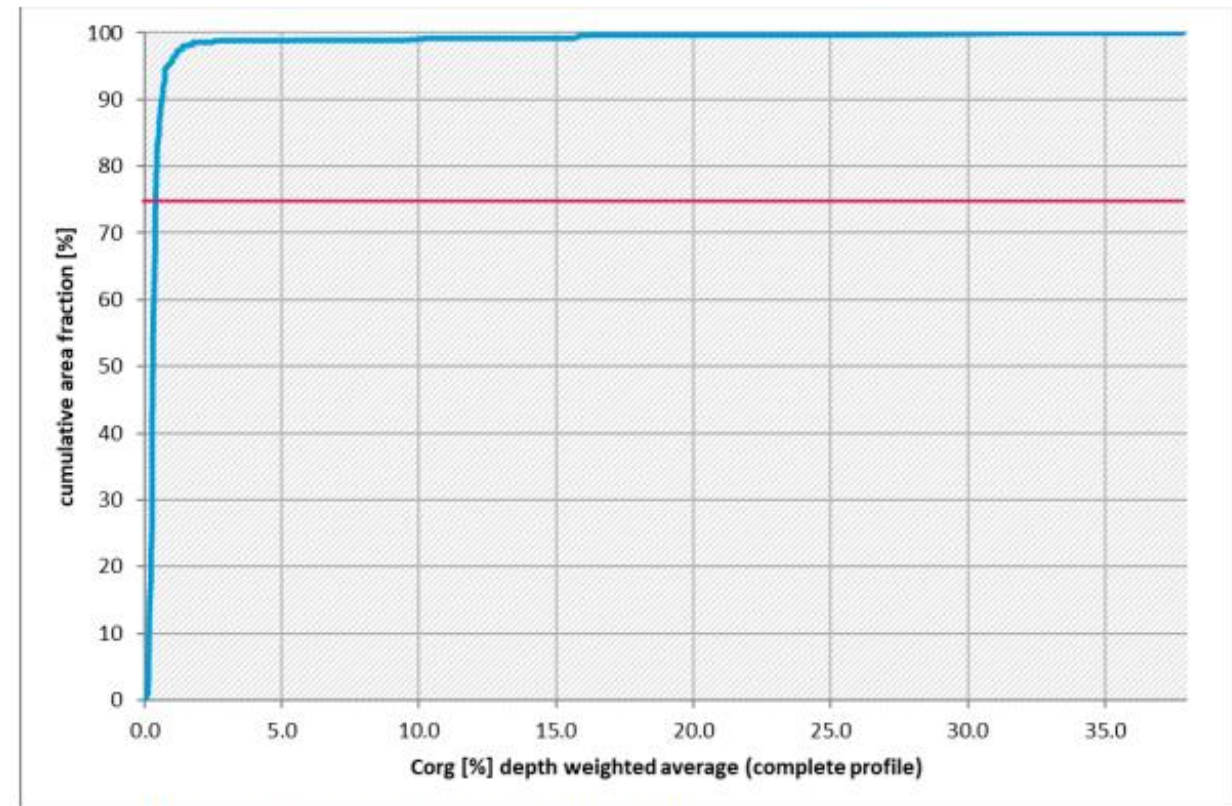
FOCUS Hamburg

- Assumes: sandy soil, low organic carbon, high winter precipitation
- Intended as a conservative “worst-case” scenario

Soil depth [cm]	OC [%]
0–30	1.5
30–60	1.0
60–75	0.2
75–200	0
0-100	0.78 → 60th
100-200	0.39 → 74th

Figure 7: Cumulative distribution function of the nationwide depth weighted organic carbon contents based on the BÜK200 compared to the FOCUS Hamburg scenario

The depth weighted organic carbon contents are related to complete soil profiles based on the BÜK200. The fuchsia colored line shows the corresponding depth weighted organic carbon content of the FOCUS Hamburg scenario as spatial percentile.



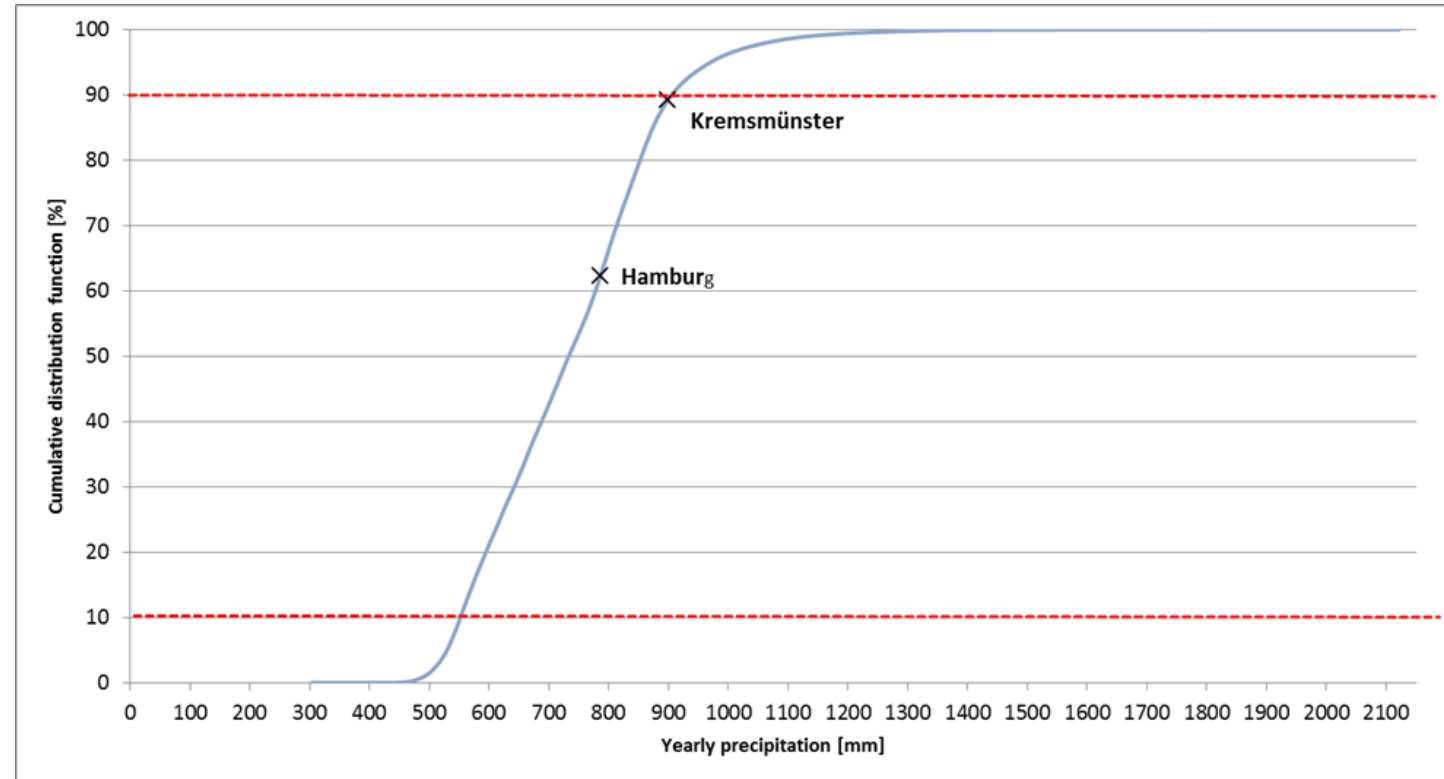
Source: own illustration, RLP AgroScience (according to BGR 2017)

FOCUS Hamburg: Rainfall is mid-range, not extreme

FOCUS Hamburg

- Assumes: sandy soil, low organic carbon, high winter precipitation,
- Intended as a conservative “worst-case” scenario

Scenario	Annual prec. [mm]
Hamburg	786 → 62.3th
Kremsmünster	899 → 89th



Why does Hamburg differ between GeoPELMO EU SDLM and GeoPELMO DE?

GeoPELMO EU SDLM

FOCUS Hamburg
Compared with:
SDLM Hamburg Zone

- large spatial domain
- Generalized soil clusters
- Uniform depth layers
- Limited subsoil OC calibration
- Hamburg emerges as apparent worst-case

GeoPELMO D

FOCUS Hamburg
Compared with:
Germany spatial domain

- Spatially explicit BÜK250 profiles
- Calibrated subsoil OC (4,249 measurements)
- Improved hydrological realism
- Hamburg not consistently national worst-case

Different spatial domains compared

→ Not a harmonised comparison

→ Additional uncertainty:
no common substance basis

Observed differences may be driven by:

→ spatial extent

→ environmental heterogeneity

NOT necessarily by:

→ soil parameterisation

→ subsoil OC

→ process representation

Required next steps:

- harmonised comparison (restrict GeoPELMO EU to Germany domain, derive comparable percentiles)
- assess model differences
- analyze drivers (soil, climate, processes)