RIVER BASINS

INTERNATIONAL CONFERENCE
ON MONITORING, MODELLING AND MANAGEMENT
OF RIVER BASINS

ABSTRACTS

Edited by
Máté Krisztián Kardos, Orsolya Szomolányi, Adrienne Clement,
Steffen Kittlaus, Karoline Morling and Stephan Fuchs

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RIVER BASINS 2024

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OF RIVER BASINS

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Abstracts of the Conference

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Influence of sampling strategies on the assessment of concentrations and loads of trace contaminants in surface waters

Ottavia Zoboli[1], Nikolaus Weber[1], Jounes Lutterbach[1], Radmila Milačič[2], Ernis Saracevic[1], Jörg Krampe[1], Matthias Zessner[1]

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The increasing number of trace contaminants found in surface waters, which are considered to pose a risk to human and environmental health, along with the evolving regulatory framework for water quality management in Europe, make it necessary to critically evaluate the adequacy of current monitoring strategies.

In particular, this research addresses two specific objectives of river monitoring, namely the robust assessment of the compliance with environmental quality standards and the reliable and accurate estimation of annual riverine loads, which in turn are required for the validation of emission models.

The aim of this study is to determine if there are significant variations in the average and maximum concentrations and calculated loads based on monthly grab samples versus composite samples obtained through continuous auto-sampling. To this purpose, two monitoring stations are being operated for one year, from July 2023 to June 2024, in the eastern region of Austria. The selection of the locations was based on their distinct catchment characteristics. The Wulka River is the main river in the region and receives up to 30% of the wastewater treatment plant effluent during low flow rates. The Nodbach River has a significantly smaller catchment area with mainly agricultural activities and no wastewater treatment plant discharges. In-situ sensors are used to continuously measure water level, turbidity and conductivity. Additionally, automatic samplers collect time- and flow-proportional composite samples over two weeks. A manual grab sample is also collected at the end of each two-week interval.

The samples are analysed for selected trace contaminants that represent different dominant sources, pathways, and transport behaviour. These include poly- and perfluoroalkyl substances (PFAS), pharmaceuticals, pesticides, and potential toxic elements (PTE).

Preliminary results (after one third of the planned samples have been analysed) indicate noteworthy differences not only between groups of contaminants, but also within each specific group. For instance, the sampling strategy appears to have a stronger influence on PFOS than on PFOA, on the pesticide Mecoprop than on AMPA and on copper more than nickel, respectively. It is not surprising that the reliability of the assessment for contaminants closely associated with sediment transport increasing through the use of volume-proportional sampling compared to grab samples. However, the reasons for the differences identified for other contaminants are more complex and provide insight into the temporal variability and complexity of processes determining their release into surface waters. The main dynamics occurring in the river catchments can be investigated in this study using the accompanying online monitoring.

The final results of this comparative monitoring survey are expected to provide a better understanding of the temporal variability of a broad spectrum of representative trace contaminants and a solid basis for planning future monitoring and sampling strategies.

Particle-bound nutrients and trace substances in small streams: Implications for the aquatic environment and presentation of a novel sampling method

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Organic and inorganic pollution pose a threat to rivers and their ecosystems, primarily due to industrial activities, (untreated) wastewater discharge, and excessive use of fertilizers and pesticides in agriculture. The pollution enters rivers through point sources and diffuse inputs from the atmosphere and surface runoff. Detecting the impacts of non-point sources is challenging due to time-delayed and non-linear physico-chemical processes. In order to understand the effects of pollutants on aquatic organisms, it is important to monitor and assess the chemical status of rivers and sediments. This assessment involves measuring transported sediments, fine sediment accumulation, and analyzing nutrients and pollutants bound to sediments. In small (headwater) streams, however, the collection of transported fine sediments is challenging, as flow velocities and/or bed gradients are usually low. These hydraulic and biotic conditions in small streams are a challenge for known samplers (e.g. clogging, bio-fouling, necessary power supply, high maintenance costs).

The novel easy-to-use concept of the "Stationary Organic and Inorganic Sampler" (SOIS) (Flödl et al., 2023) will be presented, which makes it possible to collect mobile (suspended) sediments and floating matter over a certain period of time (tested up to 2 weeks). The results of (particle-bound) nutrient and trace substance concentrations in a small stream in which the SOIS method was applied for the first time will also be presented. The measurement data show clear differences in selected trace substance concentrations (e.g. PFAS, PAH) between deposited and recently transported material. Interesting aspects of a wastewater treatment plant effluent are also revealed, indicating that selective retention of pollutants occurs. Furthermore, implications for the aquatic environment due to trace substance inputs, altered river morphology and the superimposition of climate change are discussed in a broader context (SDGs, EU Green Deal).

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Trace substance monitoring at the intersection of urban drainage and an urban river in Karlsruhe, Germany

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Sewer systems play a significant role in the emission of trace substances into surface water bodies in urban areas. These trace substances belong to various chemical groups with multiple (urban) sources. Heavy metals are strongly associated with traffic and are mainly transported in particulate-bound form in separate or combined sewers. Pharmaceutical substances, principally linked to domestic wastewater, may be emitted into rivers by combined sewer overflows (CSO). Numerous biocides with various applications (from disinfectants to facade paints) are subject to leaching by precipitation or are transported in wastewater and thus emitted into water bodies through CSO or storm sewer overflows (SSO). For many of these substances, a comprehensive and harmonized database is not yet available.

To tackle this challenge, a study using large volume samplers (1000 liters) was conducted in the city of Karlsruhe, Germany. Volume proportional composite samples were taken at three sites along the River Alb and at four sites of the urban sewer system, including both SSO and CSO, over a period of two years. More than 100 samples were collected and analyzed for 110 individual trace substances.

Median detection rate for heavy metals amounted to 78% in river samples and over 95% in urban drainage samples. Some pharmaceutical substances (e.g. Carbamazepin, Ibuprofen, Diclofenac) were also detected frequently in river samples and CSO samples. Among the biocidal substances, mainly material preservatives (e.g. Diuron, Isoproturon, Terbutryn) were found in nearly all samples, while others (such as Triclosan or Permethrin) were detected rarely or only in individual samples or sites. This reflects the variability of chemical properties and applications of the analyzed substances in urban areas.

Noticeable seasonal patterns were found for certain substances, e.g. Glyphosate concentrations peaked during its main application period in growing season. Conversely, Ibuprofen showed higher concentrations in winter and early spring, which may coincide with higher occurrence of illnesses and/or developments of the COVID pandemic. Highest heavy metal concentrations were associated with sites of untreated runoff from impervious and especially traffic areas. Additionally, elevated heavy metal concentrations at the river sites were often tied to samples taken during precipitation/flood periods, which indicates impacts from urban runoff.

The concentration data obtained in this study form a solid base for a wide variety of trace substances relevant for water quality. It facilitates analyzing contributions of urban areas to trace substance emissions. Furthermore, it allows identifying current knowledge gaps to be addressed in future research.

Benchmarking the persistence of organic micropollutants in large European rivers

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The risk posed by micropollutants is strongly depending on the exposure of biota to the pollution, which is in turn to a great extent determined by the pollutant's environmental persistence. Assessing the persistence of organic micropollutants from field data has been notoriously laborious, requiring extensive data including emissions and chemical properties, and the application of detailed mass balance models, which often contain parameters that are impossible to measure. To overcome some of these obstacles, a new persistence benchmarking technique is presented for large rivers that receive numerous emissions and provide enough residence time to observe some dissipation of compounds. We estimated the dissipation rate constants of 41 compounds (mostly active pharmaceutical ingredients) from five measurement campaigns in the Rhine and Danube rivers using concentration rate profiles with respect to carbamazepine. Dissipation rates clearly distinguished between known fast and slow-degrading compounds and campaign-specific boundary conditions had an influence on a minor subset of compounds only. Benchmarking provided reasonable estimates on summer total system half-lives in the Rhine compared to previous laboratory experiments and a mass-balance modelling study. Consequently, benchmarking can be a straightforward persistence assessment method of continuously emitted organic micropollutants in large river systems, especially when supported by field monitoring campaigns of adequate analytical quality and spatial resolution.

PFAS transport and retention during riverbank filtration and in saturated columns

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Per- and Polyfluoroalkyl Substances (PFAS) are widely used chemicals valued for their desirable physicochemical properties. Despite increasing efforts to restrict their use, they pose a threat to drinking water production due to their persistence and mobility in the environment, as well as their toxicity to humans. Riverbank filtration (RBF) represents one of the primary pathways for PFAS transport to drinking water. While RBF systems effectively remove many organic compounds and microbial pathogens, their efficiency regarding PFAS remains poorly understood. This study seeks to investigate the subsurface transport behavior of various PFAS groups through field monitoring and sorption experiments in columns.

Over a one-year period, bi-monthly samples were collected from river water and groundwater. Liquid Chromatography Mass Spectrometry was employed to analyze 32 PFAS compounds. Results indicated that most detected PFAS compounds had concentrations lower than 10 ng/l. For the majority of compounds, no concentration reduction was observed between the river and groundwater, suggesting limited removal processes. However, two sites exhibited higher concentrations of PFOA, PFOS, and GenX in the background water compared to the river, hinting at an inland source of these compounds. Presently, there are no concerns regarding drinking water, as measured concentrations fall below the legal limit established by the EU Drinking Water Directive. Nevertheless, potential future legal or industrial changes could pose challenges, as the results suggest that these compounds are not effectively removed during riverbank filtration.

To examine transport behavior under laboratory conditions, a 50 cm glass column filled with soil was injected with a 2.5 µg/l solution of 10 PFAS, and effluent samples were collected to assess transport parameters. Findings revealed that different PFAS exhibited varying degrees of sorption, with some behaving conservatively while others were entirely retained. Different sorption modules in Hydrus were tested to simulate these behaviors. Substances with higher sorption levels necessitated more complex sorption terms and could not be accurately represented by assuming equilibrium sorption.

Ongoing efforts aim to reconcile these seemingly contradictory results by developing models that simulate transport and fate at RBF sites, where sorption parameters derived from column experiments can be evaluated. Additionally, further column experiments are planned using natural soil from the monitoring sites.

Exploring human-vector dynamics using insect repellent concentrations in the river

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The growing threat of vector-borne diseases transmitted by mosquitoes and ticks is exacerbated by the effects of climate change. Although extensive research has explored the complex dynamics linking climate, vector biology, and disease transmission, the central role of human behavior has often been marginalized. In this study, we present an innovative perspective that aims to comprehensively capture human-vector dynamics in real-world scenarios.

We use waterborne concentrations of insect repellents such as DEET as a proxy for human-vector (here primarily mosquito) encounter rates, assuming that more encounters mean more DEET use. Our mechanistic model integrates vector abundance and human mobility. Calibration of the model is based on both target and non-target analysis of DEET abundance in the Rhine River in Germany. We also performed calibrations for both vector abundance and mobility. Our model reproduces long-term trends of DEET over a decade, although our primary focus is on seasonal variations.

Our results highlight the critical influence of temperature in shaping the seasonal change in DEET concentrations in water. Temperature not only has a direct effect on vector abundance, but also plays an important role in modulating human mobility. In addition, human mobility is influenced by social factors such as public holidays and the COVID-19 pandemic. For example, during the pandemic, vector abundance is not particularly low compared to other years, but human mobility is reduced. This means less human exposure to vectors and therefore lower DEET levels in the river.

We project a notable increase in DEET use under climate change scenarios characterized by hotter and drier summers. This increase, driven primarily by increased human mobility, reflects an increased risk of vector-borne diseases. The risk is expected to be even higher when invasive species are considered. This is despite the fact that overall mosquito abundance is projected to decrease slightly in the scenarios.

Calculated use of insect repellents thus has profound implications for public health and disease control efforts. This importance is particularly pronounced in the context of projected climate warming in the foreseeable future.

Assessment of diffuse heavy metal loadings by surface water and evaluation of their potential contamination

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Mining activities generate a considerable amount of tailings with high concentrations of trace metals. These tailings are subject to erosion, leading to the dispersion of metals in the environment. This is the case of the Zeïda mine, located in the north-east of Morocco, where the mining operations generated around 12 Mt of tailings and over 70 Mt of waste rock abandoned without any rehabilitation. This study aimed to quantitatively estimate and assess the load of trace metals associated with soil erosion in the Zeïda mining basin. The approach involved is using a spatial superposition method between the RUSLE model and data on trace metal concentrations in the soil. Subsequently, besides statistical analysis, the Geo-accumulation Index (Igeo), the Pollutant Load Index (PLI), and Sediment Quality Guidelines (SQGs) were used to assess the level of sediment contamination in the Moulouya River. In order to measure the concentrations of trace metals (Cd, Cu, Pb, As, and Zn) and major elements (Na, K, Ca, Mg, Al) in river sediments, a total of 10 sediment samples (0-10 cm) were collected during a sampling campaign carried out in March 2022.

The results highlight a significant variation in the spatial distribution of erosion, ranging from 0.01 to 158 $t \cdot ha^{-1} \cdot yr^{-1}$.The average annual soil loss of 9.1 $t \cdot ha^{-1} \cdot yr^{-1}$ which classify the watershed in the low erosion category. Moreover, the analysis of erosion rates based on the land use has revealed that the primary contributors to soil erosion are the steppe and forest, accounting for 55% of the total erosion in the basin. These rates exceed those of agriculture, urban areas, and bare soil. In addition, the average erosion rate in the mining area reaches 10.6 $t \cdot ha^{-1} \cdot yr^{-1}$, exceeding the average erosion rate for the watershed. This highlights the significant erosive potential associated with the mining area compared to other land uses.

The analysis of trace metals in the sediments by ICP-AES revealed clearly an increase in concentrations of all trace metals around of the tailings, particularly for Pb and Zn, which reached values of 215.21 and 108.32 mg/kg, respectively. The results of the various indexes calculated reveal significant contamination of the river sediments, mainly by Pb, with a geo-accumulation index of 2.4 classifying these sediments as moderately to heavily contaminated. The calculated indexes reveal that the most severely affected sediments are located downstream of the mine tailings, suggesting a potential dispersion of metals and contamination of the river.

Assessment of the share of sediments in the eutrophication of reservoirs: Case study from the Czech Republic

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The purpose of the project is to create a modern methodological approach to determine the effect of sediments on the quality of water in reservoirs. The research aim is to designate, what kind of sediments and their placement affect water quality the most, esp. in the growing season. By combining approaches in the fields of hydromorphology, hydrodynamics, chemistry, ecosystem ecology, etc. In order to determine the immobilisation of iron by organic substance, we want to determine the share of sediments in nutrient pollution. Monitoring has been carried out in 12 reservoir samples with different altitudes, geology of the catchment, and erosion rates, so that the findings can be extrapolated. The project will propose measures to improve properties and prevent the entry of hazardous sediments.

Sediment traps were installed in the inflow parts of the reservoirs, continuous models of sediment transport from the catchment were also compiled, and key parts of the catchment areas were defined as potential main sources of sediment. Analysed watersheds differ from 50 to more than 5000 km^2. By analysing the mineralogy and chemistry of the listed source areas, especially based on data from agrochemical analysis of agricultural soils, potential links are now being created between the sediment properties in the inlet parts of the reservoirs and the source areas defined by the model.

The paper will present the current results and the overall methodology with the aim of obtaining feedback in the discussion, because the tracing approaches of sediment fluxes in catchments and defining the importance of its chemical properties for the behaviour of reservoirs in terms of phosphorus release and sorption in time have not yet been resolved.

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Transboundary contamination risk assessment and modelling in the Drava River floodplain

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The water catchment area of the Drava has been an important area for mining and industrial activities since ancient times, which have been at their most intensive in recent centuries. Technological innovations and inventions led to a very intensive anthropogenic impact, especially in the upper part of the Drava (due to numerous mines and smelters in Austria, Italy and Slovenia). They influenced the chemical composition of the floodplains along the entire valley. Very high concentrations of potentially toxic elements (PTE) such as Pb, Zn, Cu, As and Cd were found in previous investigations in Slovenia and Croatia. The critically contaminated area covers over 130 km^2 (Šajn et al, 2011).

The study focused mainly on the lower part of the Drava in Hungary and Croatia, as it was expected that considerable parts of the Drava floodplains would be contaminated with PTE, which is important arable land. Transnational research led to the development of standardised geochemical dispersion models of PTE contamination in transboundary floodplains along the entire valley. At the same time, a risk assessment of the soil-plant-food production system and a potential risk assessment of natural riverine habitats and wetlands, one of the last refuges for riparian flora and fauna, is being carried out.

Advanced methods of linear and non-linear mathematical modelling were used to model the PTE distribution. Particularly promising are the preliminary results following the application of an artificial neural network (multilayer perceptron) to predict the change in chemical concentration in a given area as a function of various spatial and climatic parameters influencing these changes.

In addition to determining the above-mentioned transboundary effects of PTE, the study is expected to make an important contribution to the regional risk assessment of PTE and its dynamics in the food web.

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Calculating emissions to water – a simplified method implemented as a spatially and temporally distributed model

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The European Green Deal formulated the Zero Pollution Ambition. In a river basin management context, this ambition relies on baseline information on the quantities of pollutants released to surface waters ("emissions"). Despite decades of efforts within countries, good information on the total emissions of pollutants released to surface waters across Europe is still lacking.

The Water Framework Directive (WFD) requires Member States to report an inventory of emissions, discharges and losses of priority substances. Technical guidance on preparing the emissions inventory was published in 2012. A 2022 report by the European Topic Center for Inland, Coastal and Marine waters (ETC-ICM) provided a simplified method for calculating the emissions to water, describing quantification methods for the pathways for emissions to surface waters referred to in the guidance. The method focuses on priority pollutants and offers baseline information for calculating emissions. It uses emission explaining variables statistics at country scale and emission factors that are often averages based on data from different countries.

The Danube Hazard m3c Project aimed to achieve a durable and effective transnational control and reduction of hazardous substances (HS) water pollution. Supported by the collection of existing data and complementary monitoring, Danube Hazard m3c performed emission modelling at different spatial scales. A basin-scale (800,000 km^2) emission inventory was compiled for 17 HS using the ETC-ICM method, implemented however, in small spatial units (225 km^2). An underlying hydrology model was used to perform time dependent calculations following the hydrological signals of runoff and subsurface flow. The emission inventory was intended to support the development of the 2027 4th Danube River Basin Management Plan.

Detailed spatial socio-economic information (population, land use, wastewater management, etc.) was used to quantify sources and pathways and to characterize the river network and the hydrology. Thus, a better resolution of regional and local differences was expected. Time dependent emissions were quantified for 10 different hydrological years, to resolve the inter-annual variability of the emissions as affected by climate variability. In-stream concentrations were calculated and compared to field data.

For the larger rivers, the simulated concentrations showed a satisfactory agreement with measured concentrations. The uncertainty of the emission estimates increased with decreasing spatial scale however. Many spatially variable input quantities and emission factors could only be quantified country-by-country or even Europe-wide.

The method proved to provide useful results for management. Next to the overall emissions inventory, the method provided a subdivision over the pathways distinguished in the guidance, as well as maps and country inventories to elucidate spatial gradients. Exploratory scenarios were simulated to investigate the potential effect of pollution control measures, like additional treatment of wastewater, improved urban stormwater management and erosion control. The successful application to the Danube River Basin provides confidence that the method would also be applicable at the pan-European scale.

Modelling of nutrient emission in river systems (MONERIS): Presenting new perspectives and current developments of a widely used emission model

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Freshwater resources worldwide are facing multiple, anthropogenically enforced stressors such as landcover changes and climate change. Among others, water abstraction, soil sealing and compaction, tile drainages and flow regulation alter quantity and dynamics of water fluxes. In combination with climate change induced irregular hydrological patterns with extended dry periods and floods, nutrient emissions in surface waters along with their subsequent transport, transformation and retention substantially impact aquatic and terrestrial ecosystems. Therefore, effective water resource management combined with ecological assessments requires reliable and robust description and quantification of sources, sinks and emission pathways at the river basin and at sub-annual scale. The nutrient emission model MONERIS (Venohr et al., 2011, Lemm et al., 2021) calculates landuse-specific nutrient fluxes for entire river basins and has successfully been applied in many national and international projects in the last 25 years. In order to better address the above-mentioned challenges, the model was transferred to the open-source programming language R, to provide transparency of all calculation steps and to improve flexibility for the consideration of new approaches or input-data. The latest implementations include modelling at monthly time steps and the transfer from a lumped to a distributed calculation approach at a standard spatial resolution of 1 km^2. Although the publicly available body of high-resolution national input data has grown tremendously in the past years, a large part of input data is not available in equal quality in hydrologically connected neighbouring countries. Therefore, MONERIS enables the combination of alternative international input data or different national data sets. Since runoff is one of the key drivers of nutrient emissions that needs to fit to the model requirements in terms of represented pathways and environmental compartments (e.g. land-use types, groundwater-surface water boundaries, spatial-temporal resolution), a new, model-specific precipitation-runoff approach was developed and tested successfully. Here, we present the updated, open-source based framework of the long-established MONERIS model and show its practical application with the case study of the Odra River Basin (119,000 km^2). We aim to build up an open modelling platform that allows emission modelling of other parameters and substances (e.g. salinity, heavy metals or priority substances) or the consideration of additional modules for phytoplankton growth, floodplain or groyne field retention which are currently under development.

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Complex water quality simulations in Želivka River Basin and Švihov Water Reservoir (CZ)

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Želivka River Basin (1190 km^2) is the drainage area of the largest drinking water source in the Czech Republic, Švihov Water Reservoir (309 million of m^3), providing potable water for more than million inhabitants. River basin is formed by crystalline bedrock with only minor local groundwater bodies, covered mostly by cambisols. At present, 54% of the catchment area is used for agriculture, out of which 77% is made up by arable land. Intensive agriculture, together with the high proportion of drained land, puts this source of drinking water, at risk from accelerated surface and subsurface runoff and associated pollution. That is why the agricultural management is limited in selected areas to prevent pollution of surface water and, to keep water quality in reservoir on sustainable target values. The complex approach to water balance and pollution concentrations modelling was adopted, focusing on three main areas:

1. Nutrients flux variability along river branches and main tributaries, identifying of main pollution sources. MIKE BASIN model was used, covering whole river basin area (476 km of river reaches, 159 subcatchments, 21 flow gauging station, 27 points of concentration sampling). A monthly-based maps of nutrients concentration along river network were established.
2. 3D simulations of 5 scenarios of pollution spreading in water reservoir volume, including point-like accident and spring flush of pesticides from most vulnerable river basin area. MIKE3FM model was used for simulation of water movement, temperature distribution and selected pollutants propagation, calibrated against results of 3 observation field campaigns. Results of these simulations serve substantial background for efficient management of drinking water withdrawal from water reservoir volume according to particular conditions.
3. Detailed simulation of pesticide concentrations dynamics in surface water, drainage water and shallow groundwater at the three selected sub-catchments (1-

5 km^2) are conducted recently. A complex MIKE SHE WM and AD model was used focused mainly on short-time episodes of pollutant infiltration through soil profile, leaking into small water streams. This component aims to evaluation of different measures in agricultural management impact to short-term as well as to long-term pollutants concentration dynamics in surface water.

A unified platform of DHI Software file formats enhances easy data exchange of these modelling tools into complex approach, helping to adopt efficient measures in river basin area as well as in water reservoir body, considering short-term threads as well as long-term changes (as climate changes impact). Modelling approach supports timely and optimal decision-making processes in changing environment.

Developing nitrogen boundaries for surface water bodies on national and regional scale for Germany

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The nitrogen cycle has been altered tremendously by human activities. The increased release of reactive nitrogen into the environment leads to several problems such as acidification, eutrophication and biodiversity loss. The Federal Ministry for the Environment and the German Environment Agency currently develop a systemic strategy for nitrogen reduction that includes all polluter sectors to improve the condition of the affected environmental media (air, water bodies, terrestrial ecosystems, and climate) and human health equally. In this framework, the model system MoRE (Modelling of Regionalized Emissions) was utilized to compute the reduction for N emissions into German surface water bodies.

For the considered years 2016-2018, the modelled total N emissions into water bodies average to 454 kt/a. Three reduction scenarios were developed based on the yearly average concentrations of 2.6 and 2.8 mg N/L for Baltic Sea and North Sea tributaries, respectively, as demanded by the German Ordinance on the Protection of Surface Waters (OGewV). The three scenarios ranged from a very strict approach (comply with the target concentrations in each sub basin of the model) to a moderate approach taking into account dilution effects and retention in the rivers. Modelled reductions for the scenarios ranged from 69.9-92.6 kt/a (19-25% of total N emissions). The largest reduction potential can be attributed to emissions from diffuse sources (77-82%) and to northwestern and central river basins in Germany. A sensitivity analysis was conducted for one of the scenarios by varying required input data (± 10% N groundwater concentration, ± 10% N surplus). This resulted in a 5-11% deviation of the modelled total N emissions into surface water bodies and a 12-29% deviation of the modelled required reduction to meet the targets.

The results of this study highlight regional differences in terms of N emissions and required reductions as well as associated uncertainties. Further, results allow estimating the contribution of diffuse and point sources on regional scale. This study will contribute to the national strategy to develop an upper limit ensuring the overall good status of all protected receptors affected by reactive nitrogen (air, water bodies, terrestrial ecosystems, health and climate).

The new Urban Wastewater Treatment Directive from the perspective of the receiving rivers

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Effluents of municipal wastewater treatment plants (WWTPs) contribute to surface water pollution, especially when large plants discharge into rivers with smaller flow values. Recognizing this, the EU has launched the Urban Wastewater Treatment Directive (UWWTD), aiming at protecting valuable freshwater resources. After achieving much success, but not enough to reach the goals of the Water Framework Directive, a recast of the UWWTD was proposed in 2022 to further improve the status of receiving waters. The recast introduces stricter thresholds for nutrients and quaternary treatment to remove pharmaceutical residues in larger plants (those with PE above 100.000 and 10.000, respectively). In the current study, we investigate the effects of wastewater discharges on receiving streams in the current situation and after the implementation of the proposed new thresholds for total nitrogen (TN) and total phosphorus (TP). Further, diclofenac was selected to demonstrate the need for applying quaternary treatment based on identifying the risk of failing to achieve the good chemical status in the receiving waters.

A joint GIS-based database containing all municipal wastewater treatment plants in Hungary and their receiving water bodies was created for the study. In-stream concentrations were calculated based on dilution, hypothesizing no (industrial, agricultural, background) pollution sources other than municipal WWTP discharges and neglecting in-stream retention processes. We did consider the cumulative effects of series of WWTPs situated downstream of one another along a river network. Receiving river water bodies were classified according to their size (small through medium to large with a threshold of 100 and 1000 km² total catchment area) and type of catchment (hilly vs. lowland). Regarding river flow, two variants were investigated: most frequent flow (Q66% - “MFQ”) and low flow (August 80% probability flow value – “LOWQ”).

Results demonstrate that – assuming MFQ – 15-40% of the streams failed to achieve the good-moderate threshold set for TP by the river basin management plan. The figure is even worse considering LOWQ (30-70%, especially bad for small and medium-sized rivers). We found that the effect of WW discharges is lower in hilly than in lowland areas. The implementation of the recast would result in about 15% improvement in each category. For TN, the present situation is better than for TP: only 5-30% and 15-60% fail to achieve the good status considering MFQ and LOQ, respectively. However, the improvements that can be achieved with stricter TN effluent limits are also smaller than in the case of TP.

The introduction of new standards for micropollutants, i.a. pharmaceuticals, would however lead to a situation where a large portion of rivers would fail to meet water quality standards: 20-53% of the investigated streams would fail to achieve the good chemical status considering MFQ, and as high as 22-72% would do considering LOWQ.

Our overall finding is that whereas – with the introduction of the risk analysis – the recast already considers – to some extent – the differences in receiving rivers, an even further differentiation in the standards based upon load capacities of the receivers would be beneficial.

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Nitrogen and phosphorous load reduction approach for catchments to reach the water quality targets set for the Water Framework Directive

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High concentrations of N and/or P are a major impediment to meet good ecological status of many European surface water bodies. Despite decades of environmental policies, numerous surface waters across Europe continue to grapple with excessive nutrient loads stemming from agricultural practices, wastewater discharges, and various other point and diffuse sources. The imperative for load reductions is clear. However, the nature of these loads, the sources of pollution, the hydrological characteristics, connections with upstream water bodies, and the efficacy of mitigation strategies vary significantly from one water body to another.

To determine a set of mitigation measures that will result in good ecological status, policy makers prefer a method in which each sector contributes according to the polluter pays principle. To support this, we have devised a robust methodology for quantifying the nitrogen and phosphorus balance at catchment level of the surface water bodies in a river basin. This approach enables us to pinpoint specific load reduction targets and allocate responsibilities among the sectors responsible for pollution, based on their respective contributions to the overall load within the catchment. To support the policy makers in applying a transparent 'polluter-pay' principle, our methodology also factors in the anthropogenic component of diffuse pollution from agriculture, seasonal variations in load, and the intricate routing of pollutants from upstream to downstream catchments within the river basin.

The Load reduction targets are based on the exceedances of the target concentrations at the WFD monitoring sites at the downstream part of each surface water body and the results of the source-apportionment modelling that is developed for the river basin:

$$LRT\ [kg\ N] = \frac{average\ observed - WFD\ target\ concentration\ [\frac{mg}{l}]}{average\ observed\ concentration\ [\frac{mg}{l}]} \times \left(\left(\sum_{source1}^{source\ n} Load_{source} * SWR_{source}[kg\ N] \right) + load\ upstream \right)$$

The source apportion model takes into account the retention of N and P in the surface waters, so the loads from upstream are a result of the modelled point and diffuse sources upstream, corrected by the retention factor of these sources. Using the results of the source-apportionment modelling, for each surface water body the contribution of the sector to the loads are calculated, after a split was made between the loads that are assumed to originate from anthropogenic sources and loads that originate from natural (or semi-natural) causes.

Results are validated by exchanging intermediate modelled balances and comparing simulated discharge and loads against on-site monitoring within the river basin. By employing this methodology, we can assess multiple modelling scenarios featuring various load reduction measures and gauge their effectiveness in meeting reduction targets across the river basin's catchments.

The method was applied at national level (Groenendijk et at, 2016), has been further developed in several regions of the international Meuse and Rhine river basins (Schipper et al, 2021, Schipper et al, 2023), and will be evaluated in the H2020 research project New-Harmonica (Schipper et al 2024, in prep).

Efficiency of the buffer zones in nutrient load reduction under climate change conditions

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Climate change and its effects will be one of the main threats to water management in the near future. Eutrophication, caused by an increase of the outflow of the nutrients (nitrogen and phosphorus) from river catchments, may become more intensive due to increased temperature and precipitation. One of the simplest measures aimed at reducing nutrient input to surface waters is the implementation of buffer (riparian) zones. Buffer zones are defined as natural, vegetative strips located along watercourses, separating the catchment from the riverbed and reducing surface runoff.

The aim of this study was to evaluate the efficiency of buffer zones efficiency under the climate change conditions. For this purpose, a digital model of the Nurzec River catchment (eastern Poland) was developed using the Soil and Water Assessment Tool – SWAT. The calibrated and verified model was used to evaluate the current nutrient load outflow from the river catchment. Future climate projections (temperature and precipitation) based on two climate change scenarios (RCP4.5 and RCP 8.5) were used to evaluate expected future nutrient loads in three future horizons (2026–2050, 2051–2075, and 2076–2100). All scenarios were tested with four variants of buffer zone width: 2 m, 5 m, 10 m, and 20 m, using buffer width-based Vegetative Filter Strips model (VFS).

The analysis showed that current average annual nutrient output from Nurzec River (1999–2019) is 612 tonnes of total nitrogen (TN) per year and 39 tonnes per year of total phosphorus (TP). In baseline scenario, buffer zones could lead to a reduction up to 56% and 47% reduction of TN and TP respectively. In all climate change scenarios implementation of buffer zones caused reduction of nutrient loads comparing to scenarios without such implementations, expected reduction increased up to 83% of TN and 50% of TP (RCP 4.5 2026-2050). The effectiveness of buffer zones depends on their width, and the average reduction obtained in all climate change scenarios: -39%, -50%, -64%, and -79% for TN, and -25%, -32%, -40%, and -48% for 2 m, 5 m, 10 m, and 20 m, respectively.

The results showed that the full implementation of buffer zones in the Nurzec River catchment could have a strong impact on the reduction of nutrient outflow from agriculture. Even the basic variant of buffer zones (2 m) ensures a noticeable change in nutrient loads output from the catchment. Moreover, buffer zones maintain their effectiveness under expected climate change conditions. These findings are important for local decisionmakers and stakeholders responsible for implementation of measures aimed at achieving good environmental status of surface water bodies. Quantitative assessment of buffer zones effectiveness will provide basis for their implementation in programmes of measures for reducing nutrient pollution.

Abstracts of poster presentations

A harmonized Danube Basin-wide multi-compartment concentration database to support inventories of micropollutant emissions to surface waters

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Background: The European Water Framework Directive foresees the establishment of emission inventories for micropollutants (MP) to facilitate an evidence-based development of mitigation measures. Regionalized pathway analysis constitutes a moderately data-intensive approach to quantify the contribution of different pathways to the total pollution of surface waters. So far, only few European member states have created an inventory, which includes diffuse pathways. The fundamental basis to enable it is an accessible, well-structured and harmonized database with data on the concentration of MPs in multiple compartments, such as soils, groundwater, atmospheric deposition and urban systems. Combined with the water and suspended substance balance in river basins, such data enables the estimation of emission loads via specific pathways. In the Danube River Basin, but in general in Europe, a public data management platform with such scope and criteria is still lacking.

Results: We collected and harmonised MP measurements across multiple compartments and countries together with key metadata, harmonized and combined them into a new database. The resulting tool, available for download, facilitates the assessment of current

data availability, in terms of quantity and quality. For example, while the majority of available data stems from groundwater and surface water, other highly relevant compartments are scarcely represented. By examining differences in MP concentration level across compartments, the database can lead to understand the relevance of specific emission pathways and thus to prioritize data-retrieval and calculation efforts in modelling applications. Selected examples show how to exploit the metadata associated to the measurements to extrapolate the results to regions not covered by specific monitoring programmes. For example, PFAS concentrations in treated wastewater show significant dependence on the design capacity of the treatment plant.

Conclusions: This presentation showcases how such database can support the setup of emission inventories, guide data providers and national authorities in prioritizing the allocation of resources for new surveys and in optimizing their national data collection and management systems. The process tested showed a great need for enhanced data literacy across countries and institutions to increase data availability and quality to secure the exploitation of the full information potential generated via monitoring programmes.

Mercury pollution in the Lom River Basin (East Cameroon): using PEGASE model to assess small scale gold mining pressures over surface water quality

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Mercury contamination from artisanal small-scale gold mining (ASGM) activities is a major environmental concern. Worldwide, 1800 tons/year of mercury are released by anthropogenic activities among which 67% come from ASGM. In the East Cameroon region, the Lom River and its tributaries drain a watershed of 11100 km^2 where gold mining is practiced in artisanal and semi-mechanized ways. More than 50 open-pit mining sites are listed, with an estimated production of 318 Kg of gold in 2019. In this type of mining, mercury is used to extract gold by amalgamation, in equal proportions. About 5 to 45% of the used mercury is directly discharged into rivers. This study aims to assess the impact of artisanal gold mining on water quality in the Lom Basin. A physically based modelling approach involving the model PEGASE (Planification Et Gestion de l'ASsainissement des Eaux) is used to simulate the transport of mercury from mining effluents. PEGASE is a deterministic integrated basin/river model that allows predictive calculations of river water quality according to pollutant discharges and inputs. From 2021to2023, seasonal monitoring was carried out on surface water at 15 stations. Physico-chemical parameters (pH, EC, DO, TDS, TSS, Na^+, Ca^{2+}, Mg^{2+}, K^+, NH_4^+, SO_4^{2-}, Cl^-, NO^{3-}, F^-, PO_4^{3-}) and total mercury (Hg) concentrations were measured. The calibration method involved, on the one hand, the representation of open-pit mining sites in the land cover, in order to better calibrate the soil input functions. On the other hand, mercury discharges from mining effluents were considered for the representation of industrial releases. The results of the 2 simulations provided a better description of water quality in the Lom River and helped identify areas exposed to mercury pollution. Based on the European tool called Water-SEQ (System for Evaluationof the Quality of rivers), the alteration indices for oxidizable organic matter, nitrogenous matter, nitrates and phosphorus vary overall from Good to Very Good (60-100) in the riverLom. However, near inhabited areas, the various indices sometimes vary from poor to very good (40-100). Mercury concentrations are above the limit of the Environmental Quality Standard (EQS = 0.05 μg/l) near mining

sites. This revealsa mercury pollution localized to the environment close to gold mining sites. The contribution of gold mining activities assources of pollution was also highlighted. We were able to examine the potential impact of soil inputs and industrial releases, and we found that mercury and suspended matters are the main factors in the degradation of Lom water quality. Seasonal variations in the hydrodynamic regime are also a determining factor in the Lom water quality.

Seasonality in agricultural-associated river pollution: a global multi-pollutant modelling approach

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Worldwide, agricultural activities are important for food security, but emit multiple pollutants including nutrients and pesticides into our rivers. This mixture of pollutants forms a cocktail with many interactions. As a result, agricultural pollution management for one pollutant may affect others. Pollutant cocktails in rivers, and their interactions, are affected by temporal patterns in land use, hydrology and climate. However, current knowledge is still poor in understanding the monthly changes in pollutant inputs to rivers. This especially holds for a global scale taking a multi-pollutant perspective. The lack of this knowledge challenges formulations of effective management strategies to ensure clean water for ecosystems and society throughout the year. Global water quality models can help to get this knowledge, especially for data-scarce areas. However, many global models are not suitable for studying the monthly variation of pollutant cocktails in freshwater because they focus on annual inputs of (single) pollutants. Hence, this study aims to better understand how seasonal changes in land use, hydrology and climate affect monthly inputs of pollutants to rivers worldwide. We do this in four steps. First, we develop a novel modelling approach for quantifying monthly inputs of nutrients (nitrogen and phosphorus) and pesticides (e.g. glyphosate) to rivers worldwide. We do this by downscaling the existing, annual MARINA-Multi and MARINA-Pesticides models. We will quantify the monthly inputs to rivers as a function of pollutant inputs to land and their retentions on land. We will downscale the sources on land to months by adapting the existing, global, seasonal modelling approaches. Next, we will correct monthly pollutant sources on land with monthly pollutant retentions on land for diffuse sources as a function of processes on land (e.g. animal grazing), runoff, and/or, temperature. Second, we run the model for 10,226 sub-basins for the recent past. Third, we will evaluate the robustness of our model by validating the model across seasons and climate zones. Fourth, we assess patterns in pollution hotspots and hot-moments, and their dominant sources. Our knowledge advancements in monthly pollutant sources will aid policymakers in identifying effective management strategies to ensure clean water throughout the year. This is especially relevant to support Sustainable Development Goal 6 (clean water) and European

Green Deal targets. Moreover, our research opens opportunities for exploring the seasonal impacts of interactions and climate change on water pollution.

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Investment needs in water and wastewater infrastructure and inevitability of horizontal and vertical solidarity in fulfilling SDG 6

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International scientific literature and research results demonstrate a deep and wide gap in the water value. Facilities related to water and sewerage networks providing urban water utility services are more expensive than any other public service infrastructure, and yet, the tariffs of water and sewerage services are the lowest among household expenditures. While in developing countries it is the lack of infrastructure, in the developed world the replacement of assets, often aged 100 years and over, present increasingly pressing, still unresolved problems put off for decades. The cost requirements of water supply and the underlying infrastructure show marked differences along a different social stratification, as well. The smaller the unit of supply, the size of the settlement, the higher the per capita infrastructure and service costs are, at the same time this is where disposable incomes are the lowest. The basis for my research was a nationwide water utility asset valuation and a representative survey of the social water value mindset. Results revealed in the research were built on the one hand, on the asset valuation database generated by settlement, at object-level, based on replacement values adjusted by obsolescence. This database encompasses nearly a quarter of all Hungarian settlements, reflecting the size distribution of settlements in Hungary in a representative manner. The survey of the water value mindset of society was carried out using a 5000-strong nationwide representative sample.

I concluded that per capita replacement costs of water utility infrastructure in smaller settlements are several times higher than those payable by inhabitants of larger settlements and although service charges are only slightly higher, they do not nearly cover additional costs. Per capita replacement needs correlate with per capita pipe length, which are 5-times higher in small settlements than in larger ones. The situation of asset management is further exacerbated by the fact that the distribution over time of replacement needs of drinking water supply systems is concentrated over the next 15 years for a wide range of settlement groups, at the same time, replacement needs manifest in some given year at the level of the individual settlements, amount to 20-30-40 times the 50-year average value.

Social groups living in small and large settlements are aware of the substantial differences in communal water and sewerage service costs depending on the size of the settlement.

They also feel the need for the renewal of the infrastructure, and although they require it on the one hand, and are willing to compensate, demonstrate solidarity and social engagement on the other hand, they are not, however, aware of its weight and extent.

Investigating eutrophication levels in the stream network of the Danube Basin

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Managing eutrophication in running waters presents a greater challenge compared to lakes and reservoirs due to the influence of travel time and the topology of stream networks on nutrient dynamics. While the conventional approach to lake eutrophication management involves reducing nutrient loads to limit algal biomass, this paradigm has shown mixed success in stream environments. Through complex catchment modelling, it has been observed that the proliferation of phytoplankton in streams depends on the convergence of three key factors: sufficient nutrient availability, an upstream source of fluvial algae, and downstream hydromorphological conditions conducive to algal growth over time. Standing waterbodies within stream networks are not optimal habitats for fluvial algae and may disrupt phytoplankton development downstream. Conversely, algae adapted to stagnant water conditions can enter streams and temporarily influence the trophic status of downstream sections. Applying detailed eutrophication models for large river basins typically requires extensive data and computational resources. To address this challenge, we have developed a simplified stream network eutrophication model that focuses on the primary drivers of eutrophication, utilizing global and continental databases for data inputs. A case study is presented for the Danube Basin.

Event forecasting of rivers with soft computing methods

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This study employs a soft computing approach to develop a predictive model for automatic samplers, combining artificial neural networks with a rule-based control scheme. Historical data from online measurements at Tamási and Kisterenye (Koppány River and Tarján Creek, Hungary) were used for model evaluation, training and validation. The primary goal was to identify measurable state variables strongly correlated with water pollutants, distinguishing extreme values from baseline flow concentrations. Results indicate the effectiveness of utilizing historical data on water levels, conductivity, and turbidity for event prediction. Machine learning-based predictions demonstrate potential for improving sampling processes by enabling flexible event sampling start and stop conditions, although recalibration may be necessary for different locations. The literature demonstrates the use of soft computing methods for forecasting water quality parameters, though typically these methods utilize multiple location sampling use of neural networks for training data. The question arose whether having only one sampling device at one location (no spatial information) is enough for predicting future scenarios: Therefore, our study focuses on analyzing the depth of information extracting from chosen state variables by time. In our case, data collection relied on previously deployed auto samplers for two pilot areas. We discuss the possibility of forecasting high load events using soft computing predictions. The overall objective of the study was to enhance automated sample collections. To achieve our goals investigations had been carried out on selecting the tool which can be implemented in the autosamplers for process control on hardware, with addition of yielding better results than simple threshold based sampling or autoregressive-moving average method (ARMA). Examination of information content of past data regarding the possibility of forecasting and comparing results from two sub-catchments are shown. As a result, we present the combination of soft computing methods with rule based auto-calibrated process control scheme. The model results are planned to be implemented in practice for the sake of collecting relevant samples.

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Assessment of erosion phosphorus transport risk: Case study for the Elbe Basin

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The contribution presents a synthesis of the outputs of projects focused on transport of phosphorus by water erosion. The erosion and sediment transport in the entire Elbe Basin (50 000 km^2) in the Czech Republic was analysed in detail using the WaTEM/SEDEM model. Based on this model, it was possible to define the average annual input of sediment into the hydrographic network through water erosion for subcatchments. Subsequently, on the basis of the concentration of total phosphorus in the soil, the input of total phosphorus into individual parts of the hydrographic network and subcatchments was derived.

A review of the relationship between soil texture and bound nutrients was carried out for individual soil fractions. Based on soil texture data for a large area, the share of the fine fraction (<10 μm) was defined, which turns out to be essential for the transport of bound nutrients during erosion events. Subsequently, a simplified method of estimating the importance of subcatchments in terms of phosphorus source for water reservoirs was derived based on the analysed soil structure in the given area.

The aim of the presented study was to compare phosphorus inputs in subcatchments determined by the two presented methods. The method using the WaTEM/SEDEM model is based on more accurate data inputs and has already been used in a number of similar studies. The study answers the question 'How reliably is it possible to use the link between soil structure and erosive phosphorus input into surface water to estimate the main sources of erosive phosphorus and determine the main risk locations in the observed area?'

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Detecting pollutant sources and pathways: High-frequency automated online monitoring in a small rural French/German transborder catchment

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Great temporal and spatial variability of inputs make comprehensive monitoring in small and middle-sized rivers difficult. In this study, relevant inputs in a small river were recorded with suitable online monitoring equipment coupled in mobile water quality monitoring stations, the study area being a transborder catchment with French and German (Saarland federal state) subcatchments. In addition to a pronounced spatial variability necessitating a denser net of measuring points this catchment has also to be assessed in the light of different national regulations. To identify individual pollution sources and weigh their relative importance, relevant parameters were recorded over a representative monitoring period of several months: phosphorus (P) as total phosphorus (TP) and total reactive P phosphorus (TRP), nitrate (NO_3–N), ammonium (NH_4–N), total organic carbon (TOC), temperature, oxygen (O_2), pH, turbidity, and electrical conductivity (EC). The recorded data were subjected to adapted interpretation together with other catchment-related factors. In order to retrieve maximum information from the online data sets the relationships among certain parameter pairs were also analysed for both storm events and low flow periods.

Comparison of loads at the different monitoring sites could reliably verify the majority of nutrient inputs originating in the French subcatchment. Additional sampling of output channels from sewage treatment works (STWs) in the Saarland subcatchment revealed that inputs from several decentralised STWs do not result in significant loads, as opposed to inputs from one STW in France. Our holistic approach provides a basis for adopting cost-effective measures to reduce loads in small river catchments as well as cross-border harmonisation of environmental policies.

Modelling of PFAS emissions into the Upper Danube

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The PROMISCES Project is funded by the European Union under the Horizon 2020 Framework Programme to support Europe's Green Deal. PROMISCES runs from November 2021 to April 2025 and aims to investigate different recycling routes, identify (potential) obstacles caused by industrial chemicals and develop solutions. The Danube Case (Case Study #2) is one of 7 case studies within this project. The research addresses the quantification of sources and pathways of PFAS pollution in the basin and of their behavior during bank filtration using the example of the Upper Danube catchment area down to Budapest. The overall work is structured as follows:

- Monitoring of PFAS occurrences and concentrations in input pathways, in tributaries of the Danube, the Danube itself and in bank filtrate influenced by the Danube.
- Modelling of PFAS inputs in the Danube catchment upstream of Budapest using the emission model MoRE.
- Modelling the behavior of PFAS during bank filtration near Vienna and in Budapest, with the aim of being able to depict scenarios for future developments.

While results from the monitoring investigations are presented separately (Liu et al. 2024), this contribution will make use of these results to implement the MoRE emission model (Fuchs et al., 2017) for PFAS in the upper Danube Basin. While Kittlaus et al. (2022) already demonstrated the capability of the MoRE model to assess PFOA- and PFOS-emissions with sufficient accuracy at the national scale of Austria, our research enhances the model in scale (upper Danube Basin) and in the parameters considered (including PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, GenX and ADONA) as well as in the considered emission sources. In the light of the importance of PFAS hotspots, in addition to usual MoRE-pathways we updated the model towards estimation of emissions from airports and municipal landfills entering surface waters via the groundwater. In the presentation we are going the show the modelling approach, valuation results, a regionalized pathway analyses to identify most relevant emission pathways and a risk analyses to identify rivers with expected high pollution levels of PFAS. Further investigations will aim to use MoRE as a tool for scenario evaluation, providing input into a bank filtration model to relate changes in the catchment to drinking water quality of water supplied using bank filtration from the River Danube.

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Quality management in river basins starts at the micro level - Filtration systems for storm water treatment – Appropriate filter substrates

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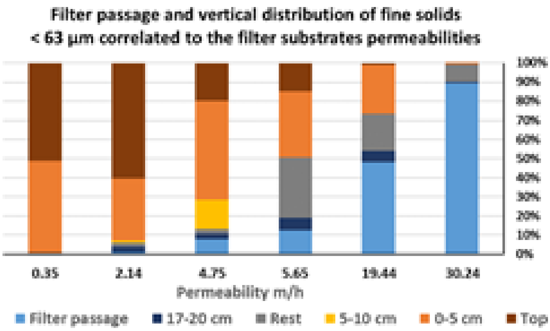
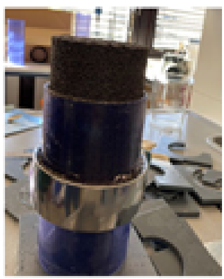
Storm water from urban areas drained into open water bodies contain contaminants like heavy metals e. g. cadmium (Cd) chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) and other pollutants like organic hazardous substances e.g. polycyclic aromatic hydrocarbons (PAH) and diethylhexyl phthalate (DEHP). To mitigate harmful impacts on the environment, pollutants need to be removed.

Pollutants are dominantly bound to particles (Grotehusmann a.o., 2013). It is also known that fine particles are consistently highly polluted and consequently target of the storm water treatment (Fuchs, 2013). Naturally finer solids (TSS63) are transported furthest, reaching open water bodies easily via drainage systems ending there. While central treatment systems are typically installed at the end of pipe, decentral systems are installed close to the places of origin. For economic reasons and to allow for the focus on hot spots, decentral systems are gaining more and more importance.

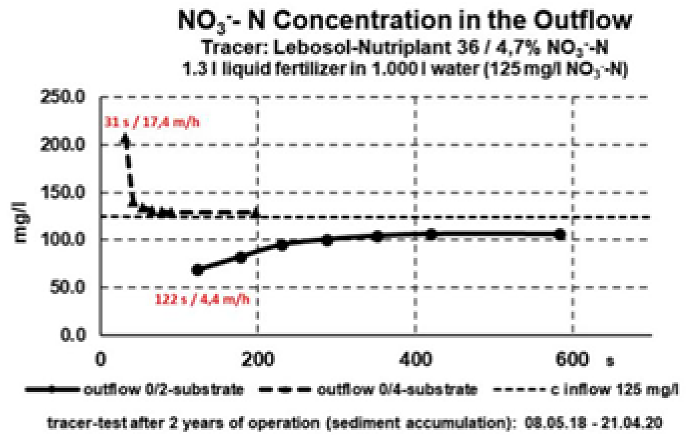




By using "filters" in central and decentral systems, operational safeness and higher efficiencies will be provided compared to pure sedimentation plants (Fuchs, 2024). When assessing efficiencies of different filter substrate grain sizes, close correlations between the substrate's permeability and removal efficiency on small particles (< 63 µm) can be found.

When the substrate's permeability (filter speed) exceeds 5 m/h, the filter passage of fine solids (< 63) increases rapidly. High filter speeds are usually found with deep bed filtration. If not maintained in time, preferential flows and filter short cuts may develop. Such flows can be identified with the help of tracers, by measuring the time span until the first outflow, the permeability of the filter area and changes of tracer concentrations in the outflow over time.

For verification a survey based on two filters was carried out by comparing a filter with low filter speed - 4 x 10-4 m/s – with a filter providing a significant higher filter speed - 2,7 x 10-3 m/s. Both were installed with same filter heights of 0,15 m parallel at a heavy trafficked road and tested with a tracer after 2 years of operation. Both with an accumulated sediment layer of 2 cm on top. Lebosol-Nutriplant (NH_4 NO_3) was used as tracer. One filter was equipped with filter grans ranging between 0 and 2 mm (0/2), while the other filter was provided with filter grains ranging between 0 and 4 mm (0/4), with 50% of the grains bigger than 2 mm. The tests revealed completely different flow characteristics.



The filter with the coarse substrate (0/4), representing the filter principle of deep bed filtration, showed with 31 seconds the shortest time up to the first outflow of the filter. The filter speed in m/s calculated (filter height 0,15 m) resulted to 4,84 x 10-3 m/s.

The filter speed calculated out of the permeability (kf-value), measured simultaneously via the drop of water level at the surface area of the filter, resulted to 9,83 x 10-4 m/s. The difference can be explained by the existence of preferential flows through sediment and filter, allowing the water to pass quicker than calculated out of the filters permeability via the drop of water level over the entire filter area, resulting to 151 seconds.

The filter cake accumulated as sediment layer on top of the filter might have been formed break throughs leading to strong spot wise flows into and through the more permeable filter substrate below. In combination with the highest tracer concentrations measured in the outflow right at the beginning the functionality of this filter could be questioned.

The filter with the finer substrate (0/2) but same sediment layer on top seemed to have a much more homogenous flow through the filter substrate. The difference in time for the first outflow within 122 seconds compared to 710 seconds calculated via the permeability measured, could be the result of breakthroughs in the sediment as well. But the finer filter substrate below was obviously redistributing the spot wise charging of the substrate, hence homogenizing the flow through the filter resulting to the lowest tracer concentration measured at the beginning of the outflow. Obviously remaining porous water in the filter (without tracer) must have been displaced first, thinning down the tracer concentrations at the beginning with increasing concentrations towards the end.

Filters based upon deep bed filtration need to be watched carefully. Signs of preferential flows might be taken as indicator to maintain / exchange these filters in time before breakthroughs occur.

Can machine learning tools support biological quality status assessment?

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The Water Framework Directive sets a target for water bodies to reach good ecological status by 2027 at the latest. To achieve this goal, it is necessary to identify which factors are the most important in influencing the status of the biological quality elements (BQE), e.g. finding the right parameters to which organisms are truly sensitive. The one out all out principle applied in the classification highlights the biological status's role in the overall status assessment of the water bodies. Furthermore, in several times measurements are not available for all qualifying elements, resulting uncertainty of the classification. In identifying the key parameters, and in estimating the status of water bodies in the lack of data, application of complex statistical methods can be a useful tool. This paper demonstrates the use of random forest for the abovementioned purposes. The method was developed for Hungarian river datasets, and tested on data reported in EU WISE, including German, Dutch and Belgian surface water quality data.

Analysis was made on Hungarian data using basic statistical methods (e.g. linear and logistic regression, boxplots), but because of the significant data gaps and the weak relationship found between the biological status and the background variables, random forest also failed to give reliable predictions for the biological status in the case of most of the river types. To test whether the bias is caused by the uncertainties of the dataset, the study was carried out with independent data from countries reporting in the EU WISE database, that carry out surface water classification in a similar way to Hungary.

This study describes the basic differences between the data published by different countries and explores the possible reasons behind these differences. Following the statistical evaluation of the data, random forest was used to predict the biological status of surface waters of the international data. Based on the predictions, the incompleteness of the input data greatly affected the applicability and the results of the prediction. The study proved that random forest is able to describe the behaviour of surface water ecosystems and model their biological status. Although due to the lack of data in all of the countries included in the research, the method can only be used as an investigative tool for biological status assessment and is not suitable as a substitute for missing measurements.

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Application of different types of catchment models to support understanding the hydrological and transport processes, emission patterns, and model limitations related to these in a meso-scale catchment

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Models that describe catchment hydrology, transport and emissions are key tools in the hand of river basin managers, to answer certain questions regarding existing and upcoming problems in river basins. Nutrient management, sediment management and the management of the emissions of hazardous substances in river basins are difficult tasks, due to the complexity of societal-economic-environmental systems. A key part of the decision making is the understanding of the processes of water movement, solute or erosion bound transport or to identify hot-spots to name a few. Catchment models support this activity by their ability to describe these processes in spatial and temporal scales of a large variety. While simple static empirical models, like the MONERIS model are aimed to give an estimate of average emissions in larger sub-catchment levels, continuous semi-distributed models like the SWAT model gives further insight in the dynamics of the hydrology and provide a finer spatial pattern related to emissions. While the former have many advantages due to its simplicity, it lacks the description of the hydrology, so it needs to be coupled to a hydrological model. SWAT however describes catchment hydrology as well, but only with limitations especially with regard to the groundwater flow processes, while it also lacks the description of direct connections between the catchment and the rivers. There are of course even more sophisticated models that have a full description of each important processes, like the Mike-SHE model, but such models are data and resource intensive to be operated on basin level.

Our aim is to test different models on a typical agricultural, hilly catchment in south-western Hungary to show the potential and weaknesses of some well-known models and finally to give a recommendation for which models or model combinations could be effectively used to answer certain questions in RBM planning. Besides MONERIS and

SWAT models, WetSPASS and MODFLOW models were tested to improve the understanding of water balance, and the simple, static but spatially distributed InVest model was used to understand better spatial patterns. Main questions to be answered: (1) what is the significance of groundwater resident times in emission modelling; (2) which are the areas around the river network which actively contribute to the constituent transport into the surface waters through surface runoff and through subsurface runoff; (3) which are the hot-spots for emissions associated with surface runoff; (4) which are the hot-spots for subsurface (5) what are the strengths and the limitations of the tested models to answer the questions above.

Funding: The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the National Laboratory for Water Science and Water Security (RRF 2.3.1 21 2022 00008) project. The research was co-financed by the National Research Development and Innovation Office (NKFIH) through the OTKA Grant SNN 143868.

Updating input data and expanding the range of substances by a harmonized approach for modelling emissions from Urban Systems and Municipal Wastewater Treatment Plants in MoRE

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Surface waters in Germany still do not meet the targeted "good chemical and ecological" status according to the Water Framework Directive. Currently, the European Union has agreed on a "zero pollution action plan" by 2050 to reduce air, water and soil contamination to such a level that it no longer poses a threat to human health and ecosystems. As urban systems and municipal wastewater treatment represent a relevant emissions pathway for several substances, for instances biocides which pose a risk to the quality of soils, rivers, and groundwater. Quantifying these emissions and pathways is crucial for developing reduction measures. Therefore, a harmonized approach in the model system MoRE (Modelling of Regionalised Emissions) is developed, input data updated and the substance spectrum expanded.

Recent measurement data from a nationwide monitoring comprising 49 municipal wastewater treatment plants (WWTP), 12 Combined Sewer Overflows (CSO) and two Storm water Outlets (SSO) form a new database to update input data for the model. Lower detection limits than in previous monitoring campaigns provide a more accurate basis. The results are statistically summarised into representative median values for each substance and emission pathway, which are then used as input data for calculating compute the emission load in Germany. Median values of the effluent from municipal WWTP are applied for computing emissions from this pathway, while surface area loads are determined based on SSO concentrations to quantify emissions via separate sewer systems. The discharge from CSOs consists of wastewater and storm water comprise. When quantifying the load from CSOs, the surface area load is used to represent the proportion of storm water, while the share of wastewater is determined by the influent concentrations of the WWTPs during dry weather.

Numerous substances can already be modelled with MoRE, while benzo(a)pyrene, bis(2-ethylhexyl)phthalate, diuron, isoproturon, terburtyn, nonylphenol and triclosan are of interest in this study. Due to the current emergence of new substances in the EQS Directive, as well as concerning findings on concentrations in water bodies of ubiquitous, persistent and toxic ones, the spectrum of substances in MoRE is expanded in this project. Based on the available data, it focuses on urban systems and municipal wastewater treatment plants. The relevant substances are carbendazim, 1,2-benzisothiazolinone, 2-methyl-3-isothiazolinone, imidacloprid, permethrin, permethric acid, propiconazole, 2-pyridinesulfonic acid, fluoranthene, phenanthrene, diethyltoluamide, perfluorooctanoate, perfluorooctane sulfonic acid and bisphenol A.

The modelled results provide a nation-wide estimation of emissions via urban systems into surface water bodies for the years 2016 to 2018. The results show the proportion of emissions from the three pathways, which varies considerably between the substances. While PAHs are primarily emitted via the separate sewer system due to their properties, other substances, such as isoproturon, are predominantly discharged into water bodies by the WWTP effluents. In conclusion, the results offer an opportunity to develop further strategies to prevent emissions of substances into water bodies by identifying the respective main pathways and approximate annual emission loads.

Heated rivers: learning from climate change and energy scenarios along a 700 km stretch of the Rhine

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Water temperature is a key factor for physical, chemical and biological processes in water bodies. Here, we investigate the temperature in the German part of the River Rhine from Basel, Rhine-km 164, until Bimmen, Rhine-km 862. We used the water quality model QSim of the Federal Institute of Hydrology (Federal Institute of Hydrology) to simulate current climate conditions with varying heat input and future climate conditions. In the validation period 2018-2020, we compared simulated and measured water temperatures along the Rhine with and without heat input of power plants. The temperature increase caused by heat input strongly depends on the location of the power plants and the measuring stations along the Rhine. From 2018-2020 in Koblenz, Rhine-km 590, the temperature difference with and without power plants accounted for about 0.7 °C, in Bimmen, Rhine-km 862, for about 0.2 °C.

We then compared a reference situation (1990-2010) with climate change scenarios in the near (2031-2060) and far (2071-2100) future. In this process, the change in climate and hydrodynamics (discharge and water level) were considered to simulate the water temperature. The model results were analysed for changes in summer (days above 25 °C and 28 °C) and winter (days below 3 °C and 10 °C). Those values were chosen as ecological significant thresholds. We found that heat inputs have a significant effect on water temperatures in the simulated stretch of the Rhine. The climate change scenarios resulted in a warming of the river. Threshold exceedances of 25 °C increased by about a month in the far future, while very hot days (≥ 28 °C) occurred more often but remained rare.

Studying the effects of water temperature, phytoplankton and discharge variations on dissolved oxygen in the German reach of free-flowing Rhine

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Dissolved oxygen (DO) in river water is an important variable for sustaining aquatic life and indication of water quality. It is required for biodegradation processes that remove organic pollutants from water. Oxygen in the river is either produced by aquatic plants or phytoplankton through photosynthesis or it enters from the atmosphere into water by diffusion. Hence, dissolved oxygen varies along the river due to deoxygenation and reaeration processes. When modelling dissolved oxygen in rivers, it is important to carefully set the boundary conditions of the model since they strongly influence the oxygen budget along the river via the effects of point source pollutions.

In this study, we investigated variations in the oxygen budget along the free-flowing German section of the Rhine from Karlsruhe (Rhine-km 359) to Bimmen (Rhine-km 862). We used the water quality model QSim to study different oxygen addition and removal processes, while accounting for the influence of variations in discharge, phytoplankton growth and temperature along the Rhine.

We compared measurements including the thermal loads for the periods 2018-2020 with simulation runs without heat inputs. The water temperature difference (ΔT) estimated with heat inputs and absence of thermal loads from power plants 2018-2020 is found to be 0.7 °C, at Koblenz station whereas it decreases downstream with a value of 0.3 °C at Bimmen station relating to the fact that major thermal power plants are located upstream of Koblenz.

Likewise, the model without heat input produced dissolved oxygen with a difference of 1.11 mg l^{-1} at Koblenz station and 0.72 mg l^{-1} at Bimmen compared to the observations including heat input. Similarly, phytoplankton abundances increased from upstream to downstream along the Rhine. In this study, we also analysed the longitudinal profiles of the modelled oxygen consumption and input rates in the Rhine River.

Exploring carbon dioxide dynamics and anthropogenic influences in the Ganga River: Implications for riverine management

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Anthropogenic activities within river catchments significantly alter water quality and material flows in riverine systems. Despite the widespread influence of these human-induced changes in Asian rivers, there has been limited exploration of their association to GHG emissions. The present study focuses on understanding CO_2 emissions at the water-air interface in the Ganga River, the largest river in the Indian subcontinent of South Asia. The study uncovers significant spatial variability in pCO_2 concentrations along the Ganga River, with an average value of 1185.3 + 99.8 μatm. Particularly, the upper reach of the Ganga exhibits the highest average pCO_2 compared to the middle and lower reaches. The spatial variation emphasizes the complex relationship between water quality and CO_2 dynamics within riverine ecosystems, highlighting the necessity for comprehensive assessments of anthropogenic influences on these systems. Notably, our findings indicate that nitrate levels in the upper stretch and dissolved oxygen (DO) and pH levels in the middle and lower stretches are key explanatory variables for pCO_2 fluctuations. Further analysis, including regression tree and importance analyses, identifies biochemical oxygen demand (BOD) as the primary factor influencing pCO_2 variations across the Ganga River. Understanding the relationships between these hydrochemical parameters and pCO_2 is crucial for elucidating the mechanisms driving CO_2 dynamics in riverine ecosystems. In conclusion, our findings emphasize the multifaceted nature of CO_2 emissions in the Ganga River, highlighting the pivotal roles of BOD, DO, and pH in influencing pCO_2 levels. This study underscores the potential for implementing restoration measures to mitigate these emissions and contribute to achieving sustainable development goals. The insights provided are invaluable for policymakers and resource managers as they work towards adopting sustainable practices for river management.

Identification of drained areas for enhanced precision in regionalized emission modelling

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In numerous agricultural regions, the installation of drainage systems is imperative to enhance the cultivable land. Regarding diffuse sources for nutrients and pollutant, these installations have a significant impact on substance transfer to surface water. An ongoing research project, funded by the German Environment Agency, endeavors to identify both drained and undrained agricultural areas, with the ultimate goal of incorporating these findings into regionalized emission modelling. The aim of this study is to determine a method to identify drained areas on a high-resolution scale using satellite data. The method uses ground movement as an indicator, which physically reflects the swelling and shrinking of the ground due to moisture. Infiltrated water in soils of fields is lead directly to adjacent surface water bodies by drainage systems. Therefore, it is assumed that the shrinking process is faster than in undrained areas, reflecting a faster drying of the soil. The ground motion is detected and analyzed using Multi-Temporal Interferometric Synthetic Aperture Radar (MTInSAR) through satellite radar data.

To assess ground movement, the average velocity is determined in millimeters per year. The annual motion exhibits variations between positive values (indicative of expansion) and negative values (indicative of contraction). Negative velocities correspond to an accelerated average shrinkage process. In test areas of varying soil properties and differing climate conditions, the results are compared to reference data. These references include land registers, regional studies on drainage systems and knowledge of local specialists. In the test areas, it is determined that drained areas and a higher ground movement velocity do correlate. Notably, all surveyed areas exhibit faster negative velocities in drained zones compared to their undrained counterparts.

This study will advance the German-wide emission modelling by improving the estimation of the drainage system’s influence as diffuse sources for nutrients and pollutants into water bodies. Furthermore, the nationwide identification of drained areas is beneficial for efficient land resource planning and cultivation management, as well as for understanding environmental impacts and enabling targeted measures to protect water bodies and biodiversity.

Estimation of hazardous substance loads in a small catchment based on composite sampling

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The pollution of our natural waters is an increasingly urgent and crucial problem. Both point and diffuse pollution can enter the river basin from a variety of sources. The streamflow - and the resulting pollutant loads - exhibit abrupt changes in behavior influenced by rainfall and surface run-off. A significant portion of the pollution is associated with short-duration event flows, which cause sudden, substantial increases in streamflow. The primary objective of my thesis is to refine the load estimation method using baseflow separation methods, specifically the Lyne-Hollick (L-H.) and Eckhardt methods. The methods were applied at two measuring stations of the Koppány stream in Somogy County, Törökkoppány and Tamási.

In addition to hourly water flow measurements, electrical conductivity and turbidity are continuously monitored in the area at five-minute intervals. A permanent point source of pollution is the treated wastewater of Balatonlelle, which is discharged into the Koppány stream as a contribution to the baseflow load. The calculation process benefited significantly from the stratified sampling method used, in which an automatic sampler is activated at a defined water flow threshold. This enables separate treatment of samples from baseflow and high flow, allowing better estimations of contaminant concentrations during high flow conditions and providing a more accurate load estimation. The calculations and evaluations were performed using the R programming language.

The estimated baseflow-index for Törökkoppány is 0.60 (L-H.) and 0.57 (Eckhardt) while for Tamási, it is 0.86 (L-H.) and 0.57 (Eckhardt). In terms of micropollutants, metals and pesticides dominate the mass for both methods, associated with high flow events. Meanwhile, pharmaceuticals, phenols, and PFAS compounds, linked to anthropogenic sources, are more prominent in the baseflow load. Based on the L-H. filter, Törökkoppány receives 91.7% of its annual 4634 kg metal compound load during high flow events. The total pesticide load is 87 kg per year, with 98% attributed to high flow events. Results from the Eckhardt filter align closely with the aforementioned findings. Based on the L-H. method at Tamási, the estimated annual metal load is 3488 kg, with 62% from high water events. while the Eckhardt method reports an annual metal load of 7408 kg (88% from high flow). Total pesticide emissions are 63kg/year (L-H.), predominantly from high flow (88%), and 171 kg (Eckhardt) with 97% attributed to high flow. Phenols, PAH and PFAS compounds are baseflow-related and do not exceed 1-2kg/year.

To understand why the two methods show such different results for Tamási, the Rimmer-Hartmann method could be an appropriate solution.

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Lesson learned from the application of a catchment-specific continuous surface water quality monitoring system

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The catchment-specific continuous surface water quality monitoring and automatic sampling system provide invaluable information on the state of water bodies. It supports sustainable water management by providing real-time data on pollutant concentrations, enabling immediate response. We have placed the online monitoring and automatic sampling systems in the Kis-Balaton Water Protection System. Based on the one-year, seasonal, continuous measurement data series, we optimized the measurement and data frequency, signal and alarm limit values, calibration density, and maintenance requirements.

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Horizontal and vertical mass fluxes between aquifer and river during river floods

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Bank storage caused by river floods contributes to the temporary storage and attenuation of not only the flood volume, but also the contaminants carried by it. Solutes from the river enter the connected aquifer though a horizontally propagating groundwater wave and, at the same time, seep vertically through the upper soil layer of the flooded overbank. After peaking, bank storage discharges back to the river; however, vertical infiltration continues to act as a sink for the water and any contaminants. Therefore, the river-aquifer mass exchange results in a residual bank storage of contaminants at the end of the flood event, which is of importance, for example, in the operation of bank-filtered groundwater wells.

In our study, we investigated the magnitude of horizontal and vertical mass fluxes between the river and the aquifer during river floods accompanied with extensive overland flooding for a broad range of river and aquifer setups. We approximated the domain with a simple prismatic geometry and specified flood hydrograph and the hydraulic properties of the soil with a moderate number of discrete parameter combinations. We used an in-house finite-difference solver that integrates three interacting models: a 1D model of the river, a 2D depth-integrated Darcy model for the groundwater and a Green-Ampt model of the unsaturated topsoil. We verified the model with the established MODFLOW software for benchmark cases. Surface and groundwater water movement was simulated for synthetic flood events. Our results show that the ratio of horizontal to vertical mass fluxes covers a wide range, and the dominance of one over the other is highly sensitive to the specific circumstances.

Assessment of pollutant emissions to support river basin management in Albania according to the EU, AMORE-AL.

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Albania is blessed with various water resources, including rivers, lakes, groundwater, and coastal areas. These water resources play a crucial role in supporting various sectors of the economy and sustaining ecosystems. Rivers are one of the biggest and most important water potentials of Albania. Albania has the status of a candidate country for the European Union (EU), and as such it has adapted the water legislation framework to that of the EU. In this context river basin management plans (RBMP) are used to achieve a holistic management of surface waters according to the EU Water Framework Directive. However, Albania has a significant need for data as a basis for RBMPs, especially the data regarding the pollutant emissions and pathways from the river basins. The Amore-AL project aims at filling these gaps for pollutant emissions by establishing an appropriate monitoring strategy coupled with modelling of pollutant pathways. Through this, the project aims at supporting Albanian institutions with their need for basic tools to improve river basins management plans. For the quantification of the nutrients and pollution emissions in the catchment, the river basin management system MoRE (Modelling of Regionalized Emissions) will be used. MoRE is a flexible open-source instrument which is able to model pathway-specific emissions and river loads on a catchment scale. Its flexibility in integrating new modelling approaches makes it a robust tool which can be used also in the case of Albanian water bodies. The whole modelling approach will be coupled with a holistic validation measuring station, which will be installed in the river stretch. The monitoring station consists in a large volume sampler that will collect water and sediment samples for analysis in the laboratory, focusing on various parameters of nutrients (N; P) and heavy metals. The investigation area will be Ishmi River catchment. The modelling results will be compared to the findings from the monitoring station to check the effectiveness of the model and to implement any further calibration. The most important outcomes of the project will consist in: Quantification of pollutant emissions in the investigated area; Understanding of urban processes in terms of substances input and transformation and definition of the most important pathway; Setting up a decision support system for an improved and integrated water resources management. The final goal of this project is to widen and facilitate the applicability to other river basins in Albania and neighboring countries.

Spatial variability of meander characteristics within a distributive fluvial system experiencing an avulsion

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Previous studies of meandering fluvial systems have focused on meanders in isolation, however, more research needs to be done to study meander characteristics in a spatial context focusing on how meanders vary across single river systems or depositional basins. This study follows the Taquari River, Brazil, which is currently experiencing an avulsion where flow is diverted from the parent channel to a new avulsion channel. Using Sentinel imagery from 2022 and Landsat imagery from 1985 the Taquari River is compared before the avulsion occurs and while the avulsion occurs to quantify differences in sinuosity, channel width, channel belt width, and meander deposit area, length, and width from the source to termination of the river system. This study will contribute to our understanding of modern fluvial processes (i.e., how subsurface fluids flow, become trapped and convey pollutants) and hazards that impact people that live along riverbanks. We will gain a better understanding of the rock record by using this work as an analogue to ancient basins which act as important hydrocarbon and CCS reservoirs, as well as reservoirs for a variety of resources such as uranium, copper, petroleum, and water which are critical to society.

Comparative isotope hydrological characterization of the elements of the water cycle in two continental catchments: Koppány (Hungary) and Ledava (Slovenia) streams

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Background: Interpretation of changes in the stable oxygen (δ^{18}O) and hydrogen (δ^{2}H) isotopic signatures of catchment waters have proved to be highly useful in identifying hydrological source areas/flow paths under different flow conditions and estimating catchment residence times. This study proposes a targeted monitoring approach at a Hungarian and a Slovenian catchment to enhance the understanding of contaminant pathways, quantify particulate transport, and delineate surface versus subsurface contributions to elements of the catchment scale water cycle.

The Hungarian catchment is located in SW Hungary covering the larger part of the Koppány Stream catchment above Tamási. It is a hilly, ca. 660 km² catchment with a significant (~78%) agricultural share and extended undisturbed forests (~20%). The mean annual precipitation is 630 mm yr^{-1}. The Ledava catchment is a cross-border area (HU / SI ,1940 km²). It is a hilly to lowland agricultural area, covered by 20% of forest, the mean annual precipitation is 798 mm yr^{-1}.

To characterize the water cycle components in both catchments, the δ^{18}O and δ^{2}H were measured in precipitation, river, and subsurface (shallow and deep) water from 2022-onward.

Results: Considering the relative vicinity and similar climatic characteristics of the studied catchments (Fig. 1) the range of the measurements of stable isotopic composition of precipitation is similar (Fig. 1: PRC_KO, PRC_LND). River- and subsurface water stable isotopic composition variability is explicitly smaller compared to that of precipitation.

In the Koppány catchment, the stable isotopic composition of river water seems to be slightly more depleted at the Törökkoppány (TK) site compared to the Tamási (TS) site. In contrast, the stable isotopic composition of subsurface water is more depleted in light isotopes than that of surface water and precipitation, most explicitly in the case of deep groundwater. River water at the Slovenian sites tends to be less negative compared to the mean value of precipitation (Fig. 1a,b). In addition, the upstream Polana (PLN) site shows slightly higher $\delta^{18}O$ and $\delta^{2}H$ values compared to Čentiba (CNT). In the case of subsurface waters, the shallow groundwater $\delta^{18}O$ and $\delta^{2}H$ values perfectly fall in line with that of the river water, while the deep groundwater is more depleted, nevertheless, not as much as in the Koppány watershed.

In the Koppány catchment, a mean residence time of river water is estimated to be ~140 days using an exponential flow model via periodic regression analysis to fit seasonal sine wave curves to annual $\delta^{18}O$ and $\delta^{2}H$ variations in precipitation and stream water (see Rogers et al., 2005). However, an associated shift is not evident when plotting them against time. The minima and maxima in the river water and precipitation show up in the same season, nevertheless, the amplitude in the river water is decreased. The estimated residence time presumably represents the mixture of young surface runoff (with residence time within a week in most of the catchment), older runoff from the reservoirs (there are quite many in the lower part of the catchment), fast response subsurface waters (the so-called "interflow" - no direct proof for that) and slow groundwater (a part of which might be very old water). Our results corroborate findings from analysis of flow data, that suggest an average 60% baseflow-to-total flow ratio for both stations (Lajkó, 2023).

Since monitoring is still ongoing, and $\delta^{18}O$ and $\delta^{2}H$ samples are yet available in a limited number for the SI sites, at this stage, only empirical analyses were conducted. Statistical tests will follow to explore the similarities and differences. The next steps include the incorporation of the above results in the catchment emission model with a special focus on nitrate contamination as soon as the results of nitrate-$\delta^{15}N$ measurements become available.

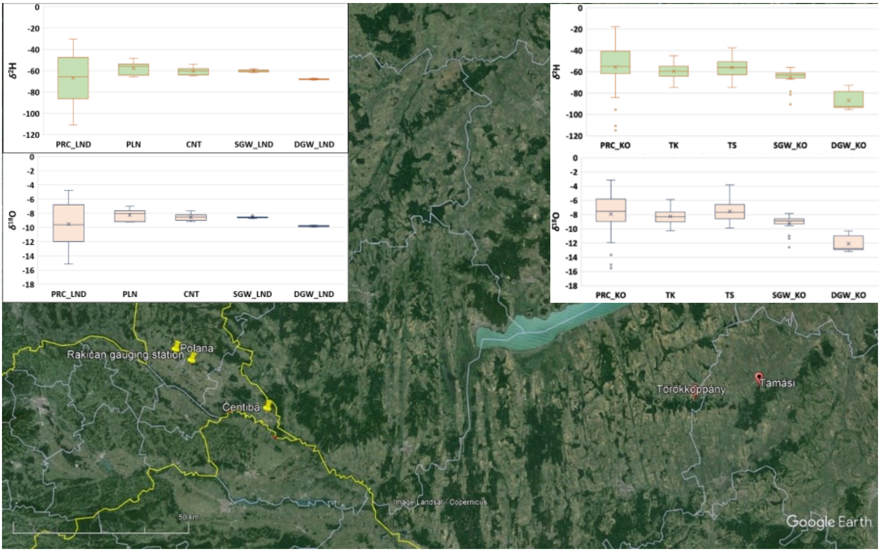

Figure 1: Location of studies catchments and monitoring sites in Hungary (Törökkoppány (TK) and Tamási (TS), red markers) and Slovenia (Rakičan (LND), Čentiba (CNT) and Polana (PLN), yellow markers). Box-and-whiskers plots of precipitation-river-subsurface water (shallow (SGW) and deep (DGW) at the sites are shown for the Ledava catchment (SI, left) and the Koppány catchment (HU, right). Basemap from Google Earth.

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A model-based case study for wetland restoration effects on the hydrological conditions at a Hungarian lowland catchment

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The alluvial character of the Great Hungarian Plain has long determined its land use. Human-environmental interactions and landscale patterns were characterized by adaptation to frequent floods and high water availability. Different socio-economical factors in the 18th and 19th centuries initiated major drainage works and river regulations. These works aimed to adjust hydrological conditions in the floodplains to meet the demands of a new land use approach. This focused on maximizing crop production as the dominant provisioning ecosystem service (ES) instead of the previous land use practice (e.g. utilization a broader range of various ES by adaptation).

Over time, this new land use-water management strategy led to a trajectory of constraints: 1) Water demands of the agricultural landscape are restricted to a much narrower range than natural hydrological conditions, leading to damages during extremely dry or wet conditions; 2) Artificial drainage attempts to ensure this narrow range during wet periods in the protected former floodplain areas; 3) However, drainage increases water scarcity and drought damage during consecutive dry periods, which cannot be compensated by the irrigation system due to its limited capacity.

As a result of this outdated strategy and contemporary processes, Hungarian landscape management is facing a crisis. Climate and hydrological changes, the aging farmer community, agricultural sector profitability, alterations in the land use subsities, preferring greening, and afforestation are among the leading factors of this crisis. These factors are likely to drive current land use conditions into a significantly altered riverine landscape scenario in the coming decades. Among the current environmental-economic-regulatory conditions, one of the most feasible alternative scenario focuses on water retention and the corresponding adaptive land use. However, the hydrological impacts of such alternative water management-land use on crop yield remain poorly understood.

We examined this by using hydrological simulations at a 272 km^2 study site located next to the River Tisza. Here, the morphology of the heterogeneous terrain offers a remarkable semi-natural storage capacity as it encompasses a deep floodplain area.

We defined six different water governance-land use scenarios. First, three water management scenarios were defined and simulated: reference, excess water retention, and flood retention. Along these scenarios inland excess water (a specific type of flooding) hazard maps were used as an indicator for potentially reclaimable floodplains. Next, an alternative land use map was derived following the prevailing Hungarian landscape planning logic, considering factors such as present location and proportion of current agricultural croplands, grasslands, forests, settlement; soil conditions, water availability (agricultural suitability), and nature conservation status.

An integrated hydrological model was set up with the MIKE SHE software to depict spatio-temporal variations in water resources under present conditions (with an operational drainage system) and for all described alternative cases (without a drainage system). Simulated groundwater levels were a key output used to estimate changes in crop yields at selected pointwise locations. The results indicate significant potential for nature-based hydrological adaptation and co-benefits for provisioning ES.

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