Modeling aquatic and terrestrial transport pathways for microplastics entering WWTP systems

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Introduction

Background:

- Microplastics may enter the environment from a number of sources and in many forms.
- Plastic particles may be present as influent into municipal wastewater treatment plants (WWTPs).
- A large portion of these are removed from the water phase during the treatment process, and generally end up in the solids (i.e., sludge).
- Sludge disposal varies by country, region and locality, including landfill, incinerator, compost, or as land-applied biosolids.
- There is potential for particles in biosolid applications to reach aquatic systems depending on application location and subsequent environmental conditions.

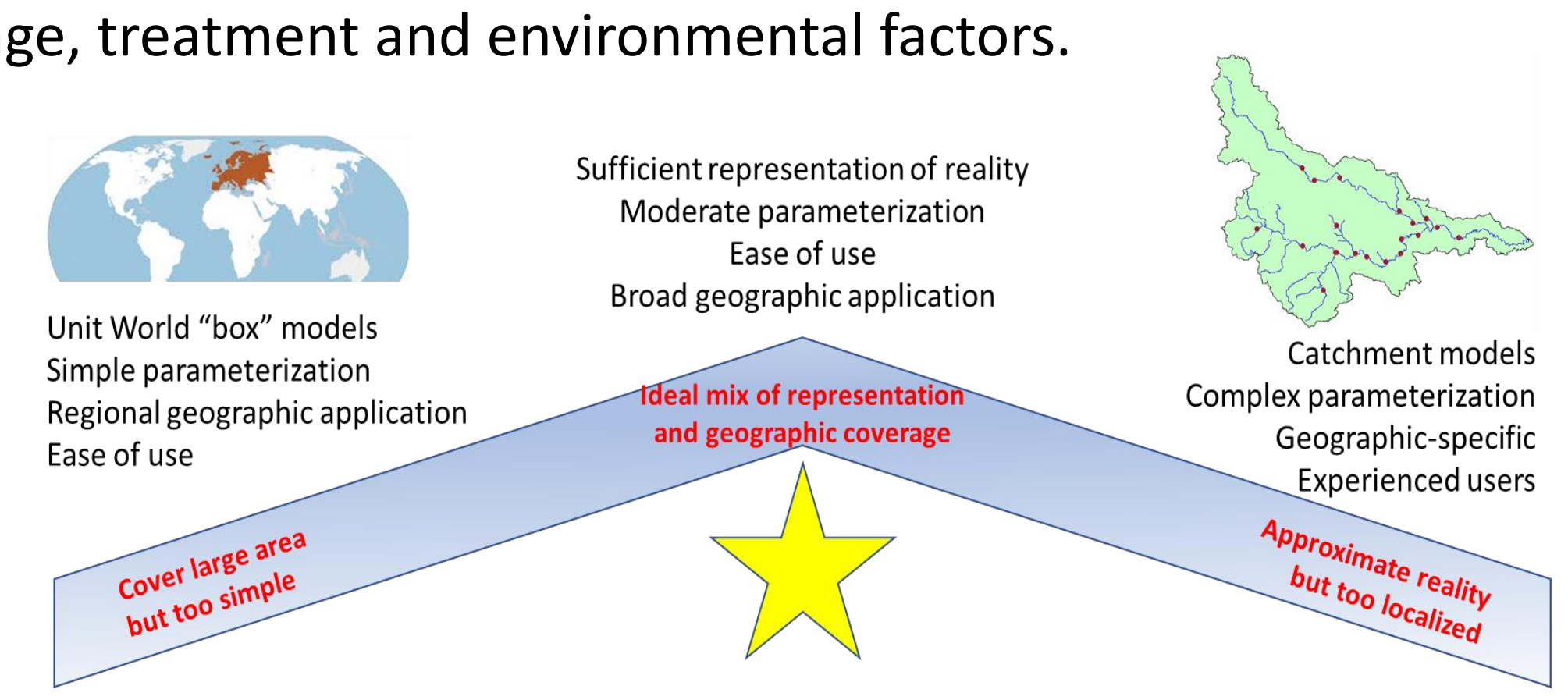
We present a broad-scale model designed to estimate emissions and model the fate of plastic particles exiting WWTPs into the terrestrial and aquatic environments

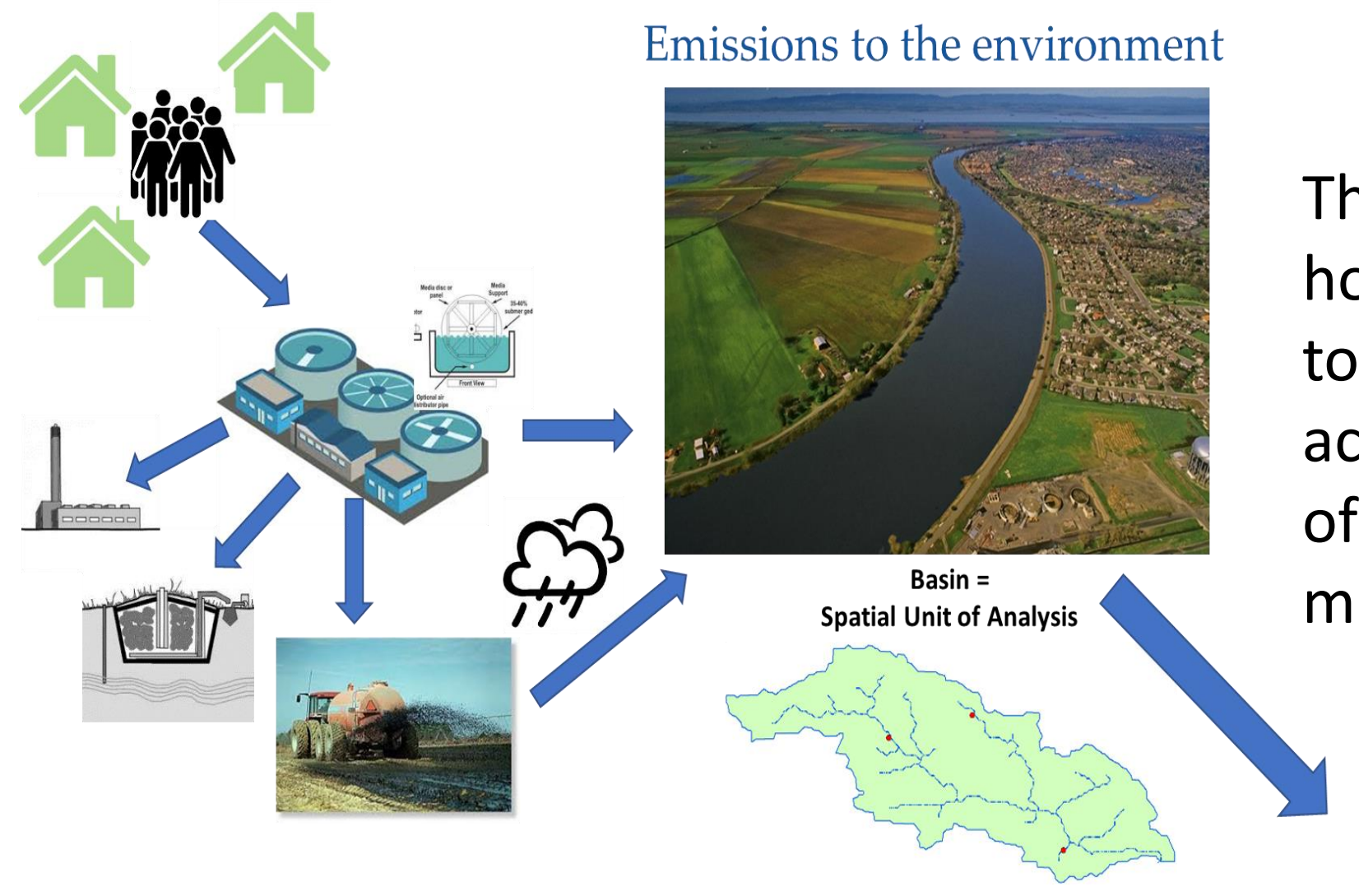
- using spatially-explicit information on WWTPs, river hydrology and terrestrial transport potential.

This regional/continental scale model is based on publicly available datasets and contained in a modular framework which is scalable and portable to multiple geographies.

Conceptual Model

The model was designed to be global in extent but incorporate sufficient local processing to capture the geographic heterogeneity of usage, treatment and environmental factors.

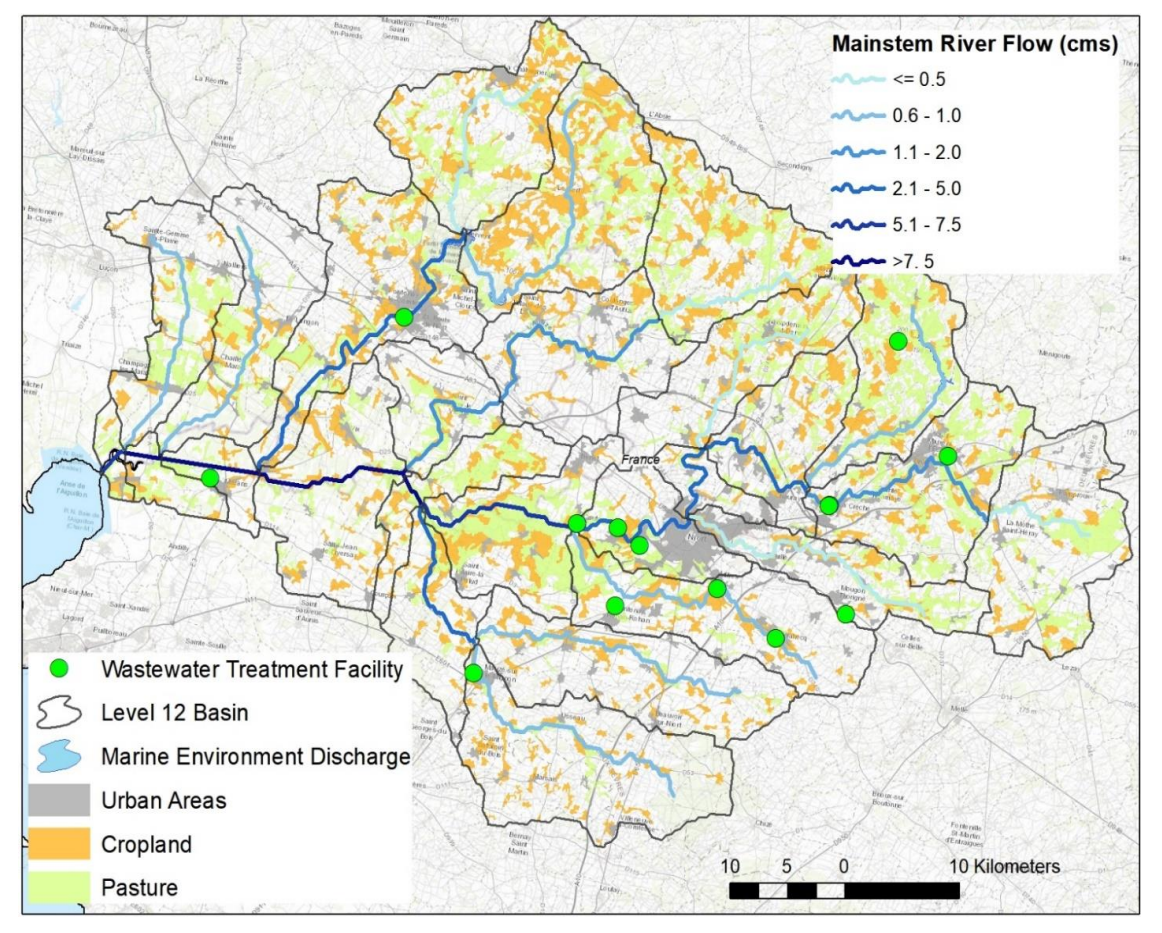




The model captures household emissions to wastewater and accounts for handling of sludge containing microplastic particles.

Unit of Analysis

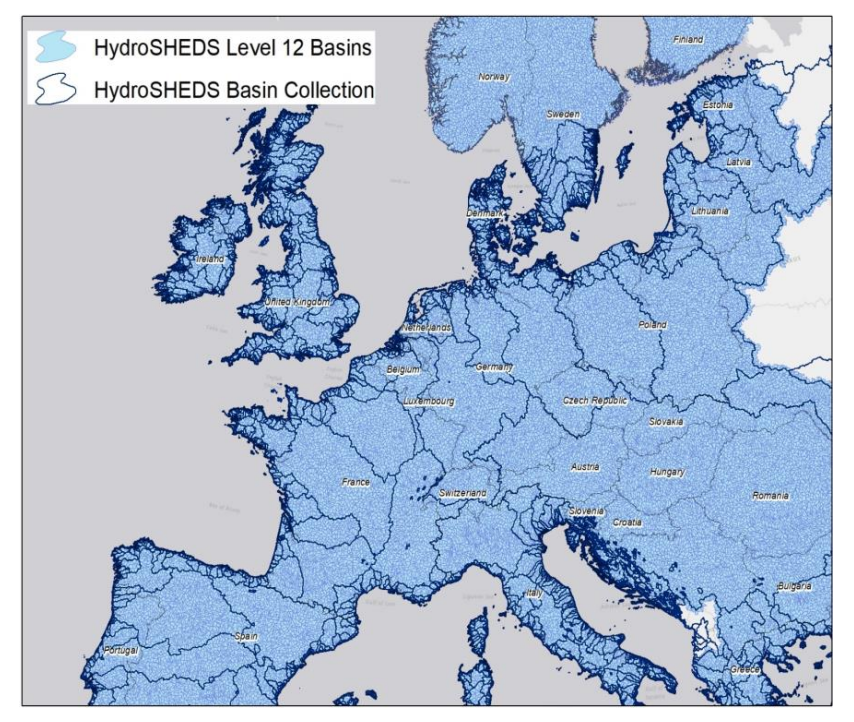
The HydroSHEDS level-12 sub-basin is the spatial unit of analysis for the model. Each sub-basin (n=38,444 for EU-30) is attributed with environmental and anthropogenic factors related to emissions and fate within the basin.



A watershed containing 28 sub-basins with corresponding land cover and WWTP locations.

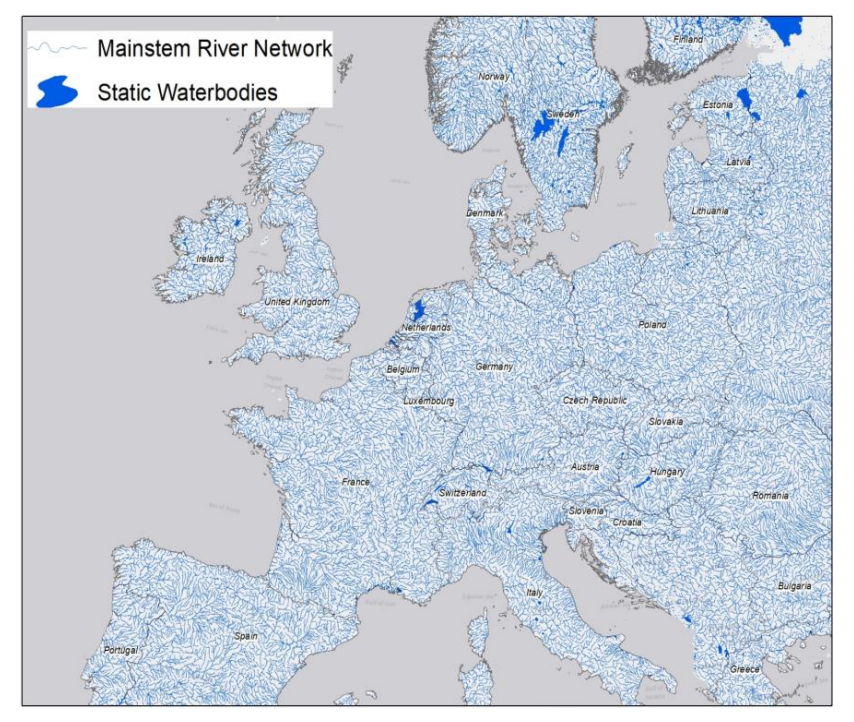
Global and Regional Environmental and Anthropogenic Data

Basins



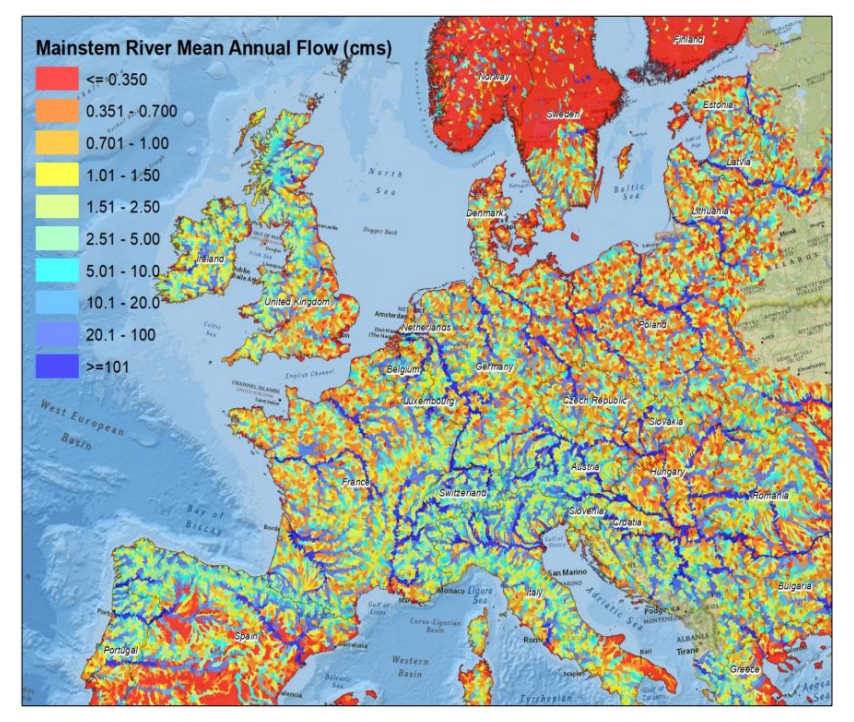
HydroSHEDS provides framework for characterization and routing

Rivers & Lakes



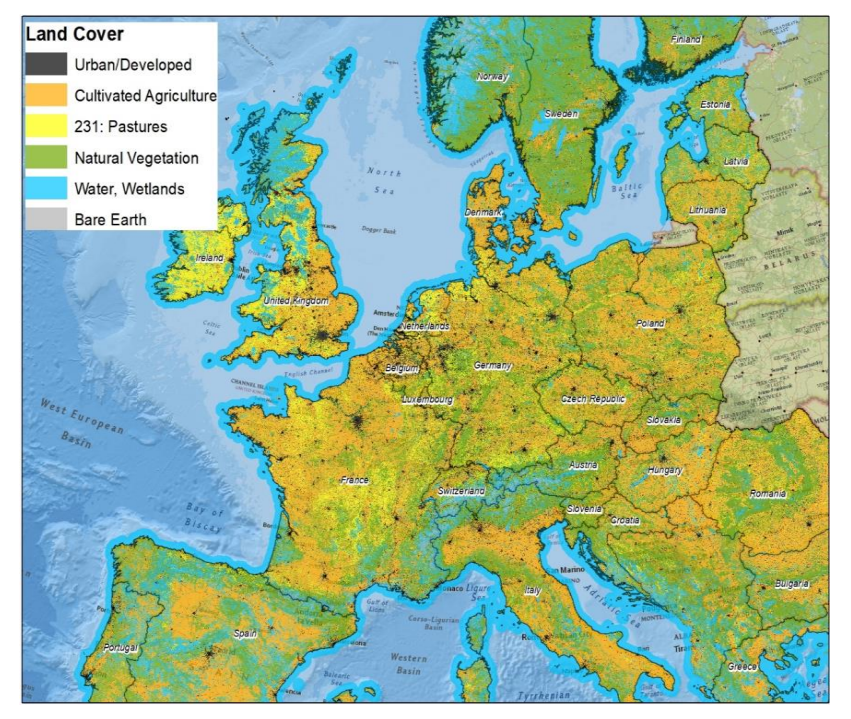
Mainstem river and lakes from HydroSHEDS (and CCM above 60N)

River Flow



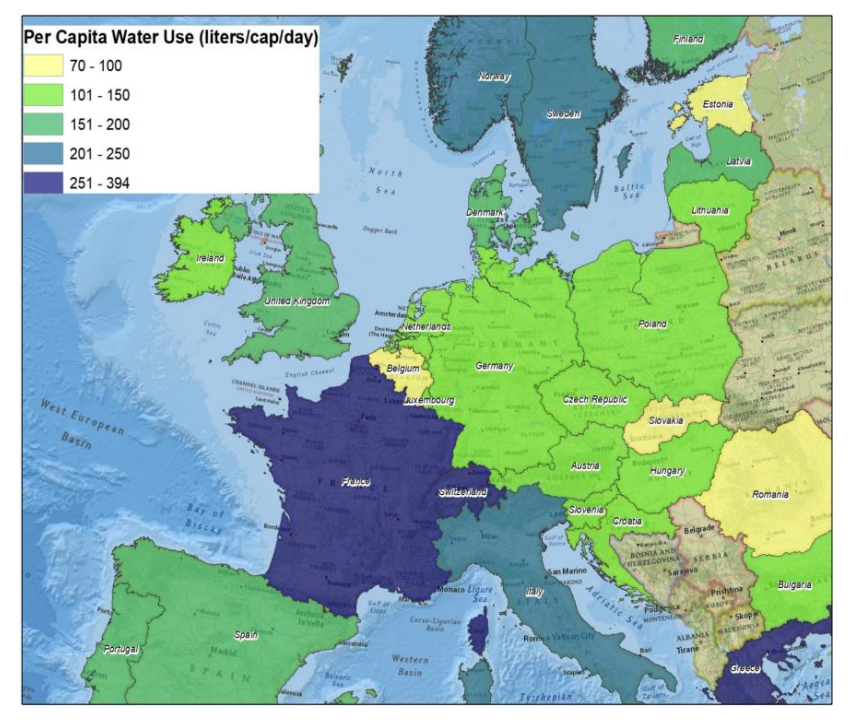
55 years of flow data available from FLO1K, overlaid on river mainstem

Landcover



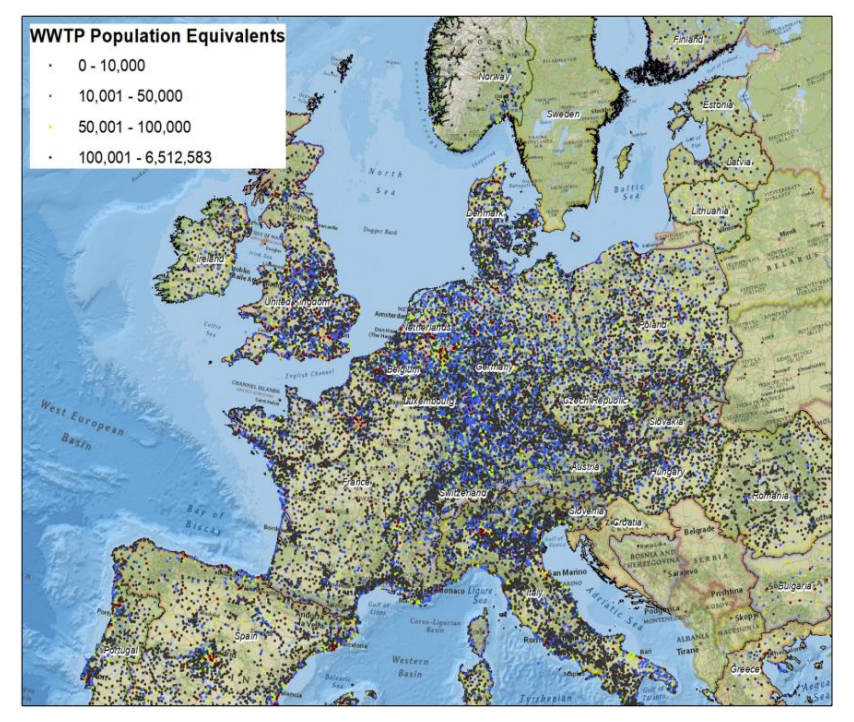
Urban, agriculture and pasture landcover from JRC Corine LC

Water Use



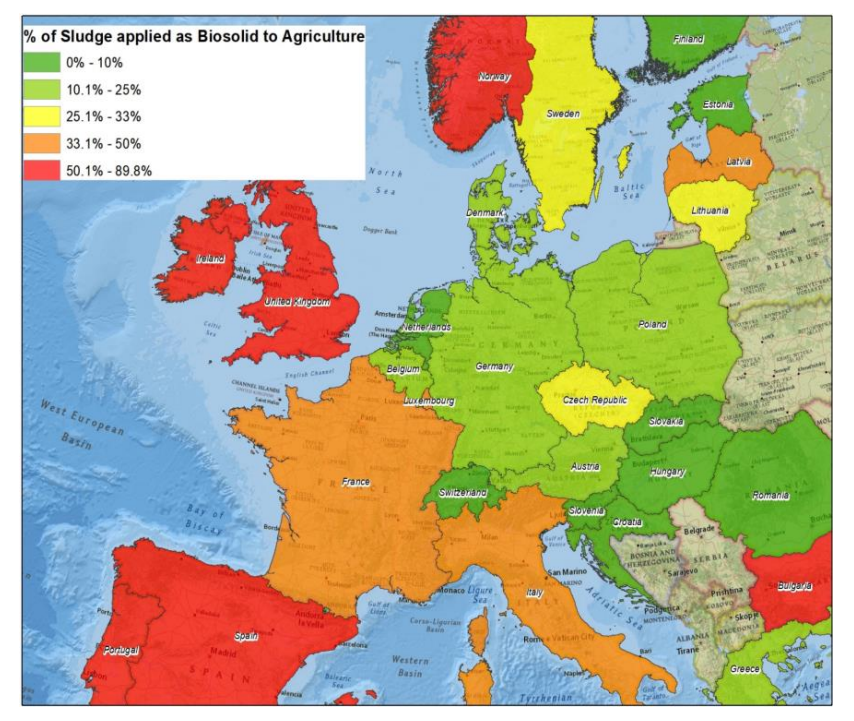
Per capita water use from Eurostat and Member State level sources

Wastewater



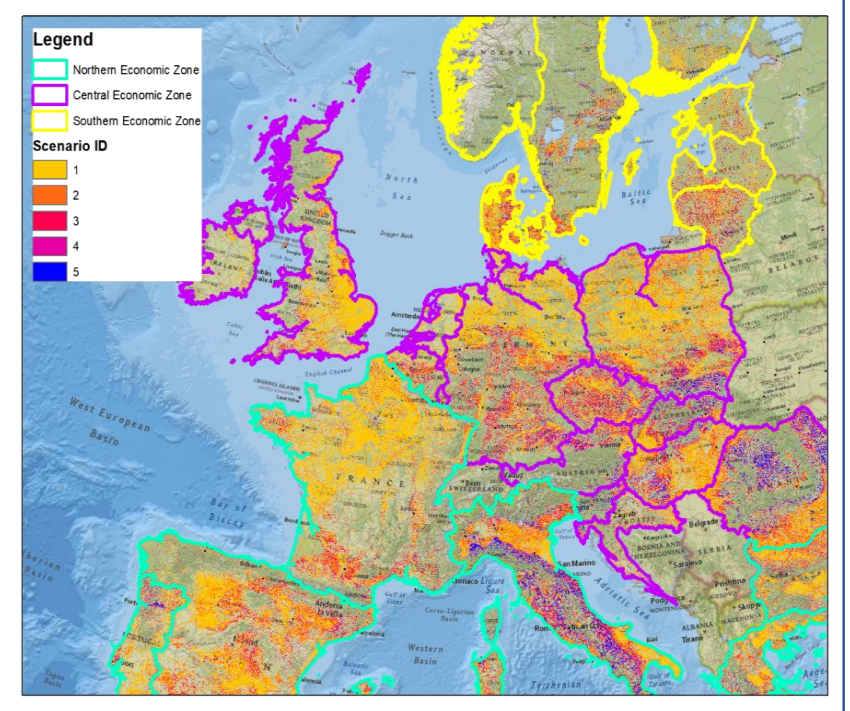
Municipal facilities from EEA's WaterBase – location and population

Biosolid Application



Sewage sludge disposal from wastewater treatment - Eurostat

Runoff Potential

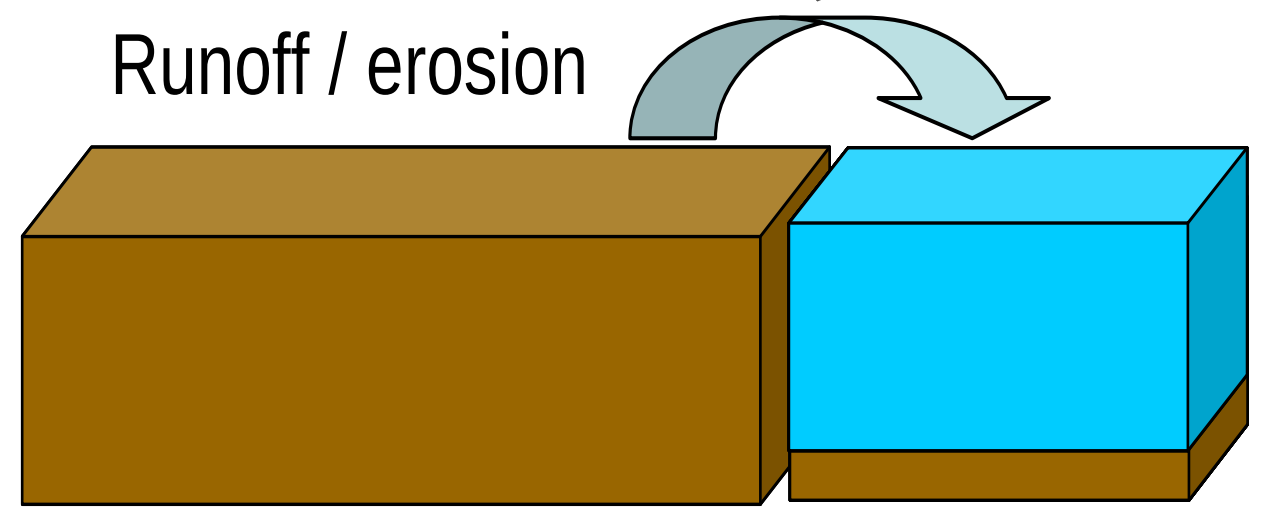


Erosion potential based on JRC soil loss data + PRZM pesticide model

Movement from the Terrestrial Environment

Microplastics captured in sludge and applied to agricultural land via biosolids are modeled with the Pesticide Root Zone Model (PRZM) using 15 scenarios covering weather and soil characteristics. Scenarios were informed by a JRC dataset using RUSLE2015 to estimate soil loss in Europe utilizing rainfall erosivity, soil erodibility, cover management, topography, and support practices (Panagos *et al*, 2015). Within each of the three defined EFSA zones, a geometric binning approach was used to identify 5 bins (0-50th, 51-75th, 76th-87.5th, 87.6-93rd, 94th-100th) in order to ensure inclusion of high erosion areas.

Biosolid application occurred twice a year to maize. One-half of the PRZM 30-year annual average % of applied mass leaving the field is conservatively assumed to occur twice a year. These aspects are configurable.

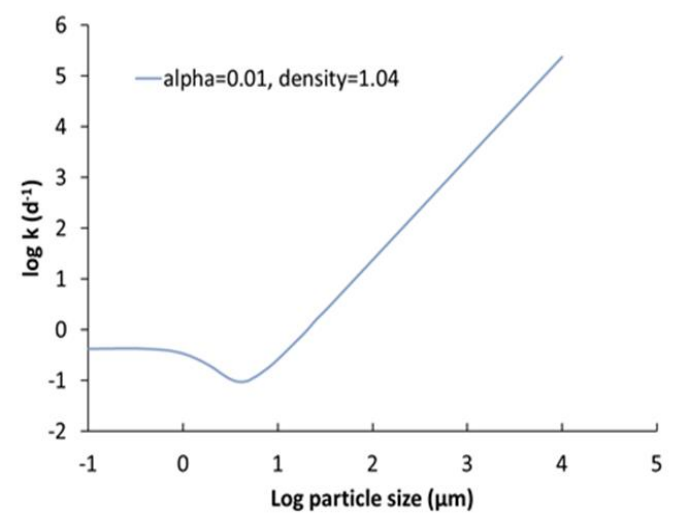


30-year annual average % of applied mass leaving the field

A "baseline" PEC is calculated excluding episodic events such as agricultural runoff. This represents the steady-state condition from continual WWTP effluent. Episodic events add additional mass (and water) to simulate a "peak" event.

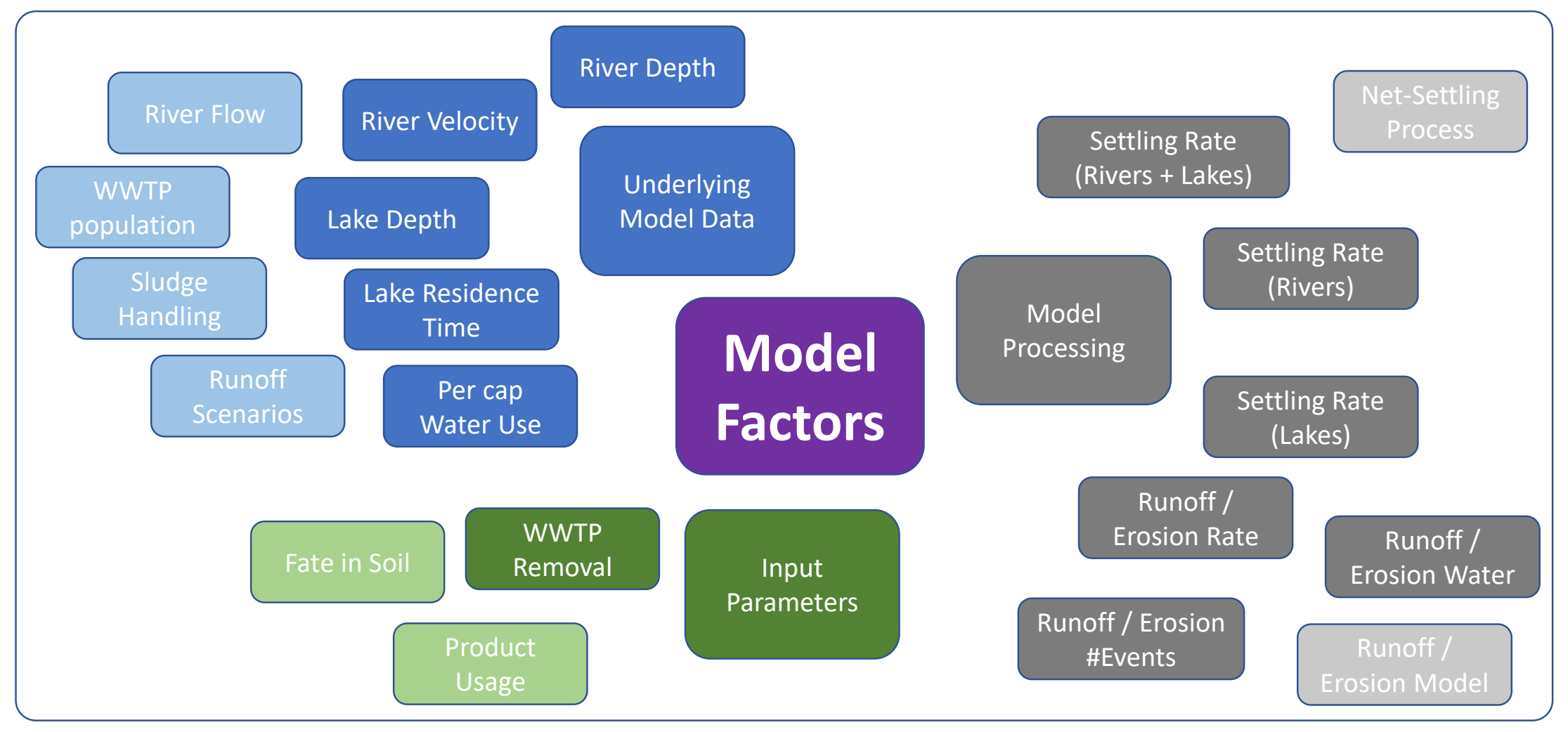
In-River Particle Settling

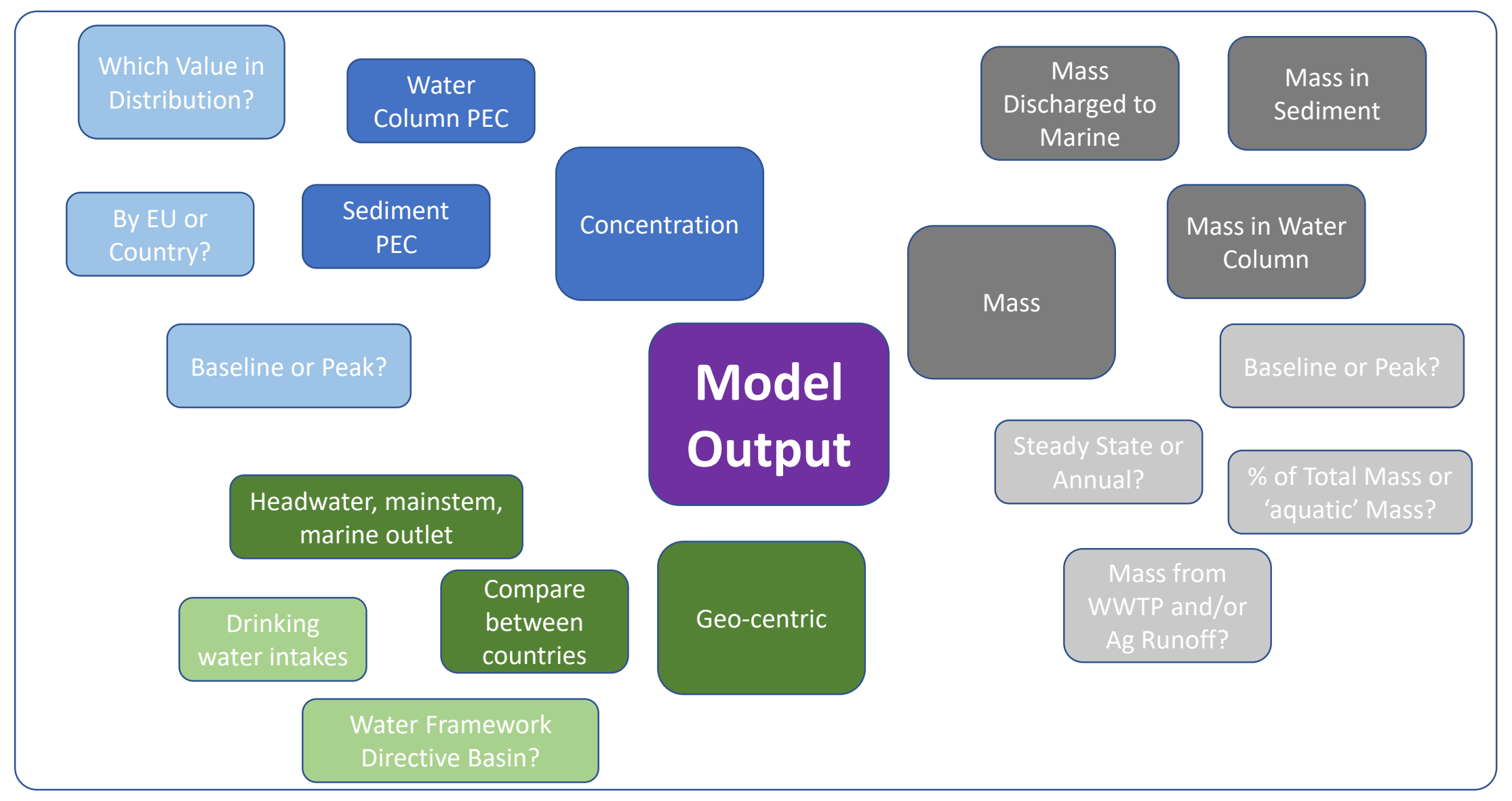
Particles settle in the river based on particle size, river depth, and time of travel, using relationships from the NanoDUFLOW model (Besseling *et al* 2017). This incorporates processes such as homo-aggregation, hetero-aggregation with natural colloids, biofouling, settling and resuspension into a generalized net settling velocity.



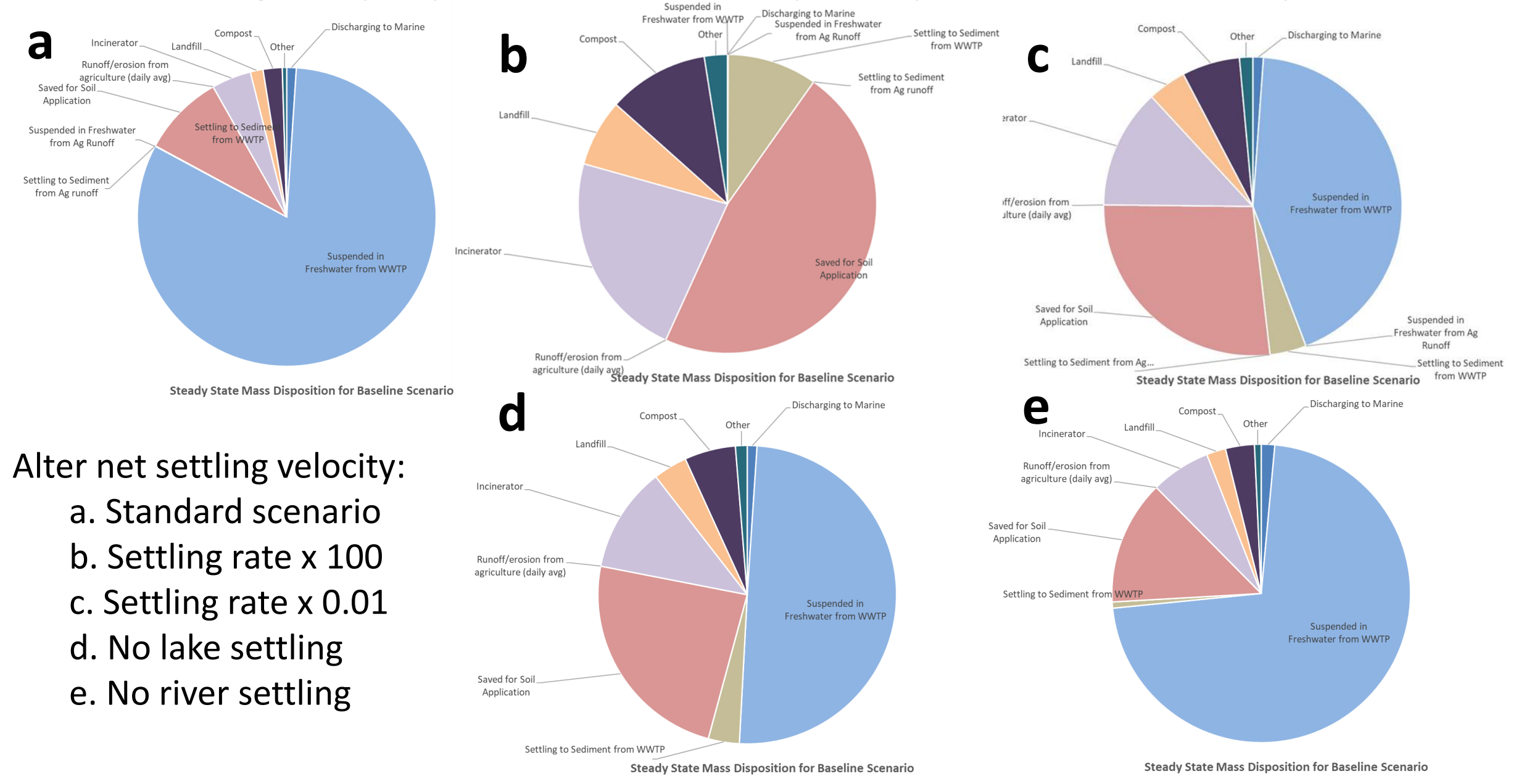
Net settling velocities are configurable and can be related to waterbody type, river velocity, or other local/regional characteristics as available.

Analysis of Model Sensitivity to User Inputs, Model Data, and Simulation Processing





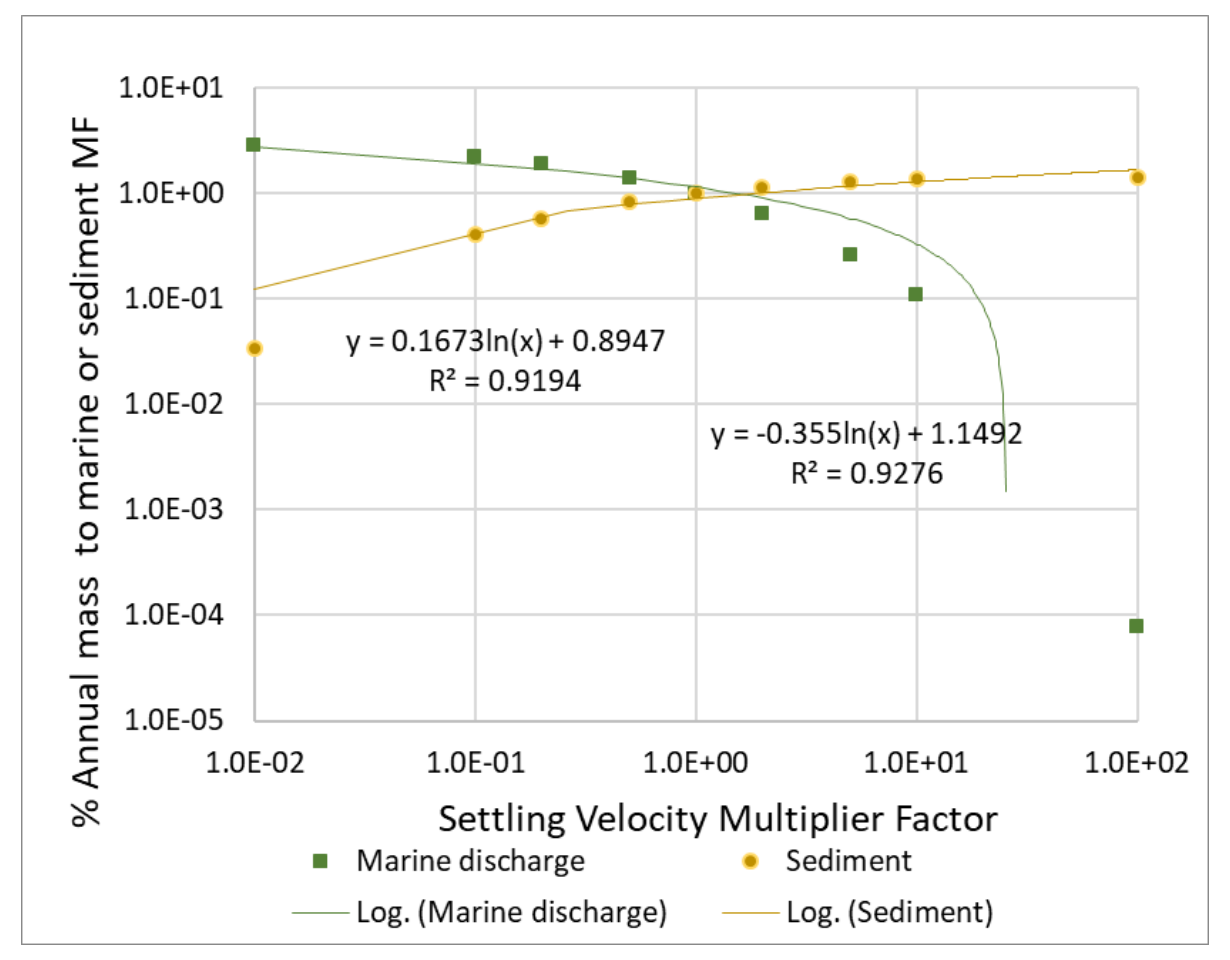
Change in proportion of mass by compartment in steady state



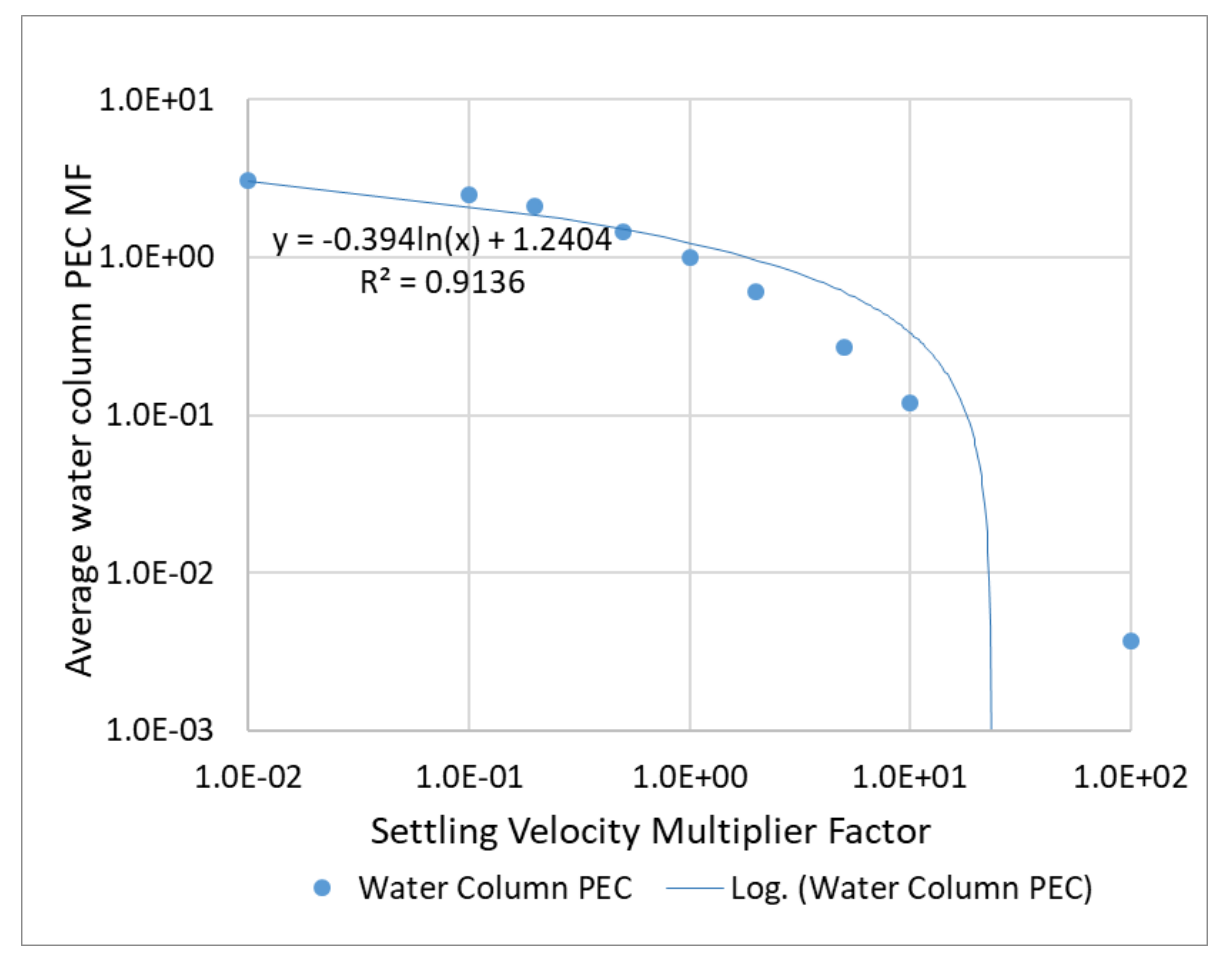
Alter net settling velocity:

a. Standard scenario
b. Settling rate x 100
c. Settling rate x 0.01
d. No lake settling
e. No river settling

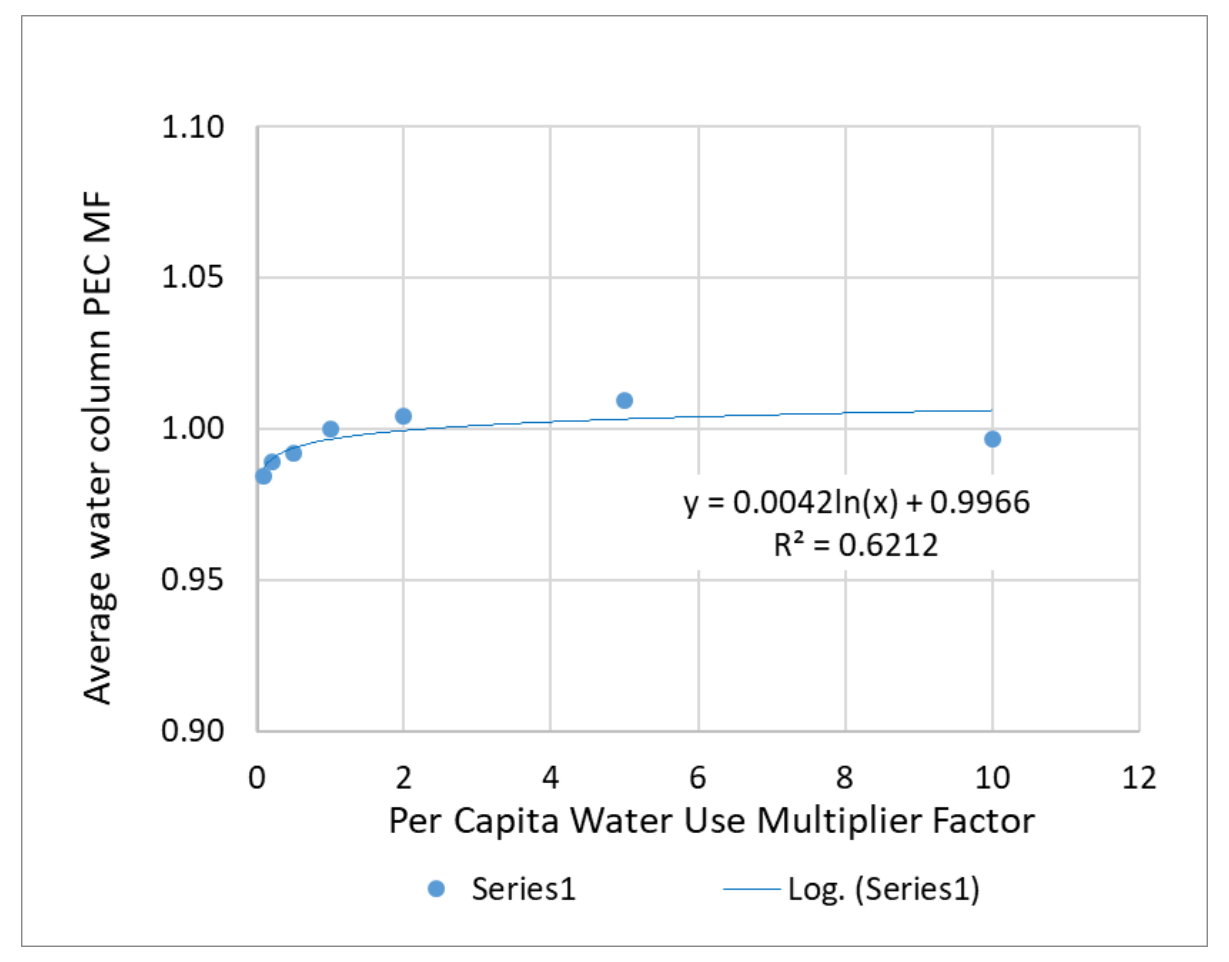
Relationships between model factors



Settling velocity & mass to marine/sediment



Settling velocity & water column PEC



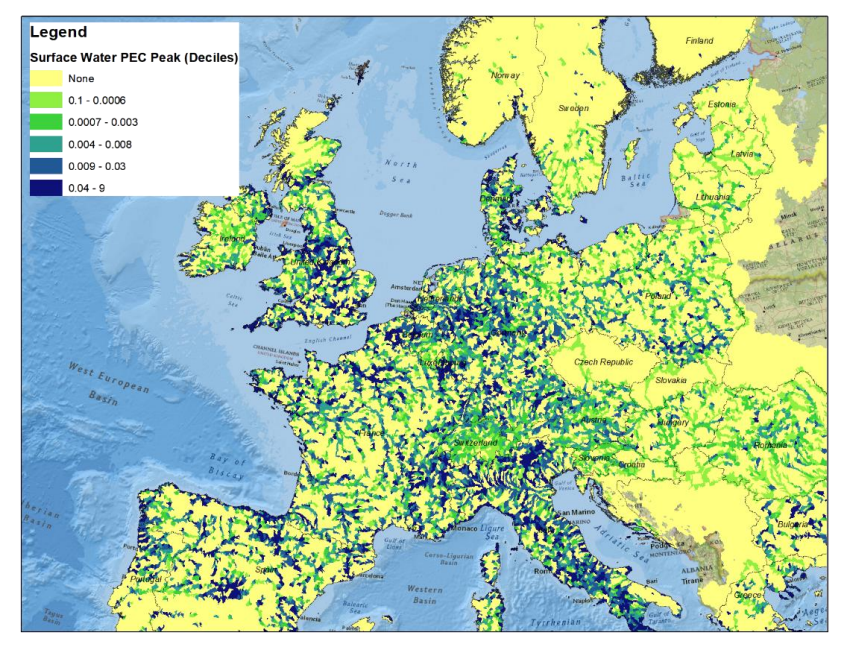
Per capita water use & water column PEC

Results and Visualization

Results from an example model run using inputs below can be summarized and visualized in several methods, from tabular output, spatial mapping, or aggregation to different spatial levels or environmental compartments.

Scenario:

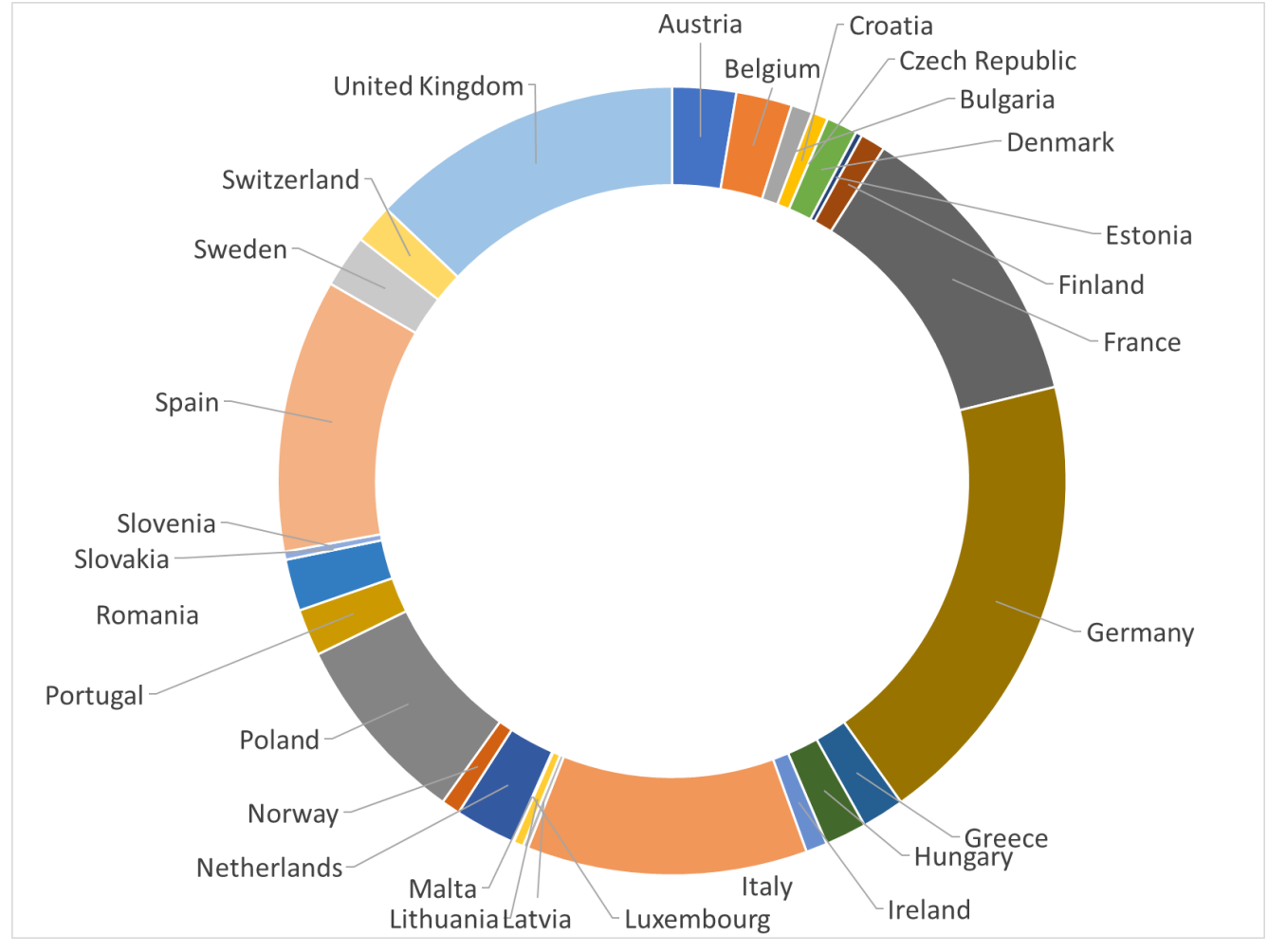
Per cap use:	1 mg/day
(except Czech Republic and Slokavia)	
Total mass modelled	213 t/yr
WWTP to effluent:	10%
WWTP degradation:	0%
WWTP to sludge:	90%
Kd for soil modelling:	10000
Soil aerobic half-life:	120 days
In-river net-settling velocity:	1.0 m/d



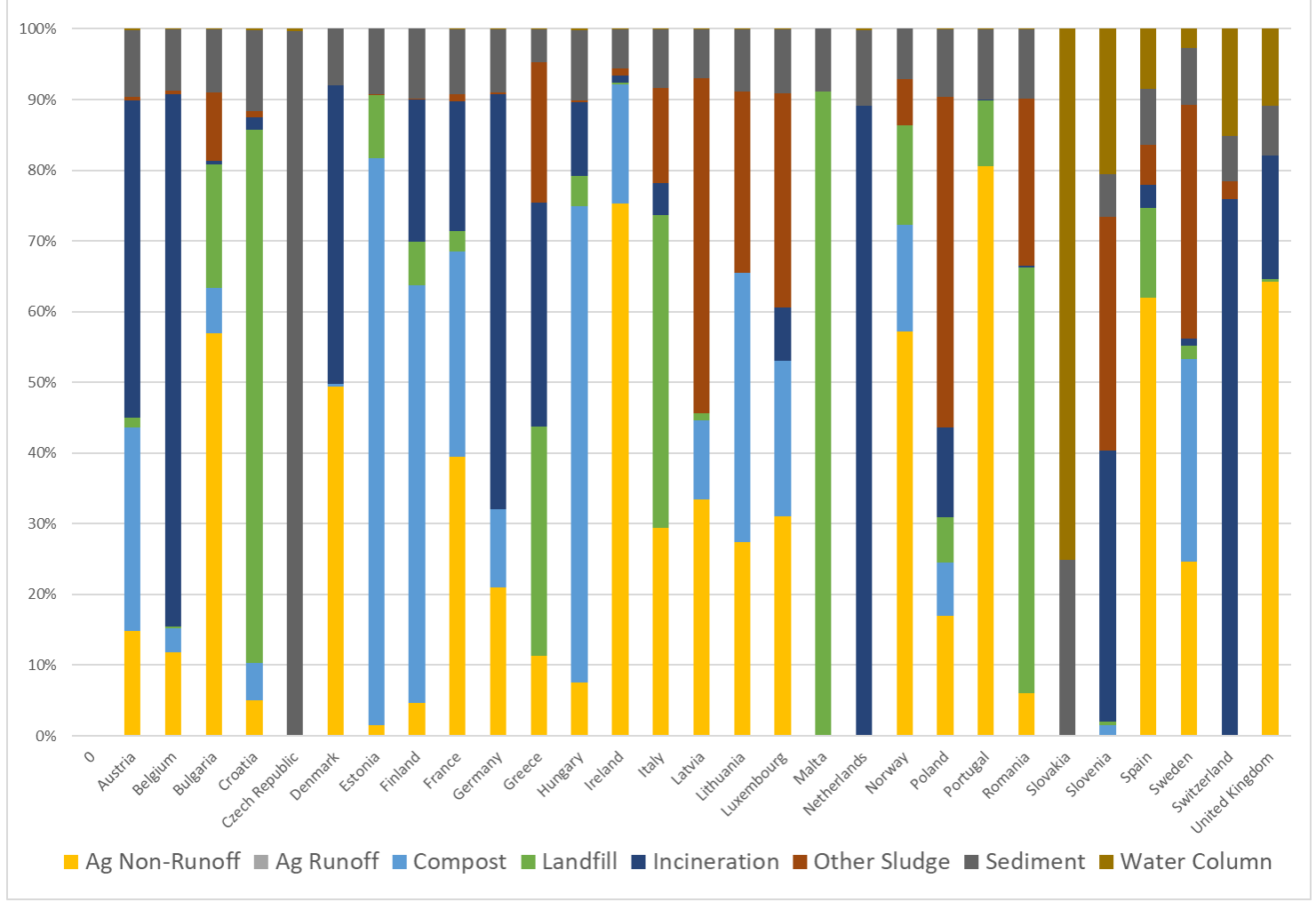
Surface Water Predicted Environmental Concentrations (PECs) for Baseline Scenario

Environmental Disposition of Annual Emitted Mass:

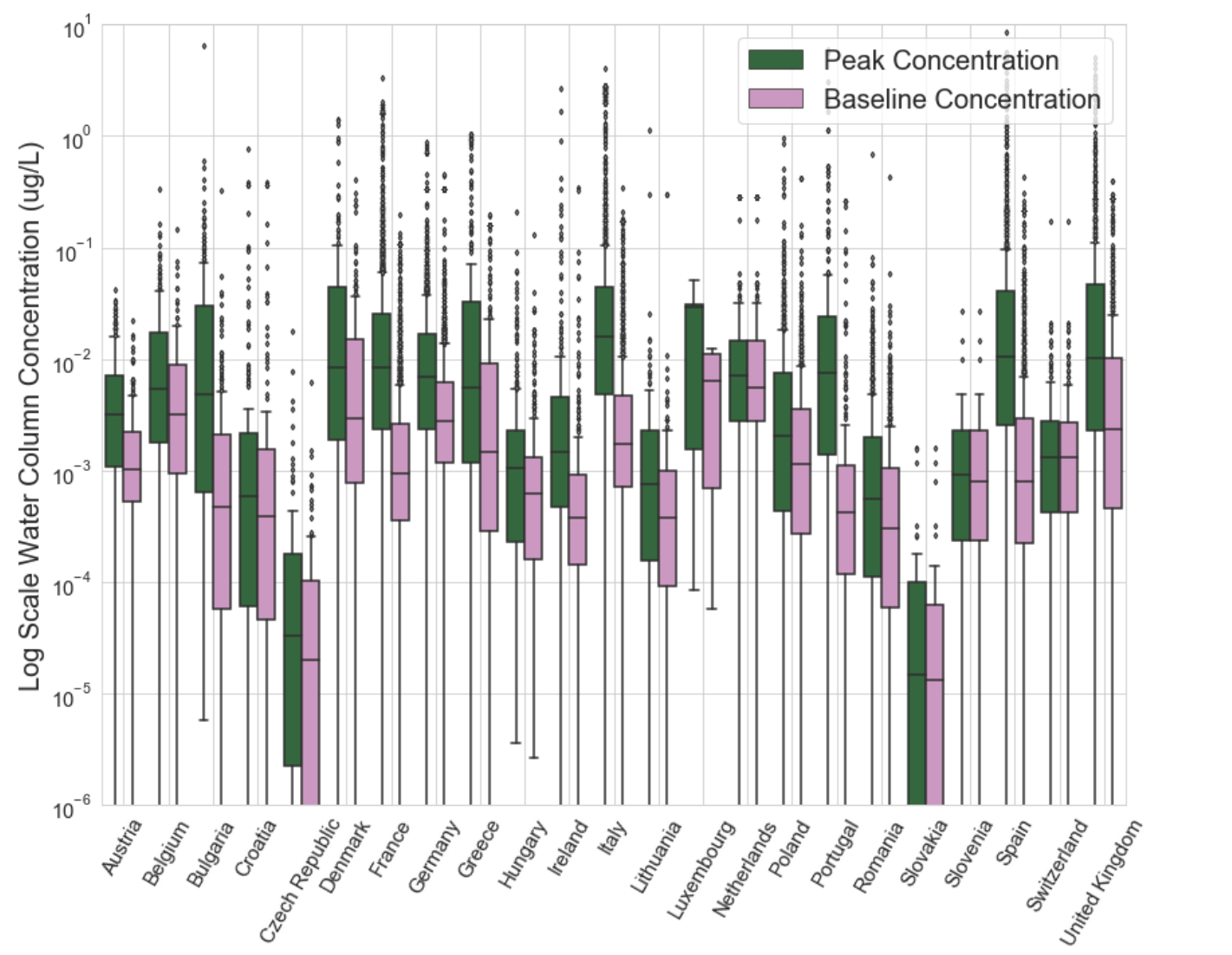
Marine	1.1%
Freshwater	0.1%
Sediment	8.7%
Agricultural runoff	0.5%
Agricultural Soil	34.5%
Incinerated	25.9%
Landfill	10.6%
Compost	10.4%
Other sludge	8.3%



Total Annual Modelled Mass Residing in the Environment



Environmental Disposition of Total Annual Mass by Country



Baseline and Peak Surface Water PECs by Country

Model Features:

Estimate environmental exposure of source microplastics entering WWTPs, including:

- Variable consumer use rate
- Variability in wastewater sludge handling practices
- Terrestrial transport using environmental factors
- Hydrologic routing using well established datasets
- Particle mass disposition within compartments
- Spatially explicit: aggregation and examination
- Scalable and extensible to other geographies

References:
1. Panagos et al., 2015. A new assessment of soil loss by water erosion in Europe. Env. Science & Policy 54 (2015) 438-447. http://dx.doi.org/10.1016/j.envsci.2015.08.012
2. Besseling, E., Quik, J.T.K., Sun, M., and Koelmans, A.A., (2017). Fate of nano-and microplastic in freshwater systems: A modeling study. Environmental Pollution 220, 540–548.

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