THE MARINA MODELS

Model to Assess River Inputs of pollutaNts to seAs

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Contents

MARINA family

In short, MARINA is a Model to Assess River Inputs of pollutaNts to seAs.

We develop the MARINA family consisting of interdisciplinary, sub-basin scale models. Our MARINA models focus on multi-pollutant issues under global change. The models aim to quantify the levels of multiple pollutants in water, their sources, and trends in relation to interactions between climate and socio-economic systems at different scales in time (annual, seasonal) and space (past, present and future). The models are used to explore effective solutions under global change.

MARINA sub-themes

Our MARINA models are developed along the four pollution sub-themes: Multiple Pollutants, Plastics, Antibiotics and Nutrients. These sub-themes consist of specific versions of the models, which can be explored per theme from the next page onwards.

MARINA modelling approach

We develop new, multi-pollutant modeling approaches to enhance our knowledge in interactions between water pollutants (eutrophication, plastics, antibiotics) and society under global change. We develop the sub-basin scale approaches that promote new thinking on solutions for clean water with synergies and trade-offs in pollution control. Our approaches can help to learn about pollution causes, interactions and support debates on effective solutions for rivers in over 10,000 sub-basins. We study interactions in pollution control. We teach and communicate our modeling approaches to society. Figure 1 shows the modeling approach, and Figure 2 shows an example of the model outputs.

Why we develop the MARINA models

We aim to contribute to effective solutions for clean water for all (the figures below). We aim for solutions that can be accepted by society. We explore options for clean water for people's consumption (drinking) and activities (agriculture, recreation), and to sustain nature.

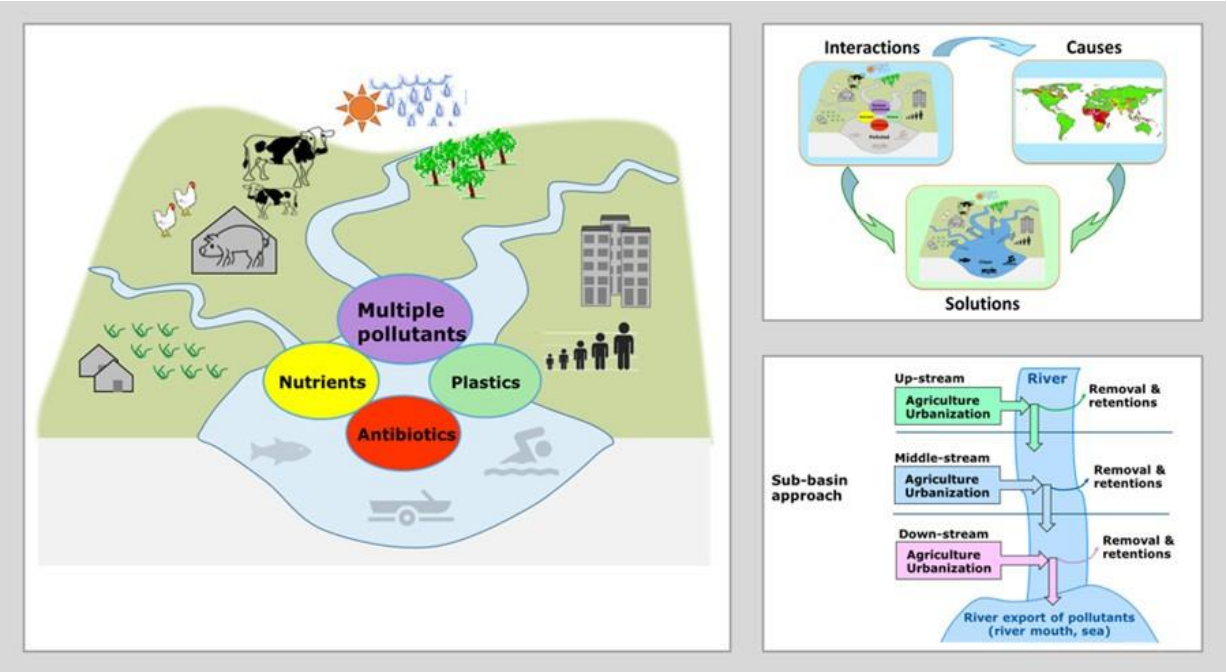


Figure 1: The MARINA modeling approaches for multiple pollutants and sub-basins.

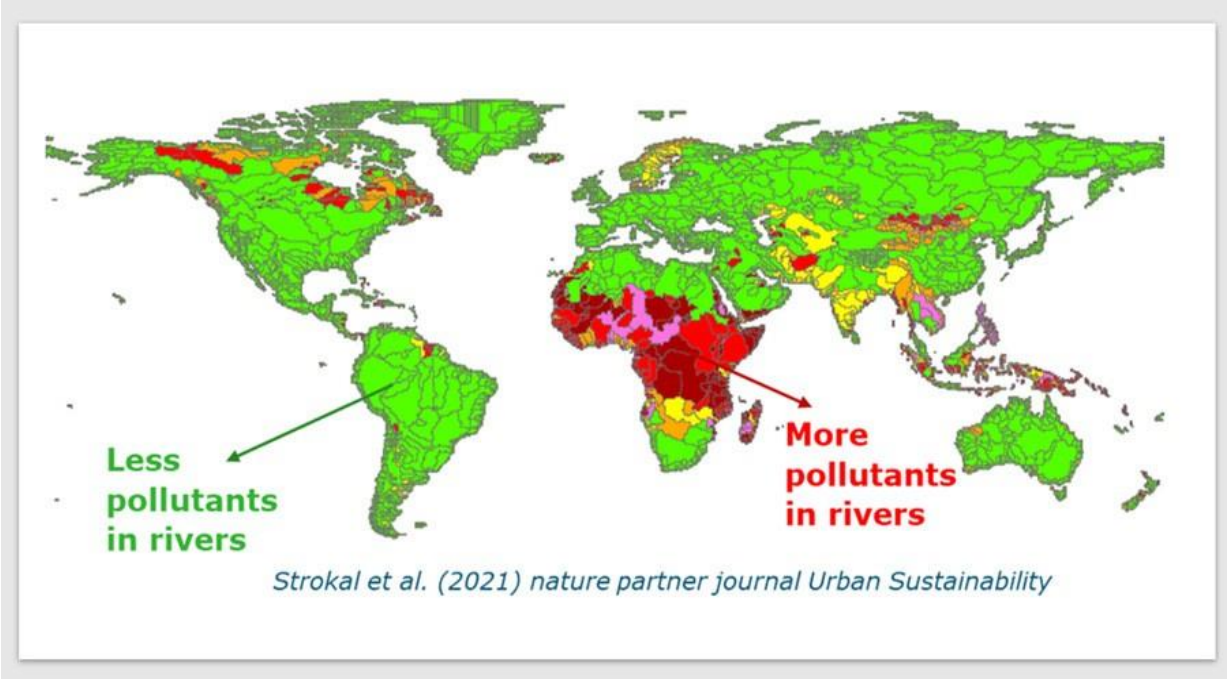
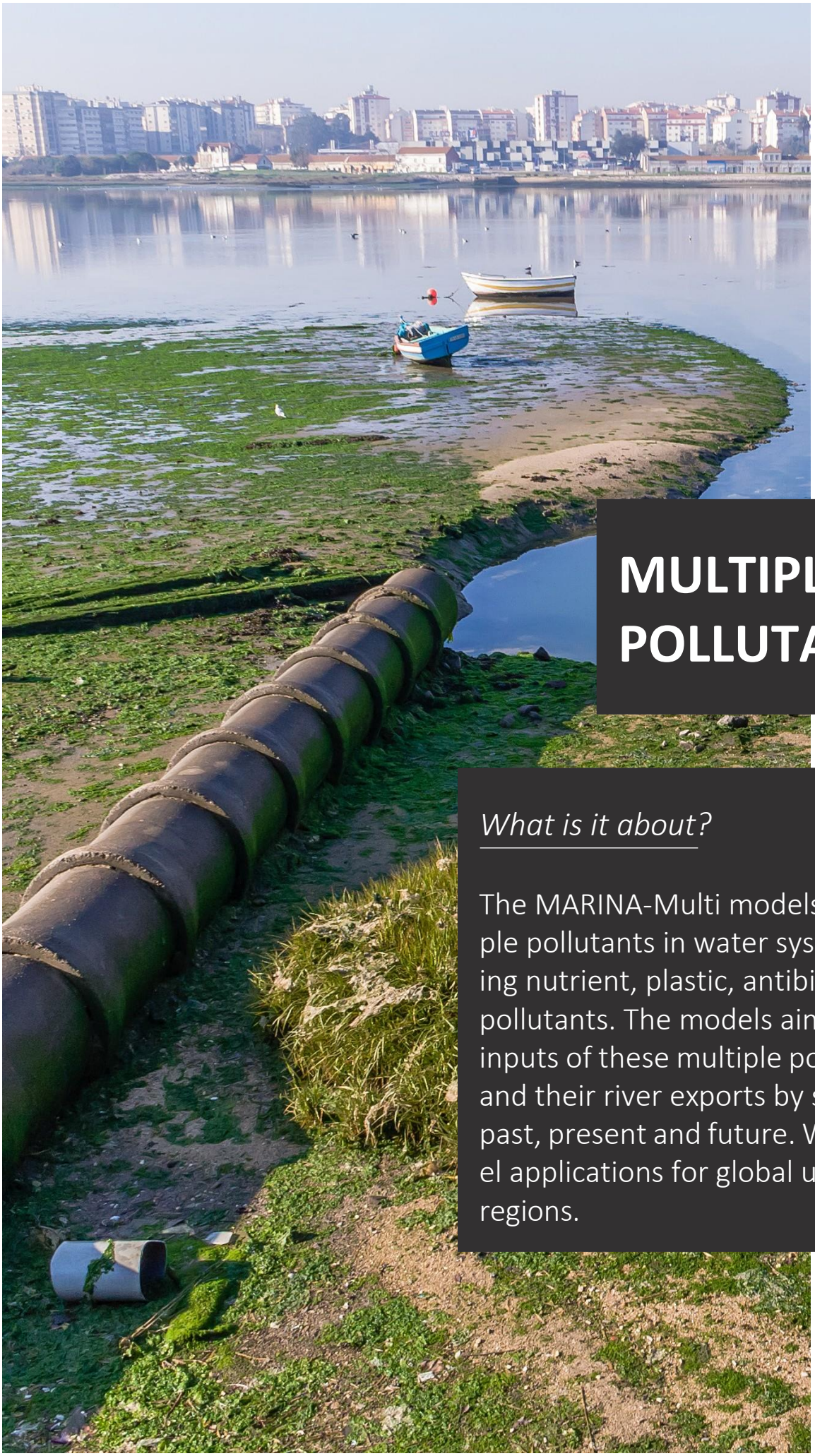


Figure 2: An example of the MARINA model outputs: River pollution in an optimistic scenario for 2050.

MARINA video's

Curious to learn more about water pollution in general and on how to use the MARINA models? We invite you to take a look at our YouTube channel 'The MARINA models' accessed through: https://www.youtube.com/channel/UC5oYrh7cZBWzuq4rS3FccFQ.



MULTIPLE POLLUTANTS

What is it about?

The MARINA-Multi models focus on multiple pollutants in water systems by combining nutrient, plastic, antibiotic and other pollutants. The models aim to quantify inputs of these multiple pollutants to rivers and their river exports by sources for the past, present and future. We develop model applications for global use and for other regions.

GLOBAL APPLICATION

Pollution due to urbanization (MARINA-Multi model: Global-1.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Global-1.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** nitrogen, phosphorus, triclosan, *Cryptosporidium*, and microplastics
- **Sources:** point (sewage and open defecation)
- **Main inputs:** population with the sewage connections, removal efficiencies, excretion . consumption rates of pollutants per capita
- **Main outputs:** inputs of multiple pollutants to rivers by source and sub-basin

Modelling approach

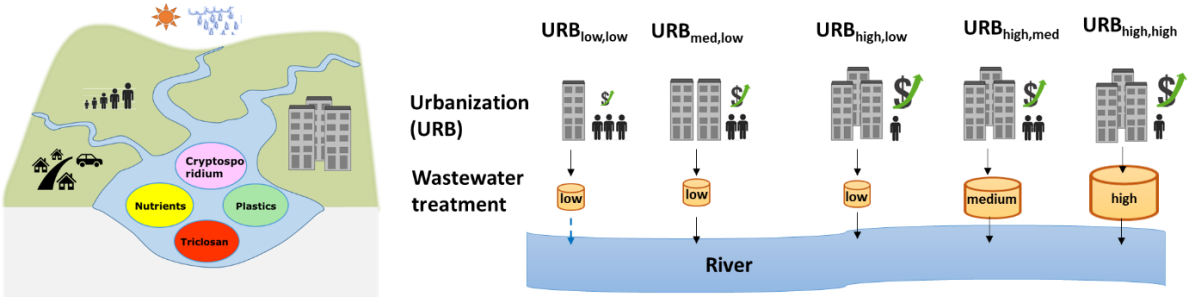


Figure 1: Conceptual framework of the model application to the world (Strokal et al., 2021)

Model outputs (examples)

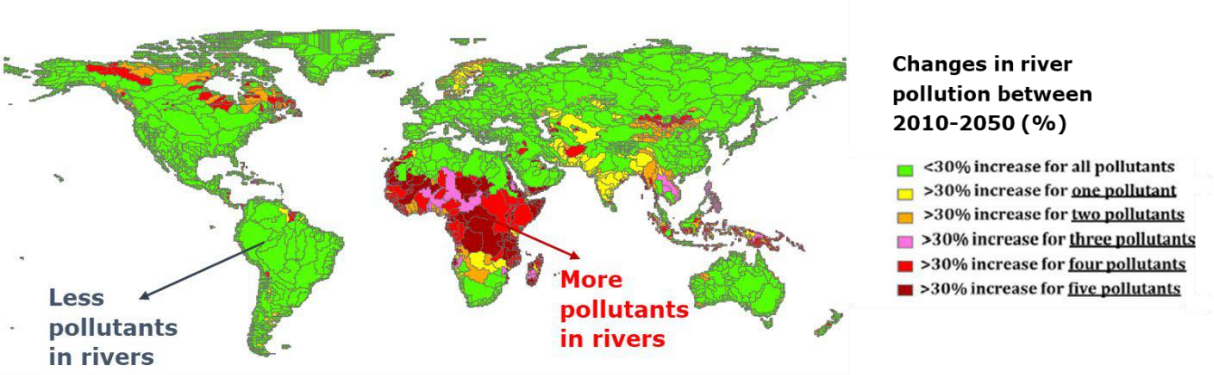


Figure 2: Changes in river pollution between 2010 and 2050 according to an optimistic scenarios that assumed the implementation of advanced technologies to treat wastewater and avoid open defecation. (%). Strokal et al., (2021).

Publications and links

- The VENI project https://www.nwo.nl/en/projects/016veni198001
- https://www.wur.nl/en/newsarticle/City- becomes-increasing-source-of-water-pollution-this-century.htm
- https://www.wur.nl/en/newsarticle/Five-ways- for-green-agriculture-and-blue-water.htm
- Contaminated waters (EGU press-conference): https://client.cntv.at/egu2018/pc3

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Pollution due to livestock production (MARINA-Multi model: Global-2.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Global-2.0 (published as MARINA-Global-L in Li et al., 2022)
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** nitrogen, phosphorus, *Cryptosporidium*
- **Sources:** diffuse sources (manure application on land) and point sources (direct discharges of manure to rivers) from livestock production
- **Main inputs:** livestock numbers, manure excretion rates, land use, crop production, hydrology
- **Main outputs:** inputs of multiple pollutants to rivers by source and sub-basin

Modelling approach

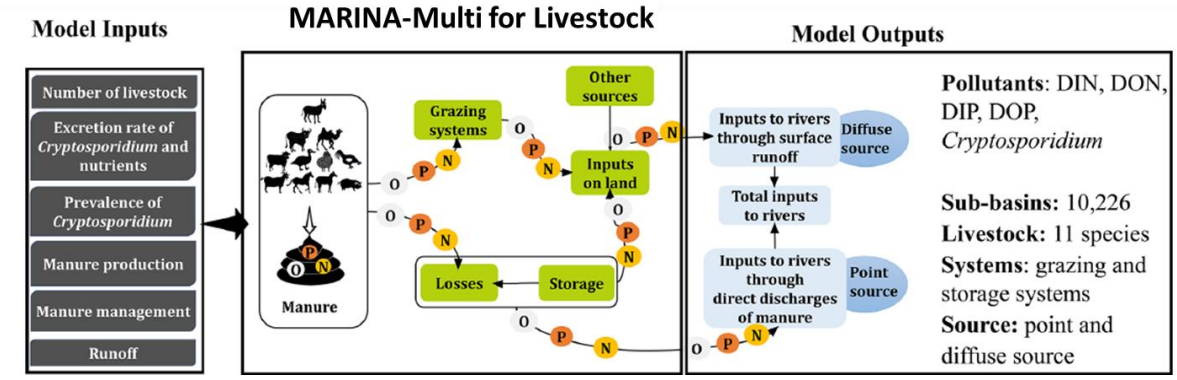

Figure 1: Conceptual framework of the model application to the world (Li et al., 2022)

Model outputs (examples)

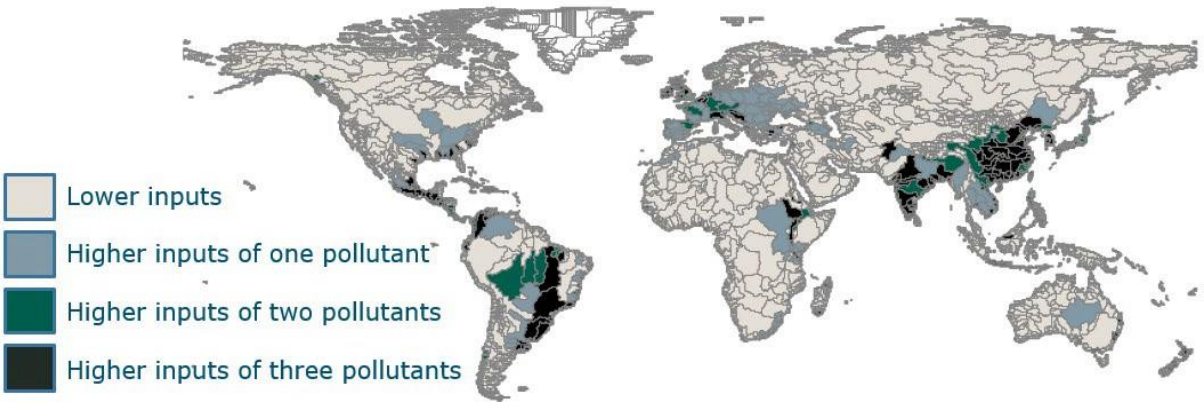

Figure 2: River pollution with three pollutants (nitrogen, phosphorus and *Cryptosporidium*) from livestock production (Li et al., 2022)

Publications and links

- Li et al (2022) DOI: 10.1016/j.watres.2021.117906 https://www.sciencedirect.com/science/article/pii/S0043135421011003
- PhD project Yanan Li: Multi-pollutant assessment of water quality and food production for agricultural green development in China: an integrated, multi-scale modelling approach

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Pollution due to COVID-19 measures (MARINA-Multi model: Global-3.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Global-3.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2020
- **Pollutants:** triclosan, microplastics, macroplastics and diclofenac
- **Sources:** point sources (sewage) and diffuse sources (mismanaged solid waste)
- **Main inputs:** mismanaged waste, population, consumption of diclofenac, plastics and triclosan, excretion rate of diclofenac, sewage systems
- **Main outputs:** inputs of multiple pollutants to rivers by source and sub-basin

Modelling approach

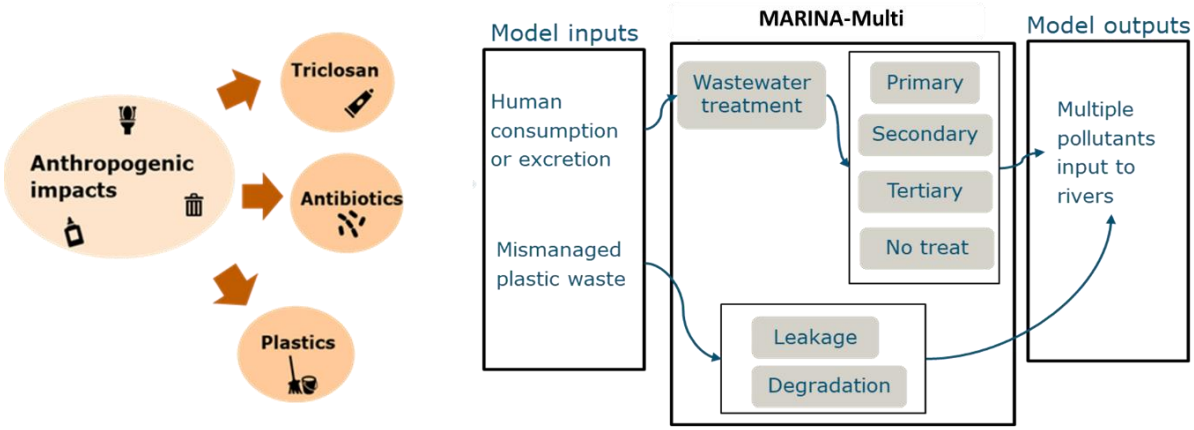

Figure 1: Conceptual framework of the model application to the world (Zhang and others, under development)

Model outputs (examples)

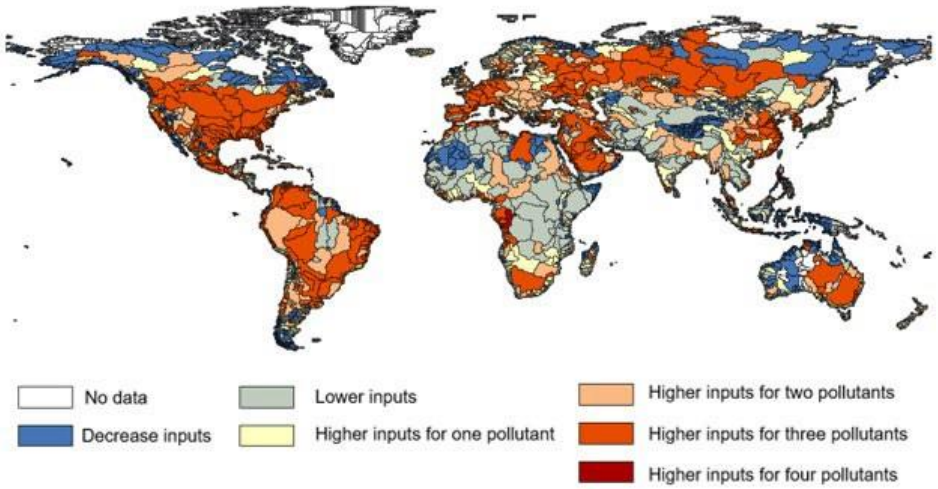

Figure 2: Changes in river pollution as a result of the COVID-19 measures (Qi zhang and others, under development)

Publications and links

- PhD project Qi Zhang: Agricultural Green Development Pathways for food and water in China

Contacts: Qi Zhang, qi.zhang@wur.nl, Maryna Strokal, maryna.strokal@wur.nl;
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Pollution due to urbanization and agriculture (MARINA-Multi model: Global-4.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Global-4.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** nitrogen, phosphorus, triclosan, microplastics, macroplastics and diclofenac
- **Sources:** diffuse sources (agricultural runoff) and point sources (sewage systems, open defecation, direct discharges of manure)
- **Main inputs:** livestock numbers, manure excretion rates, land use, crop production, sewage connections, removal efficiencies, water consumption, hydrology
- **Main outputs:** river export of multiple pollutants by source and sub-basin

Modelling approach

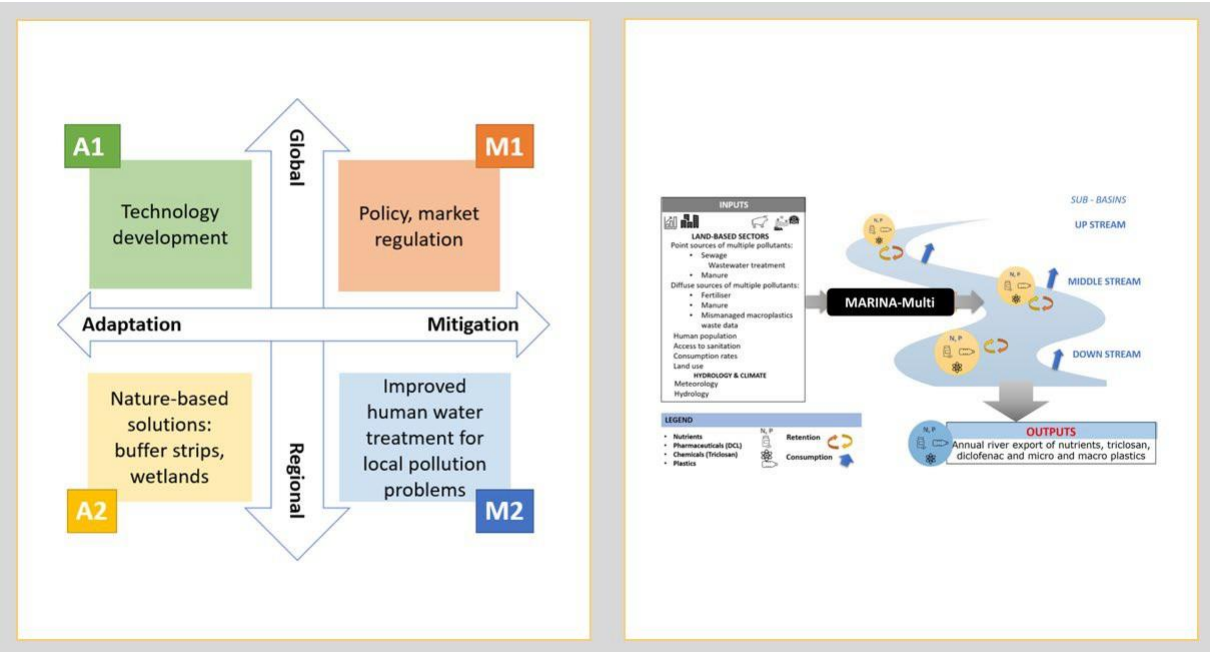


Figure 1: Conceptual framework of the model application to the world (Ilaria Micella, under development)

Publications and links

- PhD project Ilaria Micella: Innovative forecasting approaches to assess future trends in pollutant flows from land to water systems for advancing sectoral water quality service
- inventWater official website (https://inventwater.eu/)

Contacts: Ilaria Micella, ilaria.micella@wur.nl, Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

This project has received funding from the European Union's Horizon 2021 research and innovation programme under the Marie Sklodowska-Curie gran agreement 956623. MSCA-ITN-ETN – European Training Network.

Seasonality in pollution (MARINA-Multi model: Global-5.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Global-5.0
- **Application:** Global
- **Scales:** sub-basins and seasonal
- **Period:** 2010-2100
- **Pollutants:** dissolved inorganic (DIN, DON) and organic (DON, DOP) nitrogen (N) and phosphorus (P), triclosan, microplastics, macroplastics, and diclofenac
- **Sources:** diffuse sources (agricultural runoff) and point sources (sewage systems, open defecation, direct discharges of manure)
- **Main inputs:** livestock numbers, manure excretion rates, land use, crop production, sewage connections, removal efficiencies, water consumption, hydrology, temperature
- **Main outputs: :** seasonal river export of DIN, DON, DIP, DOP, triclosan, microplastics, macroplastics and diclofenac by source and sub-basin

Modelling approach

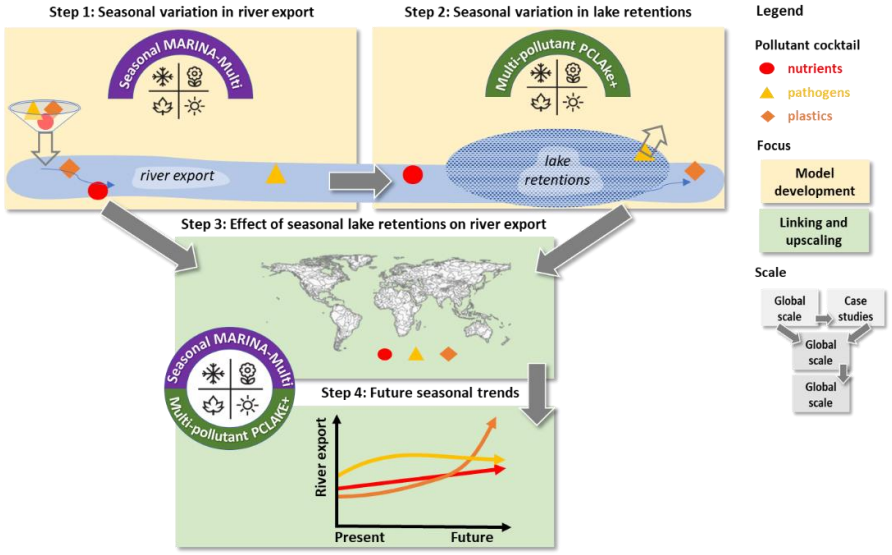


Figure 1: Conceptual framework of the model application to the world (Mirjam Bak, under development)

Model outputs (examples)

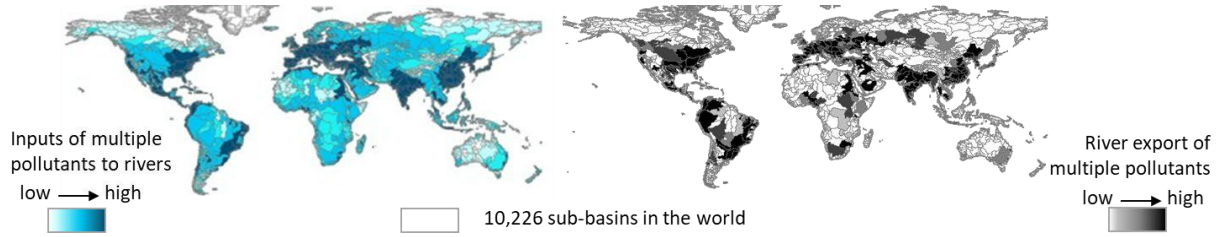


Figure 2: Inputs of multiple pollutants to rivers and their exports to seas (Mirjam Bak, under development)

Publications and links

- https://sense.nl/research/another-season-another-cocktail-modelling-seasonal-effects-of-lake-retention-on-river-export-of-pollutants/
- PhD project of Mirjam Bak

Contacts: Mirjam Bak, mirjam.bak@wur.nl, Annette Janssen, annette.janssen@wur.nl; Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

EUROPE APPLICATION

Pollution due to urbanization (MARINA-Multi model: Europe-1.0)

Model characteristics

- **Model name:** MARINA-Multi
- **Version:** Europe-1.0
- **Application:** the drainage area of the Black Sea
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** nitrogen, phosphorus, triclosan, *Cryptosporidium*, and microplastics
- **Sources:** point (sewage)
- **Main inputs:** population with the sewage connections, removal efficiencies, excretion / consumption rates of pollutants per capita
- **Main outputs:** inputs of multiple pollutants to rivers by source and sub-basin

Modelling approach

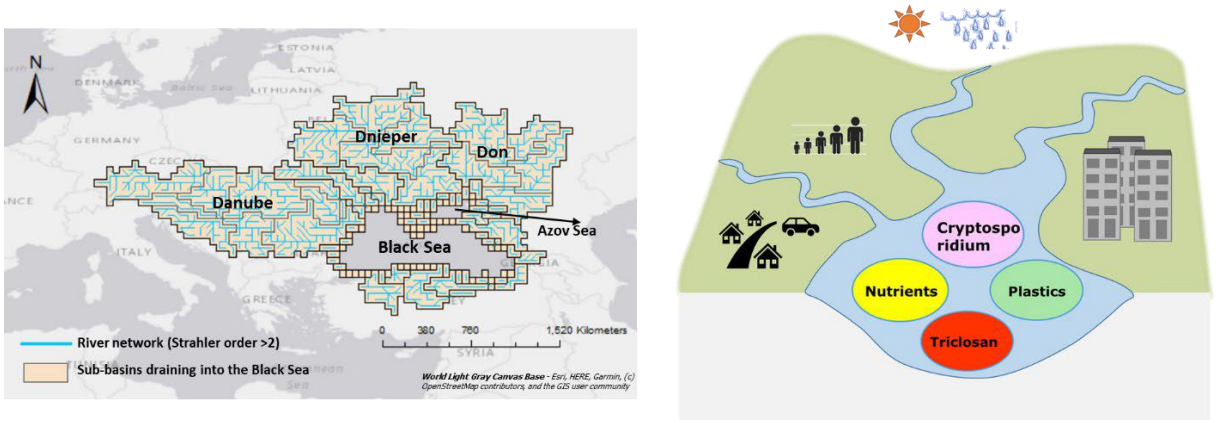


Figure 1: Conceptual framework of the model application to the Black Sea (Strokal et al., 2021)

Model outputs (examples)

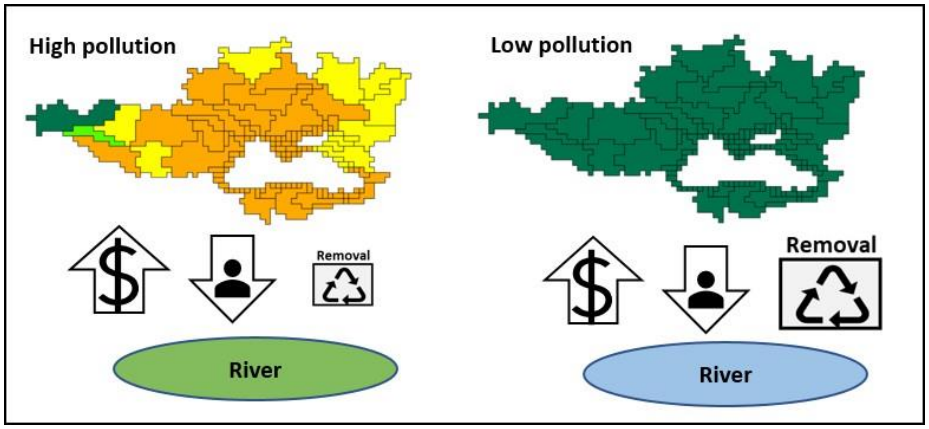


Figure 2: Future river pollution with multiple pollutants from urbanization related activities (Strokal et al., under development).

Publications and links

- Strokal et al (2022) DOI: 10.1016/j.marpolbul.2022.113633 https://doi.org/10.1016/j.marpolbul.2022.113633

Contacts: Maryna Strokal, maryna.strokal@wur.nl

PLASTICS

What is it about?

The MARINA-Plastics models focus on plastic-related water quality. Plastic inputs from rivers into seas are a major concern due to their adverse consequences to life in and around waters. The models aim to quantify inputs of macro- and microplastics to rivers and their river exports to seas by sources for the past, present and future. We develop model applications for global use and for China.

GLOBAL APPLICATION

Pollution sources of macro- and microplastics (MARINA-Plastics model: Global-1.0)

Model characteristics

- **Model name:** MARINA-Plastics
- **Version:** Global-1.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** macro- (>5mm) and microplastics (<5mm)
- **Sources:** point (sewage containing plastics from laundry, car tyres, household dust and personal care products) and diffuse (mismanaged solid waste)
- **Main inputs:** population connected to sewage systems, removal efficiencies, production of mismanaged waste, consumption/production rates for personal care products, car tyres, dust and laundry, hydrology
- **Main outputs:** river export of macro- and microplastics by source and sub-basin

Modelling approach

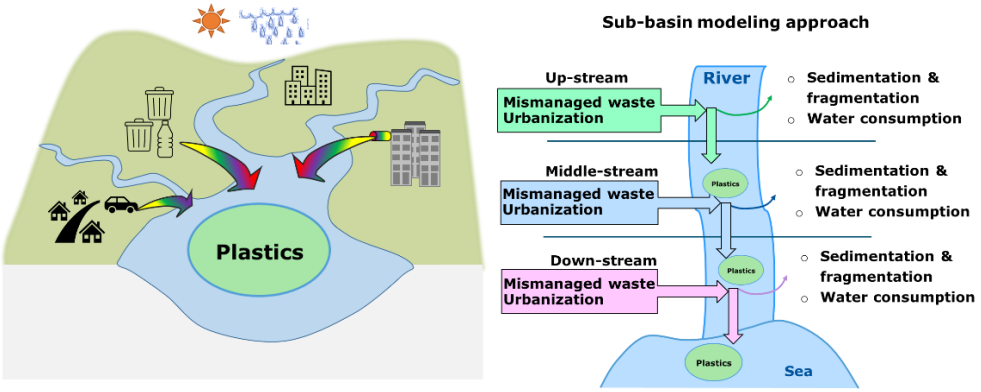


Figure 1: Conceptual framework of the model application to the world

Model outputs (examples)

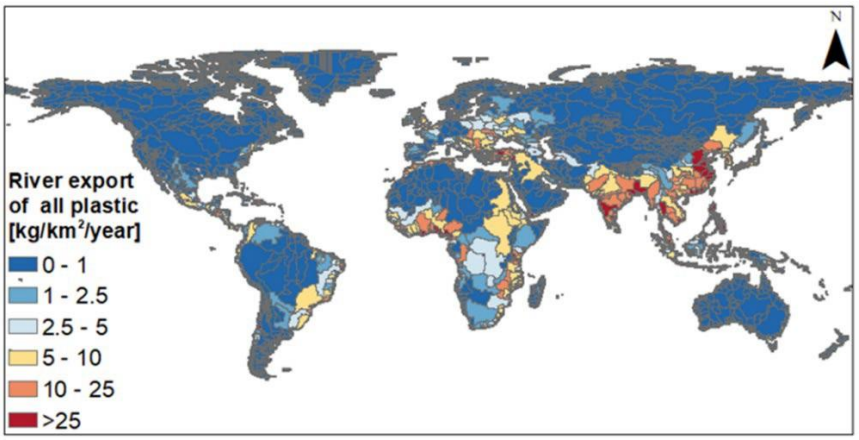


Figure 2: River export of macro- and microplastics by sub-basin (Maryna Strokal, Paul Vriend and others, under development).

Publications and links

- Strokal et al (2021) DOI: 10.5194/egusphere-egu21-649 https://ui.adsabs.harvard.edu/abs/2021EGUGA..23..649S/abstract

Contacts: Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

CHINA APPLICATION

Crop production impacts (MARINA-Plastics model: China-1.0)

Model characteristics

- **Model name:** MARINA-Plastics
- **Version:** China-1.0
- **Application:** China
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** macro- (>5mm) and microplastics (<5mm)
- **Sources:** crop production (mulching, greenhouse plastics), point sources (sewage), diffuse sources (mismanaged solid waste)
- **Main inputs:** application rates of plastics for mulching and greenhouses, residue rates of plastics in soils, population connected to sewage systems, removal efficiencies, hydrology
- **Main outputs:** inputs of macro- and microplastics to rivers by source and sub-basin

Modelling approach

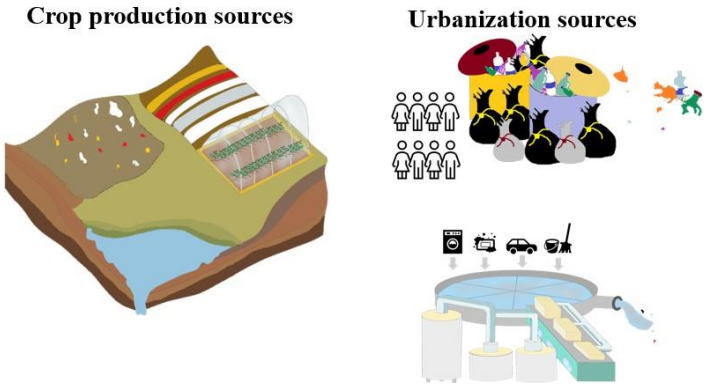


Figure 1: Conceptual framework of the model application to China

Model outputs (examples)

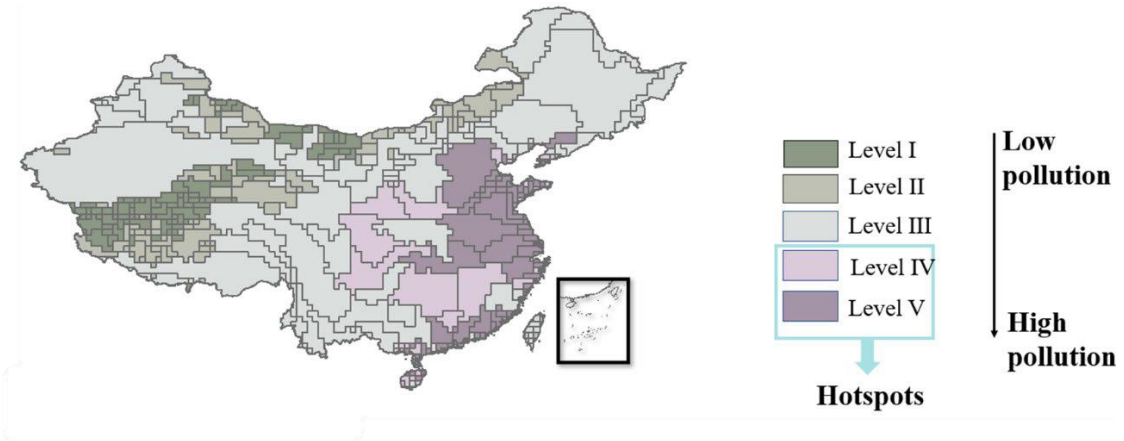


Figure 2: Inputs of plastics (macro- and microplastics) to rivers according to pollution levels (Yanan Li, and others, under development).

Publications and links

- PhD project Yanan Li: Multi-pollutant assessment of water quality and food production for agricultural green development in China: an integrated, multi-scale modelling approach

Contacts: Yanan Li, yanan.li@wur.nl; Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

EUROPE APPLICATION

Solutions for the Black Sea (MARINA-Plastics model: Europe-1.0)

Model characteristics

- **Model name:** MARINA-Plastics
- **Version:** Europe-1.0
- **Application:** The drainage area of the Black Sea
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** microplastics (<5mm)
- **Sources:** point (sewage containing plastics from laundry, car tyres, household dust and personal care products and open defecation via laundry and the use of personal care products)
- **Main inputs:** population connected to sewage systems, removal efficiencies, consumption/production rates for personal care products, car tyres, dust and laundry, hydrology
- **Main outputs:** river export of microplastics by source and sub-basin

Modelling approach

Figure 1: Conceptual framework of the model application to the drainage area of the Black Sea (Strokal et al., 2022)

Model outputs (examples)

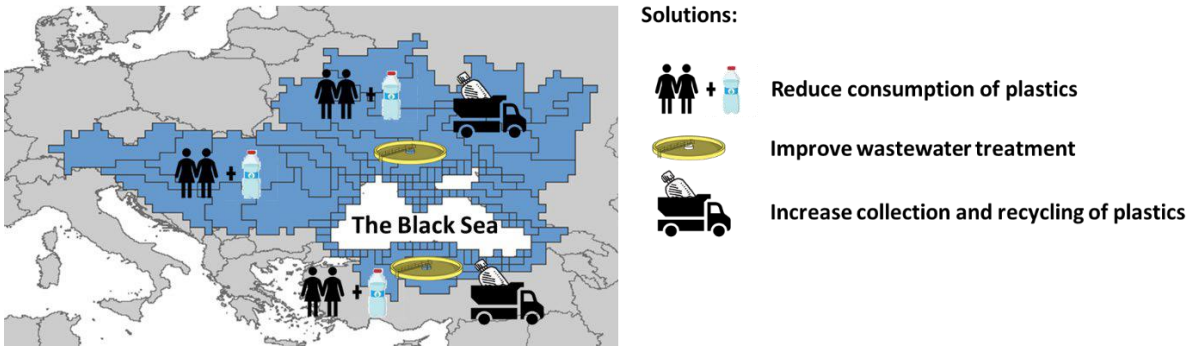


Figure 2: Identified solutions for reducing microplastics from 107 sub-basins draining into the Black Sea (Strokal et al., 2022).

Publications and links

- Strokal et al (2022) DOI: 10.1016/j.marpolbul.2022.113633 https://doi.org/10.1016/j.marpolbul.2022.113633

Contacts: Maryna Strokal, maryna.strokal@wur.nl

ANTIBIOTICS

What is it about?

The MARINA-Antibiotics models focus on antibiotic-related water quality. Antibiotic pollution happens, for example, when livestock production and pharmaceutical manufacturing wastewaters discharge into rivers or seas where they may affect the biology of living organisms. The models aim to quantify inputs of antibiotics to rivers and their river exports to seas by sources for the past, present and future.

CHINA APPLICATION

Pollution due to livestock production (MARINA-Antibiotics model: China-1.0)

Model characteristics

- **Model name:** MARINA-Antibiotics
- **Version:** China-1.0
- **Application:** China
- **Scales:** sub-basins and annual
- **Period:** 2010-2100
- **Pollutants:** 24 types of antibiotics for several animal species
- **Sources:** diffuse (manure application) and point sources (direct discharge of manure) of antibiotics in groundwater and in rivers via runoff and erosion
- **Main inputs:** livestock numbers, antibiotic consumption and excretion rates per animal type, degradation in soils, runoff and erosion rates, soil organic content, soil texture, hydrology
- **Main outputs:** inputs of antibiotics to rivers in 395 sub-basins by antibiotic type and animal species

Modelling approach

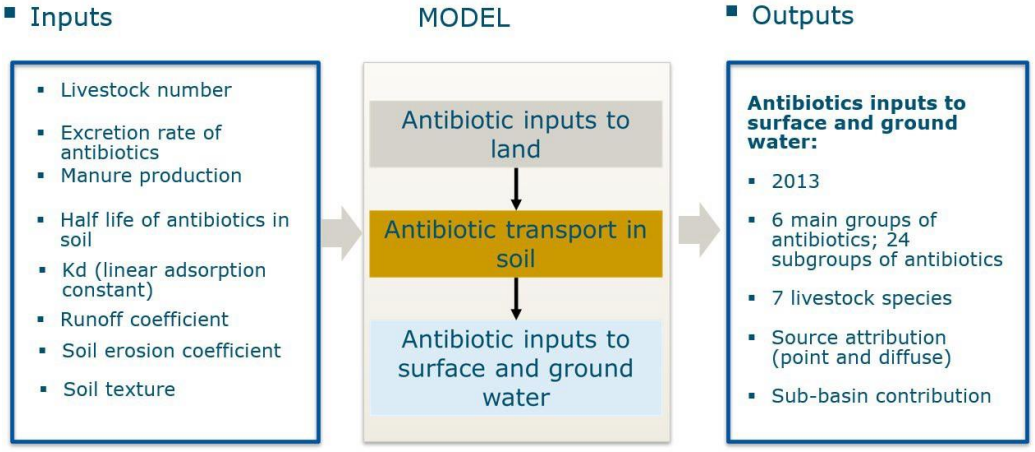


Figure 1: Conceptual framework of the model application to 395 sub-basins in China

Model outputs (examples)

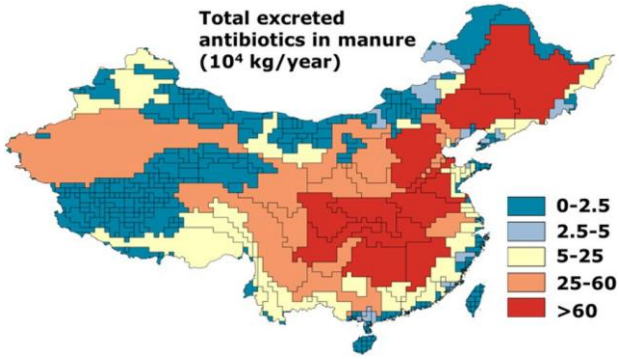
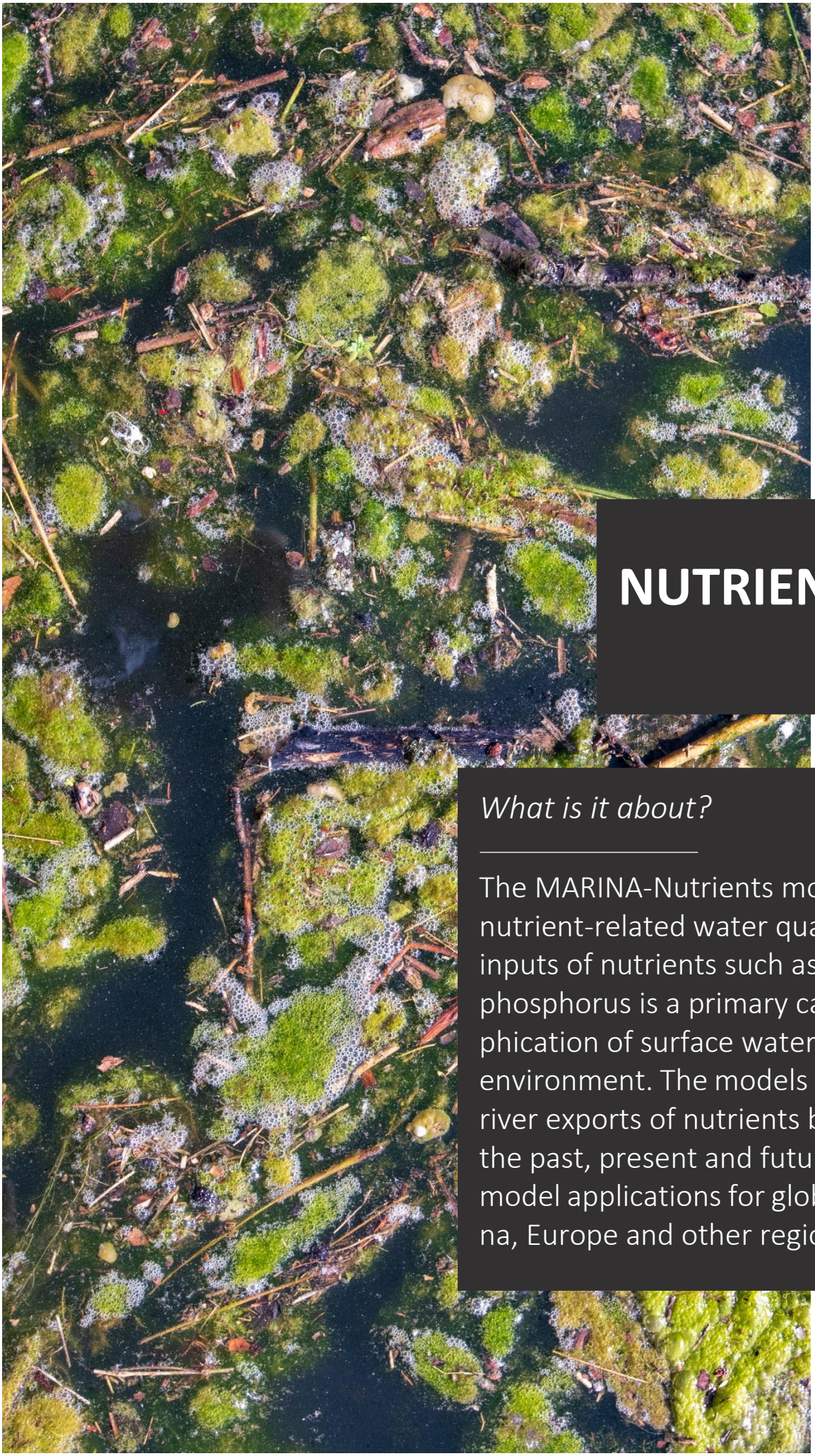


Figure 2: Total amount of antibiotics excreted in animal manure (kg/year, Qi Zhang and others, under development).

Publications and links

- PhD project of Qi Zhang: Agricultural Green Development Pathways for food and water in China

Contacts: Qi Zhang, qi.zhang@wur.nl; Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl



NUTRIENTS

What is it about?

The MARINA-Nutrients models focus on nutrient-related water quality. Excessive inputs of nutrients such as nitrogen and phosphorus is a primary cause of eutrophication of surface waters, harming the environment. The models aim to quantify river exports of nutrients by sources for the past, present and future. We develop model applications for global use, for China, Europe and other regions.

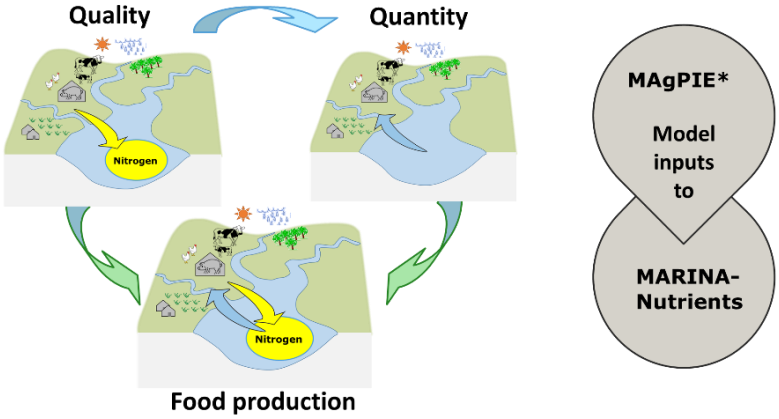
GLOBAL APPLICATION

Water scarcity analysis (MARINA-Nutrients model: Global-1.0)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** Global-1.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2050
- **Pollutants:** dissolved inorganic (DIN) and organic (DON) nitrogen (N)
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** river export of DIN, and DON by source and sub-basin

Modelling approach



**Model of Agricultural Production and its Impact on the Environment*
https://www.pik-potsdam.de/en/institute/departments/activities/land-use-modelling/magpie

Figure 1: Conceptual framework of the model application to the world

Model outputs (examples)

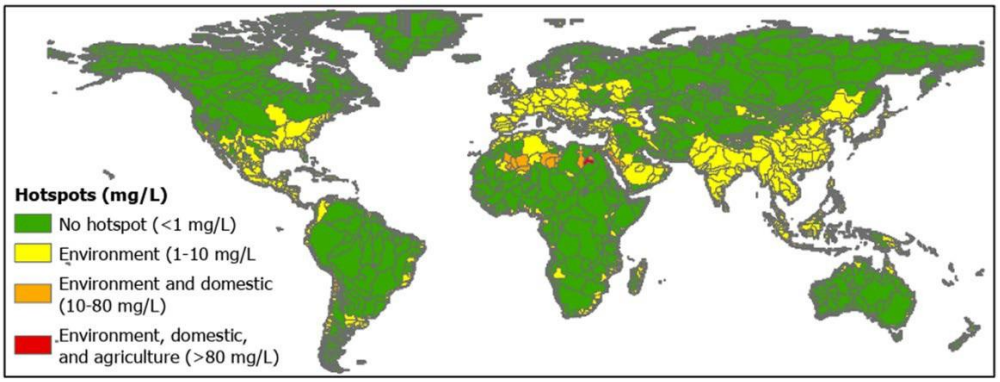


Figure 2: Total Dissolved Nitrogen (TDN) concentration hotspots for the environment, domestic sector, and agricultural sector for 2010 (mg/L). Hotspots refer to sub-basins that do not meet water quality standards for a specific purpose (Mengru Wang, Rhodé Rijneveld et al. under development).

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Global change impacts (MARINA-Nutrients model: Global-2.0)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** Global-2.0
- **Application:** Global
- **Scales:** sub-basins and annual
- **Period:** 2010-2050
- **Pollutants:** dissolved inorganic (DIN) and organic (DON) nitrogen (N)
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** river export of DIN, and DON by source and sub-basin

Modelling approach

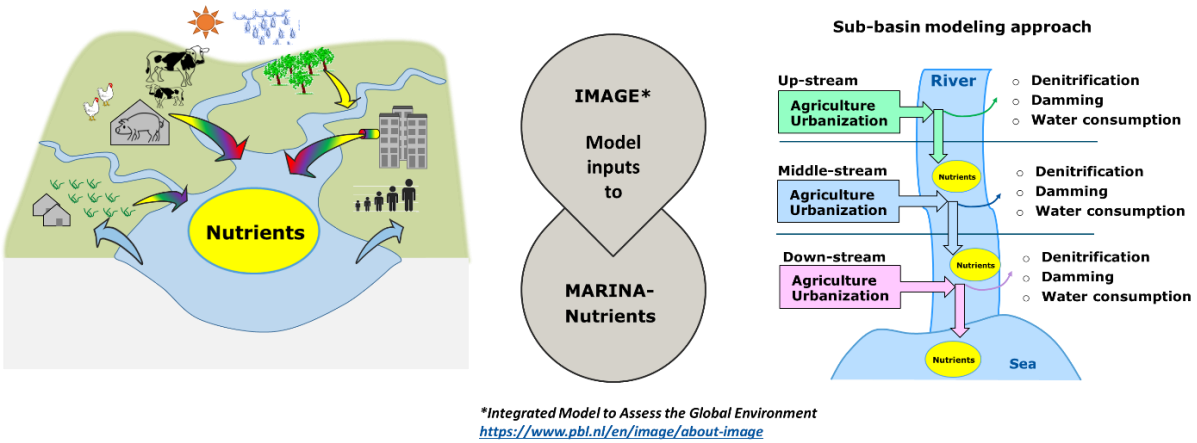

Figure 1: Conceptual framework of the model application to the world

Model outputs (examples)

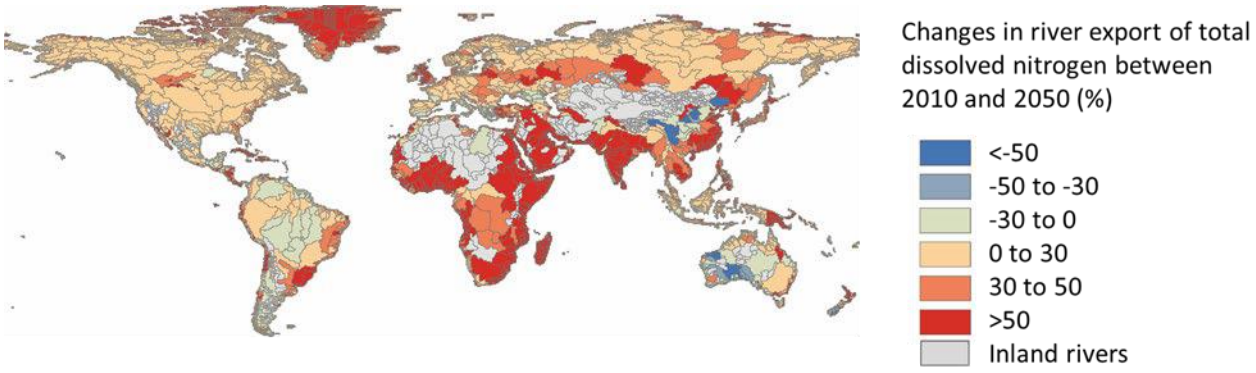

Figure 2: Changes in river export of total dissolved nitrogen between 2010 and 2050 according to a scenario assuming low policy ambitions in agriculture, high economic development and a lot of global warming (the combination of Shared Socio-economic Pathway 5 and Representative concentrative pathway 8.5). The scenario is developed in the INMS project and implemented to the MARINA-Nutrients model (Maryna Strokal, Mengru Wang, et al. under development).

Publications and links

- https://www.inms.international/

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CHINA APPLICATION

Sub-basin scale analysis (MARINA-Nutrients model: China-1.0)

Model characteristics

- **Model name:** MARINA-Nutrients (the first, original version for China)
- **Version:** China-1.0
- **Application:** China
- **Scales:** sub-basins and annual
- **Period:** 1970-2050
- **Pollutants:** dissolved inorganic (DIN, DIP), organic (DON, DOP) nitrogen and phosphorus
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** river export of DIN, DIP, DON and DOP by source and sub-basin

Modelling approach

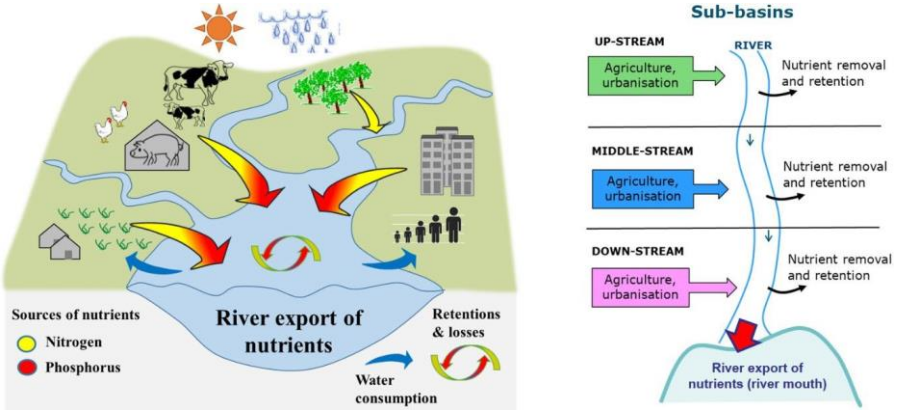

Figure 1: Conceptual framework of the model application to China

Model outputs (examples)

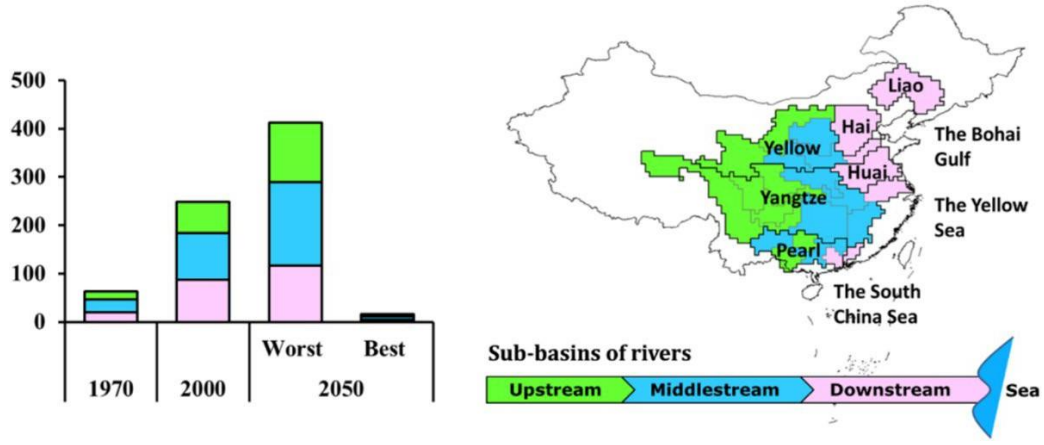

Figure 2: Total river export of phosphorus by sub-basin for 1970, 2000, and 2050 (in kton/year). Published in Strokal et al., (2016)

Publications and links

- Strokal et al (2016) DOI: 10.1016/j.scitotenv.2016.04.071 https://www.wur.nl/en/Publication-details.htm?publicationId=publication-way-353033333231
- https://blog.iiasa.ac.at/2020/02/14/cost-effective-solutions-to-manage-nutrient-pollution-in-the-yangtze/

Contacts: Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

Seasonality (MARINA-Nutrients model: China-1.1)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** China-1.1
- **Application:** China
- **Scales:** Yangtze sub-basins and seasonal
- **Period:** 2000
- **Pollutants:** dissolved inorganic (DIN)
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** river export of DIN by source and sub-basin

Modelling approach

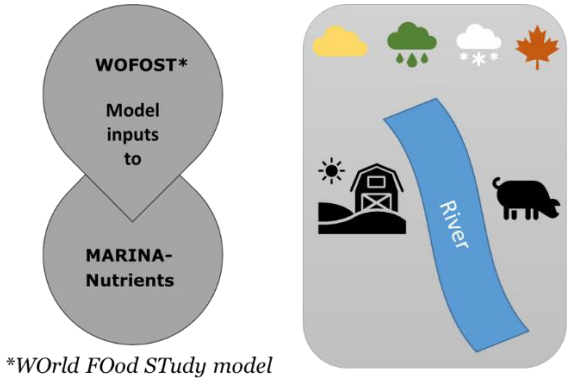

Figure 1: Conceptual framework of the model application to the Yangtze. Modified from Chen et al., (2019) and (2020)

Model outputs (examples)

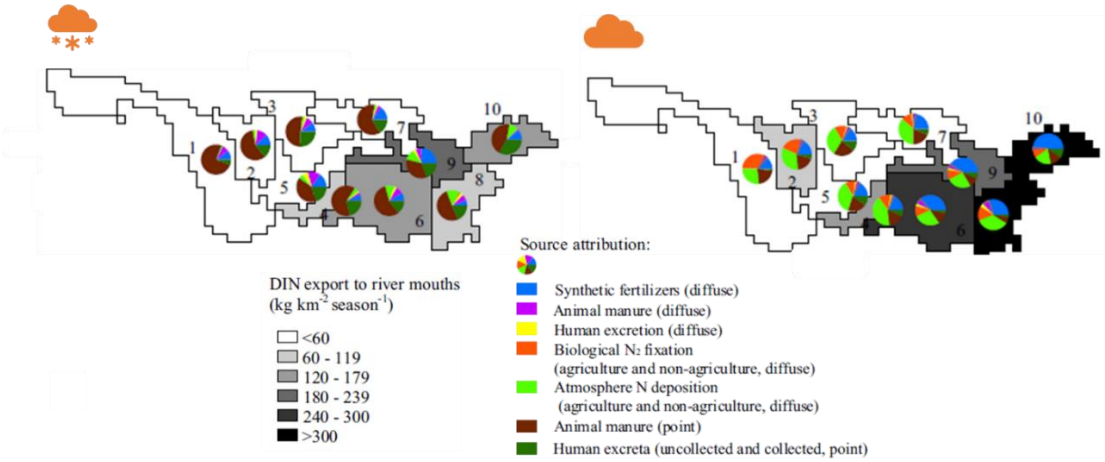

Figure 2: River export of dissolved inorganic nitrogen (kg km^{-2} $season^{-1}$). Modified from Chen et al., (2019)

Publications and links

- Chen et al (2019) DOI: 10.1016/j.scitotenv.2019.03.323 https://www.sciencedirect.com/science/article/abs/pii/S004896971931321X
- Chen et al (2020) DOI: 10.1021/acs.est.0c01333 https://pubs.acs.org/doi/10.1021/acs.est.0c01333

Contacts: Xuanjing Chen, xuanjing.chen@wur.nl; Maryna Strokal, maryna.strokal@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl

Global change and SDGs (MARINA-Nutrients model: China-2.0)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** China-2.0
- **Application:** China
- **Scales:** sub-basins and annual
- **Period:** 2012-2050
- **Pollutants:** dissolved inorganic (DIN, DIP), organic (DON, DOP) nitrogen and phosphorus
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** river export of DIN, DON, DOP, and DIP by source and sub-basin; ICEP (Indicator for Coastal Eutrophication Potential)

Modelling approach

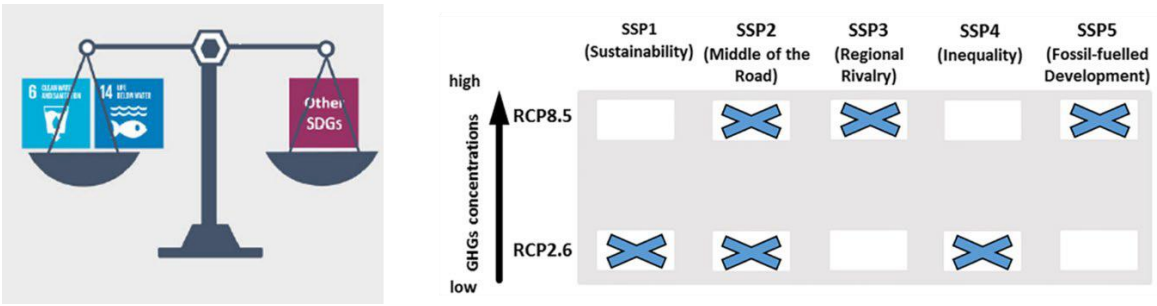

Figure 1: Conceptual framework of the model application to China for global change impacts. SSP is shared Socio-Economic Pathways (Wang et al., 2020). SDG is sustainable development goal (Wang et al., 2022)

Model outputs (examples)

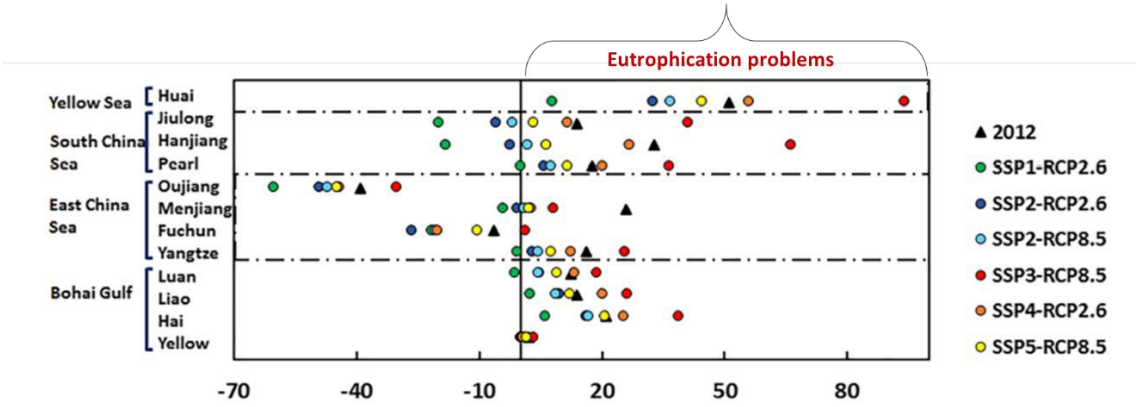

Figure 2: Indicator for Coastal Eutrophication Potential for 2012 and 2050 scenarios (kg C-eq. km^{-2} day^{-1}). SSP is Shared Socio-Economic Pathways. RCP is Representative concentrative Pathways. Published in Wang et al., (2020)

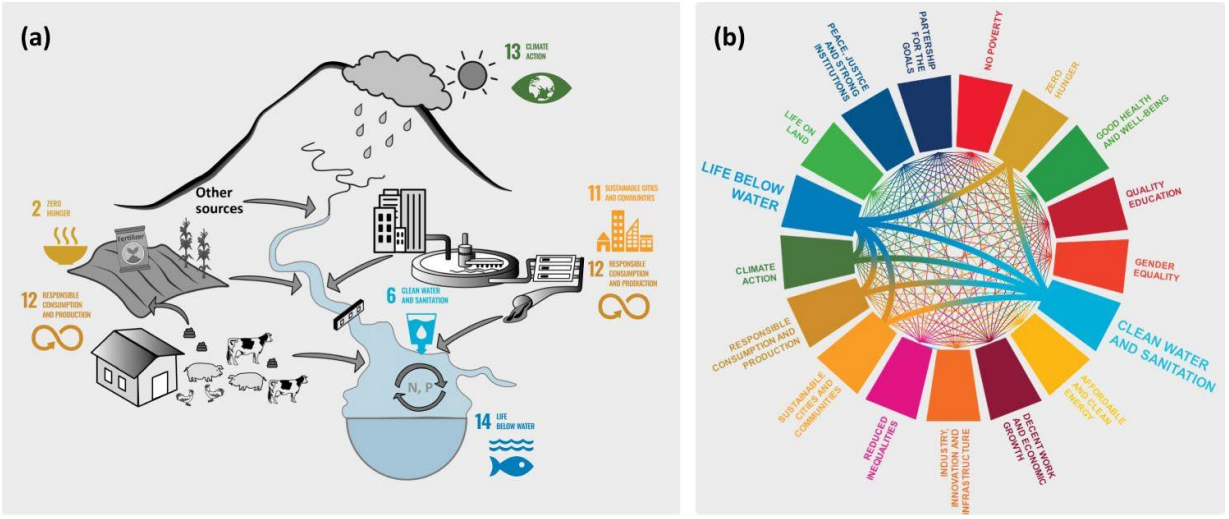

Figure 3. We found (a) Six SDGs that are highly relevant to nutrient pollution in Chinese water systems; (b) there are 319 interactions between SDG 6 "Clean Water and Sanitation", 14 "Life Below Water" and other SDGs for the case of water pollution by nutrients in China. Published in Wang et al., (2022)

Publications and links

- Wang et al (2020) DOI: 10.1029/2019EF001280 https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019EF001280#:~:text=We%20found%20that%20global%20change,on%20the%20SSP%2DRCP%20scenarios
- Wang et al (2022) DOI: 10.1038/s41467-022-28351-3 https://www.nature.com/articles/s41467-022-28351-3

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Multi-scale analysis (MARINA-Nutrients model: China-3.0)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** China-3.0
- **Application:** China
- **Scales:** sub-basins, grid of 0.5°, country and polygon (intersect of grid and county), annual
- **Period:** 2012
- **Pollutants:** dissolved inorganic (DIN, DIP), organic (DON, DOP) nitrogen and phosphorus
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** In-stream concentration of DIN, DON, DOP, and DIP, expressed in water quality classes

Modelling approach

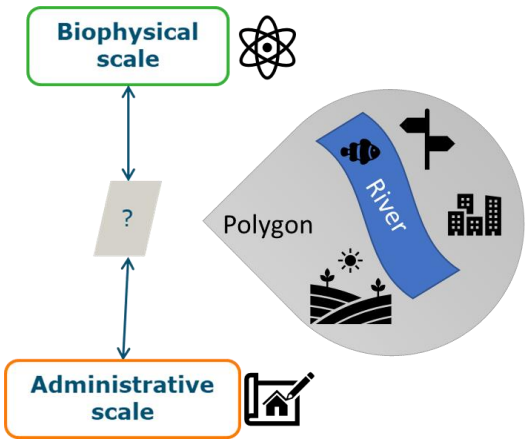

Figure 1: Conceptual framework of the model application to China for multi-scale analysis (based on Chen et al., 2019, 2022)

Model outputs (examples)

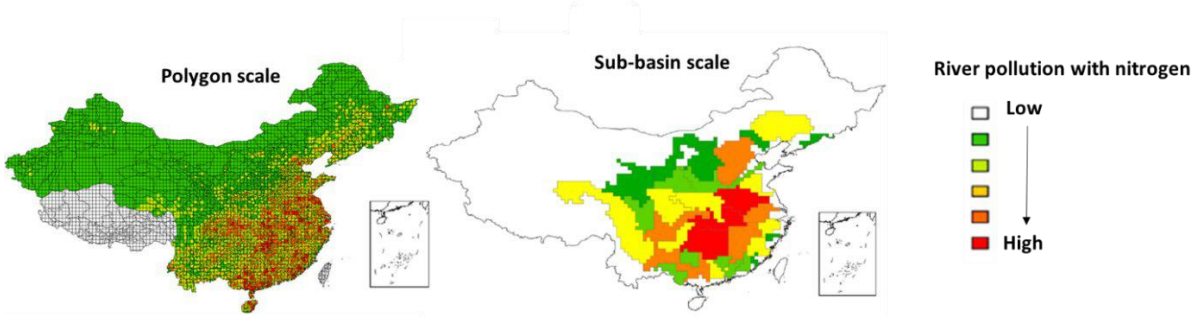

Figure 2: River export of dissolved inorganic nitrogen (kton/year). Modified from Chen et al., (2019; with CC-BY-NC-ND license)

Publications and links

- PhD project of Chen Xi: Reducing point source inputs of nutrients to rivers and their impact on ecosystems and society in China
- Chen et al (2019) DOI: 10.1021/acs.est.8b07352 https://pubs.acs.org/doi/full/10.1021/acs.est.8b07352
- Chen et al (2022) DOI: 10.1016/j.jclepro.2021.130208 https://www.sciencedirect.com/science/article/abs/pii/S0959652621043730

Contacts: Chen Xi, chen.xi@wur.nl; Carolien Kroeze, carolien.kroeze@wur.nl; Maryna Strokal, maryna.strokal@wur.nl

EUROPE APPLICATION

Water and air sources (MARINA-Nutrients model: Europe-1.0)

Model characteristics

- **Model name:** MARINA-Nutrients
- **Version:** Europe-1.0
- **Application:** EU-28 (including the UK)
- **Scales:** basins, & sub-basins, and annual
- **Period:** 2020-2050
- **Pollutants:**
  - For rivers: dissolved inorganic (DIN, DIP), organic (DON, DOP) nitrogen and phosphorus
  - For air: ammonia (NH_3), nitrous oxide (N_20), N oxides (NOx)
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:** N emissions to air by agricultural sources and basin/sub-basin, river export of DIN, DON, DIP, DOP by source and basin/sub-basin

Modelling approach and model outputs (example)

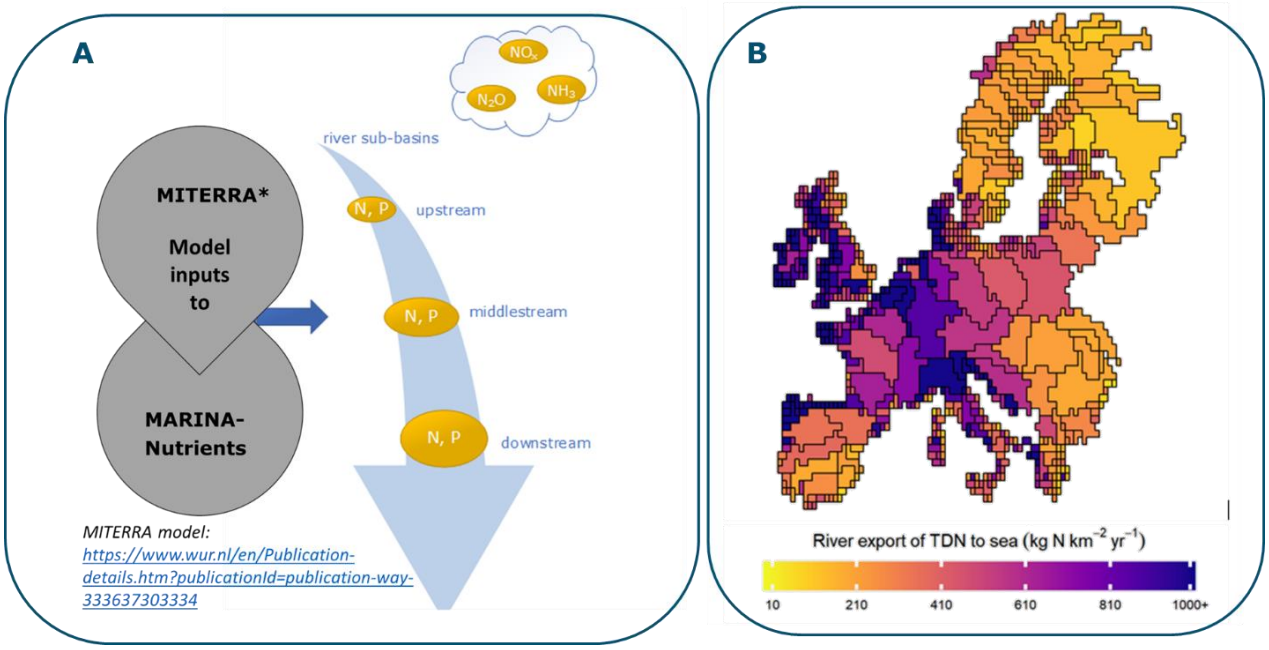

Figure 1: (a) Conceptual framework of the model application to Europe, and (B) river export of total dissolved nitrogen (TDN) to the European seas (kg km^{-2} $year^{-1}$; Aslıhan Ural and others, under development)

Publications and links

- PhD project Aslihan Ural: FertiCycle – New bio-based fertilisers from organic waste upcycling

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LOADINGS TO LAKES

Pollution sources

Collaboration

MARINA-Lakes runs at smaller sub-basins compared to the other versions of MARINA. As a result, nutrient loads can be calculated at the lake level. This creates the opportunity to link the model with PCLake+, a model that calculates the impact of nutrient loads to lake water quality in terms of nutrient concentrations, algae, water plants, zooplankton and fish. As such, the link between MARINA-Lakes and PCLake+ enables research from driver to impact.

Model characteristics

- **Model name:** MARINA-Lakes
- **Application:** lakes in China and Africa
- **Scales:** sub-basins, basins, annual and seasonal
- **Period:** past, present and future
- **Pollutants:** dissolved inorganic (DIN, DIP) and organic (DON, DOP) nitrogen and phosphorus
- **Sources:** point (sewage) and diffuse (agriculture, natural areas)
- **Main inputs:** agricultural activities, sewage systems, land use, hydrology
- **Main outputs:**
  - river export of DIN, DIP, DON and DOP by source and sub-basin to lakes
  - loadings of the nutrients from lake basins to lakes

Modelling approach

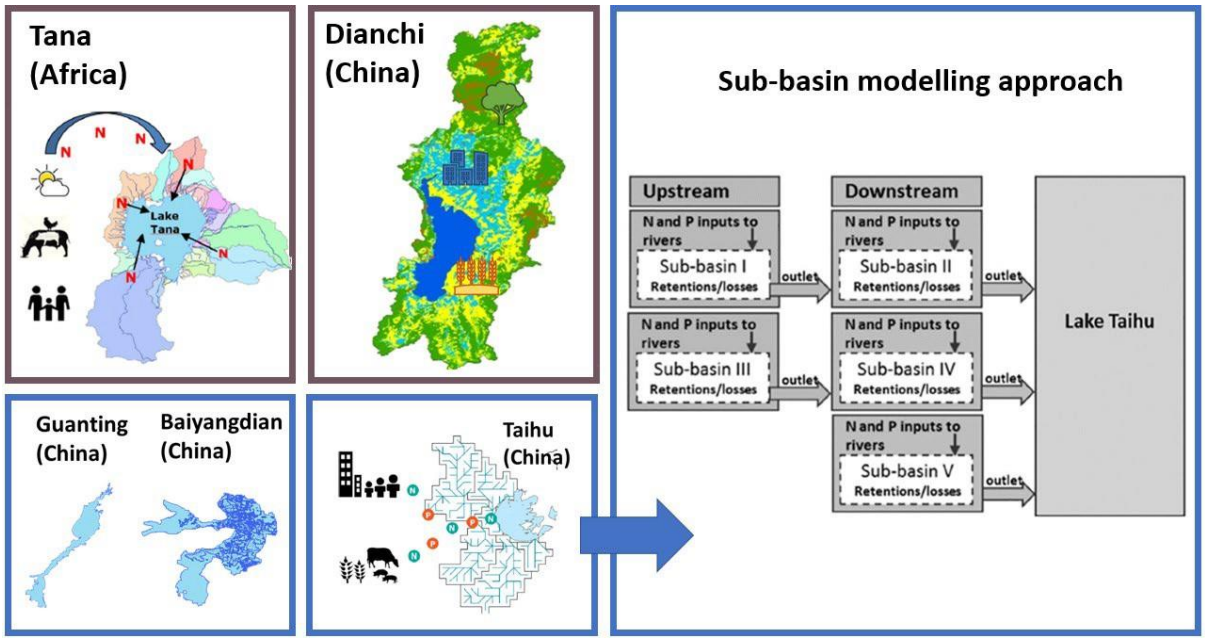

Figure 1: Conceptual framework of calculating nutrient loadings to individual lakes from sub-basins and basins (modified from Yang et al., 2019; Wang et al., 2019; Li et al., 2019; Goshu et al., 2020).

Model outputs (examples)

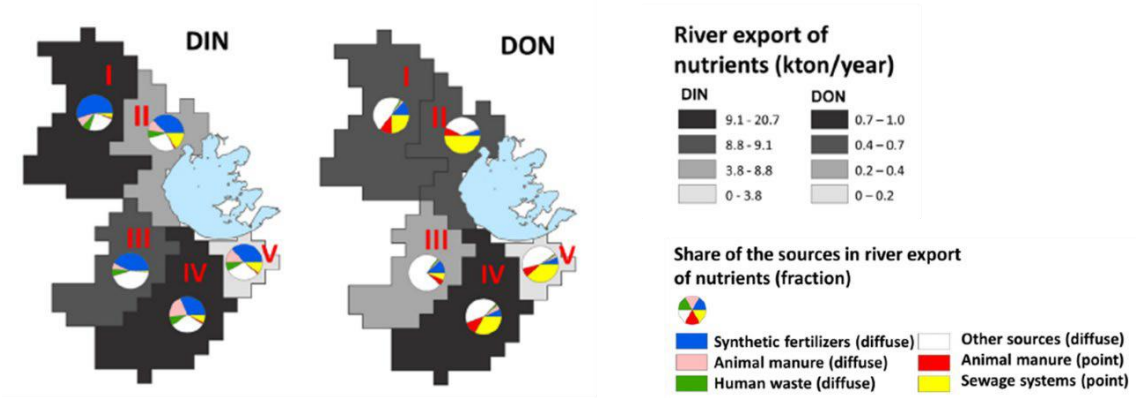

Figure 2: Example for loadings of dissolved inorganic (DIN) and organic (DON) nitrogen to Lake Taihu from basins and sources (kton/year, Wang et al., 2019).

Publications and links

- PCLake model (GitHub - pcmodel/PCModel: PCModel (PCLake and PCDitch) DATM implementation)
- Publications on MARINA-Lakes:
  - Yang et al (2019) DOI: 10.1016/j.agwat.2018.09.022 https://www.sciencedirect.com/science/article/abs/pii/S0378377418309107
  - Wang et al (2019) DOI: 10.1016/j.scitotenv.2019.02.052 https://www.sciencedirect.com/science/article/pii/S0048969719305303
  - Li et al (2019) DOI: 10.1016/j.agwat.2018.08.023 https://www.sciencedirect.com/science/article/abs/pii/S0378377418309387
  - Goshu et al (2020) DOI: 10.1016/j.scitotenv.2020.139199 https://www.sciencedirect.com/science/article/pii/S0048969720327169
  - Yang et al (2021) DOI: 10.1029/2020JG005689 https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2020JG005689
  - Ma et al (2020) DOI: 10.2166/bgs.2020.923 https://iwaponline.com/bgs/article/2/1/73/71714/Reducing-river-export-of-nutrients-and
- Publications on PCLake:
  - Janssen, A. B. G.; Teurlincx, S.; Beusen, A. H. W.; Huijbregts, M. A. J.; Rost, J.; Schipper, A. M.; Seelen, L. M. S.; Mooij, W. M.; Janse, J. H., PCLake+: A process-based ecological model to assess the trophic state of stratified and non-stratified freshwater lakes worldwide. Ecological Modelling 2019, 396, 23-32.
  - Janse, J. H.; De Senerpont Domis, L. N.; Scheffer, M.; Lijklema, L.; Van Liere, L.; Klinge, M.; Mooij, W. M., Critical phosphorus loading of different types of shallow lakes and the consequences for management estimated with the ecosystem model PCLake. Limnologica-Ecology and Management of Inland Waters 2008, 38, (3), 203-219.
  - Janse, J. H.; Scheffer, M.; Lijklema, L.; Van Liere, L.; Sloot, J. S.; Mooij, W. M., Estimating the critical phosphorus loading of shallow lakes with the ecosystem model PCLake: Sensitivity, calibration and uncertainty. Ecological Modelling 2010, 221, (4), 654-665.

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MODEL VERSIONS OVERVIEW

MARINA-Multi models

Versions	Pollutants	Spatial resolution	Temporal resolution	Water systems	Pollution sources	Reference
Global applications						
Pollution due to urbanization Global-1.0 *Published as MARINA-Global*	Nitrogen, Phosphorus, Triclosan, Cryptosporidium, Microplastics	Sub-basin	Annual	Rivers	Point (sewage, open defecation)	Strokal et al (2021)
Pollution due to livestock production Global-2.0 *Published as MARINA-Global-L*	Nitrogen, phosphorus, Cryptosporidium	Sub-basin	Annual	Rivers	Diffuse (livestock)	Yanan Li et al (2022)
Pollution due to COVID-19 measures Global-3.0	Triclosan, Microplastics, Macroplastics, Diclofenac	Sub-basin	Annual	Rivers	Point (sewage) and diffuse (mismanaged waste)	Qi Zhang et al (under review)
Pollution due to urbanization and agriculture Global-4.0	Nitrogen, Phosphorus, Triclosan, Microplastics, Macroplastics, Diclofenac	Sub-basin	Annual	Rivers, seas	Point (sewage, open defecation) and diffuse (livestock, crop production, mismanaged waste)	Ilaria Micella et al (in prep)
Seasonality in pollution Global-5.0	Nitrogen, Phosphorus, Triclosan, Microplastics, Macroplastics, Diclofenac	Sub-basin	Seasonal	Rivers, seas	Point (sewage, open defecation) and diffuse (livestock, crop production, mismanaged waste)	Mirjam Bak et al (in prep)
Europe applications						
Pollution due to urbanization Europe 1.0 *In the paper as MARINA-Global for the Black Sea*	Nitrogen, Phosphorus, Triclosan, Cryptosporidium, Microplastics	Sub-basins of the Black Sea	Annual	Rivers	Point sources	Strokal et al (under review)

MARINA-Plastics models

Versions	Pollutants	Spatial resolution	Temporal resolution	Water systems	Pollution sources	References
Global applications						
Pollution sources (macro-& microplastics) Global-1.0	Microplastics, Macroplastics	Sub-basin	Annual	Rivers, seas	Point (Sewage) and diffuse (mismanaged waste)	Strokal, Vriend et al (2021)
China applications						
Crop production impacts (macro-& microplastics) China-1.0	Microplastics, Macroplastics	Sub-basin	Annual	Rivers, seas	Point (Sewage) and diffuse (mismanaged waste, agriculture)	Yanan Li et al (in prep)
Europe applications						
Solutions for the Black Sea (microplastics) Europe-1.0 *Published as MARINA-Global for the Black Sea*	Microplastics	Sub-basin	Annual	Rivers, sea	Point (sewage)	Strokal et al (2022)

MARINA-Antibiotics models

Versions	Pollutants	Spatial resolution	Temporal resolution	Water systems	Pollution sources	References
China applications						
Pollution due to livestock production China-1.0	>20 antibiotic types	Sub-basin	Annual	Rivers	Diffuse (livestock) and point (direct discharges of manure)	Qi Zhang et al (in prep)

MARINA-Nutrients models

Focus and versions	Pollutants	Spatial resolution	Temporal resolution	Water systems	Pollution sources	References
Global applications						
Water scarcity analysis Global-1.0	Nitrogen	Sub-basin	Annual	Rivers, seas	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	Mengru Wang et al (in prep) INMS project*
Global change impacts Global-2.0	Nitrogen and phosphorus	Sub-basin	Annual	Rivers, sea	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	INMS project*
China applications						
Sub-basin scale analysis China-1.0 *Published as MARINA-Nutrients (v1.0)*	Nitrogen, phosphorus	Sub-basin	Annual	Rivers, seas	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	Strokal et al (2016)
Seasonality China-1.1 *Published as MARINA 1.1*	Nitrogen	Sub-basin	Seasonal	Rivers, seas	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	Xuanjing Chen et al (2019)
Global change and SDGs China-2.0 *Published as MARINA 2.0*	Nitrogen, phosphorus	Sub-basin	Annual	Rivers, seas	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	Mengru Wang et al (2020); Mengru Wang et al (2022)
Multi-scale analysis China-3.0 *Published as MARINA 3.0*	Nitrogen, phosphorus	Multiple	Annual	Streams	Point (sewage, direct discharge of manure) and diffuse (agriculture, nature)	Xi Chen et al (2021)
European applications						
Water and air sources Europe-1.0	Nitrogen, phosphorus	Sub-basin	Annual	Rivers, seas Air	Point (sewage) and diffuse (agriculture, nature)	Aslıhan Ural et al (in prep)
Loadings to lakes *Published as MARINA-Lakes versions*						
Pollution sources	Nitrogen, phosphorus	Basin lakes: Dianchi, Taihu, Tana, Guanting and Baiyandian	Annual and seasonal	Rivers, loadings to lakes	Point (sewage) and diffuse (agriculture, nature)	Yang et al., 2019; Wang et al., 2019; Li et al., 2019; Goshu et al., 2020

* https://www.inms.international/

For more information, visit: www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Water-Systems-and-Global-Change-Group/Research-1/Water-Quality/The-MARINA-models.htm