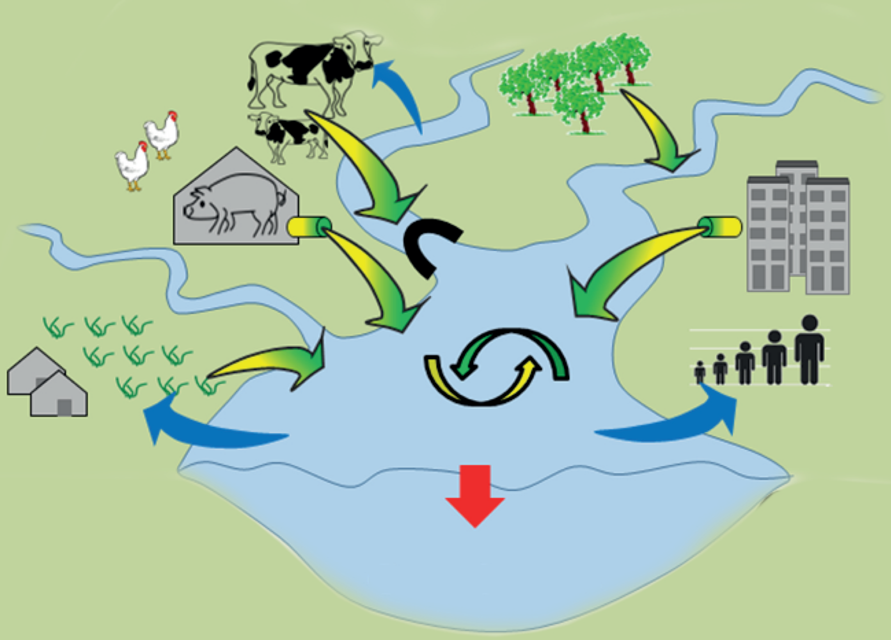
EDUCATIONAL PUBLICATION

Vita Strokal, Maryna Strokal

PRACTICALS

Modelling the impact of anthropogenic activities on water systems and future trends



Kyiv-2022

Educational publication

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PRACTICALS

for a PhD course:

«Modelling the impact of anthropogenic activities on water systems and future trends»

Part 1: Modelling water systems and scenario developments

Kyiv

2022

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Modelling the impact of anthropogenic activities on water systems and future trends. Part 1: Modelling water systems and scenario developments : practicals for a PhD candidates in specialization of Ecology / Developers: assist.professor Vita Strokal, assist.professor Maryna Strokal – Kyiv: NUBiP of Ukraine, 2022. – 52 p.

Three practicals are developed for a PhD course of “Modelling the impact of anthropogenic activities on water systems and future trends.”. These practicals provide PhD candidates the information on modeling of water quality and quantity, and facilitate PhD candidates to develop and improve their competences on scenarios developments. In addition, these practicals educate PhD candidates on understanding the impacts of anthropogenic activities on water quality in the future. Students visualize the results of the three practicals on a poster. The poster will be evaluated. Each practical, has questions to answer to check if students understood the materials.

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Learning outcomes of practicals

PhD students perform three practicals within five days.

Table 1. Shows the program including the timeline and estimated workload.

Table 1: The program, timeline and estimated workload

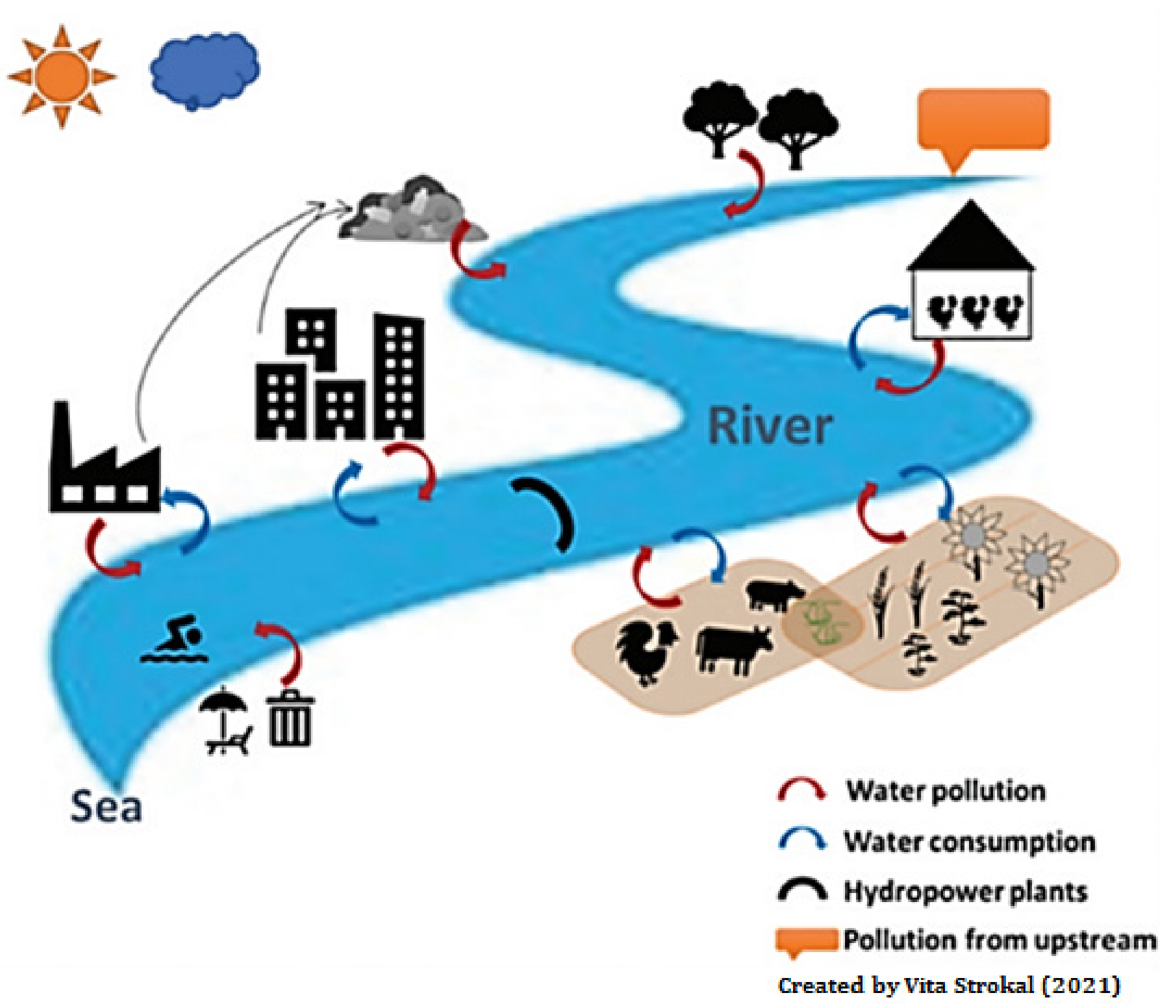
	Timeline	Workload	Visualized results
Practical 1	1st day	6 hours	A graph
Practical 2	2nd day	6 hours	A table
Practical 3	3rd - 4th - 5th day	14 hours	Graphs
		Results are shown	Poster

After these practicals, PhD students will be able to:

- Practical 1: Calculate seasonal water stress with and without water quality.
- Practical 2: Design an integrated model for water quality.
- Practical 3: Run a simple water quality model and develop simple scenarios.

Students visualize the results of the three practicals on a poster. The poster will be evaluated. Each practical, has questions to answer to check if students understood the materials. Details on the practicals are below.

On the picture you can see the process which present the modelling the impact of anthropogenic activities on water systems. According to these activities, PhD students will explain their impact and do practical assignments.



Picture 1. Impact of anthropogenic activities on water systems

Practical 1: Water stress

Introduction:

Students work with a case study for Poland. Water stress is calculated for an irrigation sector. This sector need clean water. Irrigation is used to water crops. Crops are sensitivity to water that has too much salinity. Thus, water stress should consider senility as a water quality parameter for the irrigation sector. Students analyse water stress for irrigation including and excluding salinity as a water quality parameter.

Educational objective:

After this practical, students are able to calculate seasonal water stress with and without water quality. This includes understanding of the concept of water stress.

Literature:

- van Vliet, M.T.H., Flörke, M., Wada, Y. (2017) *Quality matters for water scarcity*, nature geoscience, 10, 800 – 802, doi:10.1038/ngeo3047 http://www.nature.com/ngeo/journal/vaop/ncurrent/pdf/ngeo3047.pdf
- Vliet, M. T. H. van, Jones, E. R., Flörke Martina, Franssen, W. H. P., Hanasaki, N., Wada, Y., & Yearsley, J. R. (2021). Global water scarcity including surface water quality and expansions of clean water technologies. Environmental Research Letters 16 (2021) 2. https://iopscience.iop.org/article/10.1088/1748-9326/abbfc3

Exercises and planning:

Planning	Exercises	Tasks
10:10-11:20	Exercise 1	Read the literature (two papers)
11:50-13:10	Exercise 2	Study the two equations in Box 1 (see below)
14:00-15:20	Exercise 3	Calculate water stress with and without water quality using the two equations from Box 1 Use provided excel with data
15.35-16:55	Exercise 4	Make a graph showing water stress with and without water quality Answer questions: ○ What are the impacts of including salinity on seasonal irrigation water stress levels? ○ Which other water quality parameters could be included in calculations of irrigation water stress in addition to salinity (EC)?
17:10-18:00	Start making a poster: think about a structure and insert your graph with water stress calculations on a poster	

Box 1. The equations of water stress from the paper of van Vliet et al., (2017).

commentary

Quality matters for water scarcity

Michelle T.H. van Vliet, Martina Flörke and Yoshihide Wada

Quality requirements for water differ by intended use. Sustainable management of water resources for different uses will not only need to account for demand in water quantity, but also for water temperature and salinity, nutrient levels and other pollutants.

Box 1 | Water scarcity by sector including water quality.

We propose to assess water scarcity as the ratio of sectoral water withdrawals of acceptable water quality to the overall water availability (equation (1)). Our index considers, in addition to the required sectoral water withdrawals, also the extra water withdrawal required to obtain water of acceptable quality for each sector by dilution. In case water quality requirements are not met for a certain sector, we estimate the extra amount of water to dilute and lower concentrations below the threshold of a relevant water quality parameter according to sectoral guidelines. A water quality dimension for freshwater ecosystems can be added to the environmental flow requirements by including the relevant water quality parameters and their thresholds for freshwater ecosystems.

$$WSq = \frac{\sum_{j=1}^{n} (D_j + dq_{i,j})}{Q - (EFR + dq_{i_{eco}})} \qquad (1)$$

with:

$$dq_{i,j} = \begin{cases} 0, & C_i \leq Cmax_{i,j} \\ \left(\frac{Q \cdot C_i}{Cmax_{i,j}} - Q\right), & C_i > Cmax_{i,j} \end{cases}$$

Where WSq is the water scarcity including water quality (-); D is water withdrawal for sector j ($m^3 s^{-1}$); Q is water availability ($m^3 s^{-1}$); EFR is the environmental flow (quantity) requirements ($m^3 s^{-1}$); dq is extra water withdrawals for dilution to obtain acceptable quality for sector j and water quality parameter i ($m^3 s^{-1}$); C_i is actual water quality level of water quality parameter i (unit depends on water quality parameter considered; for example, mg l^{-1} for concentrations, °C for water temperature); and $Cmax_{i,j}$ is the maximum water quality threshold for water quality parameter i for water use sector j (for example, mg l^{-1}, °C).

Practical 2: Model design

Introduction:

Students design an integrated model for the impact of agriculture on water quality. Agriculture impacts water quality in different ways. Examples are too much synthetic fertilizers on the land (nutrients), pesticides and application of animal manure (nutrients, pathogens, antibiotics).

As a result of over-fertilization of cropland, a lot of pollutants (e.g., nitrogen, phosphorus, pesticides, antibiotics) enter rivers and then these pollutants are exported to coastal waters of the Black Sea. The focus is on the Dnieper river basin. Dnieper River is a transboundary river discharging water and pollutants to the Black Sea from over 50% of the Ukrainian land. The focus of this practical is on agriculture in the Dnieper River basin and pollutants that result in water systems from agricultural activities. The national government is asking to design an integrated model that can calculate the flows of multiple pollutants by the Dnieper River to the Black Sea from agricultural activities.

Students do not develop a model, but develop a model design: model inputs (what should be in the model) and model outputs (what the model will calculate).

Educational objective:

After this practical, students are able to design an integrated model for water quality.

Some predefined characteristics of your model design:

- It is a model for the Dnieper River basin
- It should include multiple pollutants (at least 3 pollutants) from agricultural activities
- It can be used to analyse sources of pollution
- It can be used to analyse past and future trends

Exercises and planning:

Planning	Exercises	Tasks
10:10-11:20	Exercise 1	Study pollutants that come to water from agriculture Use literature of this practical and make a list of pollutants that are relevant for agriculture (see figures 1 and 2 from Strokal et al., 2019 below)
11:50-13:10	Exercise 2	Formulate an aim of your model and define spatial and temporal level of detail - Aim: better understanding, policy support, something else? - Spatial level: Will it be for sub-basins or grids? - Temporal level: will it be annual or seasonal?

14:00-15:20	Exercise 3	Identify pollutants and interactions to be modelled (see Figure 1 of Strokal et al., 2019 as example):
		- Which pollutants will you include in your model (select <u>at least two</u>)?
		- What sources of pollution do you want to include in your model?
		- What impacts of pollution (on society and nature) do you want to include in your model?
		- What interactions between the pollutants can you think of that need to be modeled?
		    o Interactions between sources?
		    o Interactions during transport of the pollutants from land to sea?
		    o Interactions between the impacts on nature or society?
		    o Interactions between policy measures?

15.35-16:55 17:10-18:00	Exercise 4	Decide on model inputs and outputs based on Exercises 1-3 (see Figure 2 of Strokal et al., 2019 as example) - Model inputs (what datasets will be needed as input to the model?) - Model outputs (what will be the model outputs?) Fill in Table 1 for a design of your model and add this table to your poster

Figure 1

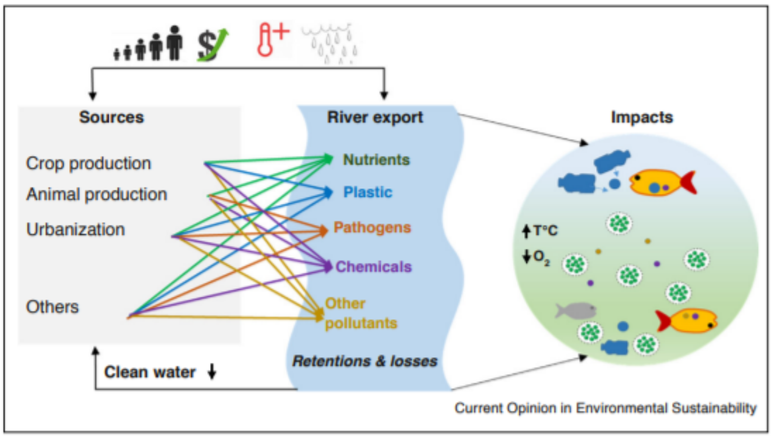


Figure 1. This figure is from the paper of Strokal et al., (2019), provided for this practical. This figure shows examples of interactions, multiple pollutants and their impacts on society and nature. This example is useful for Exercises 1-3 above.

Literature:

Strokal M et al (2019) Global multi-pollutant modelling of water quality: scientific challenges and future directions. Current Opinion in Environmental Sustainability 36, 116-125.

https://www.sciencedirect.com/science/article/pii/S187734351830023X

- Read the entire paper
- Figure 1 in the paper provides examples of multiple pollutants

Figure 2 in the paper provides an example of a model design

Figure 2

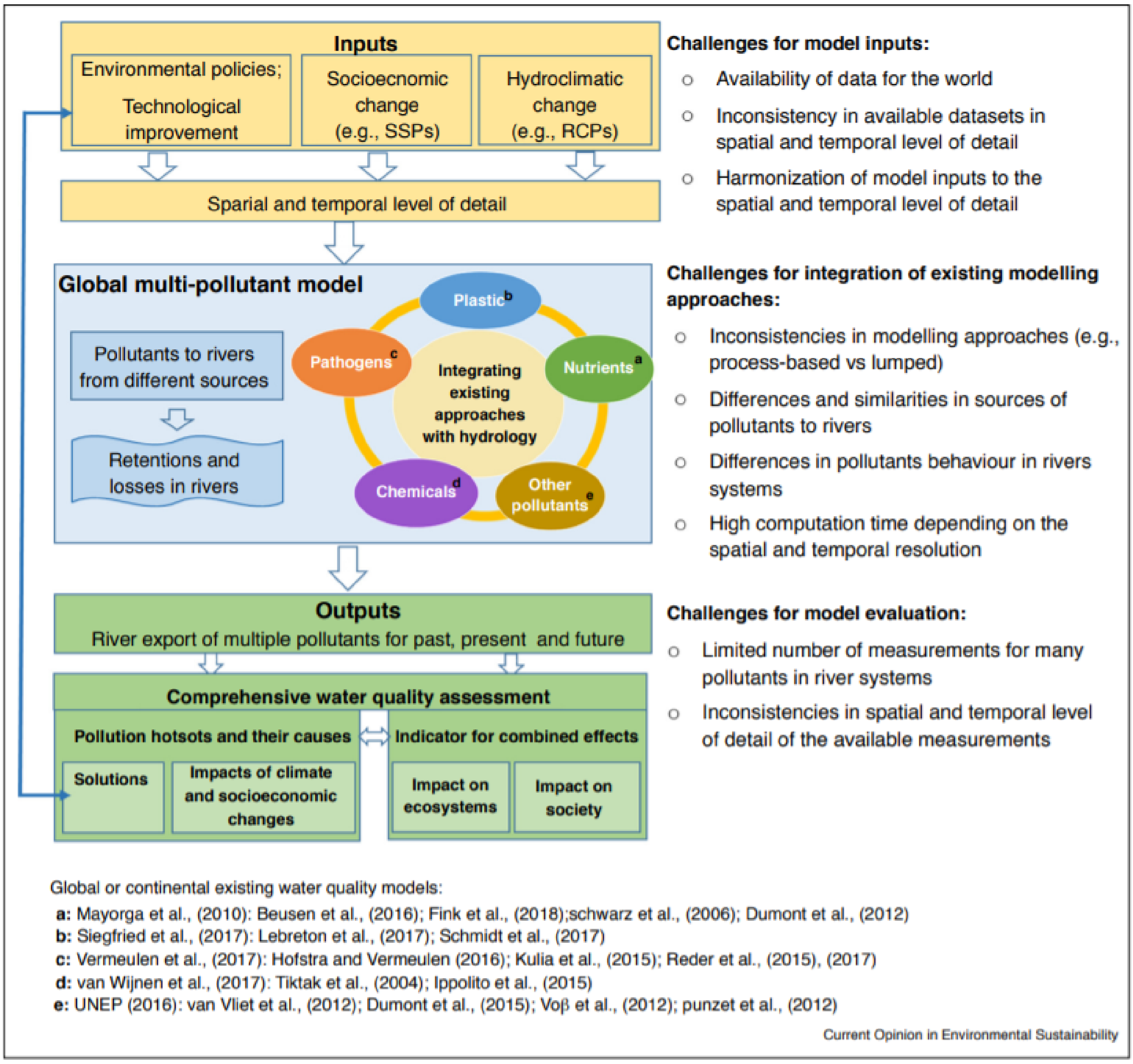


Figure 2. This figure is from the paper of Strokal et al., (2019), provided for this practical. This figure shows examples of a model design including model inputs, outputs and multiple pollutants. This example is useful for Exercise 4.

Fill in this table

Table 1. A design of your model. Fill in empty lines for your model design and add this table to your poster.

<table>
<tr><td>Inputs for your model
(What does your model need to be able to calculate outputs?)
Example: population density, animal number, water discharge</td><td>Name of your model
(be creative)</td><td>Outputs of your model
(What does your model calculate?)
Example: the output of the MARINA model is river export of nutrients for 2000, 2050 at the sub-basin scale</td></tr>
<tr><td>1. Input:.............................
2. Input:.............................
3. ...</td><td>......................</td><td>1. Output:.............................
2. Output:.............................
3. ...</td></tr>
<tr><td colspan="3">Characteristics of your model</td></tr>
<tr><td colspan="3">Aim:..
Spatial details:...
Temporal details..
Interactions modelled: ....
Pollutants modelled: ....
Sources of pollutants in water modelled:..</td></tr>
</table>

Practical 3: Model run and scenarios

Introduction:

The Black Sea suffers from eutrophication issues. Eutrophication is an enrichment of water with nutrients such as nitrogen and phosphorus. These nutrients come to the sea by rivers. The Dnieper River is the largest river in Ukraine discharging the nutrients to the sea. The Dnieper River basin covers more than 40% of Ukraine and is economically important basin. Various human activities are present in the basin such as agriculture, industries, hydropower generations, reservoirs, sewage systems, and cities. Agriculture and cities are considered as the main sources of the nutrients in the river and thus in the Black Sea. Agriculture contains activities such as application of synthetic fertilizers and animal manure. These contain nutrients. Nutrients reach the river through runoff from land. This source is defined as diffuse. On the other hand, cities have sewage systems. Sewage systems collect human waste from buildings. Human waste consists of nutrients. Sewage with nutrients goes to wastewater treatment plants. If treatment is poor, then a lot of nutrients enter the river via pipes. This is a point source.

The national government would like to explore options to reduce future water pollution in the Dnieper River and in the Black Sea. The government strongly believes that achieving the targets of Sustainable Developments Goals 2 (sustainable food production) and 11 (sustainable cities) will help to reduce water pollution.

In this practical, students focus on assessing the effects of implementing targets of Sustainable Development Goals (SDG) 2 and 11 on reducing nutrient export by the Dnieper River to the Black Sea up to 2050. For this, The MARINA model (Model to Assess River Inputs of pollutaNts to seAs) is used. MARINA is an updated version of the Global NEWS model that was applied to Ukraine and the Black Sea region (Strokal et al., 2014). The model runs for 2010 and 2050. The year 2010 is considered as the recent past. The year 2050 is considered as the baseline for the future development according to the business as usual trends.

Educational objective:

After this practical, students are able to run a simple water quality model (MARINA) and develop simple scenarios. For this, two specific learning objectives are set for a two-day practical:

1. Day 1: to learn model inputs, outputs, and run the model
2. Day 2: to develop two simple scenarios to analyse the effects of SDGs2 and 11.

Literature:

Strokal V (2021) Transboundary rivers of Ukraine: perspectives for sustainable development and clean water. Journal of Integrative Environmental Sciences 18, 67-87. https://www.tandfonline.com/doi/full/10.1080/1943815X.2021.1930058

- *read about water pollution problems in Ukraine, the Dnieper basins and the Black Sea*

Strokal M et al (2016) The MARINA model (Model to Assess River Inputs of Nutrients to seAs): model description and results for China. Science of the Total Environment 562, 869-888.https://www.sciencedirect.com/science/article/pii/S0048969716307549

- *this paper describe the MARINA model for China. The same principle is applied for the MARINA model for the Dnieper river basin;*
- *read only the principles of the model and pay attention to equation 1 (no need to remember all equations)*

Strokal MP, Kroeze C, Kopilevych VA, Voytenko LV (2014) Reducing future nutrient inputs to the Black Sea. Science of the Total Environment 466–467, 253-264. https://pubmed.ncbi.nlm.nih.gov/23906857/

- *An example of how to make simple scenarios with reduction options for nutrient export by rivers to the Black Sea*

Videos:

- Six videos are provided on the MARINAtraining folder
- The MARINAtraining folder contains model inputs, outputs and scripts to run the model
- The MARINAtraining folder is designed for educational purposes and should not be used for other activities without permission of the model developer (Maryna Strokal, maryna.strokal@wur.nl)
- Students use the MARINAtraining folder to run the model and develop simple scenarios.

Exercises and planning for Day 1:

Planning	**Exercises**	**Tasks**
Day 1: to learn model inputs, outputs, and run the model		
10:10-11:30	Exercise 1	Study thee papers of Strokal (2021) on water pollution issues, and Strokal et al., (2016) on the MARINA model
11:50-13:10	Exercise 2	Download and unzip the MARINAtraining folder; study this folder. For this, watch two videos: o a_How_to_unzip_folder_Windows_laptops.mp4 o 2_Intro_MARINAtraining_folder.mp4 Open the MARINAtraining folder and study the structure and files there.
14:00-15:20	Exercise 3	Study model inputs and outputs. For this, look at figures 1-5 and watch three videos: o 3_Intro_inputs_folder.mp4 o 4_Intro_outputs_folder.mp4 o 5_Intro_script.mp4 Open excel files for model inputs and outputs (in .csv formats) and study them. Use the readme files in the excel files (see Figure 6). Open the script and study it.
15.35-16:55	Exercise 4	Run the model. For this, look at figures 3-5 and watch a video: 6_How_to_run_Windows_laptops.mp4 In case of errors, try first to solve by yourselves. Use google to solve R-language (script) related issues. If you cannot manage, then email the practical developers with questions. After running the model, open the model outputs and analyse them. The model outputs are for 2010 and 2050 baseline scenario. Make two graphs: 1. A graph showing nitrogen export by the Dnieper River by source (diffuse and point) to the Black Sea for 2010 and 2050 2. A graph showing phosphorus export by the Dnieper River by source (diffuse and point) to the Black Sea for 2010 and 2050 Answer the questions: 1. Is nitrogen export by the Dnieper River projected to increase or decrease between 2010 and 2050? 2. Why increase or decrease?

Exercises and planning for Day 2:

Planning	Exercises	Tasks
Day 2: to develop two simple scenarios to analyse the effects of SDGs2 and 11		
10:10-11:30	Exercise 1	Study “g5inputs.csv” and “g5outputs.csv” (Figures 1-2)
11:50-13:10	Exercise 2	Decide which SDG you want to focus: SDG2 or SDG11 Study the baseline scenario and SDG 2 and SDG 11 (https://sdgs.un.org/goals/) Develop a storyline for SDG 2 (one paragraph) or SDG11 (one paragraph in your own words)
14:00-15:20	Exercise 3	Translate your storyline into model inputs in “g5inputs.csv” (Figure 7) o Identify and select model inputs that reflect the targets of your SDG o Decide to what extent to change them for your nutrient (your assumptions) o Change them. It is easy to spend a lot of time on making assumptions, try to limit to your discussions to 15 minutes
15.40-17:10	Exercise 4	Run the model with changed model inputs (see Day 1) Analyse the results: - Add one bar to each of the two graphs that you made in Day 1 - One bar is for river export of nitrogen and one bar for river export of phosphorus based on your alternative scenario Answer the questions: 1. Is future nitrogen export by the Dnieper River projected to increase or decrease according to your new scenario relative to 2010 and 2050? 2. Why increase or decrease? Add the two graphs to a poster with short answers to the questions.

Exercises and planning for Day 3:

Planning	Exercises	Tasks
Day 3: to present a poster		
10:10-11:30	Part 1	To present a poster
11:50-13:10	Part 2	Discussion and get a evaluation

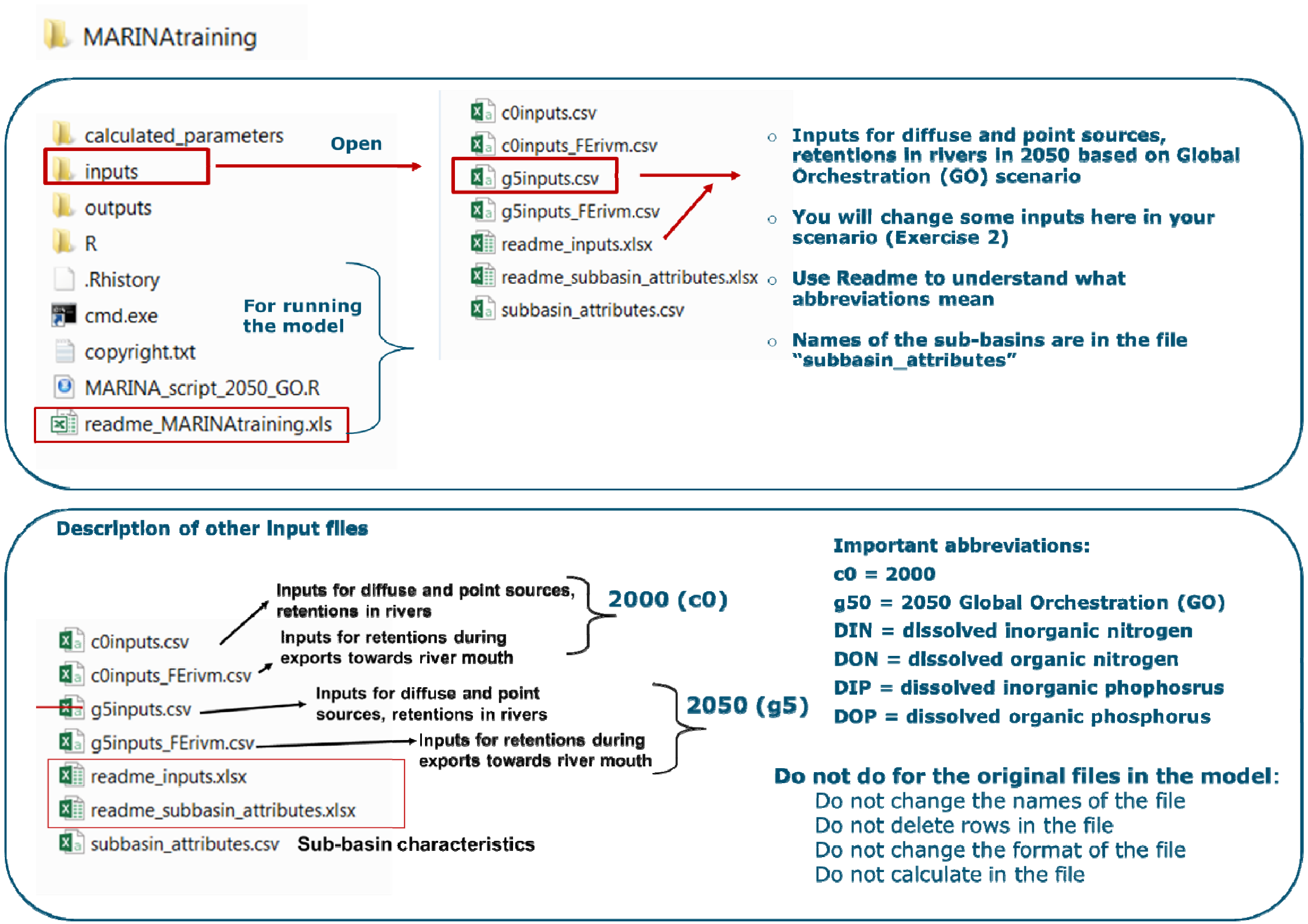


Figure 1. Inputs of the MARINA model in the MARINAtraining folder. Study "g5inputs" first. You can have a quick look at other input files. See video 3 in the "Videos" folder

Outputs: MARINAtraining -> outputs -> “g5outputs”

Readme file: MARINAtraining -> outputs -> “readme_outputs.xlsx” for description of the variables in “g5outputs”

Readme file: MARINAtraining -> inputs -> “subbasin_attributes.xlsx” for sub-basin names

“g5outputs”

Six sub-basins of the Pearl river:

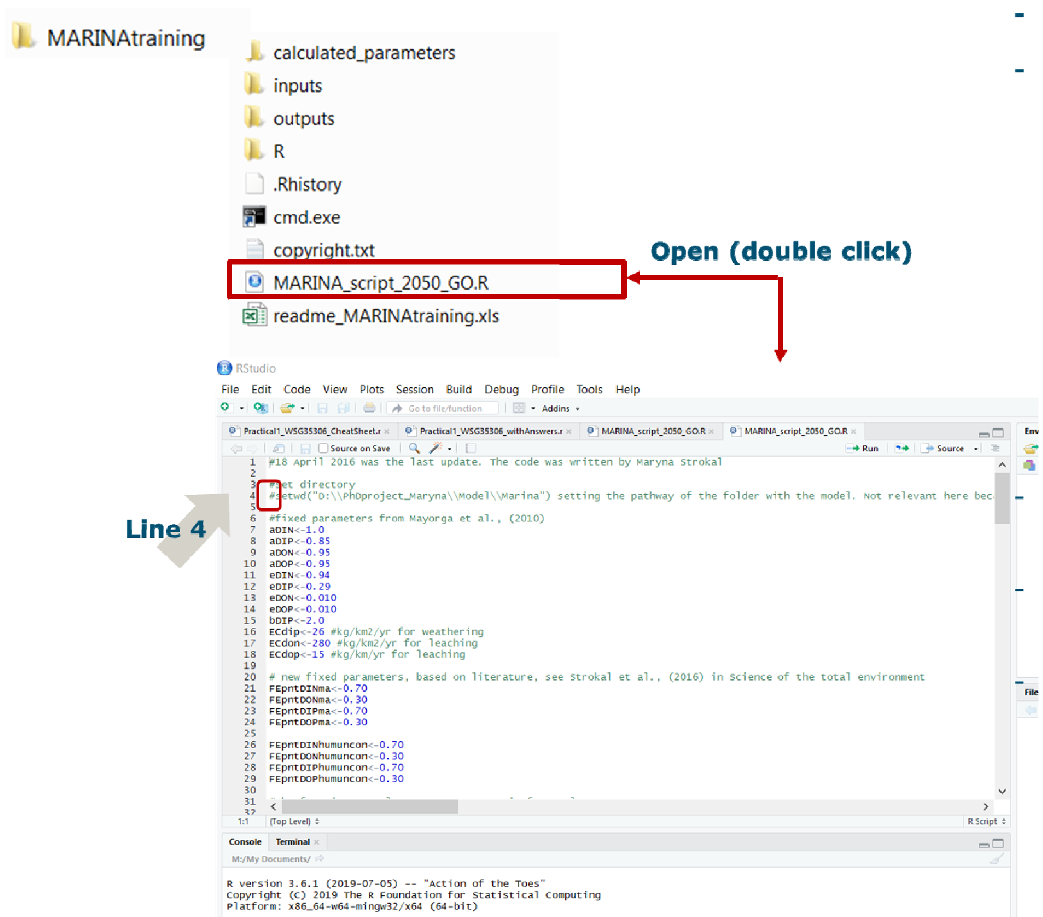
- **Upstream (1 and 2 codes)**
- **Midstream (3 and 4 codes)**
- **Downstream (5 and 6 codes)**

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	code	DINdiffe	DINdifma	DINdifhum	DINdiffxag	DINdifdpa	DINdiffxna	DINdifdpn	DINpntma	DINpnthur	DINpnthur	DONdiffe	DONdifi
2	1	13544084	9282005	1835608	1697308	13049818	3963815	11243448	19152429	1687128	865200.7	386279.1	2647.
3	2	2834196	2650555	1362498	480291	2972417	5016888	12268061	7427272	2163550	1035216	94297.15	88187.
4	3	37746784	25712470	4944017	4940799	29037466	4975292	13265021	54069390	5591353	2795321	1602656	10917
5	4	23259494	8680150	2396390	1115793	7888543	3357804	10083037	12507244	1502426	0	882134.3	329201
6	5	20018043	7681517	1856527	1148615	7486729	3531564	7751331	11539208	1217981	889495.7	690302.7	264889
7	6	43218709	13552531	2537374	2510287	13485771	6205025	17117320	22283556	1842822	12652402	1002552	314380

Columns B-K: River export of dissolved inorganic nitrogen by source from 6 sub-basins (kg/year)
Columns L-S: River export of dissolved organic nitrogen by source from 6 sub-basins (kg/year)
Columns T-AB: River export of dissolved inorganic phosphorus by source from 6 sub-basins (kg/year)
Columns AC-AK: River export of dissolved organic phosphorus by source from 6 sub-basins (kg/year)

To calculate total river export of nutrient from all sources and sub-basins : sum over columns and rows for your nutrient (analysing trends for totals)
To calculate total river export of nutrient from all sources for each sub-basin: sum over rows for your nutrient (analysing sub-basin contribution)
To calculate total river export of nutrient from all sub-basins for each source: sum over columns for your nutrient (analysing source attribution)

Figure 2. Model outputs of the MARINA model in the MARINAtraining folder. Study “g5outputs” first. See video 4 in the “Videos” folder



- You will see many lines in the Rstudio screen
- **Line 4 specifies a working directory (the location of the MARINAtraining folder in your laptop)**. The line is not active (with # in front) because we use a common prompt (**cmd.exe**) to run the model where the location of the MARINAtraining folder is identified automatically. If the common prompt does not work, then you need to activate this line by removing # and specifying the location of the MARINAtraining folder on your laptop (type your location in Line 4 between "….").
- **Lines 7-30 specify model parameters.** They are fixed for all sub-basins in the model.
- **Lines 33-102 calculate retentions** of nutrients in soils and in rivers.
- **Lines 108-162 calculate river export of nutrients** to the sea by source and sub-basin. Equations are explained in Strokal et al., (2016) (see literature for Lecture 4).

Figure 3. The script of the MARINA model in the MARINAtraining folder. Open the script on your laptop. The script is for 2050 Global Orchestration scenario of the Millennium Ecosystem Assessment. The script calculates river export of nutrients by the Pearl River from the six sub-basins into the South China Sea. For Windows laptops, go to Figure 4 and try to run the model using Option 1. If that does not work, go to Figure 5, activate Line 4 (as explained here) and use Option 2 to run the model. See videos 5-6 for Windows laptops. For Mac laptops, see video 1b.

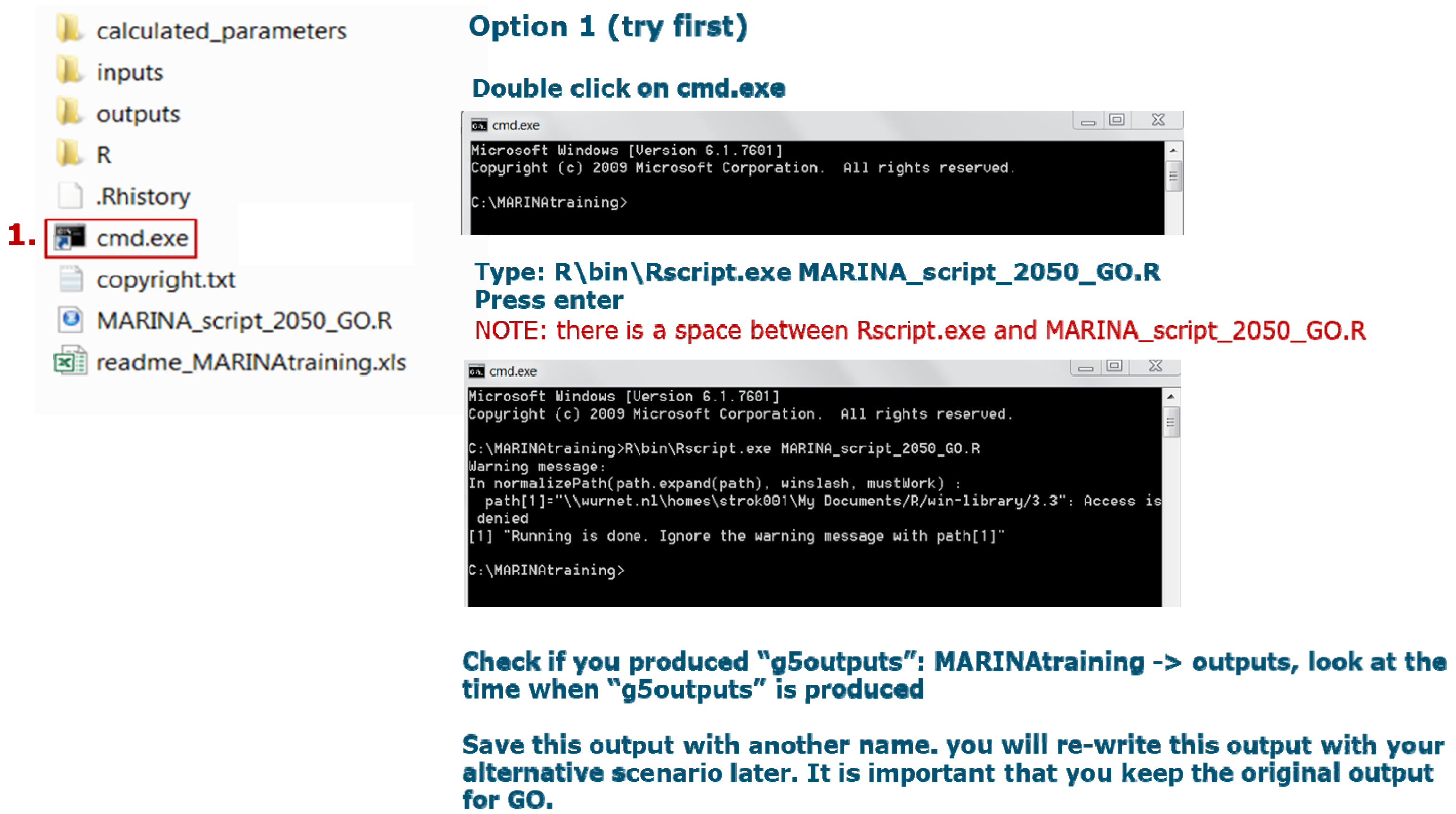


Figure 4. Option 1 for running the MARINA model for 2050 Global Orchestration using the MARINAtraining folder for Windows laptops. If you have questions, post them in the chat MS Teams "General" or your group chat. Check you produced outputs for 2050: go to MARINAtraining folder -> outputs -> g5outpts.csv (check the date when this file was produced).

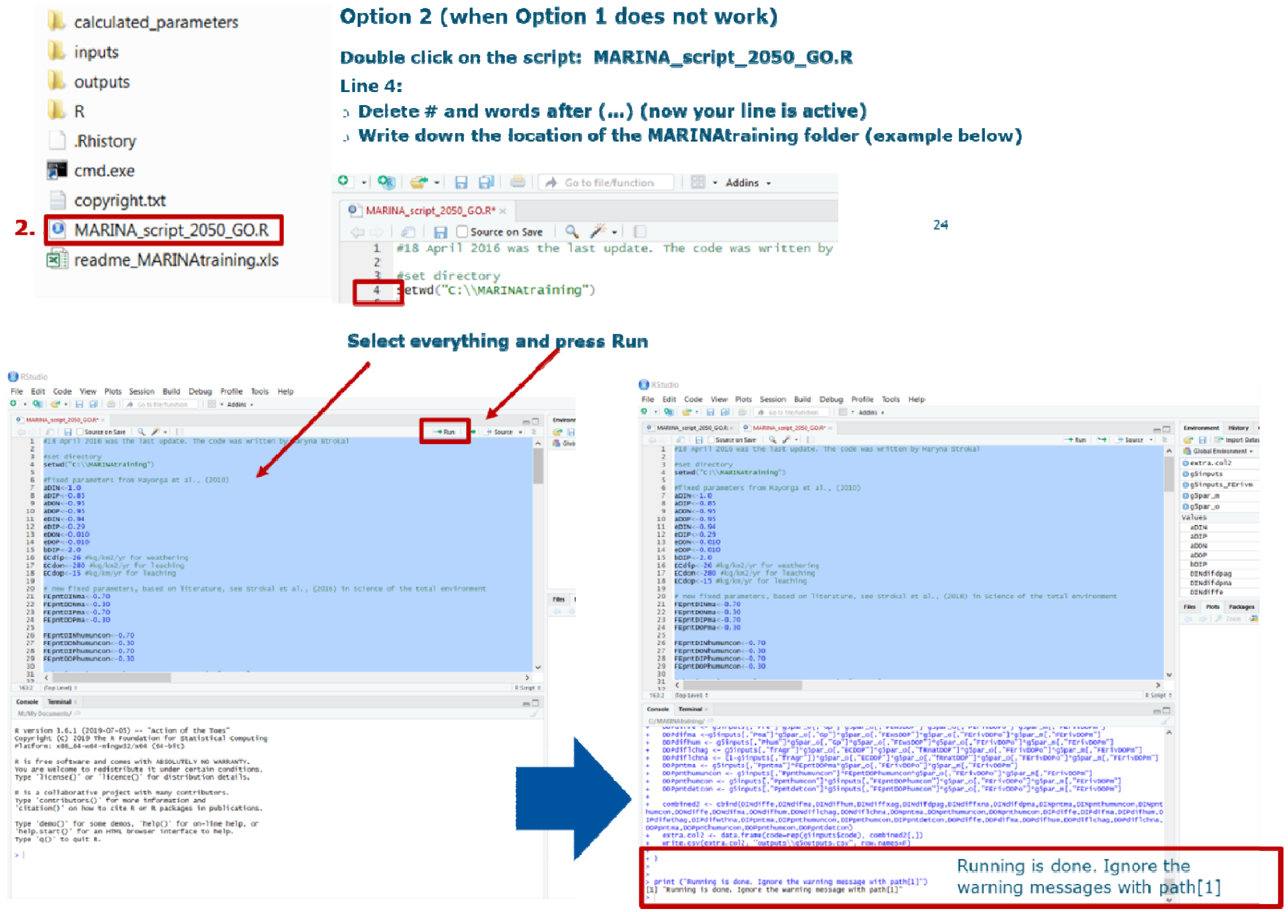


Figure 5. Option 2 for running the MARINA model for 2050 Global Orchestration using the MARINAtraining folder for windows laptops. If you have questions, post them in the chat MS Teams "General" or your group chat. Check you produced outputs for 2050: go to MARINAtraining folder -> outputs -> g5outpts.csv (check the date when this file was produced). Make sure that you save the produced output (the original GO outputs). You will re-write this output in your alternative. scenarios. Thus, it is important to keep the original output for GO. You cannot read all lines on these pictures, no problem (pictures are just indications). Look at your script. We provide videos 5-6 and 1b how to run on Windows and Mac laptops

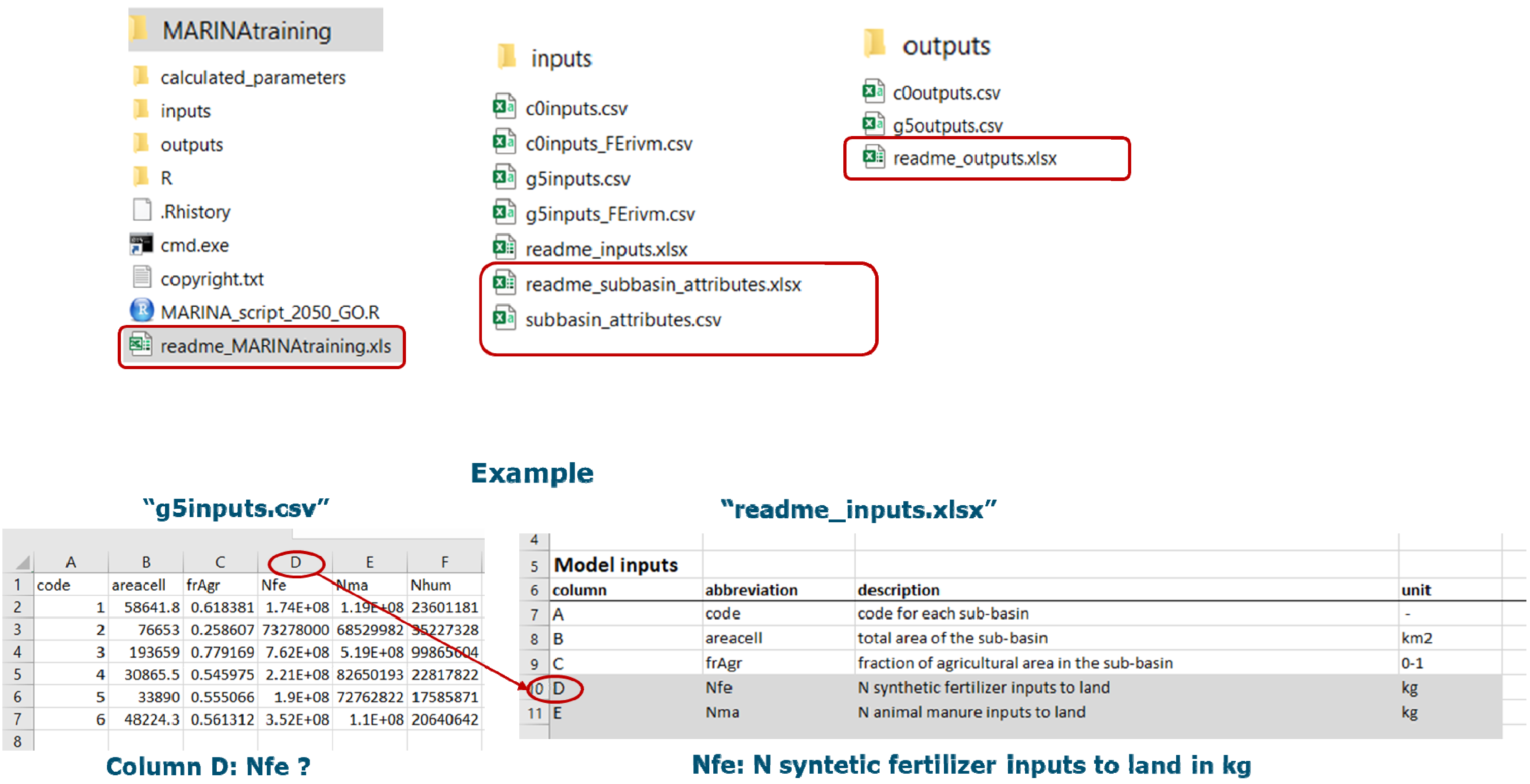


Figure 6. Illustration where to find readme files and how to use them.

- **Identify and select relevant model inputs**

MARINAtraining folder -> inputs -> readme_inputs
(here you can find the list of model inputs that are given in "g5inputs")

4				
5	**Model inputs**			
6	column	abbreviation	description	unit
7	A	code	code for each sub-basin	-
8	B	areacell	total area of the sub-basin	km2
9	C	frAgr	fraction of agricultural area in the sub-basin	0-1
10	D	Nfe	N synthetic fertilizer inputs to land	kg
11	E	Nma	N animal manure inputs to land	kg
12	F	Nhum	N human waste inputs to land	kg
13	G	Nfxag	biological N2 fixation by agricultural crops	kg
14	H	Ndpag	atmospheric N deposition on agricultural land	kg
15	I	Nex	N export from agricultural land via crop harvesting and animal grazing	kg
16	J	Nfxna	biological N2 fixation by natural vegetation	kg
17	K	Ndpna	atmospheric N deposition on on-gricultural land	kg
18	L	Npntma	N manure point source: the amount of manure directly discharged to rivers	kg
19	M	Npnthumuncon	N human waste point source from unconnected to sewage population: the amount of human excretion directly discharged to rivers from unconnected people to sewage systems	kg
20	N	Npnthumcon	N human waste point source from connected to sewage population	kg
21	O	Pfe	P synthetic fertilizer inputs to land	kg
22	P	Pma	P animal manure inputs to land	kg
23	Q	Phum	P human waste inputs to land	kg

s(y)inputs | (sy)inputs_FErivm

Grey: relevant for SDG2 (Target 2.4)

Green: relevant for SDG6 (Target 6.3)

- **Decide to what extent to change the selected model inputs (your assumptions)**
- **Change the selected model inputs:**
  - **Open "g5inputs": MARINAtraining -> inputs**
  - **Copy the model inputs that you want to change**
  - **Open a new excel file**
  - **Paste those model inputs and save the file with a different name**
  - **Do calculations and copy the calculated inputs (new inputs)**
  - **Past the new inputs in "g5inputs" to the same columns where they were before (paste as values; NO formulas)**
  - **Save changes in "g5inputs". Keep the same format and name**
  - **Close "g5inputs". It may ask you to keep the format, click Yes.**

Figure 7. Translating the storyline into model inputs.

Assessment strategy

Table 1. Rubric to assess the practicals of the PhD course. EO-educational objectives, presented below the table

Activity	Criteria	Grade (2-5 - did not pass; 6 – pass; 7-good, 8-very good; 9-10 - excellent)						Education outcomes (EO)	Weight of the total grade (%)	
		2-3	4-5	6	7	8	9-10		Criteria	Practical
Practical 1 (water stress)	**Water stress indicator**	no indicator	Indicator calculated, but not right	Indicator calculated right, but with considerable supervision	Indicator calculated right with some supervision	Indicator calculated right mostly independently	Indicator calculated right independently	EO1	4%	12%
	Impact of salinity on seasonal water stress	No such analysis	Analysis present, but not correctly	Analysis present correctly, but with considerable supervision	Analysis present correctly, but with some supervision	Analysis present correctly, mostly independently	Analysis present correctly and independently	EO1	4%	
	Other water quality parameters for water stress by irrigation	Other parameters are not presented	Other parameters are presented, but not suitable for irrigation	Other parameters are presented, but with considerable supervision	Other parameters are presented, but with some supervision	Other parameters are presented, mostly independently	Other parameters are presented independently	EO1	4%	
Practical 2 (model design)	**Aim**	No aim	Aim is formulated, but has not logic in view of the analyzed problem	Aim is formulated, but vague	Aim is formulated mainly clear	Aim is formulated clear	Outstanding aim is formulated leading to an innovative model design	EO2	3%	30%
	Level of detail	No spatial and temporal aggregation	Spatial and temporal aggregation is present for one of them, but vague	Spatial and temporal aggregations are presented, but in some places not clear	Spatial and temporal aggregations are presented and clear in most places	Spatial and temporal aggregations are presented and clear in all places	Spatial and temporal aggregations are presented and very clear in all places, leading to an innovative model design	EO2	3%	

	Pollutants (at least 3)	No pollutants	Pollutants are identified, but have no logic in view of the analyzed problem	Pollutants are identified and some are relevant	Pollutants are identified and most are relevant	Pollutants are identified and all are relevant	Pollutants are identified, all are relevant and form an excellent basis for an innovative model design	EO2	3%	
	Interactions (at least 3)	No interactions	Interactions are identified, but have no logic in view of the analyzed problem	Interactions are identified and some are relevant	Interactions are identified and most are relevant	Interactions are identified and all are relevant	Interactions are identified, all are relevant and form an excellent basis for an innovative model design	EO2	3%	
	Model inputs	No model inputs	Model inputs are identified, but have no logic in view of the analyzed problem	Model inputs are identified and some are relevant	Model inputs are identified and most are relevant	Model inputs are identified and all are relevant	Model inputs are identified, all are relevant and form an excellent basis for an innovative model design	EO2	5%	
	Model outputs	No model outputs	Model outputs are identified, but have no logic in view of the analyzed problem	Model outputs are identified and some are relevant	Model outputs are identified and most are relevant	Model outputs are identified and all are relevant	Model outputs are identified, all are relevant and form an excellent basis for an innovative model design	EO2	5%	
	Model design	No model design	A model design is created, but have no logic in view of the analyzed problem	A model design is created, but has some errors with model inputs and/or outputs	A model design is created, a few errors occur in model inputs and/or model outputs	A model design is created, no errors occur in model inputs and/or model outputs	A model design is created without any errors in model inputs and model outputs, and an excellent consistency between inputs and outputs	EO2	8%	

Practical 3 (model run and scenarios)	**Running the model and MARINAtraiuning folder (Day 1)**	Run was not performed and MARINAtraining folder was not studied	Run was not performed, but the MARINAtraining folder was hardly studied and required substantial supervision	Run was performed and the MARINAtraining folder was studied with substantial supervision	Run was performed and the MARINAtraining folder was studied with supervision in some aspects	Run was performed and the MARINAtraining folder was studied with little supervision	Run was performed and the MARINAtraining folder was studied independently	EO3	8%	40%
	Trends in water pollution (model outputs, answered to Question 1, Day 1)	Trends are not analysed	Trends are somewhat analysed, but answers are not provided	Trends are analysed, but answers are not correct	Trends are analysed and most answers are provided correctly	Trends are analysed and all answers are provided correctly	Trends are analysed and all answers are provided correctly in such a way that give concise insights on the studied problem	EO3	8%	
	Sources of pollution (model inputs and outputs, answers to Question 2, Day 1)	Sources are not analysed	Sources are somewhat analysed, but answers are not provided	Sources are analysed, but answers are not correct	Sources are analysed and most answers are provided correctly	Sources are analysed and all answers are provided correctly	Sources are analysed and all answers are provided correctly in such a way that give concise insights on the studied problem	EO3	8%	
	Alternative scenario development (assumptions for scenarios with SDGs, Day 2)	Alternative scenario(s) are not developed	Alternative scenario(s) are not developed, but some attempts are made to make assumptions to incorporate SDGs	Alternative scenario(s) are developed, but not specific enough for SGD 2 and/or 11	Alternative scenario(s) are developed, specific enough for SGD 2 and/or 11, but have some errors	Alternative scenario(s) are developed, specific enough for SGD 2 and/or 11, and without errors	Alternative scenario(s) are developed, specific enough for SGD 2 and/or 11, without errors and have new insights how to incorporate SDGs into scenarios compared to existing literature	EO3	8%	

	Effects of SDG2 and/or 11 on river export of nutrients in the future (answers to questions, Day 2, Questions 1-2)	Effects are not analysed	Effects are somewhat analysed, but answers are not provided	Effects are analysed, but answers are not correct	Effects are analysed and most answers are provided correctly	Effects are analysed and all answers are provided correctly	Effects are analysed and all answers are provided correctly in such a way that give concise insights on the studied problem	EO3	8%	
Poster and its presentati on	**Content**	No insights from three practicals	Lacking insights from three practicals	Results of three practicals are included, but not always clear	Results of three practicals are included, but not always clear in some places	Results of three practicals are included, and clear	Results of three practicals are included in a creative way and very clear	EO1-3	6%	18%
	Structure	No structure	Chaotic (mixed) structure, making almost impossible to understand the content	A reasonable structure that allows to understand some content	A good structure that allows to understand most of the content	A good structure that allows to easily understand the content	An excellent, creative structure that allows to easily understand the content without asking 3%questions for clarifications	EO1-3	6%	
	A way of presenting	Vague, fast talking, not clear	Vague and fast talking	Fast talking, clear in some places	A reasonable speed of talking, not clear in some places	A good speed of talking, clear in most places	A very good speed of talking (non-native English speakers can understand easily) and clear in all places	EO1-3	6%	
									Total: 100%	

Education outcomes (EO) of the course:

EO1 (Practical 1): to calculate seasonal water stress with and without water quality. This includes understanding of the concept of water stress.

EO2 (Practical 2): to design an integrated model for water quality.

EO3 (Practical 3): to run a simple water quality model (MARINA) and develop simple scenarios. For this, two specific learning objectives are set for a two-day practical:

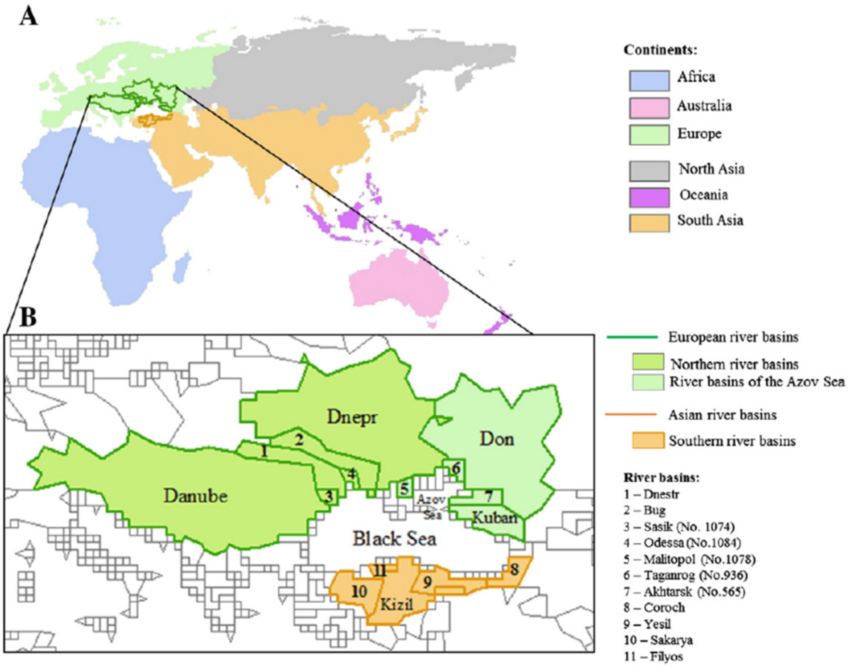
1. Day 1: to learn model inputs, outputs, and run the model
2. Day 2: to develop two simple scenarios to analyse the effects of SDGs2 and 11.

Appendixes

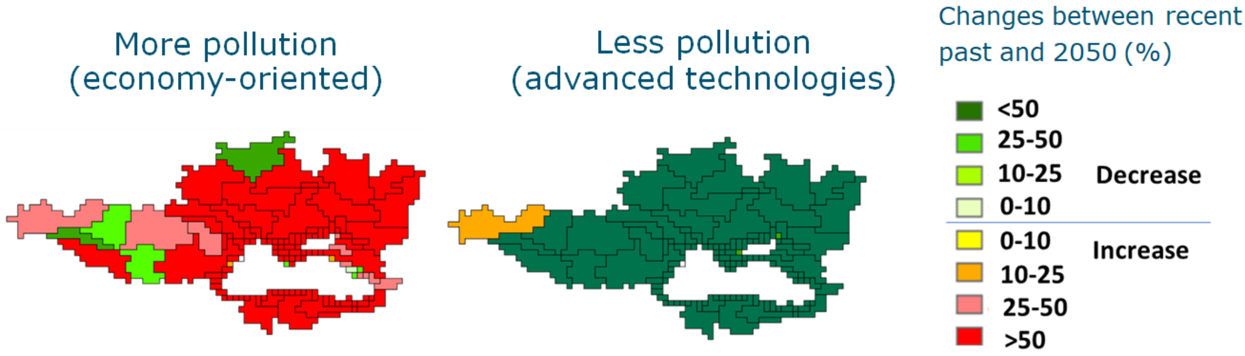
1. Integrated modelling of water pollution worldwide

Black Sea

- Strokal et al. (2014)
- NULES and WUR



Future inputs of microplastics from cities to rivers in the Black Sea region



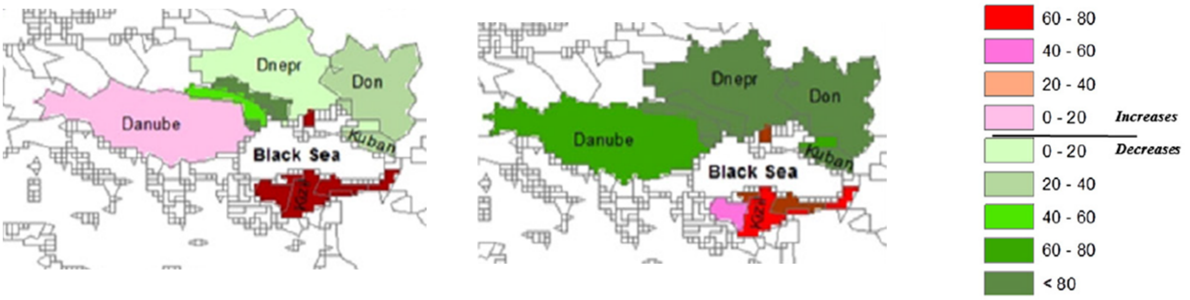
Strokal et al. (unpublished) NULES and WUR ongoing collaboration

Future inputs of phosphorus from rivers to the Black Sea (agriculture+cities)

More pollution
(economy-oriented)

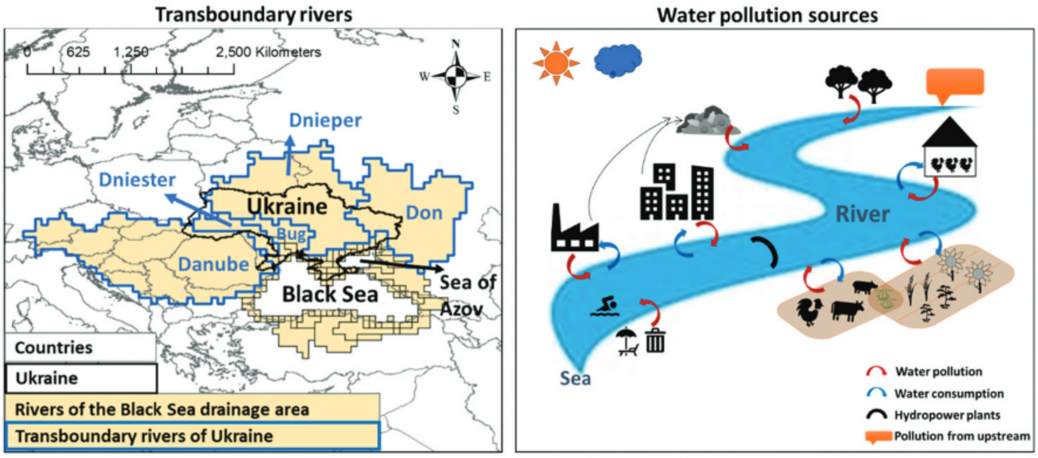
Less pollution
(advanced technologies)

Changes between recent past and 2050 (%)



Strokal et al. (2014) NULES and WUR ongoing collaboration

2. River pollution



Characteristics of rivers

River	Flow through main countries	River mouth country	Drain into the sea	Drainage area (10^3 km^2)
Dnieper	**Ukraine**, Belarus, Russia	Ukraine	The Black Sea	510
Dniester	**Ukraine**, the Republic of Moldovia	Ukraine	The Black Sea	72
Danube	Germany, **Romania**, Austria, Hungary, Serbia, Bulgaria, Croatia, Slovakia, Ukraine,	Romania, Ukraine*	The Black Sea	795
Don	Russia and Ukraine	Russia	The Sea of Azov	436
Southern Bug**	**Ukraine**	Ukraine	The Black Sea	63

Figure 1. Overview of Transboundary Rivers flowing through Ukraine and river pollution sources

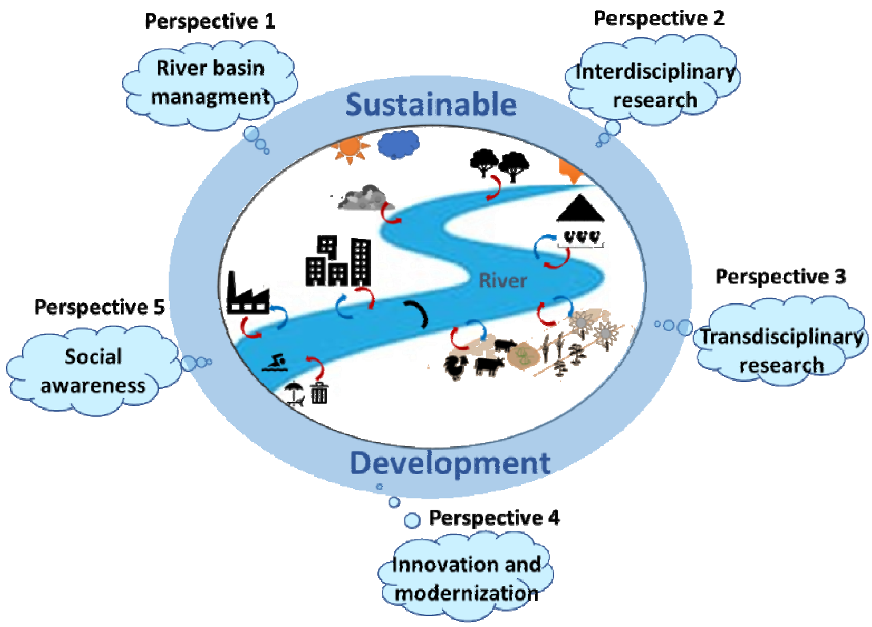


Figure 2. Perspectives for sustainable development and clean rivers

Resourse: Vita Strokal (2021). Transboundary rivers of Ukraine: perspectives for sustainable development and clean water. Journal of Integrative Environmental Sciences. Vol.18, No.1 P. 67-87 Available at: https://www.tandfonline.com/doi/pdf/10.1080/1943815X.2021.1930058

3. Legislation and implementation of EU Directives in the field of water resources management in Ukraine

Table A.1 – Legislation and implementation of EU Directives in the field of water resources management (***Resourse:*** Vita Strokal (2021). Transboundary rivers of Ukraine: perspectives for sustainable development and clean water. Journal of Integrative Environmental Sciences. Vol.18, No.1 P. 67-87 Available at: https://www.tandfonline.com/doi/pdf/10.1080/1943815X.2021.1930058)

Protocol on Water and Health to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (adopted in 2003) https://zakon.rada.gov.ua/laws/show/994_030	Defined targets that are relevant to the standards and results that must be achieved or maintained to ensure a high level of protection of the population from diseases connected with water. Since 2017, an active review of national targets has begun in the framework of the project entitled "European Union Water Initiative for the Eastern Partnership Countries". As a result of the revision of the current national targets and 32 indicators, approved in 2011 to 10 target areas of the Protocol, in 2020 42 national indicators and 76 indicators of progress were proposed for all 20-target areas of the Protocol
Methods of hydrographic and water management zoning of the territory of Ukraine in accordance with the requirements of the Water Framework Directive of the European Union (adopted in 2013)	Proposed methods of hydrographic and water management zoning for the territory of Ukraine, which allows to improve the management system in the field of using and protecting water and reconstitution of the country's water resources through its real implementation on the basin principle in accordance with the requirements of the European Union Water Framework Directive.
Water strategy of Ukraine for the period up to 2025 (adopted in 2015) http://iwpim.com.ua/wp-content/uploads/2015/10/11_03_2015.pdf	Identified the strategic goals and objectives of the water strategy, directions and stages of implementation, monitoring of water resources, the main results that have to be achieved by 2025.

Law of Ukraine "On Amendments to Legislative Acts of Ukraine on the Implementation of Integrated Approaches to Water Resources Management on the Basin Principle" (adopted in 2016) https://zakon.rada.gov.ua/laws/show/1641-19	Identified the areas of river basins. Introduced: basin councils, river basin management plan, water management balances of water resources. Updated the water monitoring procedure, identified and classified bodies of water.
Resolution of the Cabinet of Ministers of Ukraine № 336 "On approval of the Procedure for developing a river basin management plan" (adopted in 2017) [https://zakon.rada.gov.ua/laws/show/336-2017-%D0%BF	Determined the structure of the river basin management plan (characteristics of groundwater and surface water, anthropogenic impacts on their quantitative and qualitative status, protected areas, mapping of the monitoring system and its results, list of economic and environmental objectives)
Order of the Ministry of Ecology and Natural Resources (now the Ministry of Energy and Environmental Protection) "On approval of the Model Regulation on Basin Councils" (adopted in 2017) https://zakon.rada.gov.ua/laws/show/z0231-17	Identified the Basin Councils, which became a consulting and advisory body within the river basin. Included the issue of ecological, quantitative and qualitative state of the water resources of the river basin, analysis and assessment of risks of failure to improve the ecological state of the water resources of the river basin and the consequences of its changes for natural ecosystems and sectors of the economy, as well as the forecast of processes that affects the quality of water resources and volumes of water use.
Order of the Ministry of Ecology and Natural Resources (now the Ministry of Energy and Environmental Protection) "On the allocation of sub-basins and water management areas within the established areas of river basins" (adopted in 2017)	Approved the names of sub-basins and water management sites within the river basin districts. *The Dnipro River Basin Area:* Upper Dnipro Sub-Basin (Dnipro River from the State Border to the Beginning of the Kyiv Reservoir (Including the Sozh River on the territory of Ukraine)), *The Middle Dnipro Sub-Basin* (Kyiv Reservoir within the

https://zakon.rada.gov.ua/laws/show/z0208-17	Braginka River on the territory of Ukraine, excluding the Pripyat and Teteriv and, Irpen Rivers); The Dnipro River from the dam of the Kiev Reservoir to the dam of the Kanevsky Reservoir (excluding the Desna River, the Trubizh River), the Dnipro River from the dam of the Kanev Reservoir to the Dam of the Kremenchug Reservoir (excluding the Ros, Supiy, Sula, Tyasmyn and other rivers), *Sub-basin of the Lower Dnipro* (the Dnipro River from the Dniprodzerzhynsk Dam reservoirs to the dam of the Dnipro reservoir (excluding the Orel, Samara rivers), the Dnipro river from the dam of the Dnipro reservoir to the dam of the Kakhovsky reservoir) the Dnipro river from the dam of the Kakhovsky reservoir to the mouth (excluding the Ingulets river) and others), *the Sub-basin of the Pripyat river, the Sub-basin of the Desna river.* *The Dniester river basin Area.* *The Danube River Basin Area:* Tisza Sub-Basin, Prut River Sub-Basin, Siret River Sub-Basin, Lower Danube Sub-Basin. *The Southern Bug river basin Area.* *The Don river basin Area:* Siversky Donets sub-basin, Lower Don sub-basin. *The Vistula river basin Area:* Western Bug sub-basin, San sub-basin.
Order of the Ministry of Ecology and Natural Resources (now the Ministry of Energy and Environmental Protection) "On approval of the boundaries of river basins, sub-basins and water areas" (adopted in 2017) https://zakon.rada.gov.ua/laws/show/z0421-17	Approved the boundaries of river basins, sub-basins and water areas, in particular outlined the lines of the state border, settlements.

Order of the Ministry of Ecology and Natural Resources (now the Ministry of Energy and Environmental Protection) "On approval of the List of pollutants to determine the chemical status of surface water and groundwater and the ecological potential of artificial or significantly altered surface water" (adopted in 2017) https://zakon.rada.gov.ua/laws/show/z0235-17	Approved the list of pollutants, which is divided into three categories: for surface water, for groundwater, for the ecological potential of artificial or significantly altered surface water.
Resolution of the Cabinet of Ministers of Ukraine "On approval of the Procedure for state water monitoring" (adopted in 2018) https://zakon.rada.gov.ua/laws/show/758-2018-%D0%BF	Prescribed the main program of state water monitoring. Gave the main procedures (principles of implementation) of types of state monitoring: the procedure of diagnostic monitoring of surface water and groundwater; procedure of operational monitoring of surface and groundwater massifs; procedure of research monitoring of surface water massifs; sea water monitoring procedure. Specified that diagnostic, operational and research monitoring is carried out on a basin basis.
Order of the Ministry of Ecology and Natural Resources (now the Ministry of Energy and Environmental Protection) "On approval of the Procedure for the development of water balances" (adopted in 2017) https://zakon.rada.gov.ua/laws/show/z0232-17	Identified the mechanism of development of water balances for water management areas allocated within the river basin districts. Described that water balances are developed to assess the availability and possibility of using water resources within water management areas, taking into account the amount and degree of development of usable water resources. Gave the structure of the water balance, which includes the income and expenditure parts, as well as the result of the water balance. The result of the water balance is characterized by the presence of reserves or runoff deficits.

Green Paper "Strategy of Water Policy of Ukraine" (under development)	Demonstrates the vision of the problem of water resources management in the implementation of responsible environmental policy to achieve a "good" environmental, quantitative and chemical status (potential) of water resources of Ukraine. Considers the implementation of integrated water resources management by ensuring the implementation of river basin management plans, preparation and implementation of the National Marine Environmental Strategy and the relevant program of measures for its implementation.
Water sector directives (water quality and water management, including marine environment)	
The EU Water Framework Directive (Directive 2000/60 / EC on the establishment of a framework for Community action in the field of water policy) https://zakon.rada.gov.ua/laws/show/994_962	Contributed to the formation of the structure of protection of inland waters, transitional waters, coastal waters and groundwater. Also the creation of river basins within the national territory of Ukraine for cross-border cooperation.
Result: Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Concerning the Implementation of Integrated Approaches to Water Resources Management on the Basin Principle" of October 4, 2016 № 1641-VIII; Order of the Ministry of Environment "On the allocation of sub-basins and water management areas within the established areas of river basins" from 01/26/2017 № 25; Order of the Ministry of Environment "On approval of the boundaries of river basins, sub-basins and water management areas" from 03.03.2017 № 103; Order of the Ministry of Environment "On approval of the List of pollutants to determine the chemical status of surface and groundwater and the ecological potential of artificial or significantly altered surface water" from 06.02.2017 № 45; Order of the Ministry of Environment "On approval of the Standard Regulations on Basin Councils" from 01/26/2017 № 23; Resolution of the Cabinet of Ministers of Ukraine "On approval of the Procedure for developing a river basin management plan" of May 18, 2017 № 336; Law of Ukraine "On Ratification of the Agreement between the Cabinet of	

Ministers of Ukraine and the Government of the Republic of Moldova on Cooperation in the Sphere of Protection and Sustainable Development of the Dniester River Basin" of June 7, 2017.	
Marine Strategy Framework Directive (Directive 2008/56 / EC establishing a framework for Community action in the field of marine environmental policy) https://menr.gov.ua/files/docs/2008%2056%20%D0%84%D0%A1.pdf	Ukraine, located in the Black, Azov and Baltic Seas, has contributed to the development of strategic directions of environmental policy for the protection and reproduction of the marine environment. The directive introduces new approaches to the environmental policy of states on the protection of the marine environment - the gradual achievement of good ecological status (hydroelectric power station) of the marine environment. This state is determined by 11 descriptors (short descriptions), which cover 60 indicators.
The result: the directive is at different stages of implementation by EU member states, which opens up new opportunities for Ukraine on an equal footing and together with them to find and implement ways to ensure hydropower in the Black and Azov Seas.	
Urban Wastewater Directive (EU Directive 91/271 / EEC "On urban wastewater treatment") https://zakon.rada.gov.ua/laws/show/994_911	Contributes to the solution of sanitation problems through mandatory sewerage and wastewater treatment of all settlements and industrial facilities with a population equivalent of more than 2000. The Directive sets high standards for wastewater treatment (primary, secondary and tertiary treatment) before discharge into water bodies. taking into account the size of settlements and vulnerable zones for discharges of treated wastewater.
Result: Law of Ukraine "On Amendments to the Law of Ukraine" On Drinking Water and Drinking Water Supply "of May 18, 2017 № 2047-VIII	
Floods Directive (Directive 2007/60 / EC "On the assessment and management of floods") https://zakon.rada.gov.ua/laws/show/994_b29	Provides for the preparation of river basin management plans and public consultation, improvement of Ukrainian legislation on flood risk assessment and management, preliminary flood risk assessment, preparation of flood risk and risk maps,

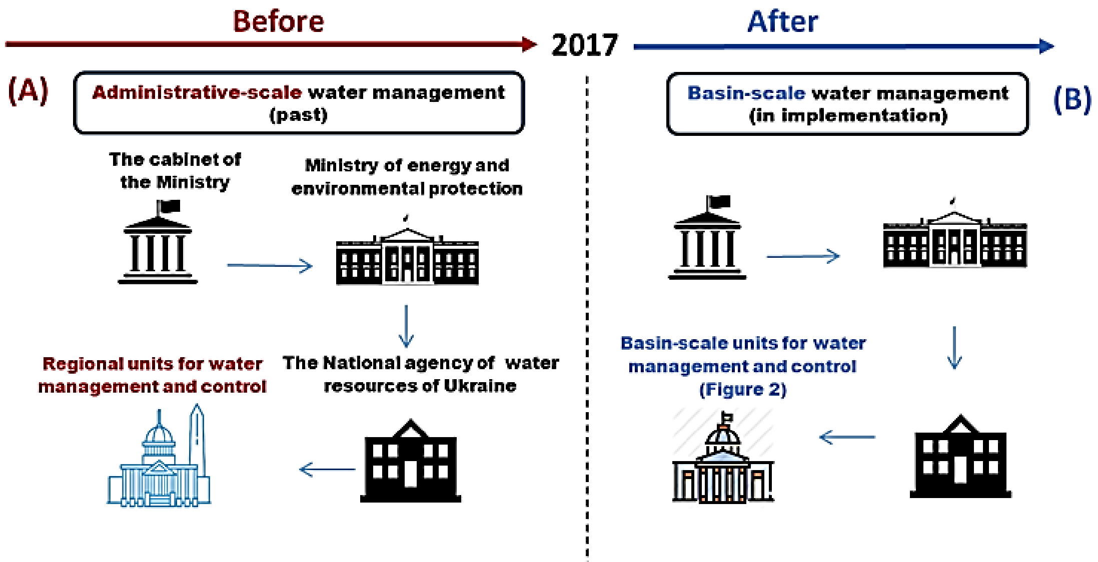
	introduction of flood risk management plans.
Result: Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Concerning the Implementation of Integrated Approaches to Water Resources Management on the Basin Principle" of October 4, 2016 № 1641-VIII (Article 107-1)	
Drinking Water Directive (EU Directive 98/83 / EC on the quality of water intended for human consumption) https://zakon.rada.gov.ua/laws/show/994_963	Identifies the main aspects of people's access to water quality. The directive established water quality standards (48 microbiological and chemical indicators) for all water supply systems serving more than 50 people or supplying more than 10 m3 per day. It has also established monitoring and mandatory reporting rules for all operators that supply more than 1,000 m3 per day and serve more than 5,000 consumers.
Result: Law of Ukraine "On Amendments to the Law of Ukraine" On Drinking Water and Drinking Water Supply "of May 18, 2017 № 2047-VIII	
The Nitrates Directive (Council Directive 91/676/EEC on the protection of waters against pollution caused by nitrates from agricultural sources) https://menr.gov.ua/files/docs/91%20676%20%D0%84%D0%95%D0%A1.pdf	Provides protection of the water system from nitrate pollution of sensitive areas, which include sources of drinking water supply in rural areas, monitoring of nitrate pollution of water. These measures complement measures to improve access to sanitation in rural areas and the introduction of appropriate small sanitation systems (local treatment plants and sustainable ecosanitary technologies) (composting of animal and human waste) for the safe reuse of organic fertilizers.
Result: Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Concerning the Implementation of Integrated Approaches to Basin-Based Water Resources Management" of October 4, 2016 № 1641-VIII	

Table A.2 – List of river basin districts, sub-basins and Basin water resources management (official website of the State Water Resources Management of Ukraine: https://www.davr.gov.ua/basejnovi-upravlinnya-vodnih-resursiv) (***Resourse:*** Vita Strokal (2021). Transboundary rivers of Ukraine: perspectives for sustainable development and clean water. Journal of Integrative Environmental Sciences. Vol.18, No.1 P. 67-87: https://www.tandfonline.com/doi/pdf/10.1080/1943815X.2021.1930058)

№	The name of the river basin district	Basin water resources management	Rivers in the basin
1	The Dnipro river basin area:		
	The Sub-basin of the upper Dnipro The Sub-basin of the Desna River	Basin water resources management of the Desna river (subordinate: Sumy Regional Department of Water Resources)	The Dnipro river The Ros River The Pripyat river The Desna river
	The Middle Dnipro Sub-Basin	Basin water resources management of the middle Dnipro (subordinate: Poltava and Cherkasy regional departments water resources)	
	The Sub-basin of the Lower Dnipro	Basin water resources management of Lower Dnipro (subordinate: Dnipropetrovsk Regional Department of Water Resources)	
	The Sub-basin of the Pripyat river	Basin water resources management of the Pripyat river (subordinated: Volyn, Rivne and Khmelnytsky regional water resources management)	
2	The Danube River Basin Area		
	The Lower Danube Sub-Basin.		The Tisza river The Prut river The Siret river
	The Tisza Sub-Basin	Basin water resources management of the Tisza river	
	The Prut Sub-Basin	Basin water resources management of the Prut and Siret rivers	
	The Siret Sub-Basin		
3	The Dniester river basin Area.	Basin water resources management of the Dniester river (subordinate: Ternopil Regional Department of Water resources)	The Dniester river
4	The Southern Bug river basin Area.	Basin water resources management of the Southern Bug river	The Southern

<table>
<tr><td></td><td></td><td>(subordinate: Kirovograd and Nikolaev regional departments of water resources)</td><td>Bug river</td></tr>
<tr><td>5</td><td>The Don river basin Area:</td><td></td><td></td></tr>
<tr><td></td><td>The Siversky Donets Sub-basin</td><td rowspan="2">Basin water resources management of the Siversky Donets (subordinate: Donetsk-Luhansk Regional Department of Water Resources)</td><td rowspan="2">The Siversky Donets and The Lower Don</td></tr>
<tr><td></td><td>The Lower Don Sub-basin.</td></tr>
<tr><td>6</td><td>The Vistula river basin Area:</td><td></td><td></td></tr>
<tr><td></td><td>The Western Bug sub-basin</td><td rowspan="2">Basin water resources management of the Western Bug and the San</td><td rowspan="2">The Western Bug and The San</td></tr>
<tr><td></td><td>The San sub-basin.</td></tr>
<tr><td>7</td><td>The Black Sea river basin</td><td>Basin water resources management of the Black Sea and of the Lower Danube</td><td>The Black Sea rivers and The Lower Danube rivers</td></tr>
<tr><td>8</td><td>Crimea river basin</td><td>Crimean basin management of water resources</td><td></td></tr>
<tr><td>9</td><td>The basin of the Azov rivers</td><td>Basin water resources management of the Azov rivers</td><td></td></tr>
</table>

4. The structure of water management

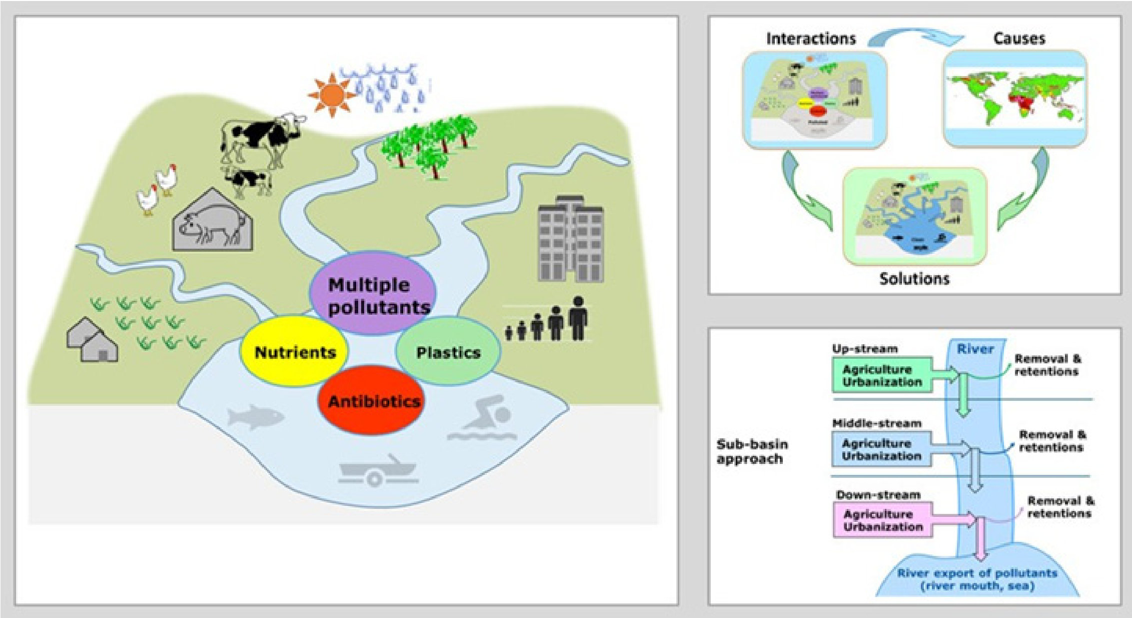


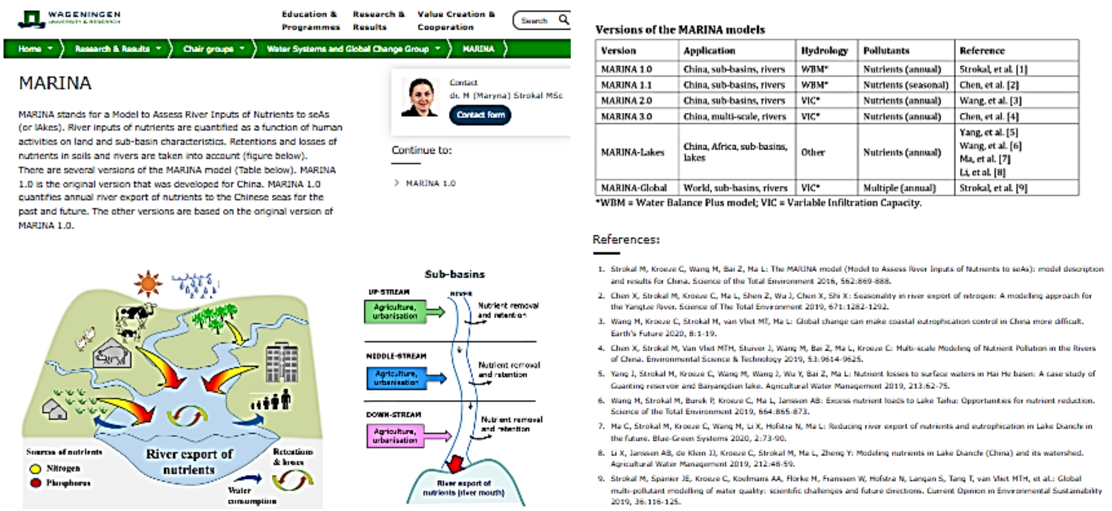
Summarized the structure of water management and its approaches before and after 2017 (infleunced by EC)

Resourse: Strokal, V.P. Kovpak A.V. The basin approach for water resources management in ukraine: the swot analysis / Scientific journal "Biological systems: theory and innovation", Том 11, № 4 (2020). URL: http://journals.nubip.edu.ua/index.php/Biologiya/issue/view/598, DOI: http://dx.doi.org/10.31548/biologiya2020.04.004

4. MARINA Models: sub-themes and aims/focus

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





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MARINA

MARINA stands for a Model to Assess River Inputs of Nutrients to seAs (or lAkes). River inputs of nutrients are quantified as a function of human activities on land and sub-basin characteristics. Retentions and losses of nutrients in soils and rivers are taken into account (figure below). There are several versions of the MARINA model (Table below). MARINA 1.0 is the original version that was developed for China. MARINA 1.0 quantifies annual river export of nutrients to the Chinese seas for the past and future. The other versions are based on the original version of MARINA 1.0.

Contact
dr. M (Maryna) Strokal MSc
Contact form

Continue to:

> MARINA 1.0

Versions of the MARINA models

Version	Application	Hydrology	Pollutants	Reference
MARINA 1.0	China, sub-basins, rivers	WBM*	Nutrients (annual)	Strokal, et al. [1]
MARINA 1.1	China, sub-basins, rivers	WBM*	Nutrients (seasonal)	Chen, et al. [2]
MARINA 2.0	China, sub-basins, rivers	VIC*	Nutrients (annual)	Wang, et al. [3]
MARINA 3.0	China, multi-scale, rivers	VIC*	Nutrients (annual)	Chen, et al. [4]
MARINA-Lakes	China, Africa, sub-basins, lakes	Other	Nutrients (annual)	Yang, et al. [5] Wang, et al. [6] Ma, et al. [7] Li, et al. [8]
MARINA-Global	World, sub-basins, rivers	VIC*	Multiple (annual)	Strokal, et al. [9]

*WBM = Water Balance Plus model; VIC = Variable Infiltration Capacity.

References:

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2. Chen X, Strokal M, Kroeze C, Ma L, Shen Z, Wu J, Chen X, Shi X: Seasonality in river export of nitrogen: A modelling approach for the Yangtze River. Science of The Total Environment 2019, 671:1282-1292.
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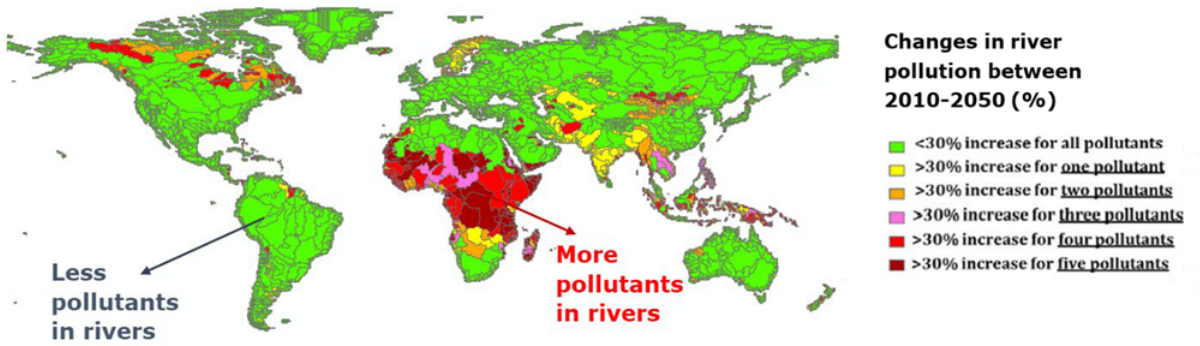
8. Li X, Janssen AB, de Klein JJ, Kroeze C, Strokal M, Ma L, Zheng Y: Modeling nutrients in Lake Dianchi (China) and its watershed. Agricultural Water Management 2019, 212:48-59.
9. Strokal M, Spanier JE, Kroeze C, Koelmans AA, Flörke M, Franssen W, Hofstra N, Langan S, Tang T, van Vliet MTH, et al.: Global multi-pollutant modelling of water quality: scientific challenges and future directions. Current Opinion in Environmental Sustainability 2019, 36:116-125.

Resourse: web-site WUR - https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Water-Systems-and-Global-Change-Group/MARINA-2.htm

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.

Model outputs (examples)



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.

Model outputs (examples)

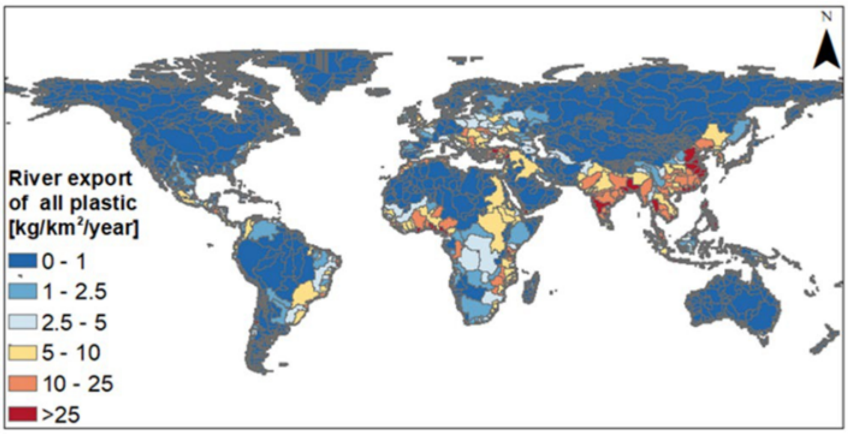
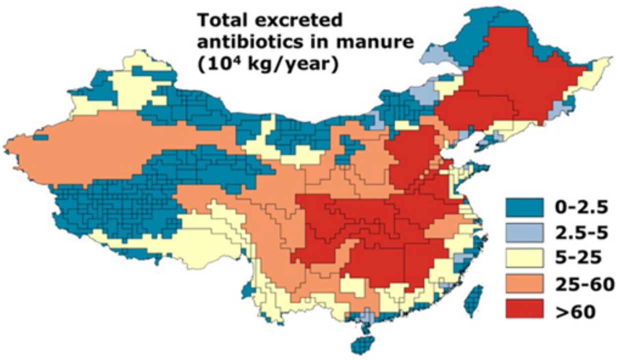


Figure 2: River export of macro- and microplastics by sub-basin (Maryna Strokal, Paul Vriend and others, under development).

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.

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¶

The MARINA-Nutrients models focus on nutrient-related water quality. Excessive inputs of nutrients such as nitrogen and phosphorus is a primary cause of eutro- phication of surface waters, harming the environment. The models aim to quantify river exports of nutrients by sources for the past, present and future.

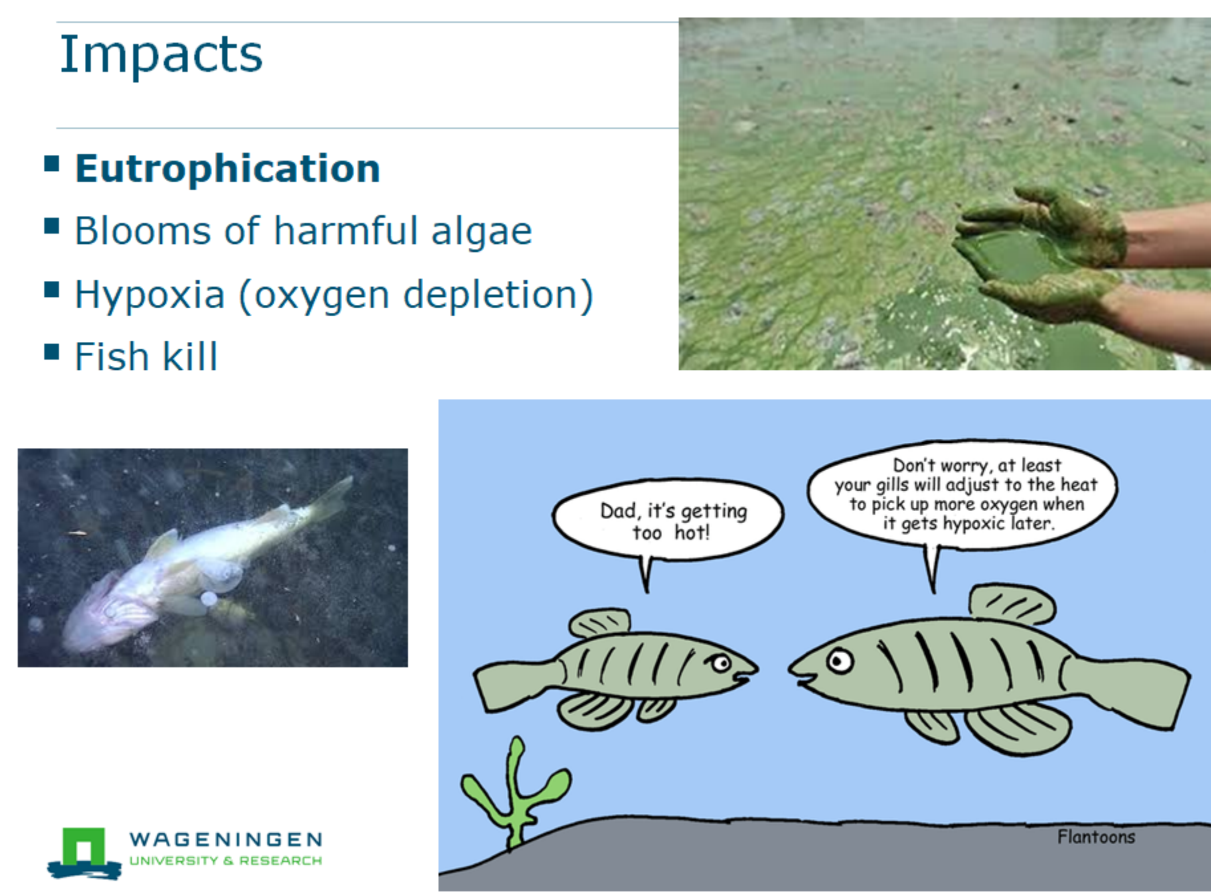
Model outputs (examples)

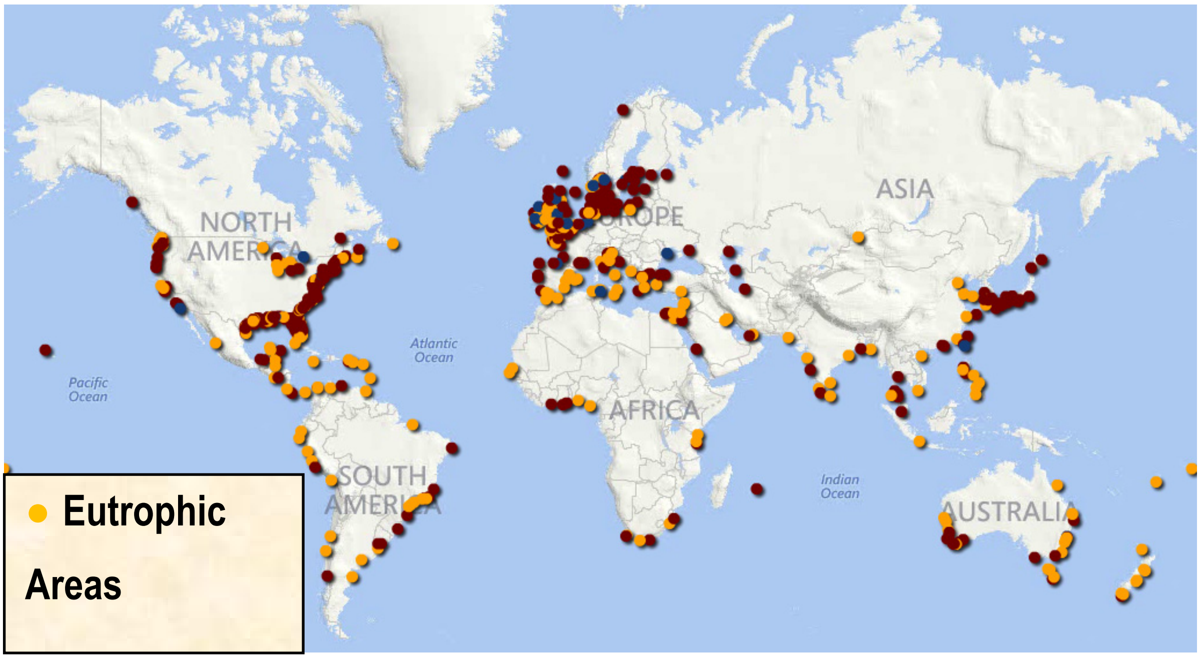
Figure 2: Total Dissolved Nitrogen (TDN) concentration hotspots for the environment, domestic sector, and agricultural sector for 2010 (mg/L). Hotspots refer to sub-basins that do not meet water quality standards for a specific purpose (Mengru Wang, Rhodé Rijneveld et al. under development).

5. Water quality modelling for nutrients: introduction

A. Nutrient impacts

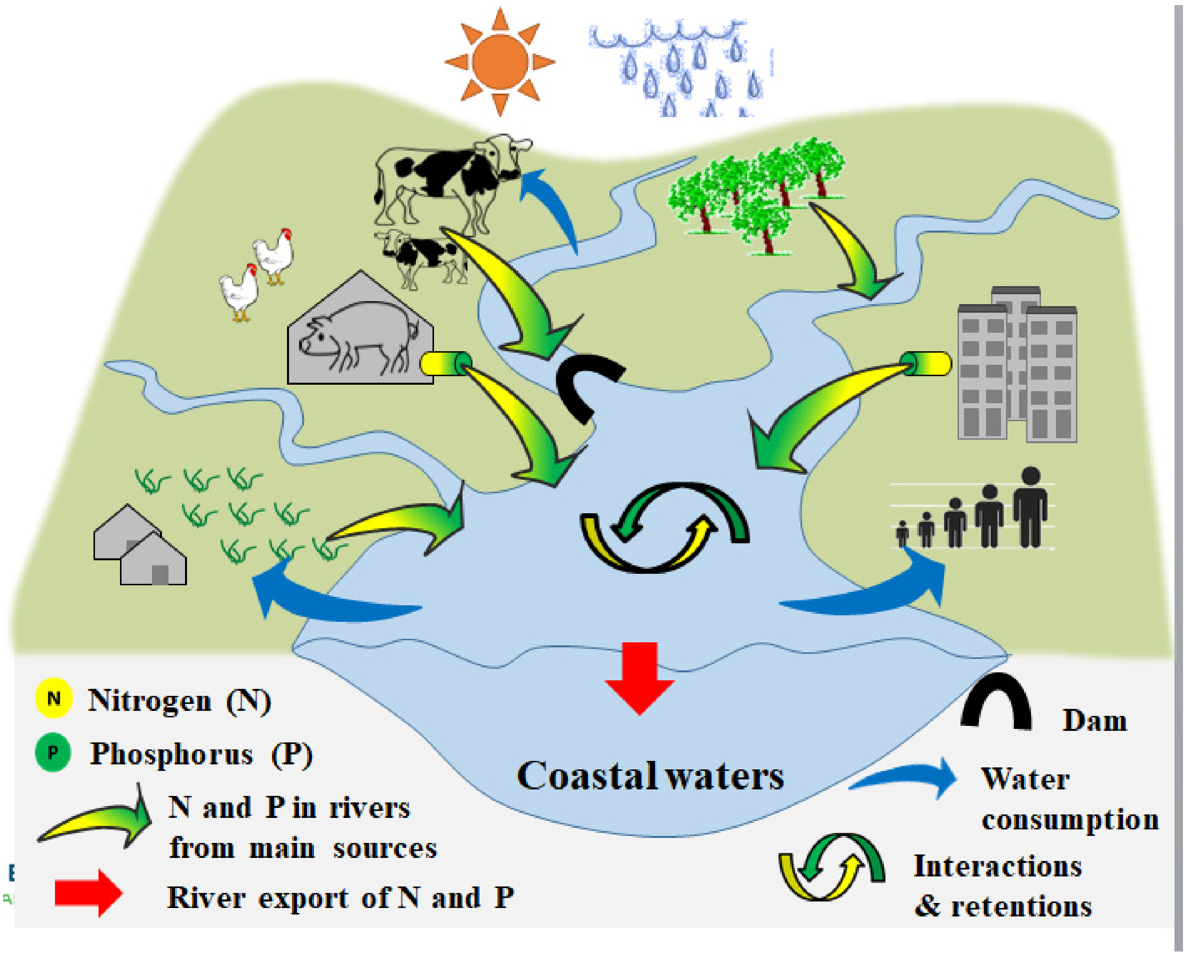
- –video: https://www.youtube.com/watch?v=92TFJTtuq6k





B. N and P export by rivers

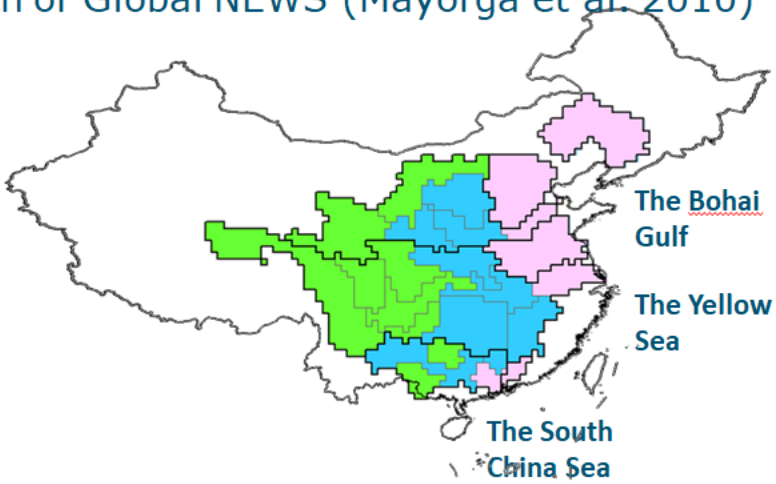
- Movie on N and P cycles: https://www.youtube.com/watch?v=leHy-Y_8nRs



Resourse: Strokal et al., (2016)

MARINA:
Model to Assess River Inputs of Nutrients to seAs

- Downscaled version of Global NEWS (Mayorga et al. 2010)
- 25 sub-basins
- Nitrogen (N)
- Phosphorus (P)



Inputs (sub-basin scale)

Human activities:
- Population, urbanization
- Animal manure
- Synthetic fertilizers
- Atmospheric N deposition
- Biological N fixation

Sub-basin characteristics:
- Hydrology
- Land use

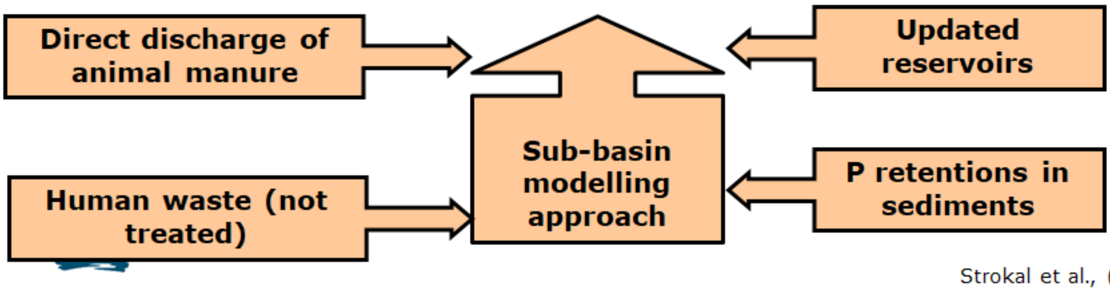
The MARINA model

Retentions in rivers

Outputs (sub-basin scale)

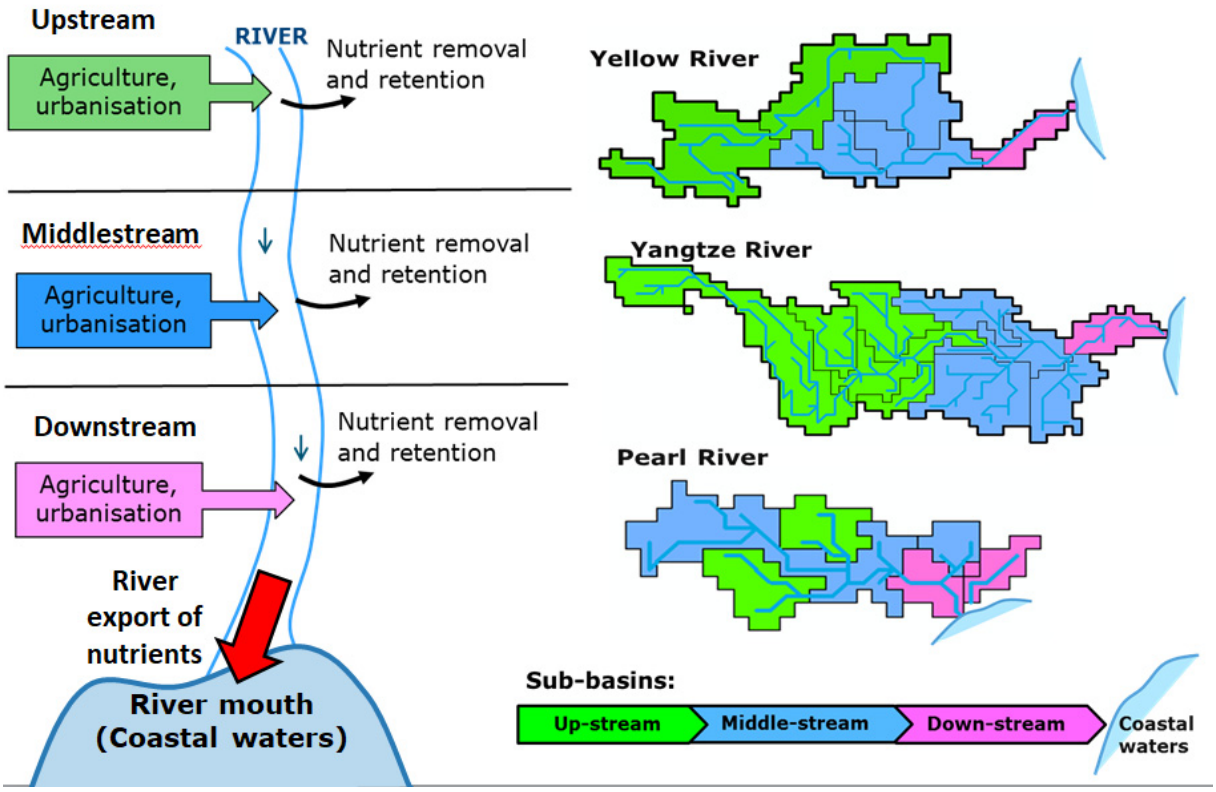
Annual river export of nutrients (river mouth)
- Dissolved N, P
- Source attribution
- Sub-basin contribution

1970, 2000, 2050



Strokal et al., (2016)

Sub-basin scale modelling approach



Nutrient forms

- DIN: Dissolved Inorganic Nitrogen
- DON: Dissolved Organic Nitrogen
- DIP: Dissolved Inorganic Phosphorus
- DOP: Dissolved Organic Phosphorus

- **Eq. 1** in Strokal et al., (2016)

Inputs of nutrient to rivers from source (y) in sub-basin (j) (kg/year)

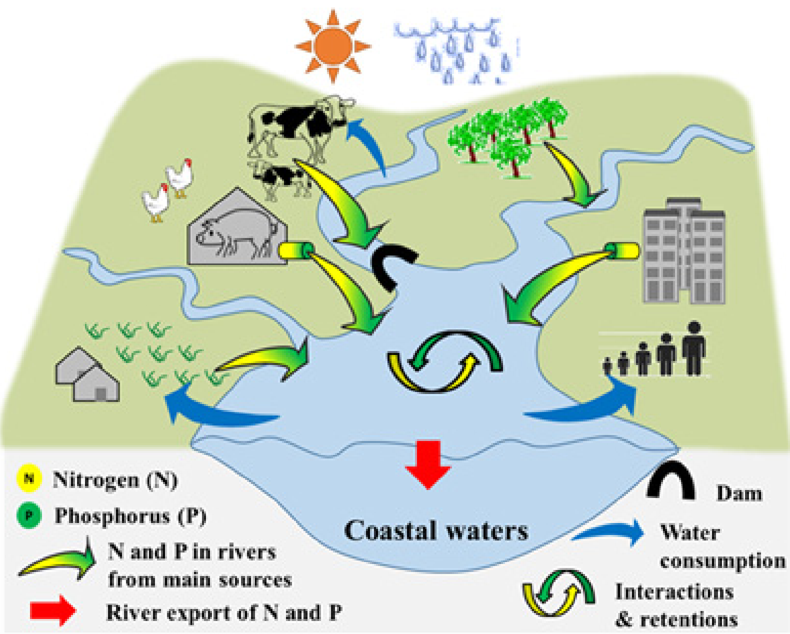
$$M_{F.y.j} = RS_{F.y.j} \cdot FE_{riv.F.outlet.j} \cdot FE_{riv.F.mouth.j}$$

River export of nutrient by source (y) from sub-basin (j) (kg/year)

Fraction of nutrient reaching **the outlet** of sub-basin (j) (0-1)

Fraction of nutrient reaching **the coastal waters** from the outlet of sub-basin (j) (0-1)

Diffuse and point sources



- Agriculture (point)
  - Direct discharges of manure to rivers
- Agriculture (diffuse)
  - Chemical fertilizer use
  - Animal manure use
  - Fixation & deposition
- Cities (mainly point)
  - Sewage systems

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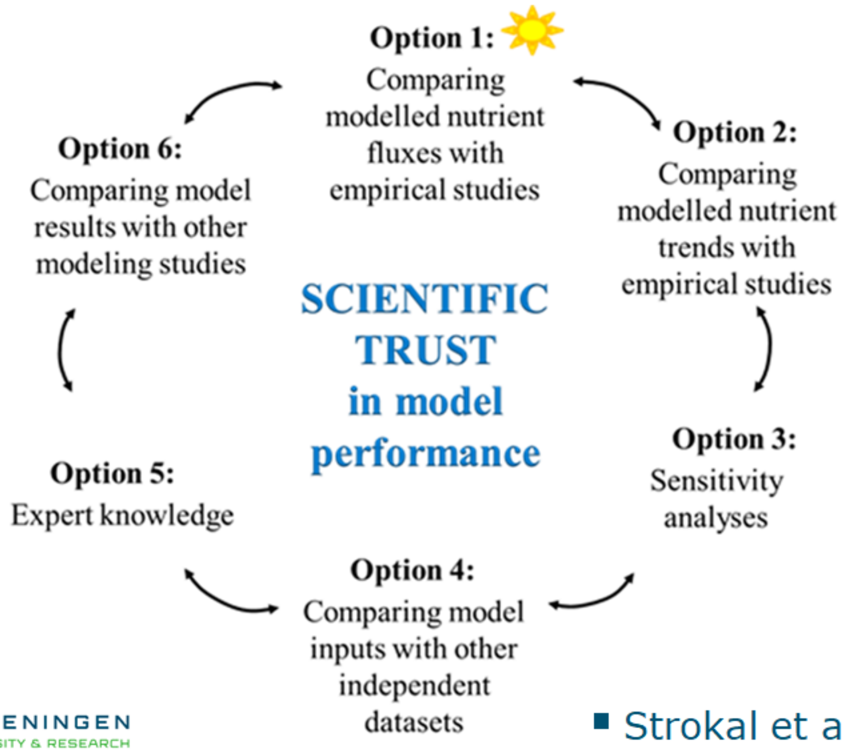
Model evaluation – "building trust" approach



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- Strokal et al. 2016

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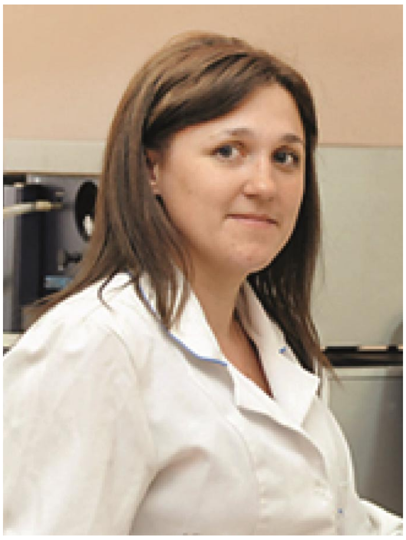

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