Simulating wastewater-derived microcontaminant pollution to prioritize investments in Europe

Janick Klink, Morgan Abily, David Martínez, Wolfgang Gernjak, **Lluís Corominas**

(Catalan Institute for Water Research)

ICRA
Institut Català de Recerca de l'Aigua

inspiring change

https://github.com/icra/wOtter

WHY DO WE NEED A PAN-EUROPEAN MODEL FOR MICROCONTAMINANTS FATE AND REMOVAL?

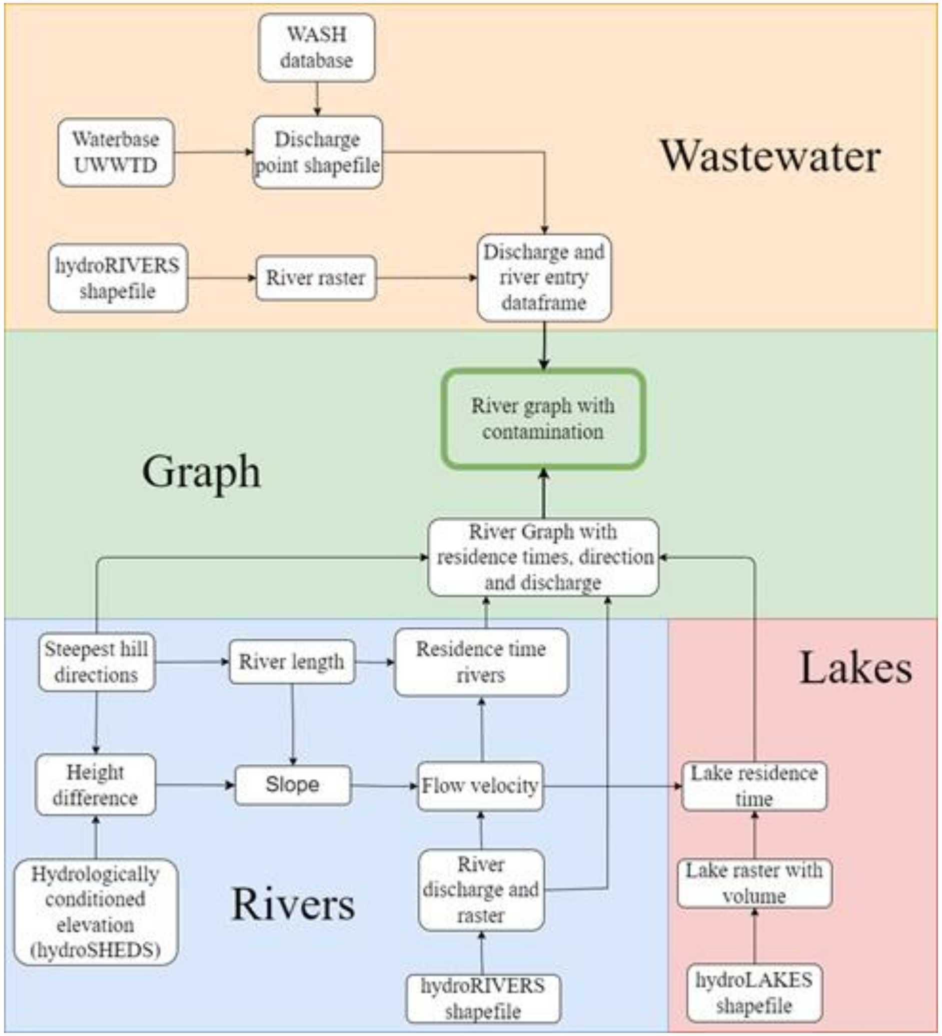
- Provide common evidence base for EU water policy
- Proritize action across Europe, not basin by basin
- Support decisions where monitoring data are missing
- Test policy scenarios before investing
- Identify where advanced treatment delivers the highest benefit

Respond to new EU wastewater treatment directive!

- Upgrade to quaternary treatment WWTPs serving > 150,000 PE

HOW DO WE BUILD THE MODEL

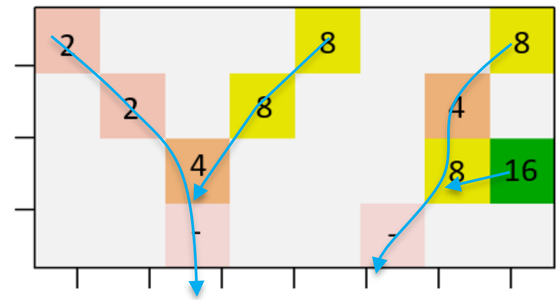
- Pan-European Scale
- Programmed in python
- Steady-state
- 1 simulation takes 1 second
- Open source

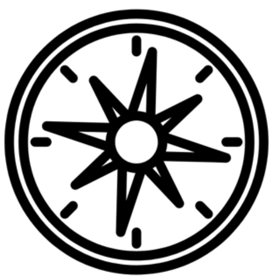


HOW DO WE BUILD THE MODEL FLOW PROPAGATION

- HydroSHEDs: Global, Raster File

Elevation digital model, Runoff, Directions, Accumulated flows

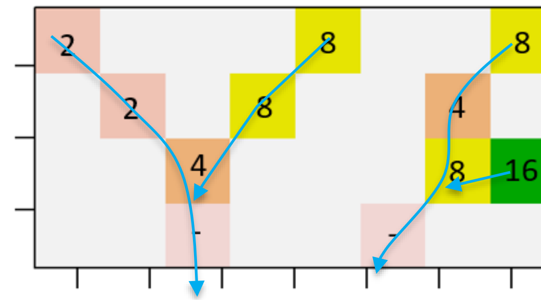


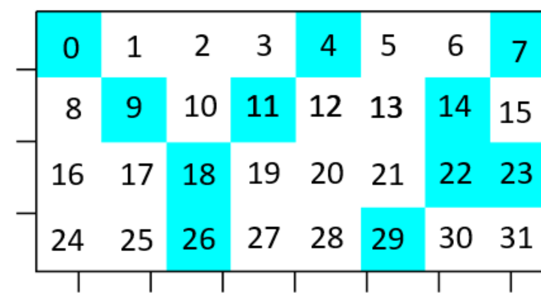


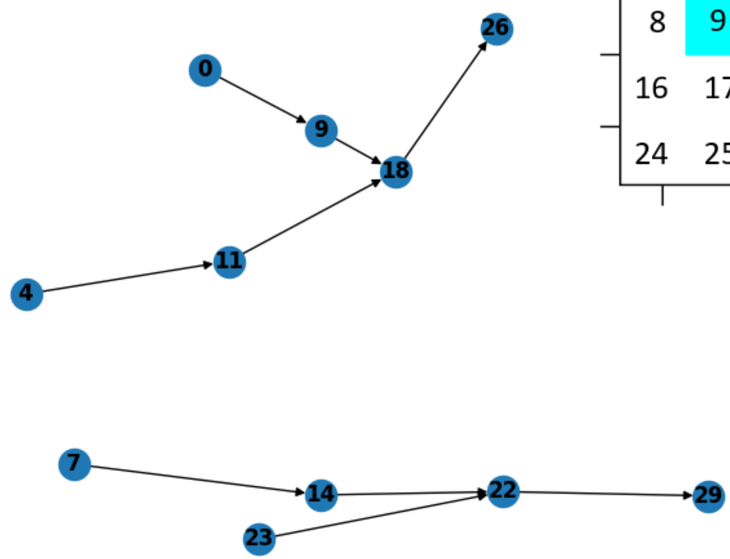
32 (NW)	64 (N)	128 (NE)
16 (W)	-1	1 (E)
8 (SW)	4 (S)	2 (SE)

HOW DO WE BUILD THE MODEL FLOW PROPAGATION

- Creation of the graph and use of NetworkX package







HOW DO WE BUILD THE MODEL CONTAMINANT LOADS GENERATION

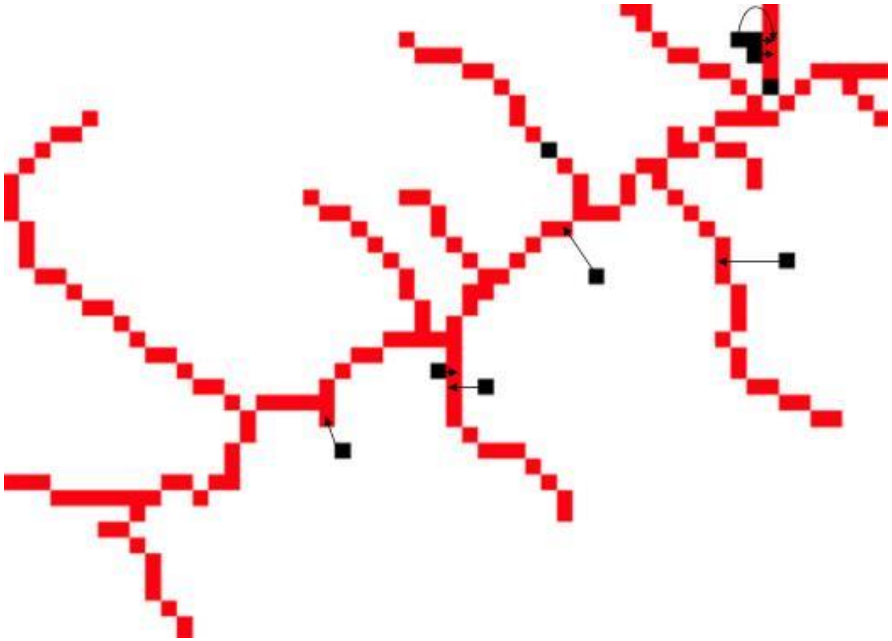
- European WWTPs > 2000 PE
- Data available:
  - Coordinates of WWTP
  - Coordinates of discharge points
  - Influent loads (PE)
  - Flows
  - Treatment level

- WHO – WASH data
- Data available at country level:
  - Proportion of population unimproved
  - Prop pop. Emptied and treated
  - Prop pop. Wastewater treated
  - Prop pop. Latrine and other
  - Prop pop. Septic tanks
  - Prop pop. Sewer connections

In-situ / Raw discharge / treated WWTP

Country, area or territory	Year	Rural							Urban							Total						
		Proportion of population using improved sanitation facilities (excluding shared)				Proportion of population using improved sanitation facilities (including shared)			Proportion of population using improved sanitation facilities (excluding shared)				Proportion of population using improved sanitation facilities (including shared)			Proportion of population using improved sanitation facilities (excluding shared)				Proportion of population using improved sanitation facilities (including shared)		
		Safely managed	Disposed in situ	Emptied and treated	Wastewater treated	Latrines and other	Septic tanks	Sewer connections	Safely managed	Disposed in situ	Emptied and treated	Wastewater treated	Latrines and other	Septic tanks	Sewer connections	Safely managed	Disposed in situ	Emptied and treated	Wastewater treated	Latrines and other	Septic tanks	Sewer connections
Afghanistan	2015	**20**	19	<1	<1	41	2	1	**19**	16	<1	3	41	27	8	**19**	18	<1	1	41	8	3
	2024	**25**	24	<1	<1	54	3	1	**25**	22	<1	3	55	34	8	**25**	24	<1	1	54	12	3
Albania	2015	-	-	-	10	52	14	32	**34**	4	2	28	7	2	90	**41**	15	6	20	26	7	65
	2024	-	-	-	14	69	8	23	**63**	6	5	52	12	2	86	**69**	17	14	38	32	4	64
Algeria	2015	**54**	14	3	38	9	21	58	**66**	2	<1	64	1	3	94	**62**	5	1	56	4	8	84
	2024	**56**	12	2	41	9	18	65	**65**	<1	<1	64	<1	<1	97	**62**	3	<1	59	2	5	90
American Samoa	2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**42**	8	7	27	4	44	50
	2024	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**43**	6	6	31	<1	41	57
Andorra	2015	**96**	<1	<1	96	<1	-	>99	**96**	<1	<1	96	<1	-	>99	**96**	<1	<1	96	<1	-	>99
	2024	**>99**	<1	<1	>99	<1	-	>99	**>99**	<1	<1	>99	<1	-	>99	**>99**	<1	<1	>99	<1	-	>99
Angola	2015	-	-	-	-	4	23	<1	-	-	-	-	6	67	15	-	-	-	-	5	51	10
	2022	-	-	-	-	<1	29	<1	-	-	-	-	<1	80	10	-	-	-	-	<1	64	7
Anguilla	2015	-	-	-	-	-	-	-	-	-	-	-	4	94	1	-	-	-	-	4	94	1
	2017	-	-	-	-	-	-	-	-	-	-	-	4	94	1	-	-	-	-	4	94	1
Antigua and Barbuda	2015	-	-	-	-	19	76	2	-	-	-	-	31	62	2	-	-	-	-	22	73	2
	2024	-	-	-	-	21	78	<1	-	-	-	-	37	60	2	-	-	-	-	25	74	<1
Argentina	2015	-	-	-	2	38	37	5	**49**	13	5	30	13	24	61	**49**	14	7	28	15	25	57
	2024	-	-	-	-	-	-	-	**46**	12	4	30	10	22	68	-	-	-	-	-	-	-
Armenia	2015	-	-	-	<1	58	5	21	**<1**	<1	<1	<1	2	<1	97	**11**	11	<1	<1	22	2	69
	2024	-	-	-	<1	57	6	22	**<1**	<1	<1	<1	<1	<1	>99	**11**	11	<1	<1	21	2	72
Aruba	2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	91	5
	2024	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	91	5
Australia	2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**95**	2	2	91	<1	7	93
	2024	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**96**	1	1	93	<1	6	94
Austria	2015	**>99**	16	<1	84	<1	15	84	**>99**	<1	<1	98	2	<1	98	**>99**	7	<1	92	1	7	92
	2024	**96**	10	2	84	<1	15	84	**>99**	<1	<1	98	2	<1	98	**99**	5	1	93	1	6	93

HOW DO WE BUILD THE MODEL CONNECTING CONTAMINANT LOADS TO RIVERS



Finding a closest discharge point in the rivers for the discharge points in black

HOW DO WE BUILD THE MODEL CONTAMINANT LOADS ATTENUATION

The contamination load L_l $[\mu g\,h^{-1}]$ coming from a WWTP indexed by l is then:

- $L_l = \gamma * Estimated\ Population_l * (1 - \epsilon_{t_l}) = \gamma * d_l$

First-order attenuation is applied to each river node according to its residence time (RT)

- $L_i = \left(\sum_{j \in P_i} L_j + \gamma \sum_{l \in D_i} d_l\right) \exp\{-RT_i k\}$

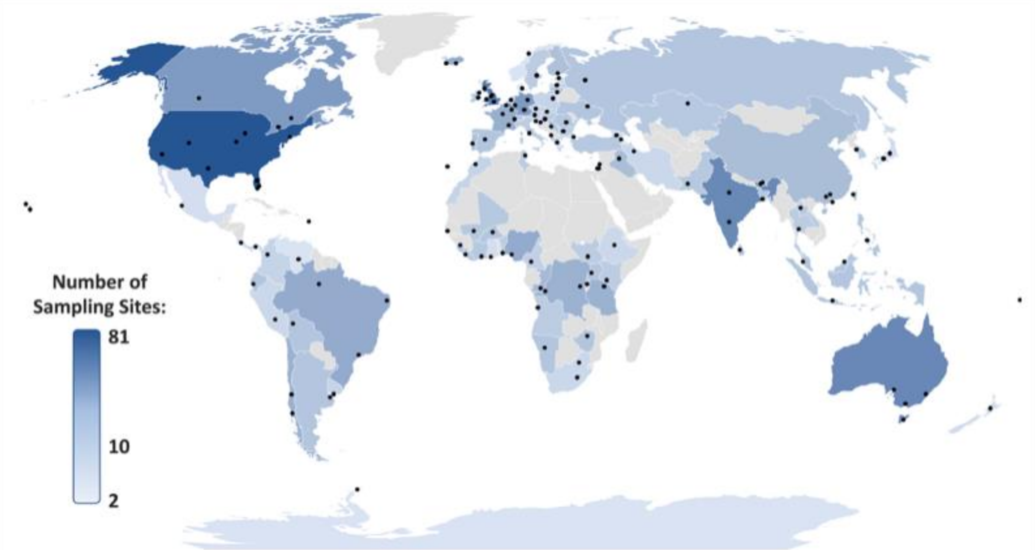
Concentrations calculation

- $c_i = \frac{L_i}{q_i}$, [ng·L^{-1}] Letting q_i be the discharge $[m^3\,h^{-1}]$, derived from the HydroSHEDS dataset

MODEL CALIBRATION

- Using observations from Wilkinson et al. (2022)

Fig. 1.



Locations of studied rivers/catchments (n = 137) for our global study (Dataset S2). Points indicate groups of sampling sites across respective river catchments and countries are shaded based upon the total number of sampling sites.

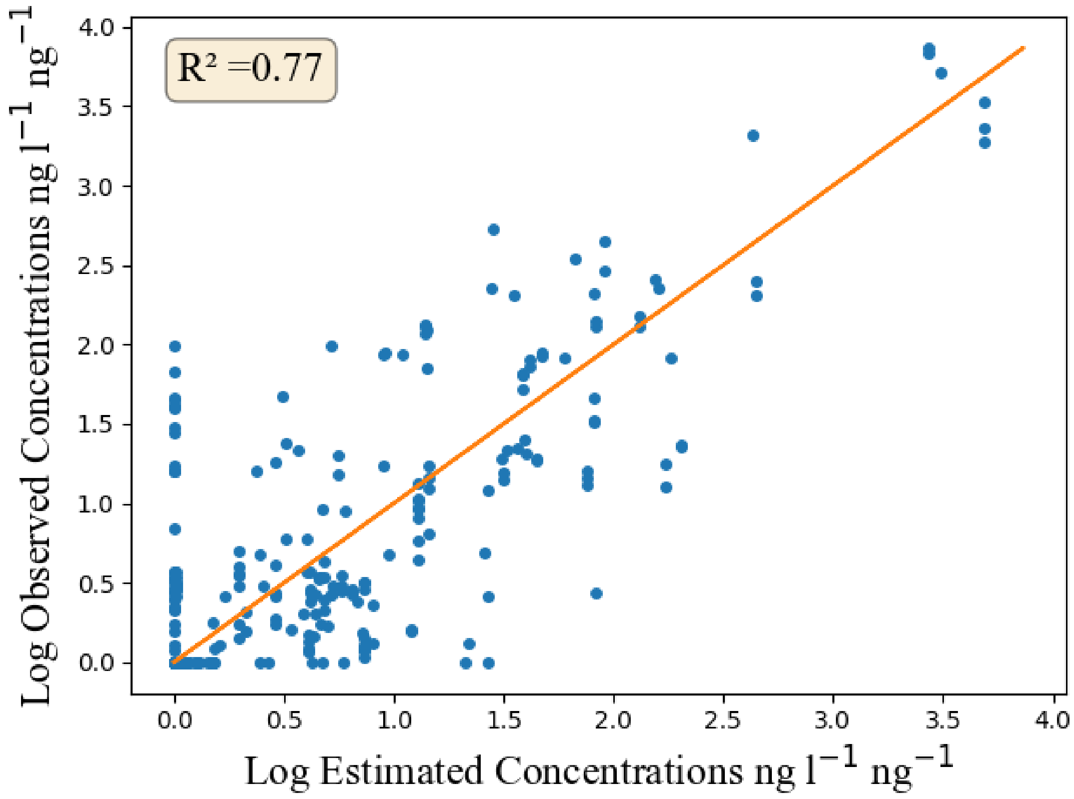
273 sampling sites in Europe used for calibration
61 Pharmaceuticals measured
Lumped contaminant as the weighted sum of 14 PhaCs

Atenolol, Citalopram, Codeine, Cotinine, Desvenlafaxine, Diltiazem, Fexofenadine, Lidocaine, Propranolol, Ranitidine, Sitagliptin, Sulfamethoxazole, Trimethoprim, Venlafaxine

MODEL CALIBRATION

- Observations from Wilkinson et al. (2022) in the area of Madrid

MODEL CALIBRATION

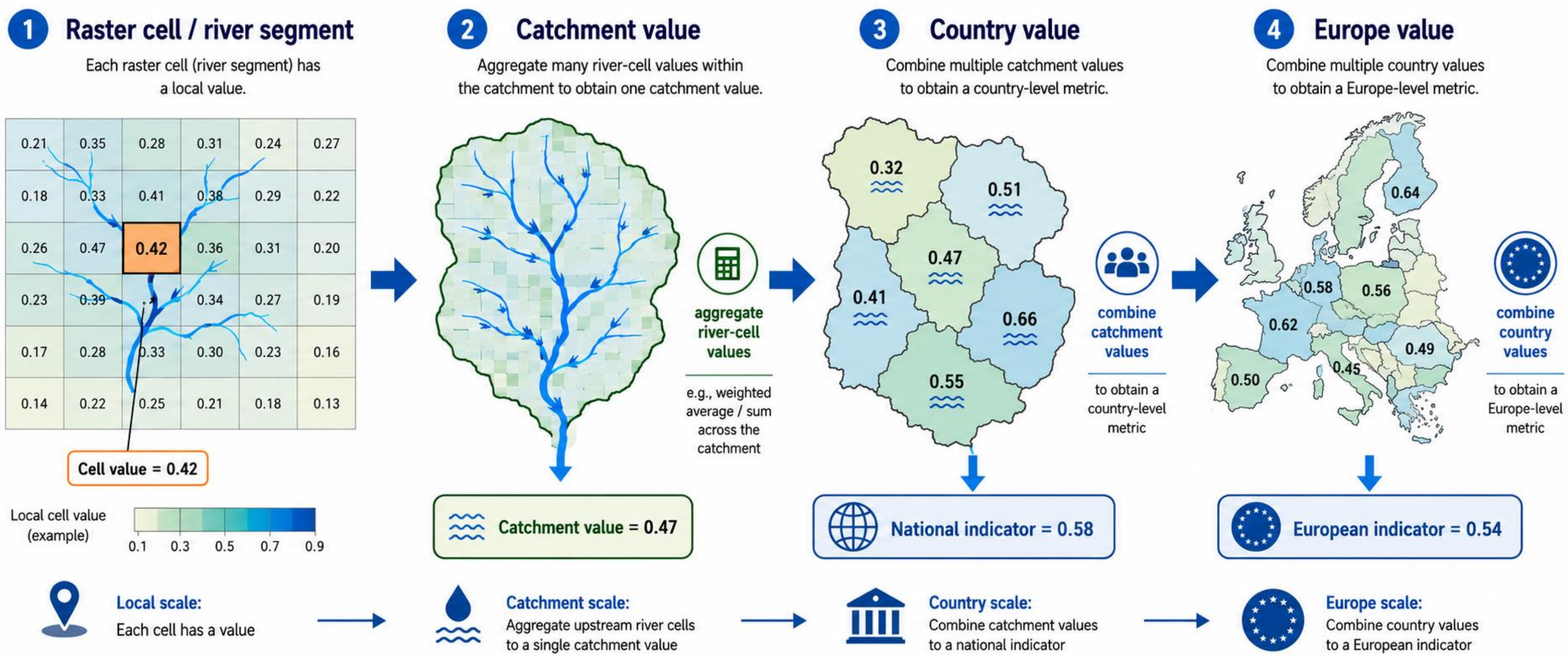


MODEL SIMULATION RESULTS

- Example of simulation results: wOtter.html

MODEL SIMULATION RESULTS

- Contamination score



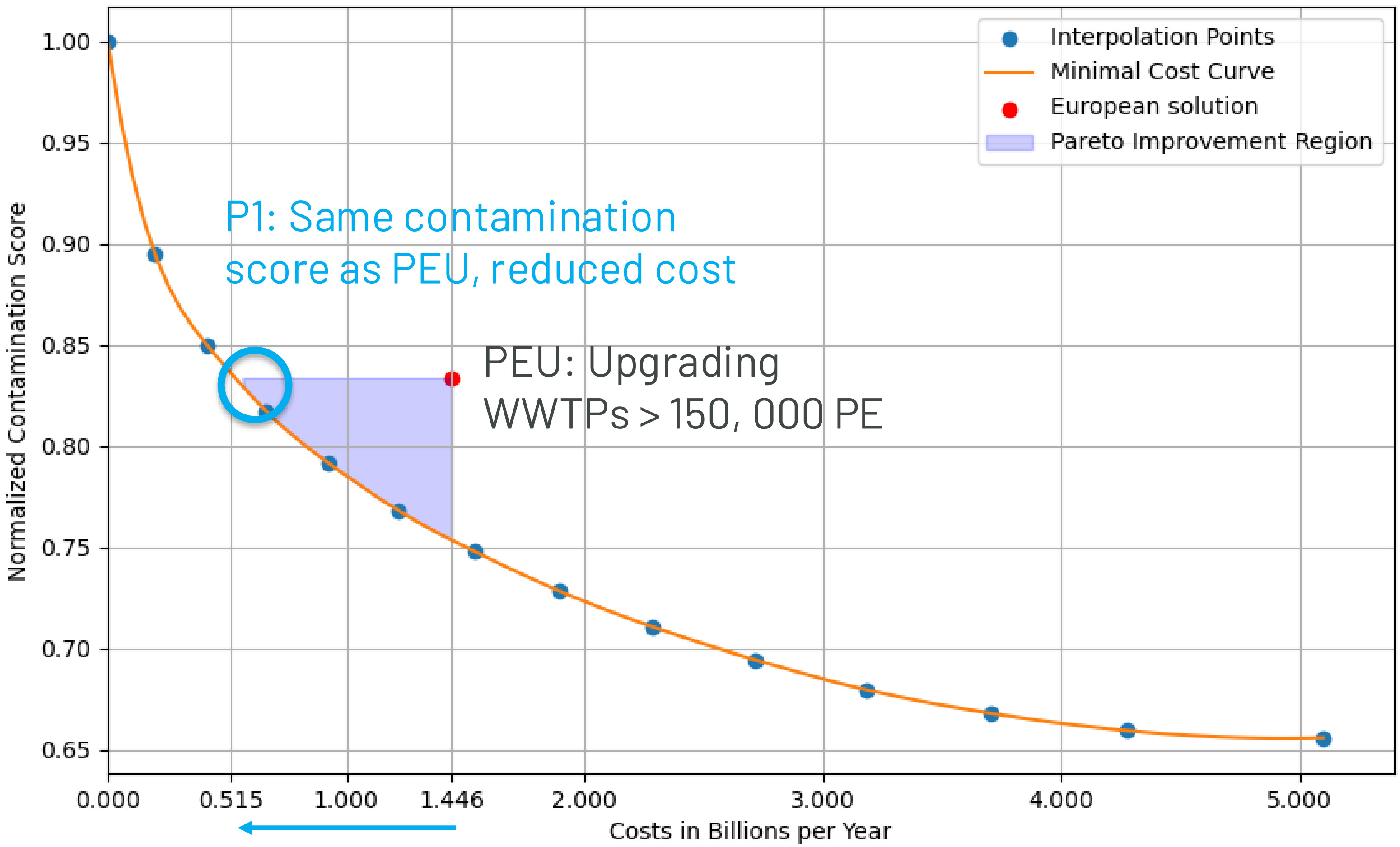
Higher-discharge rivers receive more weight

Highly contaminated cells contribute more than proportionally

APPLICATION OF THE MODEL TO ALLOCATE INVESTMENTS (STRATEGIES SIMULATED)

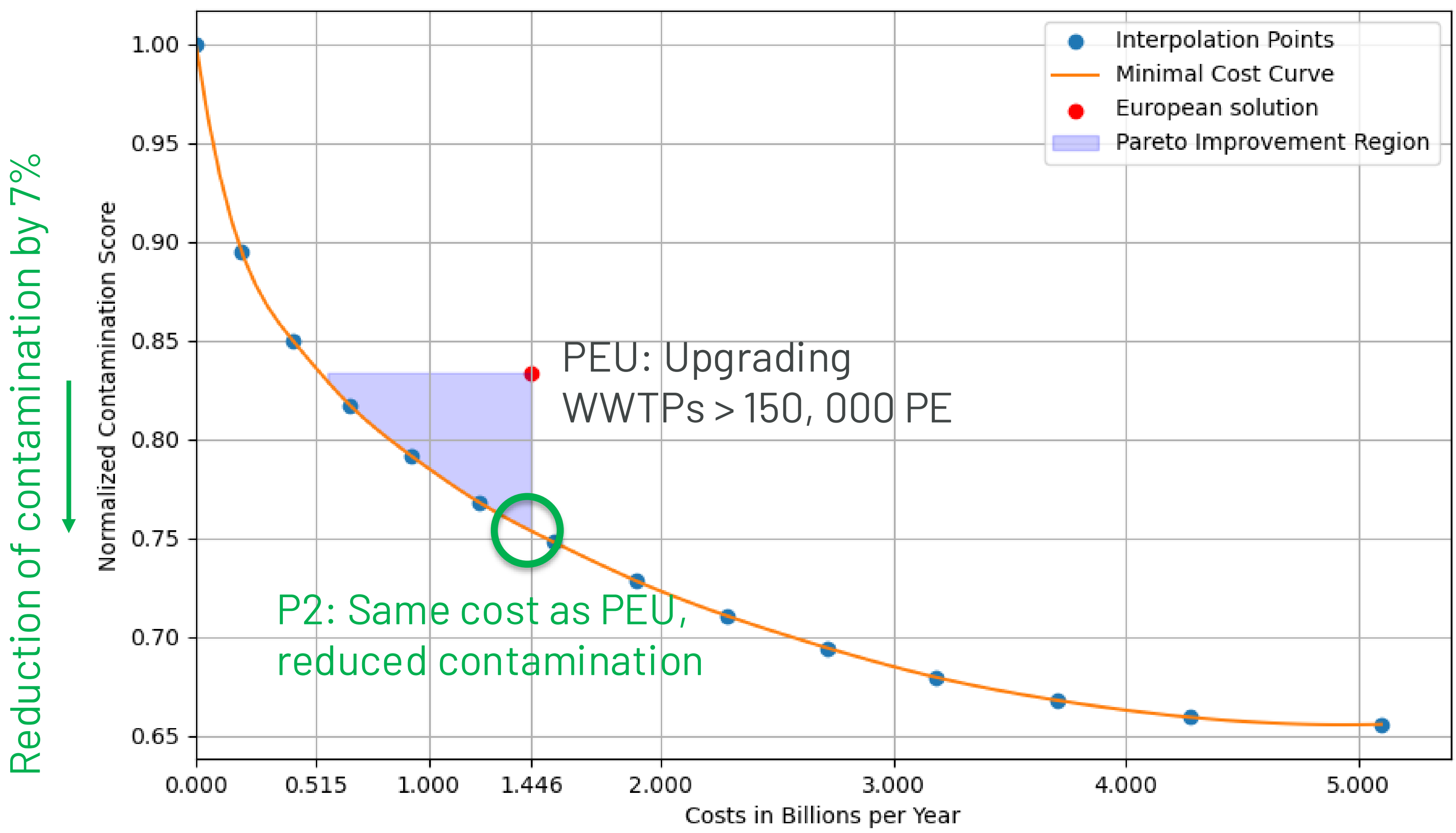
- Scenarios
  - P0: Situation from 2025
  - PEU: Upgrading WWTPs > 150, 000 PE
  - P1: Same contamination score as PEU, reduced cost
  - P2: Same cost as PEU, reduced contamination
- Method
  - Quaternary treatment: Ozonation + sand filtration
  - Cost functions with PE taken from literature (Gimeno et al. 2018, and Iglesias 2016)
  - Branch and bound optimization algorithm

APPLICATION OF THE MODEL TO ALLOCATE INVESTMENTS (STRATEGIES SIMULATED)



Reduction from 1.5 to 0.5 billions €/year!

APPLICATION OF THE MODEL TO ALLOCATE INVESTMENTS (STRATEGIES SIMULATED)



APPLICATION OF THE MODEL TO ALLOCATE INVESTMENTS
SIZE OF WWTPS RECOMMENDED TO UPGRADE

P1: Same contamination score as PEU, reduced cost

P2: Same cost as PEU, reduced contamination

Size Class (PE)	P_1	P_2	$P_{\mathbf{EU}}$
<10,000	25	215	0
10–50,000	236	924	0
50–150,000	168	431	0
>150,000	107	211	435
Total	551	1781	435

CONCLUSION

- This study shows that prioritizing WWTP upgrades based primarily on size thresholds leads to inefficient investment strategies for micropollutant removal


Environmental Modelling and Software 178 (2024) 106049

Contents lists available at ScienceDirect

Environmental Modelling and Software

journal homepage: www.elsevier.com/locate/envsoft

ELSEVIER

Coupling hydrological and sanitation datasets to simulate wastewater-derived contamination in European rivers: Model development and calibration

Janick Klink[a,b], Laura Aixalà Perelló[a,b], Morgan Abily[a,b], Joan Saló[a,b], Ignasi Rodríguez-Roda[a,c], Rafael Marcé[a,b,e], Wolfgang Gernjak[a,d], Lluís Corominas[a,b,*]

[a] Catalan Institute for Water Research (ICRA-CERCA), Emili Grahit 101, 17003, Girona, Spain
[b] University of Girona, Plaça de Sant Domènec, 3, 17004, Girona, Spain
[c] Laboratory of Chemical and Environmental Engineering (LEQUIA), Institute of the Environment, University of Girona, 17071, Girona, Spain
[d] Catalan Institution for Research and Advanced Studies (ICREA), Passeig Lluís Companys 23, 08010, Barcelona, Spain
[e] Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Accés a la Cala Sant Francesc 14, 17003, Blanes, Spain

Find out more at

http://iwa-mia.org/

https://iwa-connect.org