Prospective Modelling of Microplastic Exposure in Freshwater Systems

Seminar 4: Modelling of Microplastics in the Environment – Policy or Regulatory Implications?

SETAC Virtual Seminars | 16 March – 6 April 2021

What We Know and What We Need To Know:
The Analysis, Monitoring and Effects of Microplastics in Humans and the Environment

Christopher M. Holmes
Applied Analysis Solutions, LLC
March 25, 2021

Introduction

Modelling

Predict

Confirm

Context

Challenges

Spatial

Temporal

Landscape heterogeneity

Human activity

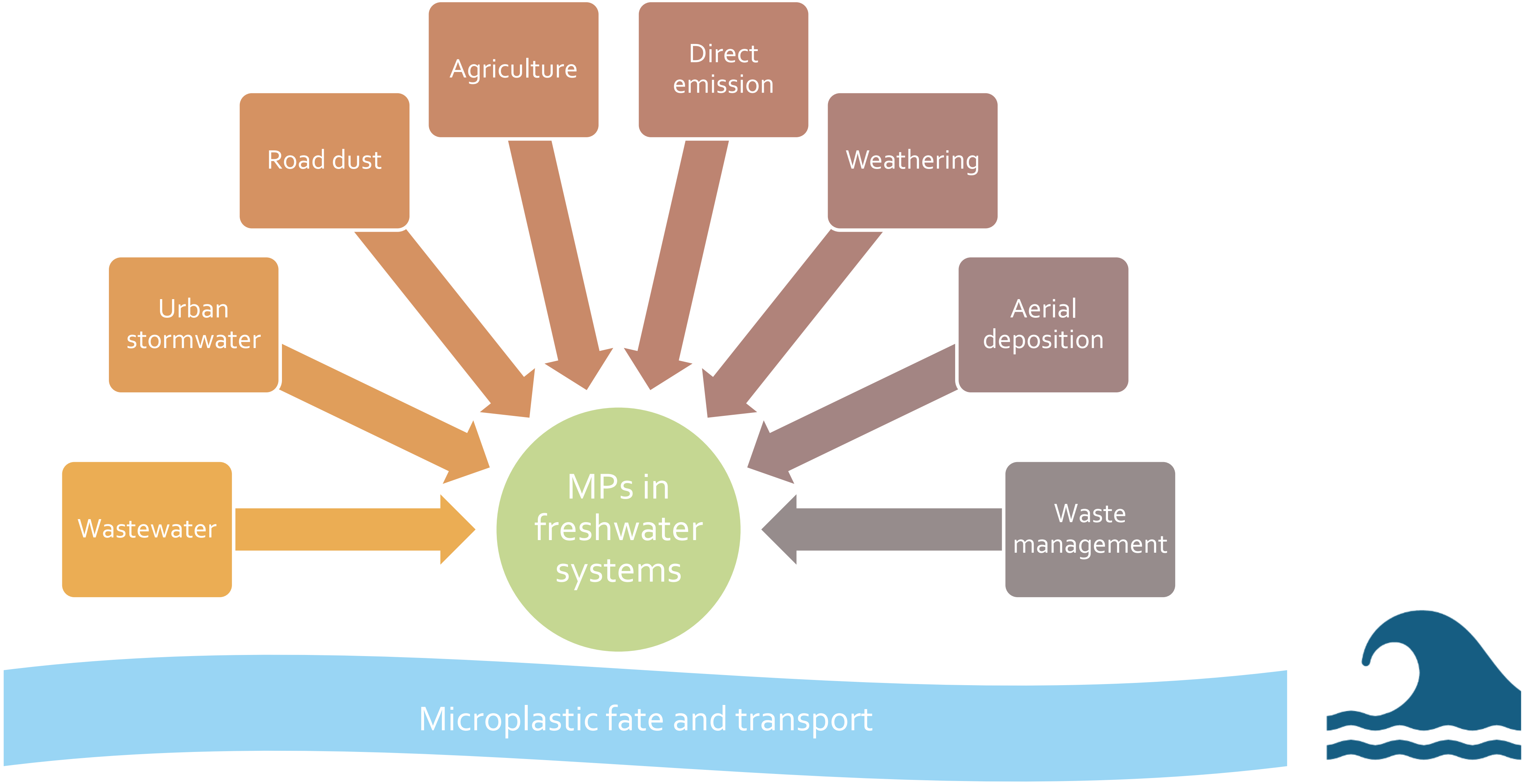
Freshwater

Receptor

Transport

Regulatory

Sources of microplastics for freshwater systems



Wastewater treatment plants (WWTPs)

- Early focus on microplastic emissions from municipal wastewater

Opequon Wastewater Treatment Plant, Frederick County Sanitation Authority, Winchester VA, USA

Opequon Creek, Frederick County, VA, USA
Source: Winchester Star, Jan 23, 2018 (link)

Range finding at a national scale

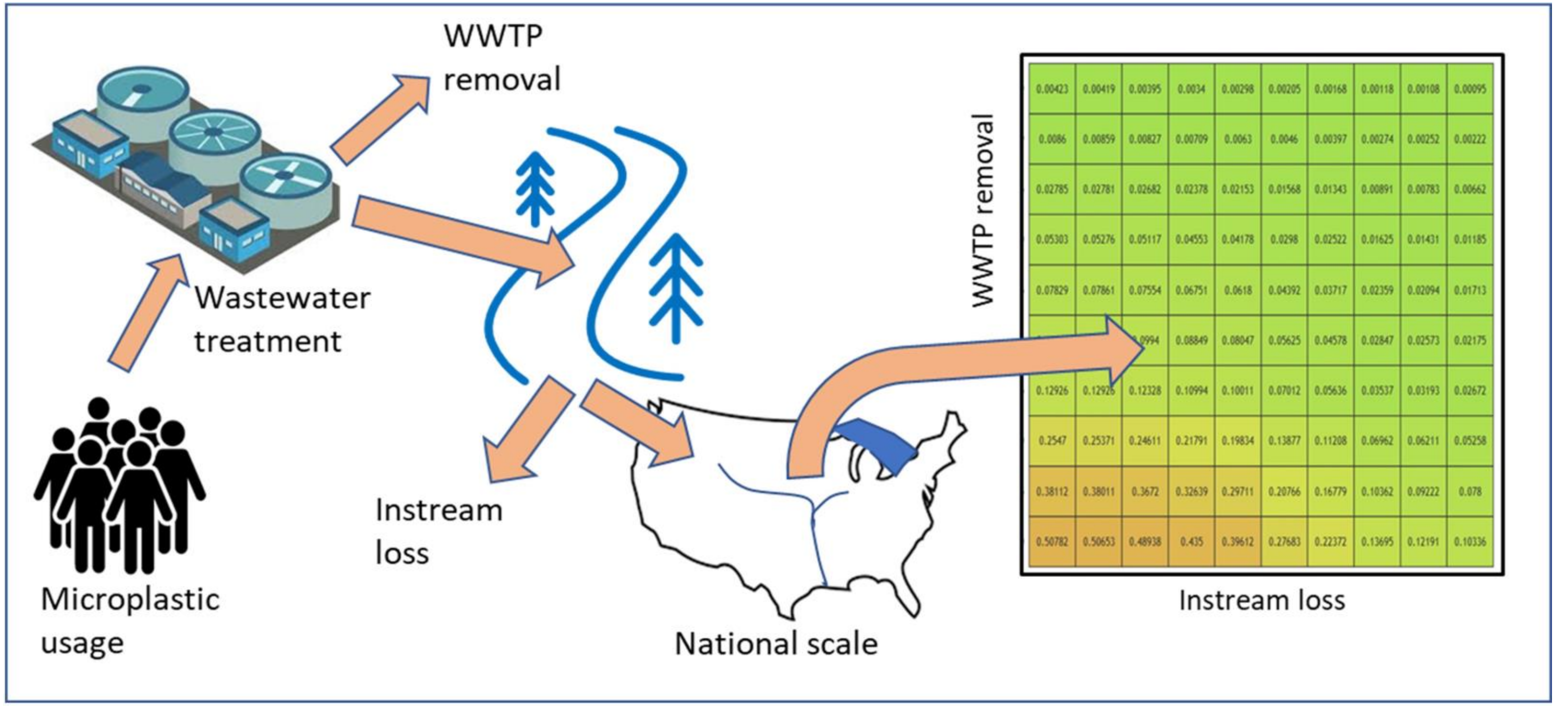
Environmental Toxicology and Chemistry—Volume 39, Number 1—pp. 210–219, 2020
Received: 11 August 2019 | Revised: 16 August 2019 | Accepted: 2 October 2019 210

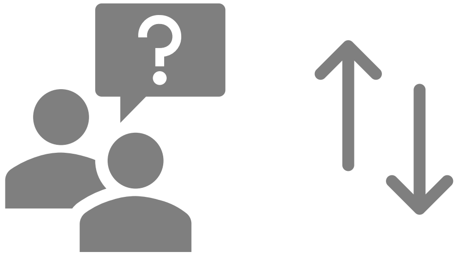
Environmental Toxicology

A National-Scale Framework for Visualizing Riverine Concentrations of Microplastics Released from Municipal Wastewater Treatment Incorporating Generalized Instream Losses

Christopher M. Holmes,[a,*] Scott D. Dyer,[a,b] Raghu Vamshi,[a] Nikki Maples-Reynolds,[a] and Iain A. Davies[c]

[a]Waterborne Environmental, Leesburg, Virginia, USA
[b]LeTourneau University, Longview, Texas, USA
[c]Personal Care Products Council, Washington, DC, USA

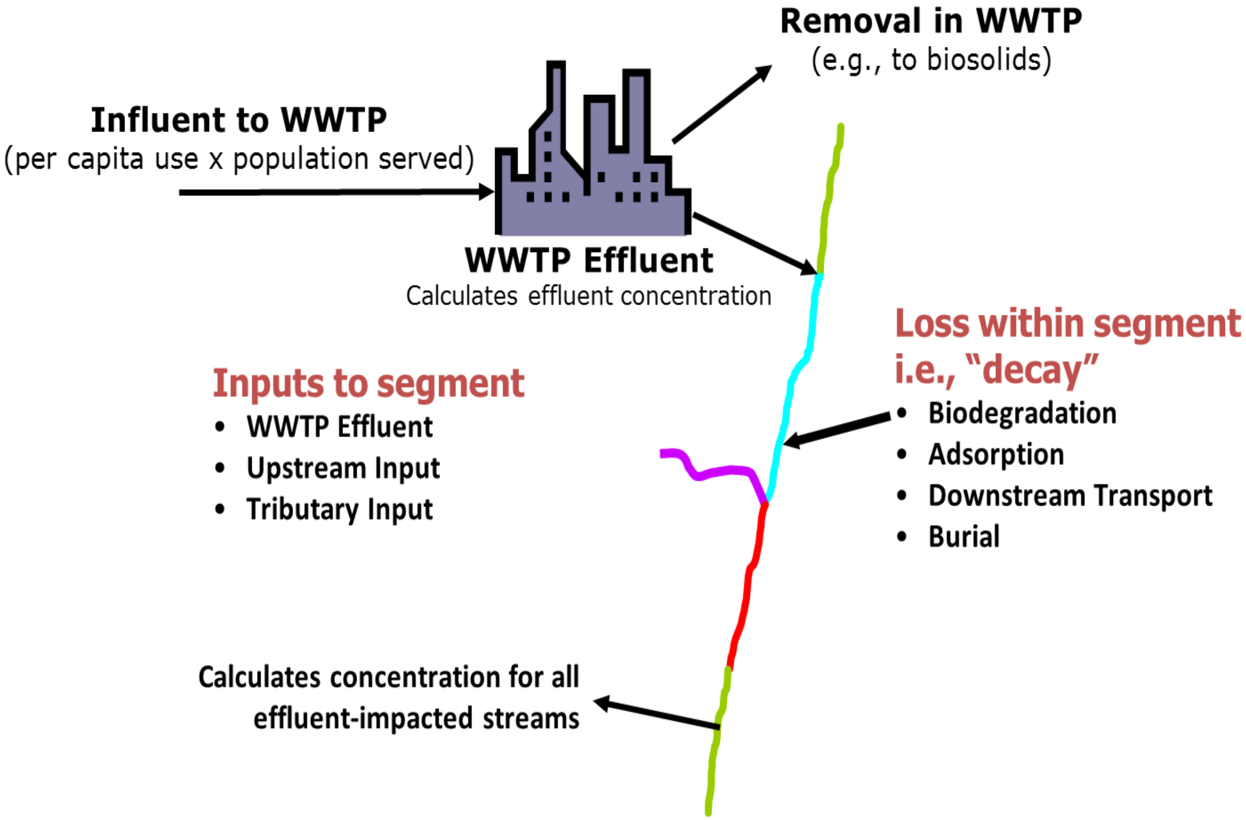


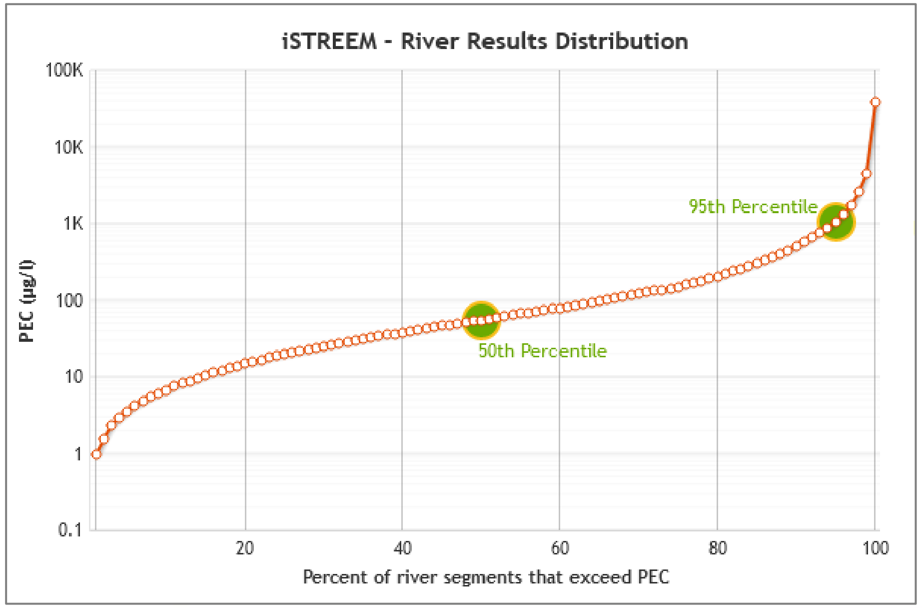


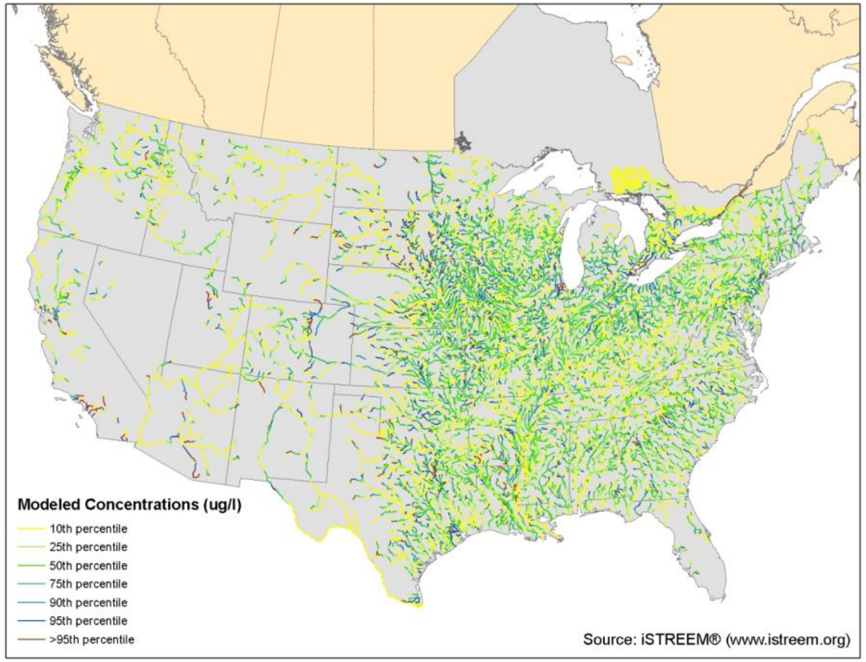
https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4610

Personal Care Products Council

iSTREEM®

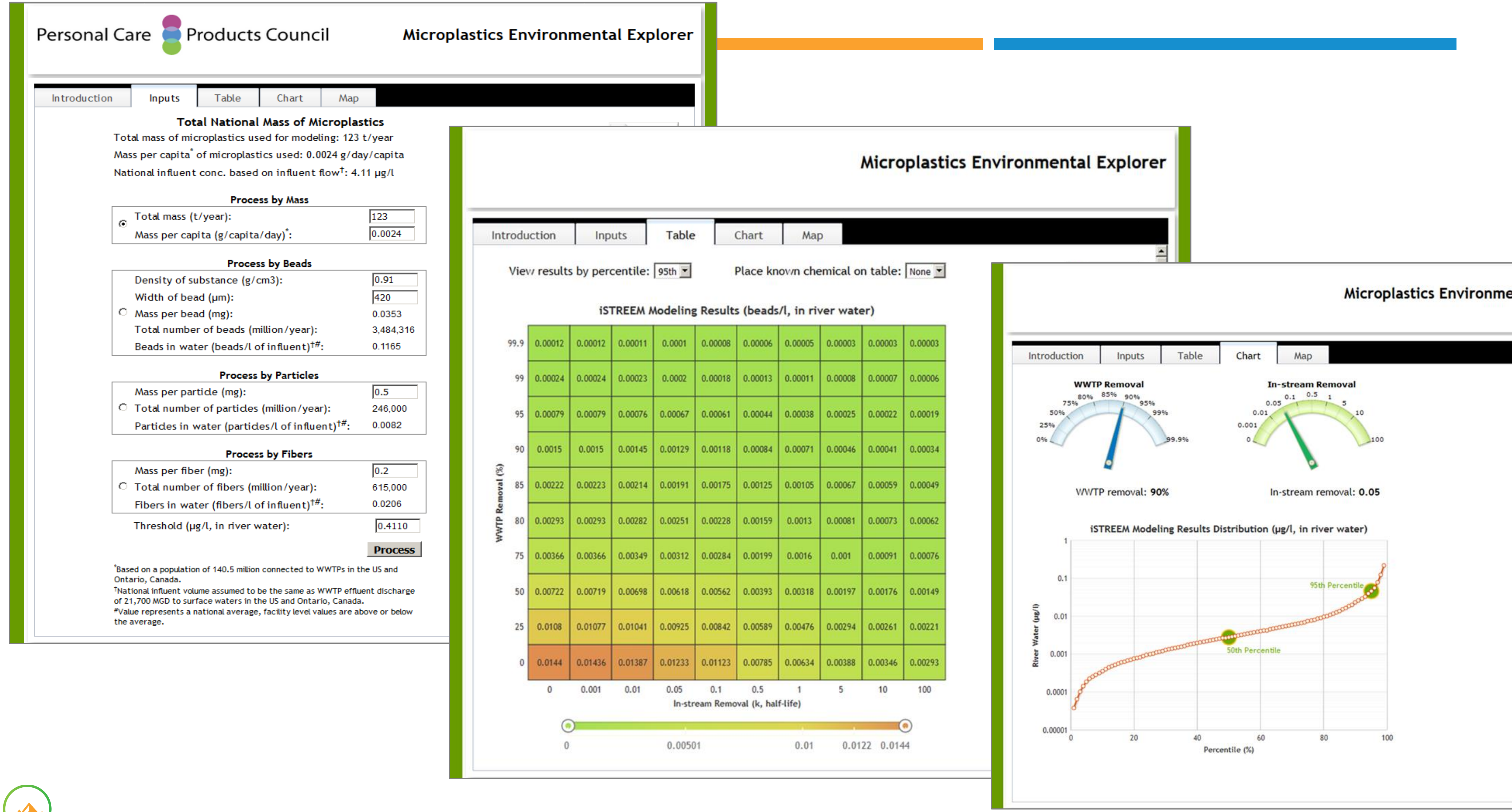






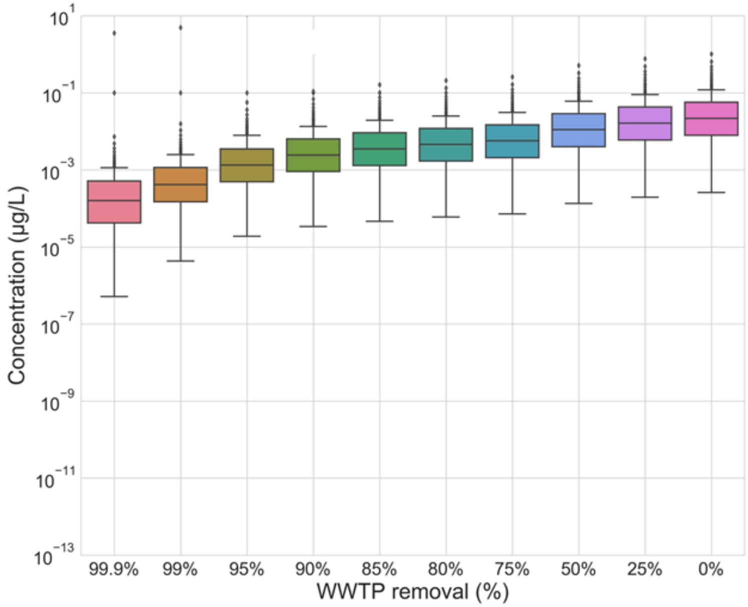
iSTREEM

https://www.istreem.org/

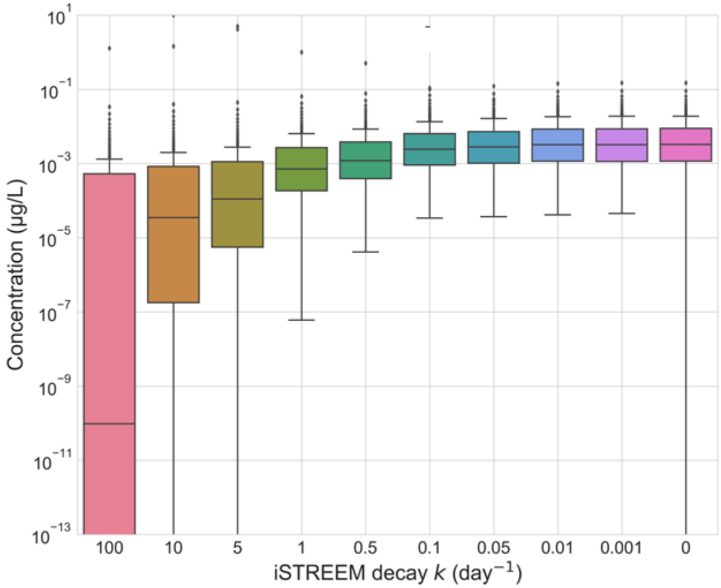


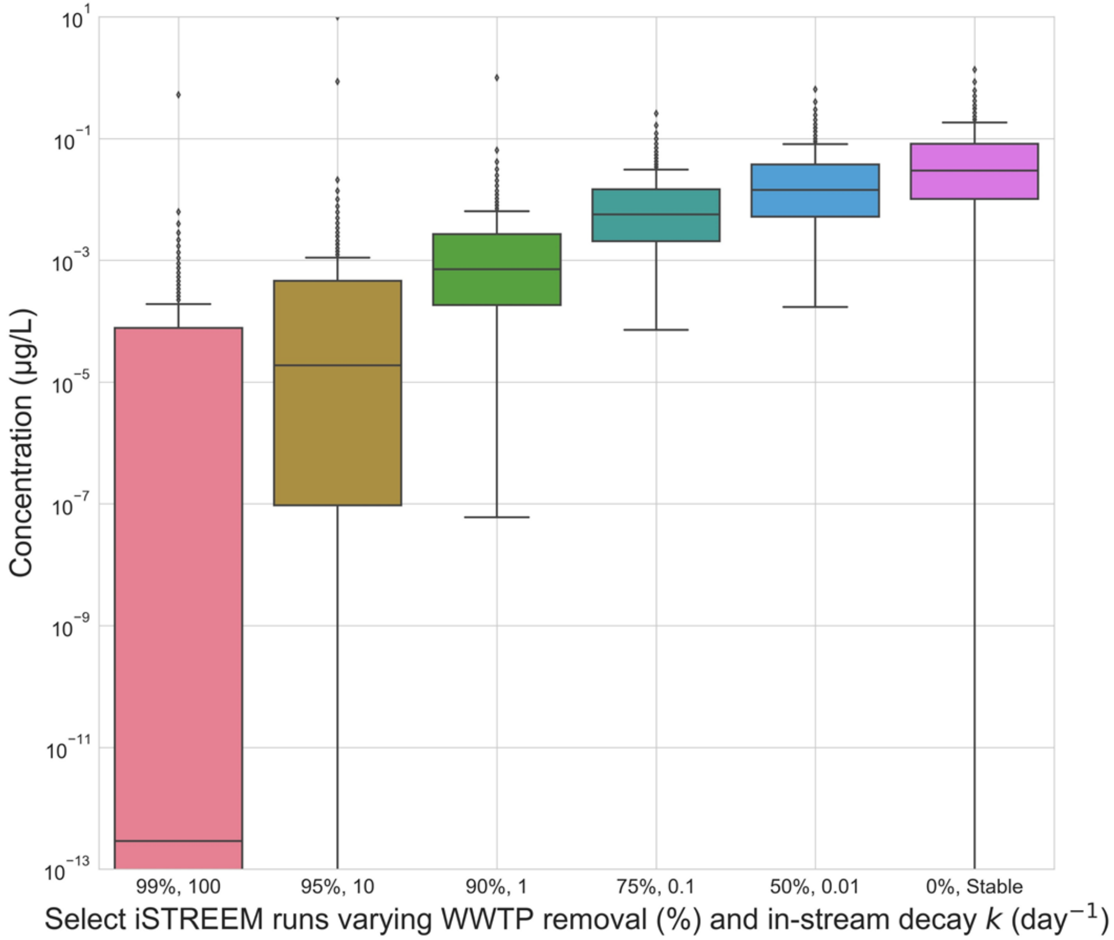
WWTP Removal (%) \ In-stream Removal	0	0.001	0.01	0.05	0.1	0.5	1	5	10	100
99.9	0.00012	0.00012	0.00011	0.0001	0.00008	0.00006	0.00005	0.00003	0.00003	0.00003
99	0.00024	0.00024	0.00023	0.0002	0.00018	0.00013	0.00011	0.00008	0.00007	0.00006
95	0.00079	0.00079	0.00076	0.00067	0.00061	0.00044	0.00038	0.00025	0.00022	0.00019
90	0.0015	0.0015	0.00145	0.00129	0.00118	0.00084	0.00071	0.00046	0.00041	0.00034
85	0.00222	0.00223	0.00214	0.00191	0.00175	0.00125	0.00105	0.00067	0.00059	0.00049
80	0.00293	0.00293	0.00282	0.00251	0.00228	0.00159	0.0013	0.00081	0.00073	0.00062
75	0.00366	0.00366	0.00349	0.00312	0.00284	0.00199	0.0016	0.001	0.00091	0.00076
50	0.00722	0.00719	0.00698	0.00618	0.00562	0.00393	0.00318	0.00197	0.00176	0.00149
25	0.0108	0.01077	0.01041	0.00925	0.00842	0.00589	0.00476	0.00294	0.00261	0.00221
0	0.0144	0.01436	0.01387	0.01233	0.01123	0.00785	0.00634	0.00388	0.00346	0.00293

Vary WWTP removal, constant in-stream removal (k=0.1 d^{-1})

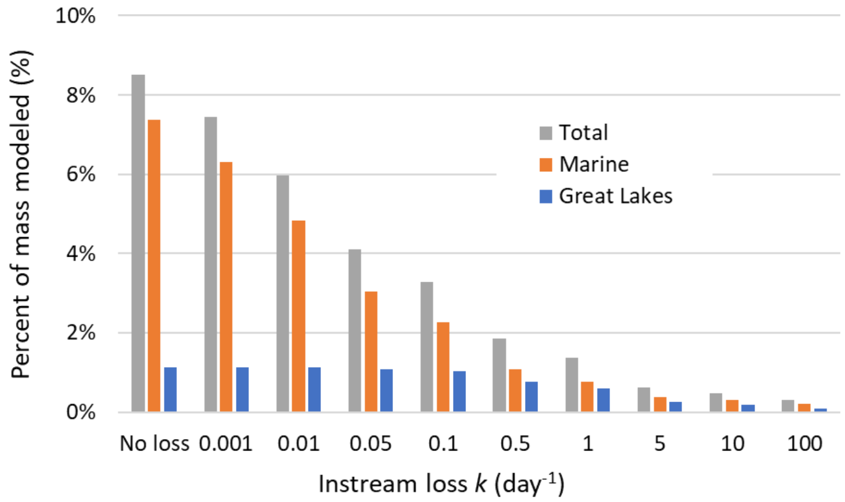


Vary in-stream removal, constant WWTP removal (90%)

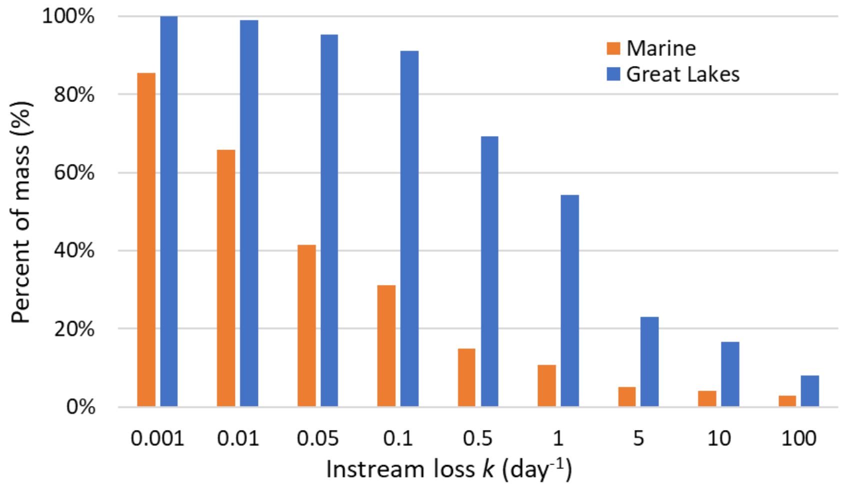




Marine and Great Lakes river emission



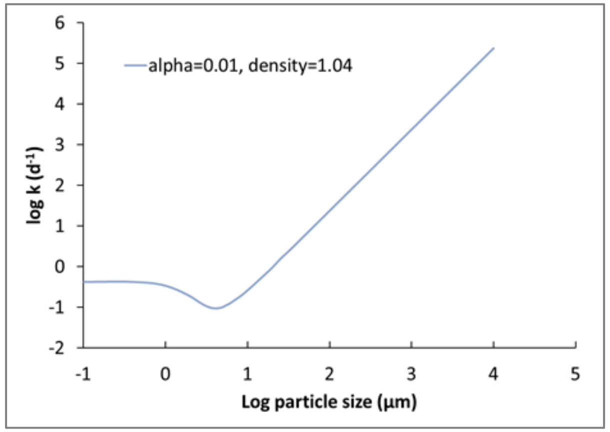
Percent of total modeled microplastic mass entering WWTPs that was present in the water column at the terminal river reaches, assuming 90% WWTP removal.



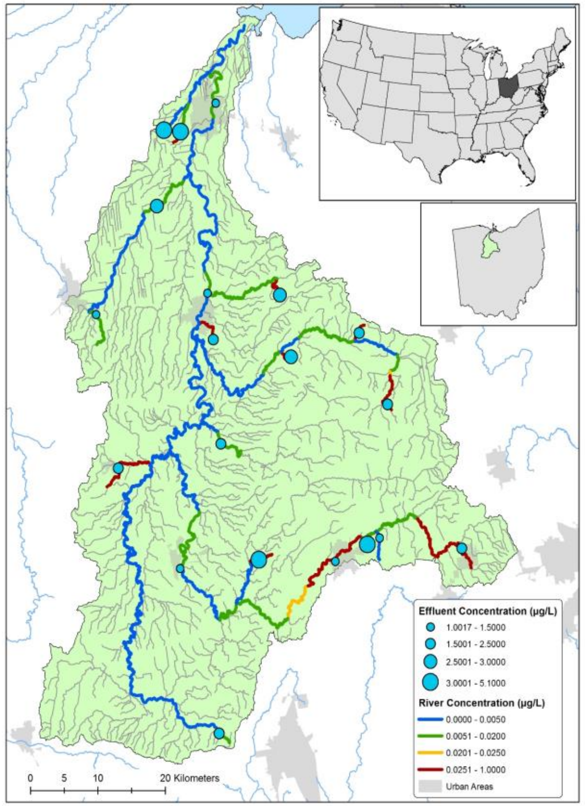
Comparison of total microplastic mass at the terminal segments for each instream loss rate compared to the “no loss” scenario.

Holmes, C.M.; Dyers, S.D.; Vamshi, R.; Maples-Reynolds, N.; Davies, I.A. 2020. A National-Scale Framework for Visualizing Riverine Concentrations of Microplastics Released from Municipal Wastewater Treatment Incorporating Generalized Instream Losses. Environmental Toxicology & Chemistry 2020, 39 (1), 210-219.

Modeling riverine transport of microplastics emitted from WWTPs in the Sandusky River watershed



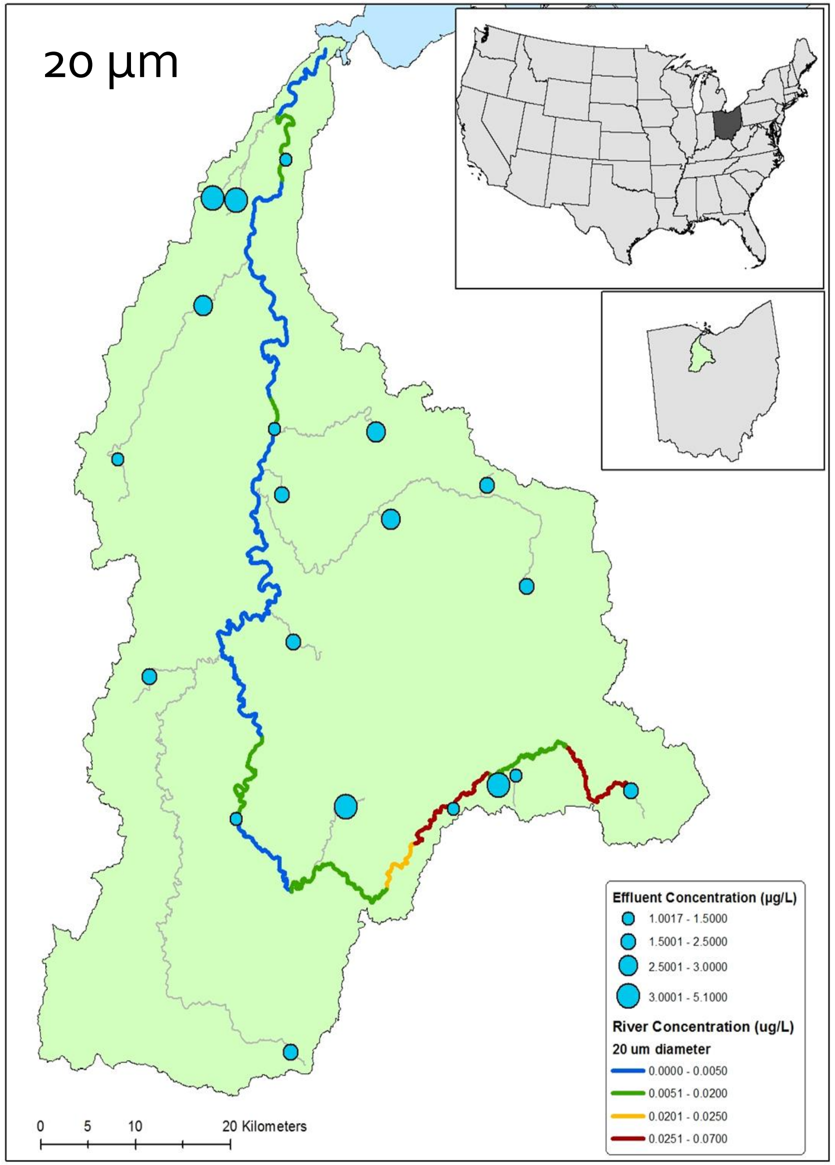
- NanoDUFLOW net-settling of nano/micro particles applied to Dommel River (Besseling *et al*, 2017)
- Specific net-settling rates by size
  - 10 sizes from 0.1 µm to 10mm
- Single density spheres (1.04 g/cm^3)

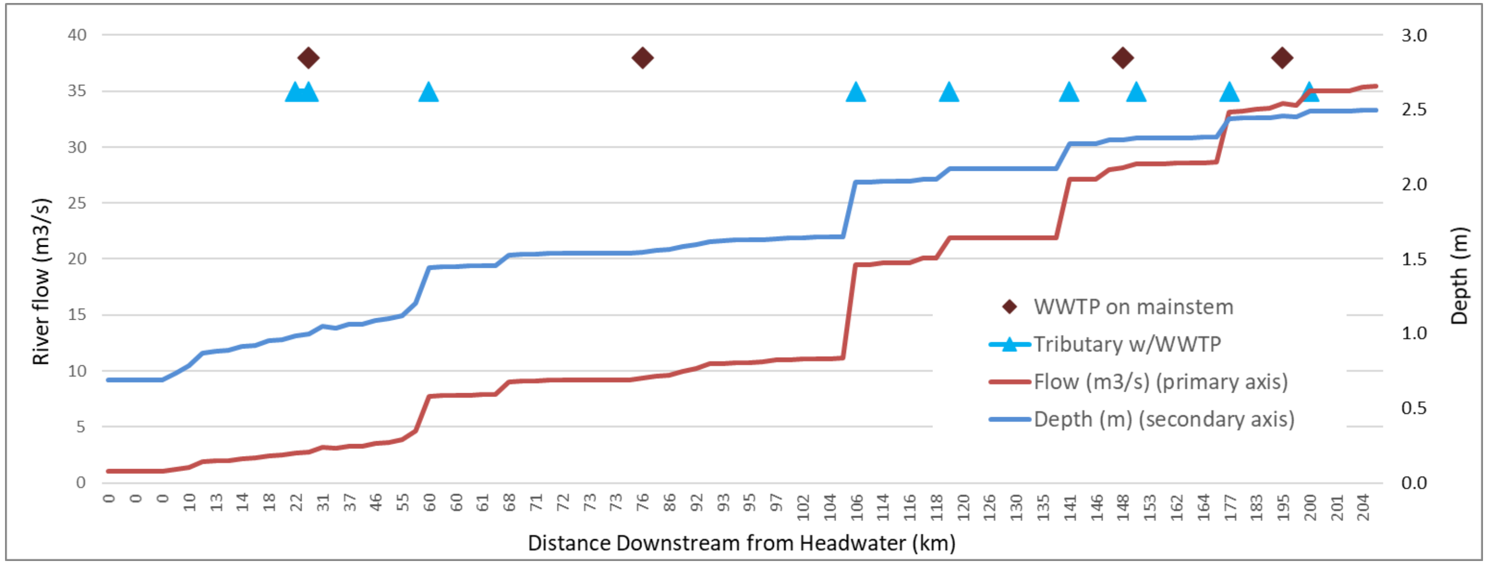


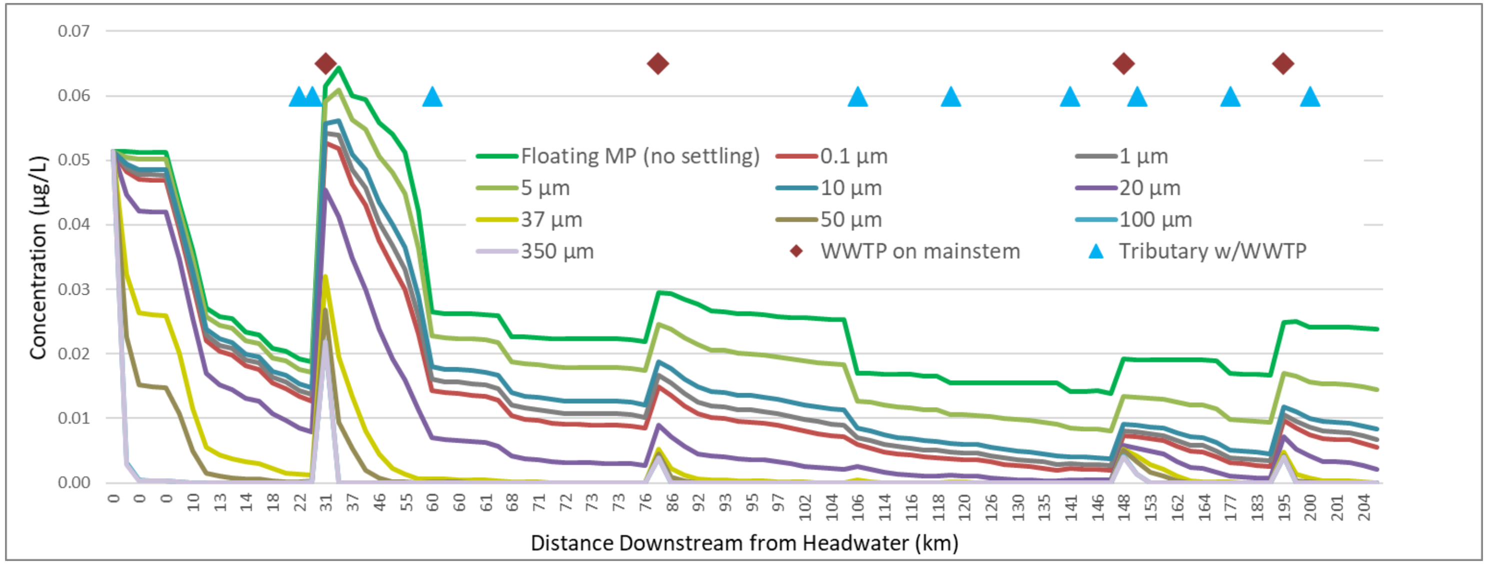
- iSTREEM – Spatially explicit with individual river segments
- Post-processed for net-settling using river segment depth, travel time and net-settling rate from NanoDUFLOW

Besseling, E.; Quik, J. T. K.; Sun, M.; Koelmans, A. A. Fate of nano- and microplastic in freshwater systems: a modeling study. Environ. Pollut. 2017, 220, 540–548

Holmes, C.; Dyer, S.; and Koelmans, A. A. 2021. Modeling riverine transport of microplastics emitted from wastewater treatment plants in the Sandusky River watershed (submitted)


20 µm
Effluent Concentration (µg/L)
1.0017 - 1.5000
1.5001 - 2.5000
2.5001 - 3.0000
3.0001 - 5.1000
River Concentration (ug/L)
20 um diameter
0.0000 - 0.0050
0.0051 - 0.0200
0.0201 - 0.0250
0.0251 - 0.0700
0 5 10 20 Kilometers

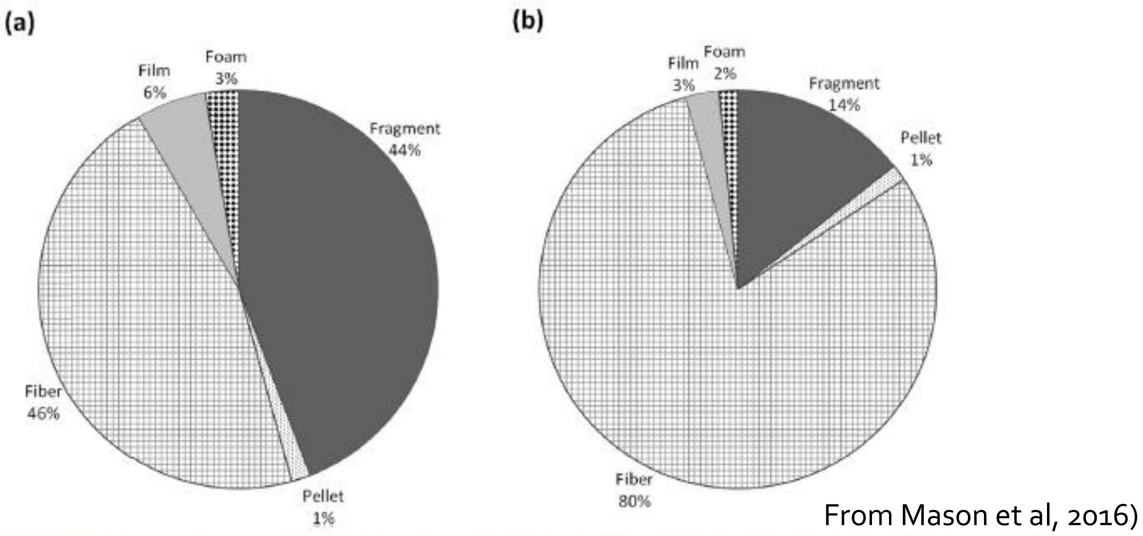

River flow (m3/s)
Depth (m)
Distance Downstream from Headwater (km)
WWTP on mainstem
Tributary w/WWTP
Flow (m3/s) (primary axis)
Depth (m) (secondary axis)


Concentration (µg/L)
Distance Downstream from Headwater (km)
Floating MP (no settling)
0.1 µm
1 µm
5 µm
10 µm
20 µm
37 µm
50 µm
100 µm
350 µm
WWTP on mainstem
Tributary w/WWTP

Relevant mixture of particle sizes

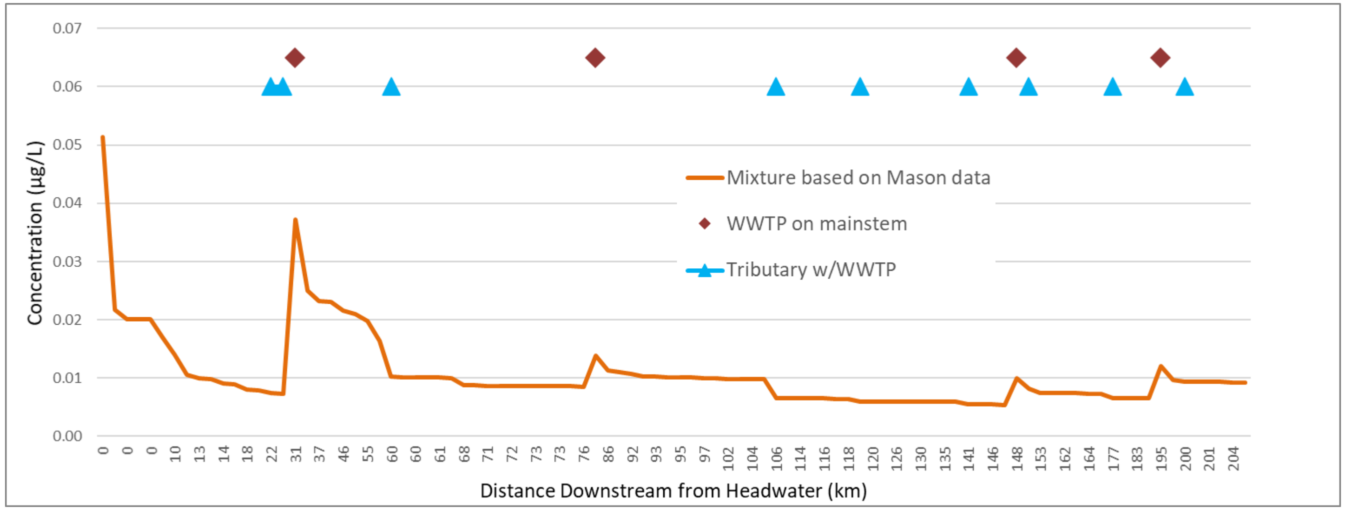
- Based on measured data from 17 WWTPs (Mason *et al*, 2016)
- Proportions of five particle types in two size classes (125 – 355 µm, > 355 µm)
- Representative total mass concentration profile
  - Mass proportions of the size classes for weighting factors
  - Weighted linear combination of individual size class runs

Sphere diameter	% of mixture mass
10 µm	0.01
37 µm	0.17
100 µm	18.7
350 µm	42.5
Buouyant	38.7



From Mason et al, 2016)

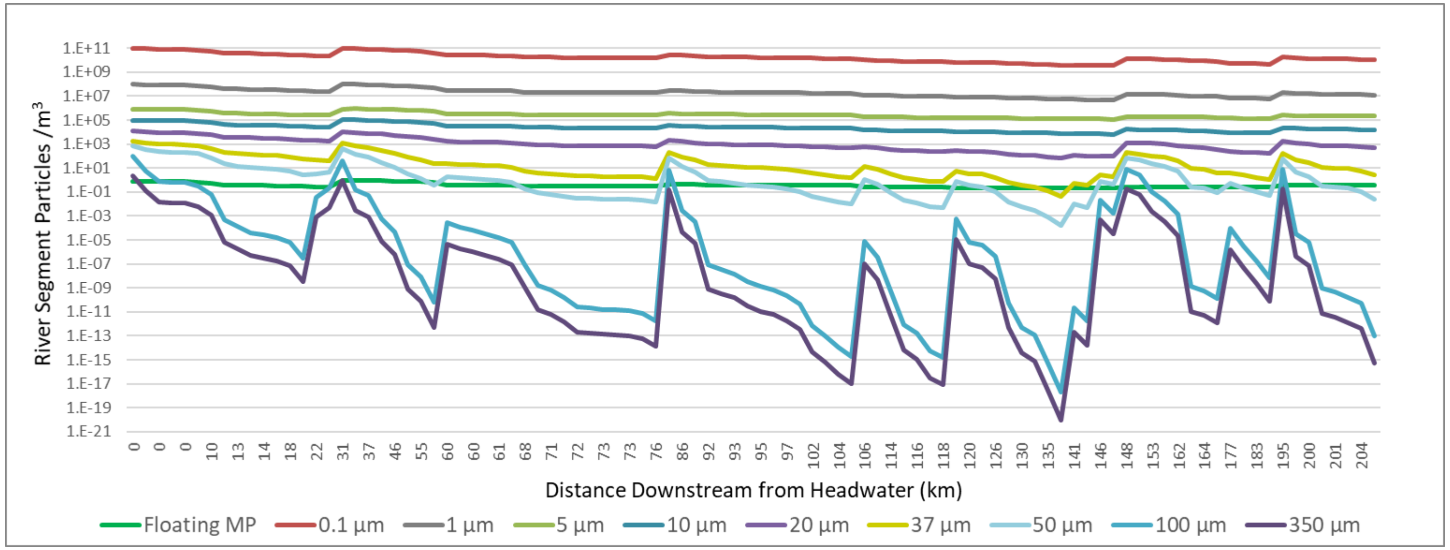
Fig. 2 Percentage of microparticle by type (*Fragments*, dark solid grey; *Fibers*, mesh; *Films*, light solid grey; *Foam*, black diamonds; *Pellets*, dotted) for each size classification, 0.125–0.355 mm (a) and >0.355 mm (b).

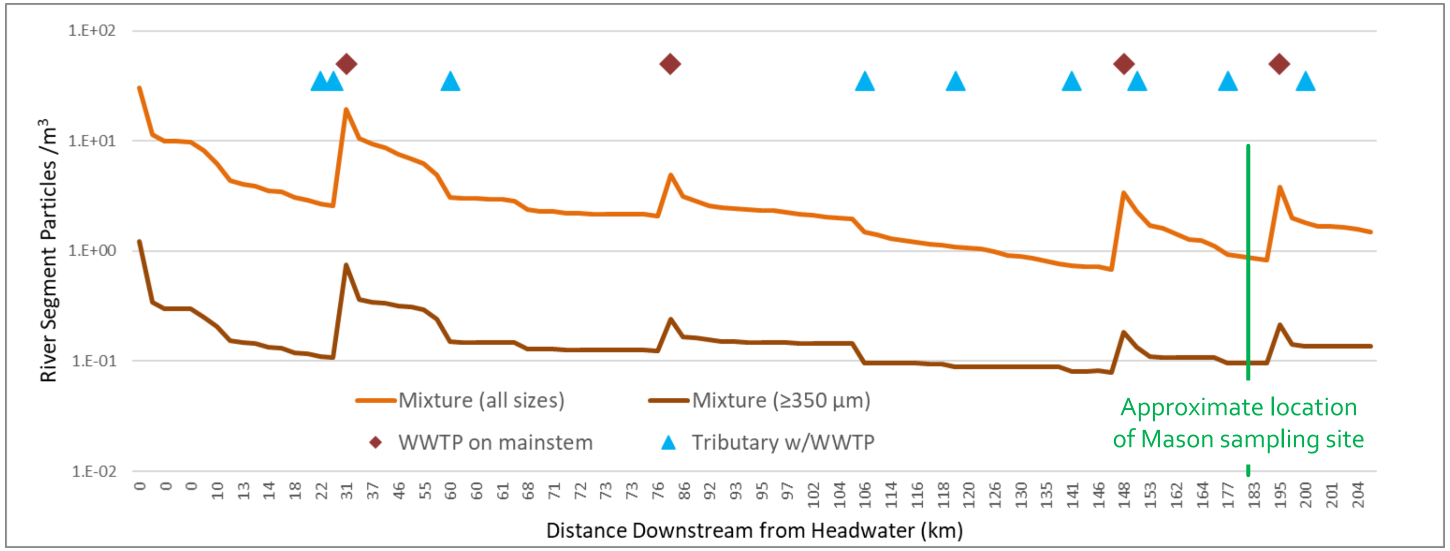


Mason, S. A.; Garneau, D.; Sutton, R.; Chu, Y.; Ehmann, K.; Barnes, J.; Fink, P.; Papazissimos, D.; Rogers, D. L. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environ. Poll. 2016, 218, 1045-1054.

Compare to measure data

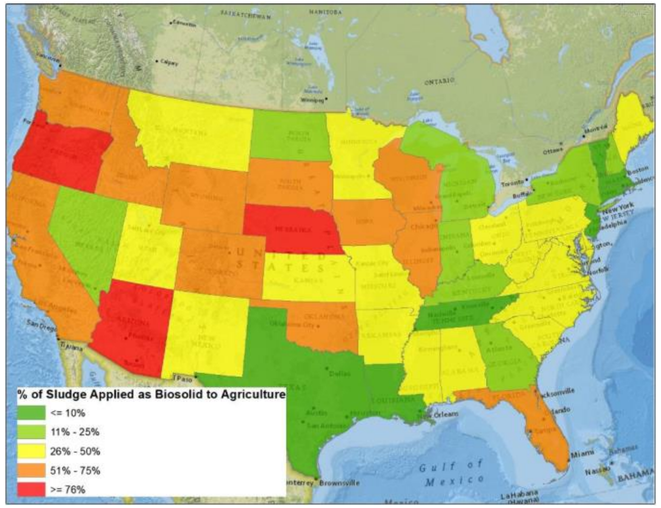
- Particle counts (4 dates) at the Sandusky River USGS station (Baldwin *et al*, 2016)
- Three size classes: 355 – 1000 µm, 1 – 4.75 mm, and > 4.75 mm
- Baldwin: 1.48 to 6.41 particles/m^3 all size classes
- Modelled: 0.86 particles/m^3 using all sizes
- Modelled: 0.10 particles/m^3 only sizes >350 µm
- Comparison as expected
  - Only modelling particles emitted by WWTP



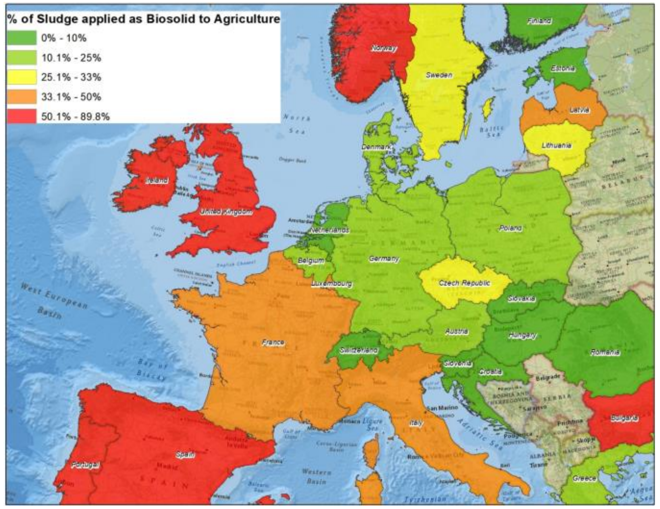


Baldwin, A.K.; Corsi, S.R.; Mason, A.A. Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. *Environ. Sci. Technol*. **2016**, *5*, 10377-10385.

Not WWTP particles are discharged to rivers

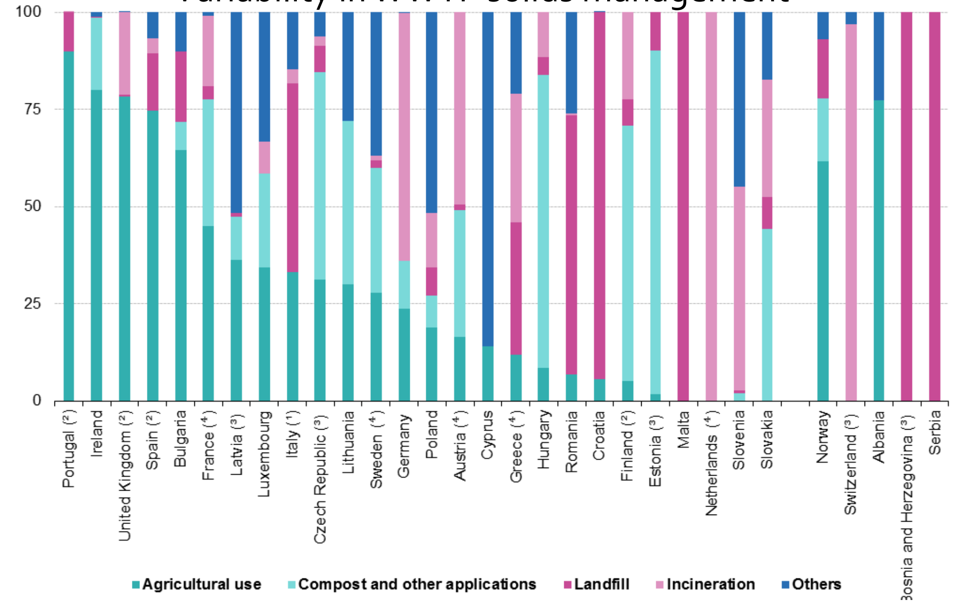


Data from U.S. and State-by-State, Biosolids Regulation, Quality, Treatment, and End Use and Disposal Data. 2007. https://www.nebiosolids.org/
Image from Holmes *et al* 2018.



Data from Eurostat, https://ec.europa.eu/Eurostat.
Image from Ritter *et al* 2020.

Variability in WWTP solids management



https://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics

Environmental Science & Technology — Viewpoint — pubs.acs.org/est

Are Agricultural Soils Dumps for Microplastics of Urban Origin?

Luca Nizzetto,*,†,‡ Martyn Futter,§ and Sindre Langaas†

†Norwegian Institute for Water Research, NO-0349, Oslo, Norway
‡Research Centre for Toxic Compounds in the Environment, Masaryk University, 62500, Brno, Czech Republic
§Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden

Holmes, C.; Amos, J.; Ritter A.; and Williams, W. 2018. Estimating environmental emissions and aquatic concentrations of sludge-bound CECs using spatial modeling and US datasets. SETAC North America 39th Annual Meeting. Sacramento, CA. 2018

Ritter, A.; Roy, C.; and Holmes, C. 2020. Geospatial model to estimate microplastics entering waterways from wastewater systems and land applied biosolids. American Chemistry Society Fall 2020 annual meeting. August 17-20, 2020. Virtual.

Movement from soils to surface water

Environmental Science
Processes & Impacts

ROYAL SOCIETY OF CHEMISTRY

PAPER

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Cite this: *Environ. Sci.: Processes Impacts*, 2016, 18, 1050

A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments†

Luca Nizzetto,*[ab] Gianbattista Bussi,[c] Martyn N. Futter,[d] Dan Butterfield[a] and Paul G. Whitehead[c]

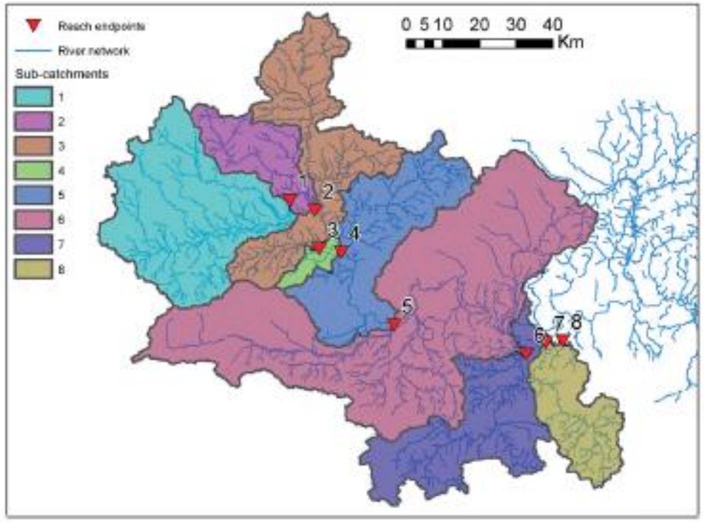


Fig. 1 The non-tidal part of the Thames River catchment used in the simulations showing reach endpoints and sub-catchment structure.

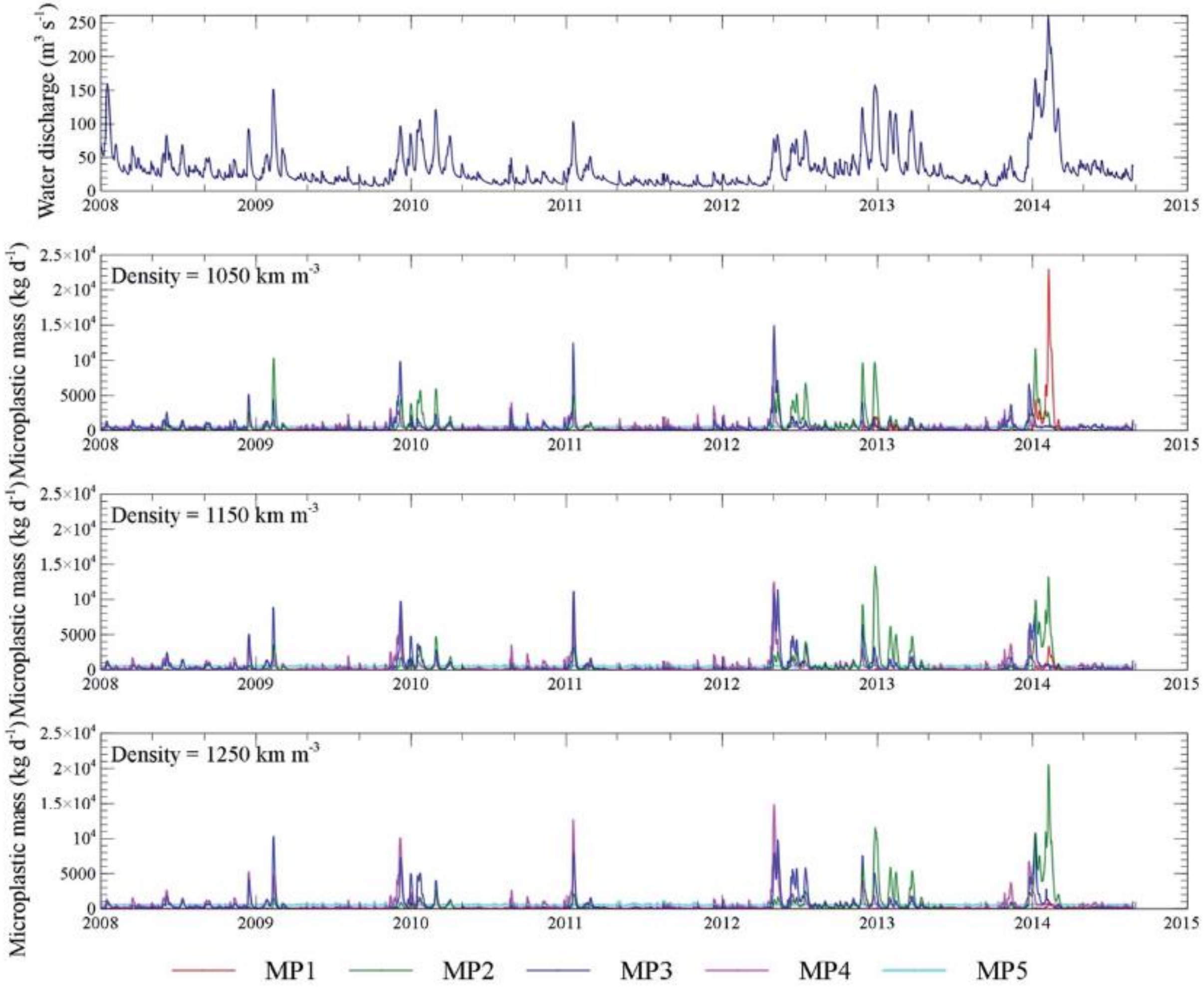
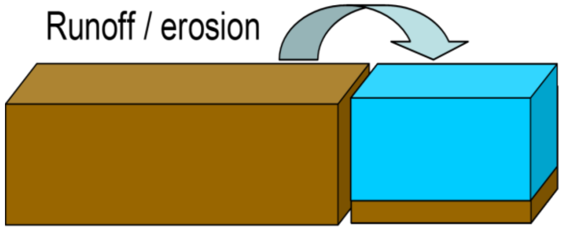
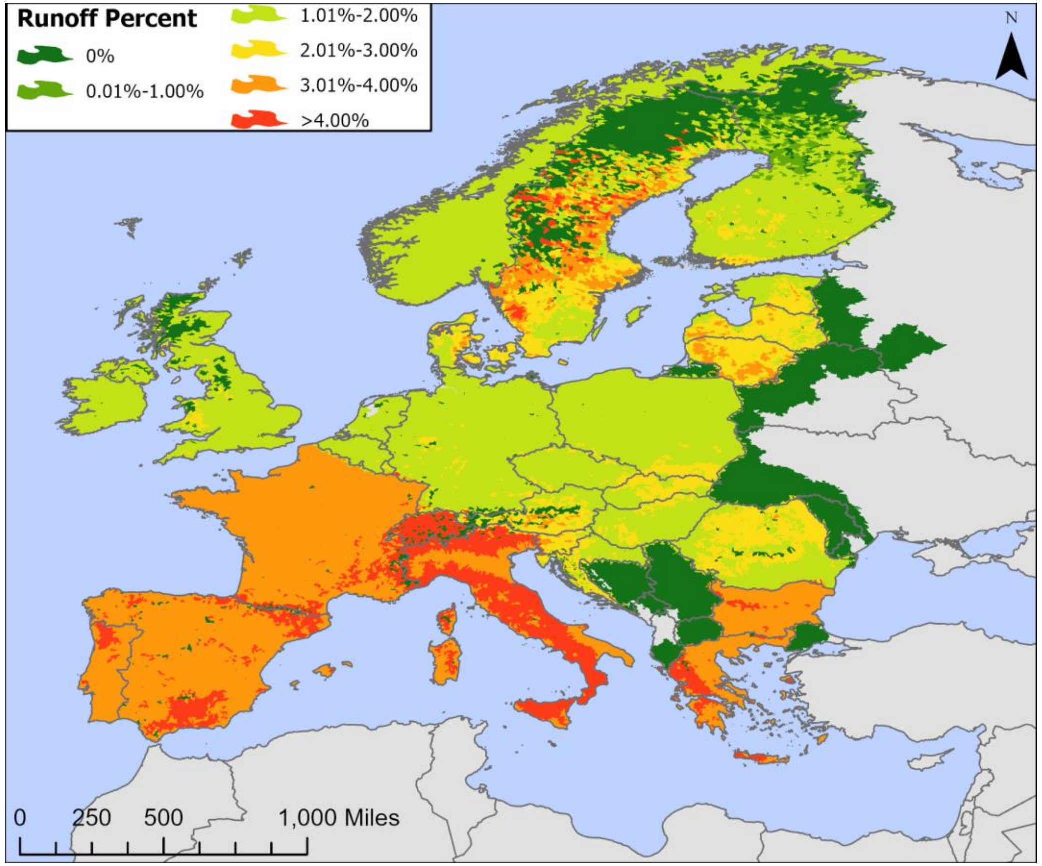


Fig. 3 Simulated discharge fluxes for 5 size classes of MPs (MP1: 0.3–0.5 mm, MP2: 0.1–0.3 mm; MP3: 0.05–0.08 mm; MP4: 0.01–0.05; MP5: 0.001–0.005) and selected 3 different density values.

Leveraging other available models

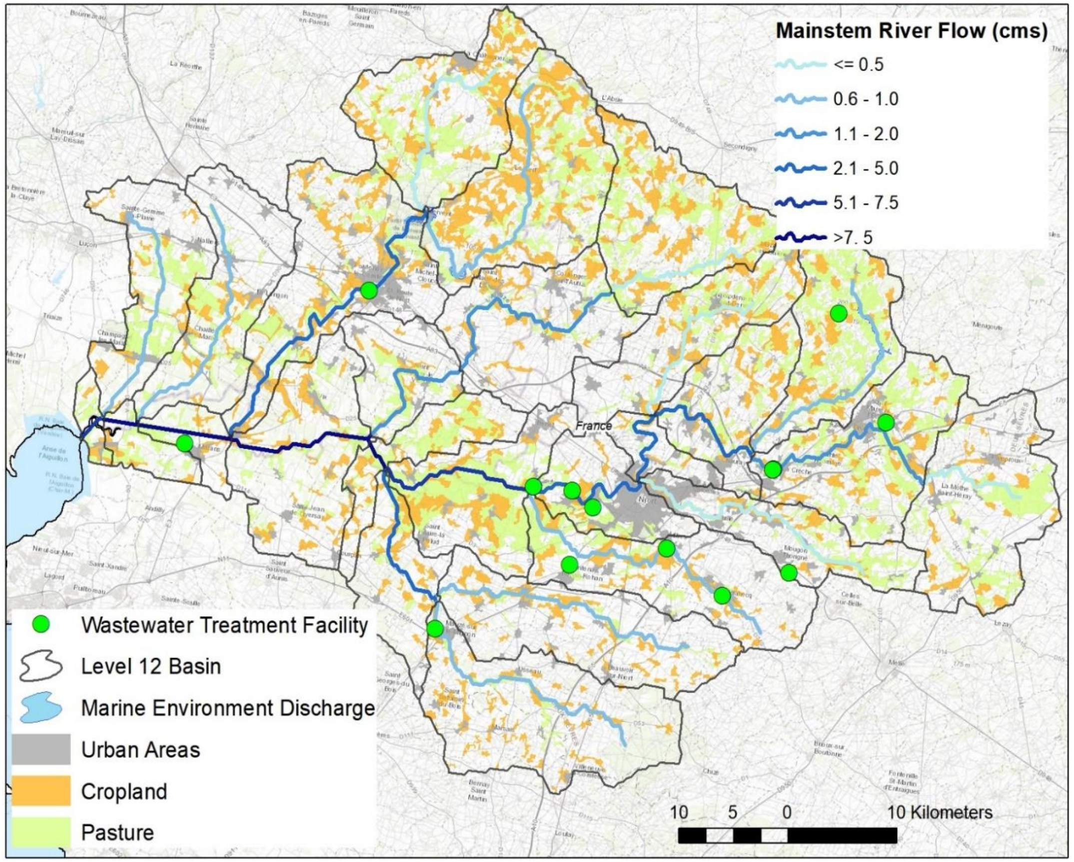


- Pesticide Root Zone Model (PRZM)
  - Model plastic particle as soil particle (erosion)
  - 30-year annual average % of applied mass leaving the field
- 15 scenarios covering weather and soil characteristics
- Based on JRC estimates of soil
  - Rainfall erosivity, soil erodibility, cover management, topography, and support practices
- Biosolid application twice a year to maize
- Assumes direct adjacency of field to water

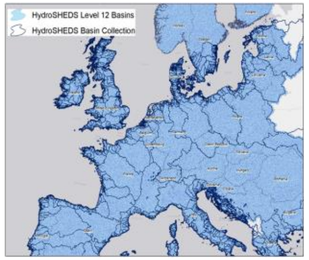


Ritter, A.; Roy, C.; and Holmes, C. 2020. Geospatial model to estimate microplastics entering waterways from wastewater systems and land applied biosolids. American Chemistry Society Fall 2020 annual meeting. August 17-20, 2020. Virtual.

Addressing both WWTP emissions and land applied biosolids

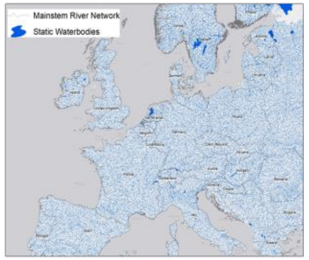


Basins



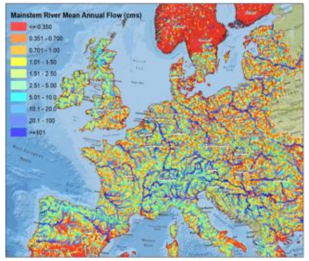
HydroSHEDS provides framework for characterization and routing

Rivers & Lakes



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

River Flow

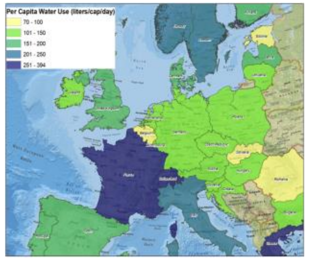


55 years of flow data available from FLO1K, overlaid on river mainstem

Landcover

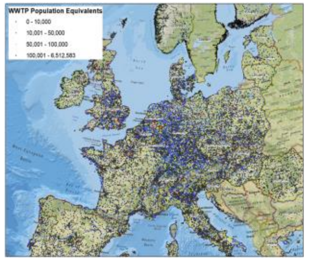
Urban, agriculture and pasture landcover from JRC Corine LC

Water Use



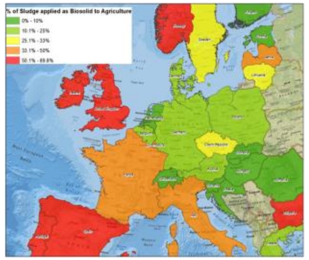
Per capita water use from Eurostat and Member State level sources

Wastewater



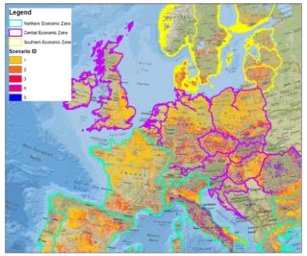
Municipal facilities from EEA's WaterBase – location and population

Biosolid Application



Sewage sludge disposal from wastewater treatment - Eurostat

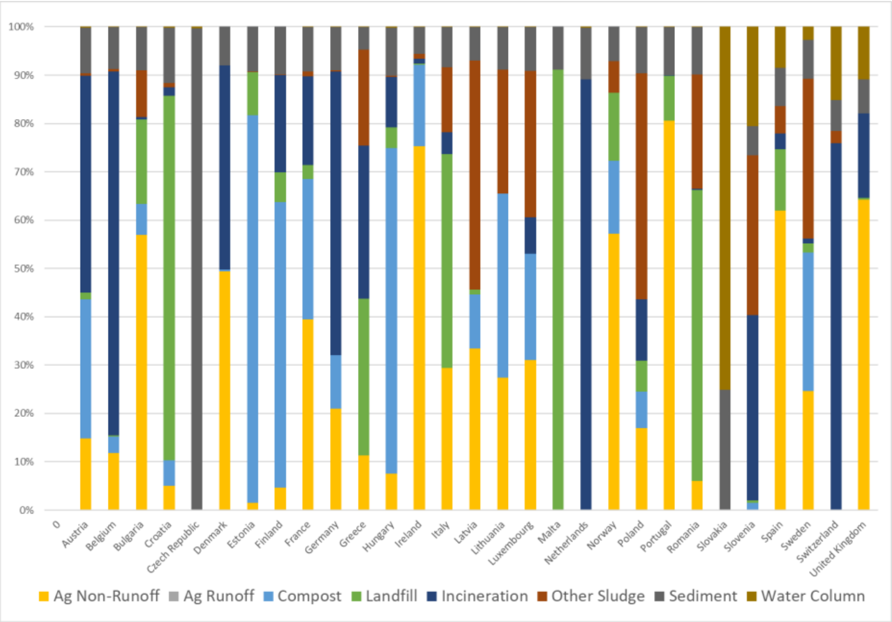
Runoff Potential



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

Holmes, C.; Amos, J.; and Dyer, S. 2019. Modeling aquatic and terrestrial transport pathways for microplastics entering WWTP systems. SETAC North America 40th Annual Meeting. Toronto, Ontario, Canada. 2019

Environmental disposition of microplastic particles in wastewater

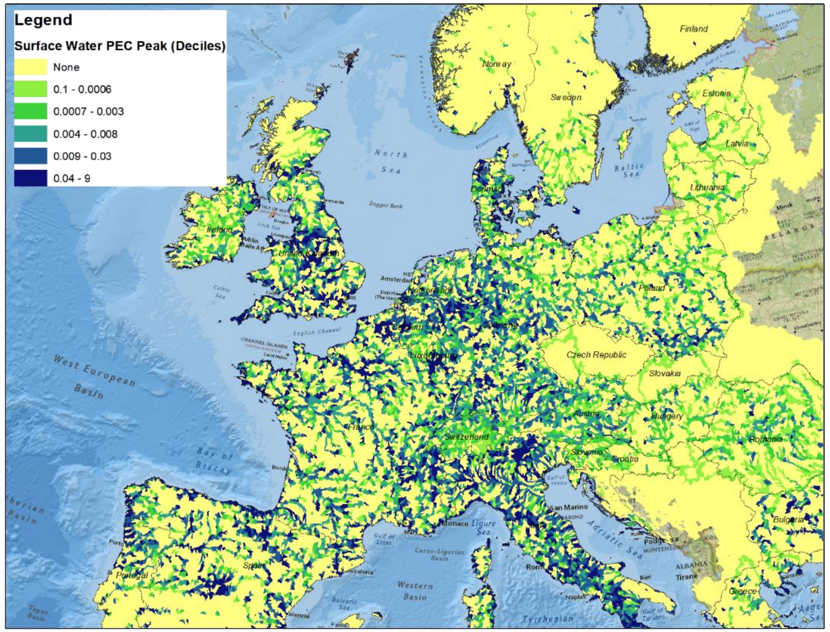


<u>Hypothetical Scenario:</u>

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

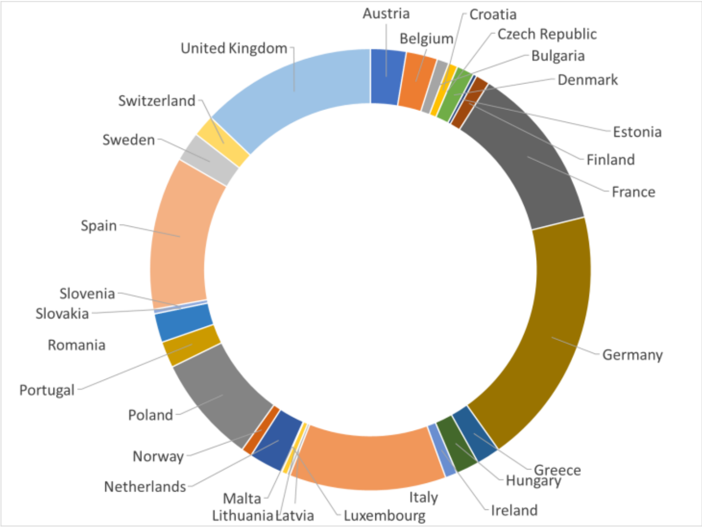
<u>Environmental Disposition of Annual Emitted Mass:</u>

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%



Surface Water Predicted Environmental Concentrations

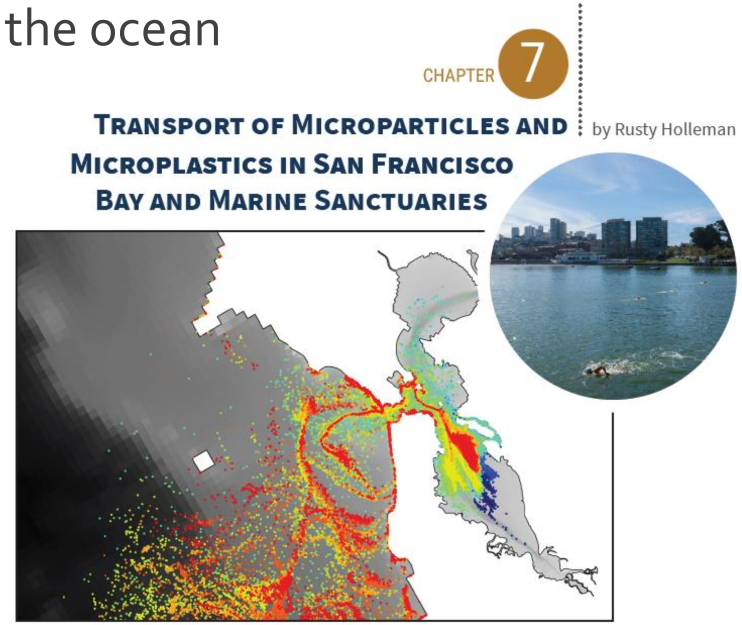
Total Annual Modelled Mass Residing in the Environment



Holmes, C.; Amos, J.; and Dyer, S. 2019. Modeling aquatic and terrestrial transport pathways for microplastics entering WWTP systems. SETAC North America 40th Annual Meeting. Toronto, Ontario, Canada. 2019

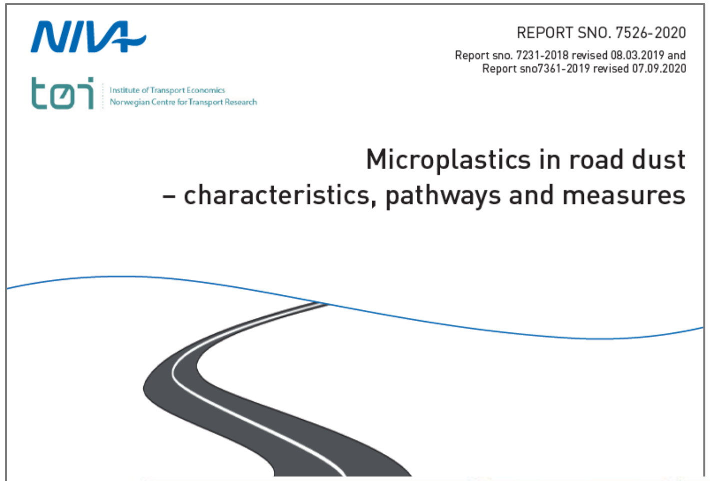
Urban stormwater runoff

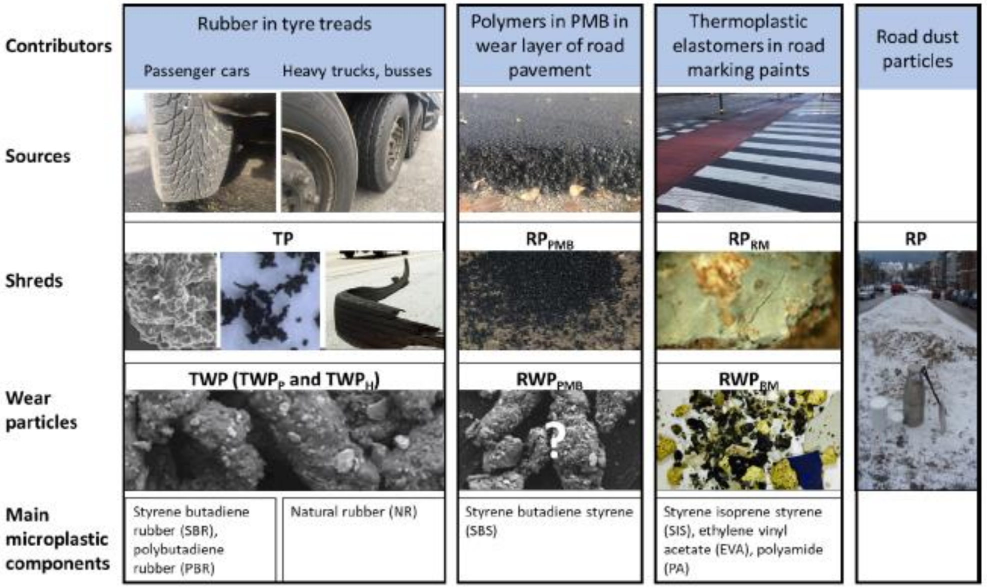
- Microplastic loading from stormwater runoff was 300 times greater than the load generated from WWTPs discharging to the San Francisco Bay
- Also, somewhere between freshwater and marine …
- 3-dimensional hydrodynamic model – move particles through bay to the ocean



Sutton, R.; Lin, D.; Sedlak, M.; Box, C.; Gilbreath, A.; Holleman, R.; Miller, L.; Wong, A.; Munno, K.; Zhu, X.; Rochman, C. **2019**. Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region. Richmond, CA: San Francisco Estuary Institute. https://www.sfei.org/

Tire wear particles





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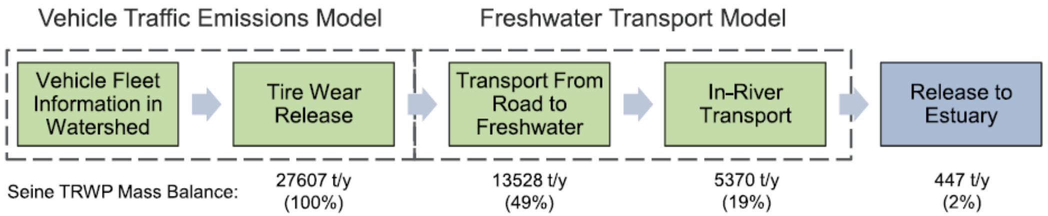
Characterizing export of land-based microplastics to the estuary - Part I: Application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed

K.M. Unice [a,*], M.P. Weeber [b], M.M. Abramson [a], R.C.D. Reid [a], J.A.G. van Gils [b], A.A. Markus [b], A.D. Vethaak [b,c], J.M. Panko [a]

[a] Cardno ChemRisk, Pittsburgh, PA, United States
[b] Deltares, PO Box 177, 2600 MH Delft, the Netherlands
[c] Vrije Universiteit, Department of Environment and Health, Amsterdam, the Netherlands



Challenges in prospective exposure modelling

Multitude of types, shapes, and sizes

Primary & secondary particles

Variability of the natural world

Model verification / validation

We keep learning and our perspective can change

Applied Analysis Solutions, LLC

ChrisHolmes@AppliedAnalysis.solutions

https://AppliedAnalysis.solutions/