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Integrated modelling solutions for data-driven holistic management of urban water quality – the Urban M_2O digital tools

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Abstract

The increasing demands for reducing urban pollutant emissions and protecting water resources necessitate significant amounts of data for designing, implementing, and reviewing pollution control actions. The EU-funded URBAN M_2O project aims to address these challenges by developing digital tools, including Digital Urban Water Twins (DUWT) and holistic Data Management Systems (DMS). The DUWT will track pollutants across urban areas and water matrices, supporting in the planning and evaluation of pollution reduction strategies, while the DMS will ensure smooth information transfer across stakeholders and administrative boundaries. These tools will integrate data from novel water quality monitoring technologies, providing urban water managers with updated city-wide data. The project will apply these tools in three European cities, each facing unique challenges. The DUWT will identify pollution hotspots and assess health and environmental risks, while the DMS will facilitate data integration and sharing. The project aims to promote the application of open-source modelling tools for holistic pollution management in urban areas worldwide, fostering collaborations within the urban drainage modelling community.

Highlights

- Open-source fit-for-purpose modelling tools for tracking pollutants in urban areas
- Holistic approach for data collection and sharing across the whole water cycle
- Multiple water matrices and water quality indicators investigated

Introduction

The increasing demands for reducing pollutant emissions from urban areas and protecting water resources require significant amounts of data to design, implement, and review different pollution control actions (ranging from source-control to end-of-pipe treatments). Furthermore, ever-increasing threats (emerging pollutants, new diffuse and point sources, climate change, socio-economic development, ageing infrastructure and leakages) require an integrated perspective of the whole water cycle shared across multiple stakeholders and administrative entities. Multiple water quality monitoring solutions are available, but they struggle to provide adequate information to support city-wide pollution control actions. It is a herculean task to monitor all the pollutant pathways with a sufficient time resolution for all the potential threats, especially those posed by Contaminants of Emerging Concerns (CECs). Integrated modelling tools (Bach et al., 2014) and digital twins of water infrastructure can support monitoring efforts by providing city-wide results with higher spatial and temporal resolution across multiple elements of the urban water infrastructure. However, current integrated models seldom assimilate real-time data and are affected by several sources of uncertainty. Also, data fragmentation, with data storage dispersed across different systems and administrative entities, hinders data availability to decision-makers. This and the often-prevailing lack of interoperability lead to substantial challenges for effective, data-driven tools.

The recently started EU-funded URBAN M_2O project will address these issues by developing digital tools that include: (a) Digital Urban Water Twin (DUWT) to track pollutants across urban areas, allowing the planning and evaluation of current and future pollution reduction strategies in cities undergoing a circular transition; and (b) a holistic DMS to ensure smooth information transfer across stakeholders and administrative entities. These digital tools will be integrated with data provided by novel monitoring technologies, targeting different water quality indicators (Figure 1). This will provide urban water managers with city-wide and constantly updated data to design, implement and evaluate pollution control strategies.

This paper describes the major modelling approaches the URBAN M_2O project will apply during the next 4 years. The purpose is thus to promote the application of the developed open-source modelling tools to support the implementation of holistic pollution management strategies in urban areas worldwide, and to favour potential collaborations across the urban drainage modelling community.

Methodology

Digital Urban Water Twins for pollution tracking

Pollution sources in urban areas will be quantified by combining information on emission sources with GIS information on economic activities and land usage, following the Source Classification Framework from Lützhøft et al. (2012). This will enable to quantify releases of multiple CECs into the wastewater collection network. The CEC fluxes and environmental fate across the integrated urban water systems will be simulated by using the IUWS_MP library (Delli Compagni et al., 2020; Vezzaro et al., 2014), implemented in the open-source CITY DRAIN© software (Achleitner et al., 2007; Burger et al., 2016). This will allow for building "fit-for-purpose" integrated models, which can be tailored to each city/catchment characteristics, pollution threats, and planned implementation of water circular approaches (e.g. water reuse, Nature Based Solutions, blue-green infrastructures). Also, a new linkage between groundwater models (MODFLOW), accounting for hydrochemical processes in the porous medium and CITY DRAIN© will be created. This will enable the simulation of interactions of the urban water infrastructure with other environmental compartments (e.g. exfiltration and contamination of groundwater used for water supply, e.g. De Keyser et al. (De Keyser et al., 2010)).

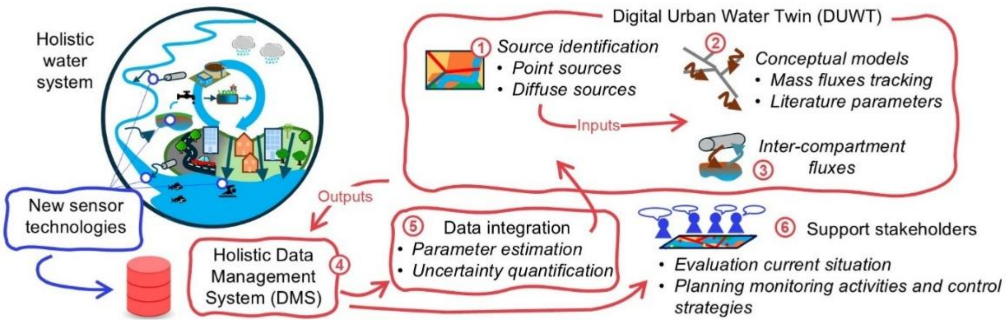

Figure 1. Schematic representation of the steps and modelling elements that will be integrated during the Urban M_2O project.

The DUWT "uncertainty baseline" will be quantified by using a forward uncertainty analysis with a Monte Carlo approach to consider the variability in the pollutant sources and chemical fate processes for a wide range of indicators.

Holistic Data Management System for data and models integration

Existing Data Management Systems (DMS) at the city level will be extended to (i) continuously incorporate data provided by new sensor technologies and distributed data from different data owners (water utilities, municipalities), (ii) master changes in the data production side (new communication system requirements for new sensor technologies) and aim at interoperability to be ensured at data production stage, and also (iii) support the data exchange with the DUWT. Specifically, data provided by monitoring campaigns will be utilised to calibrate inputs and parameter distributions. The data integration frequency will be defined according to the application and the dynamics of the pollutant transport and generation processes (e.g. CSO warning requires higher frequency than groundwater pollution transport). The comparison of the DUWT prediction uncertainty before and after data integration will allow to quantify the benefits of the proposed combined approach. The DMS will be based on an existing open-source platform and will facilitate access to environmental data (aligned with the FAIR principles), supporting research activities of the urban drainage modelling community. The approach to the DMS will be based on the already existing DMS in the Copenhagen (Denmark) case, which among others. includes an existing hydrometry system to codify water flows and levels, thus constituting the basis for the digital twins (DUWT).

Case study

The Urban M_2O project will develop the DUWT in three European cities: Sant Adrià de Besòs (Barcelona-Spain), Copenhagen (Denmark), and Zurich (Switzerland). These cities represent different challenges that European urban areas face (water scarcity, climate adaptation, ageing infrastructure) and elements of the integrated urban water systems (including quaternary wastewater treatment, Nature Based Solutions (NBS) and hybrid grey-blue-green systems). Modelling efforts will focus on different water matrices (and interactions between them), pollution hotspots, climatic challenges, ageing infrastructure and diverse digitalisation and data availability levels (Figure 2). In each city, detailed hydrodynamic models (built in e.g. SWMM, MIKE, or MODFLOW software) are available. These models will be simplified by using existing simplification routines, providing the basis for the conceptual models that are at the core of the DUWT. Monitoring activities are currently carried out in all three sites: specifically for the Swiss case, data and experiences from the Urban Water Observatory will provide an extensive database for model development and performance evaluation.

The developed DUWT will be applied in each Case Study to identify pollution hotspots and to highlight sites and periods with higher health and environmental risks. These predictions will be cross-validated by comparing predicted and measured health and environmental risks (e.g. in a confusion matrix).

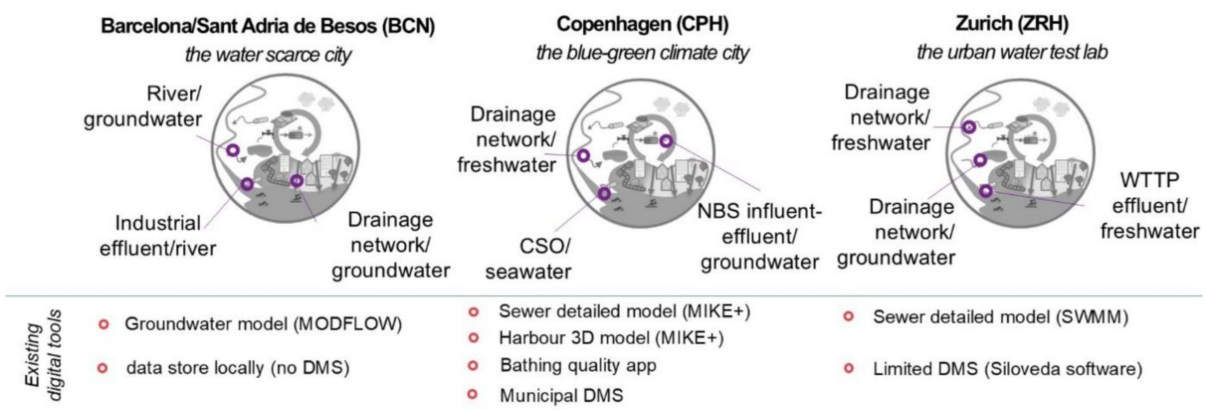

Figure 2. Schematic representation of the water matrices and interfaces that will be modelled in the three Case Study cities, along with available digital tools (detailed hydrodynamic models and DMS).

This will allow for assessing the DUWT performance in "data-poor" contexts (i.e., in urban areas with limited resources for monitoring activities). Statistical methods (e.g. Global Sensitivity Analysis) will be used to quantify the importance of monitoring locations for DUWT data integration, identifying sites and sensors with high information content, i.e. key locations and parameters leading to a significant improvement of the DUWT performance. In each case, a DMS will be established (or extended, as in the CPH case) to accommodate for data from the technical infrastructure (e.g. drainage network) and from the environmental monitoring (natural waters), allowing both surveillance and operational monitoring.

Conclusions

The Urban M_2O project is still taking its first steps, and major results will be obtained in the next 4 years. These will provide the urban drainage modelling community with a range of tools that will favour a widespread and more robust application of integrated models, including:

- Pollutant source and quantification tools at the catchment/city scale
- Integrated model library for tracking micropollutant fluxes and environmental fate across the various elements of the integrated urban water system (collection system, centralized and decentralized treatment, receiving waters)
- Procedures for building Digital Urban Water Twins (DUWT) from existing detailed hydrodynamic models
- Tools for continuous assimilation of measurement data into DUWT, quantifying result uncertainties and identifying optimal monitoring locations, decreasing the overall uncertainty
- Holistic Data Management Systems (DMS) to share data across multiple stakeholders and platforms, while increasing data interoperability.

The Urban M_2O activities will be open to collaborations with the UDM research community, and all the tools and generated data will be open-source. Thus, the project will contribute to advancing the activities in the field, and will provide tools that are urgently required and of uttermost importance to plan the reduction of pollution emissions from urban areas, hence contributing to the achievement of the EU Zero Pollution Action Plan.

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References

Achleitner, S., Möderl, M., Rauch, W., 2007. CITY DRAIN © – An open source approach for simulation of integrated urban drainage systems. Environ. Modell. Softw., 22, 1184–1195. doi: 10.1016/j.envsoft.2006.06.013

Bach, P.M., Rauch, W., Mikkelsen, P.S., McCarthy, D.T., Deletic, A., 2014. A critical review of integrated urban water modelling - Urban drainage and beyond. Environ. Modell. Softw., 54, 88–107. doi: 10.1016/j.envsoft.2013.12.018

Burger, G., Bach, P.M., Urich, C., Leonhardt, G., Kleidorfer, M. and Rauch, W., 2016. Designing and implementing a multi-core capable integrated urban drainage modelling Toolkit: Lessons from CityDrain3. *Adv. Eng. Softw.*, *100*, 277-289, doi: 10.1016/j.advengsoft.2016.08.004

De Keyser, W., Gevaert, V., Verdonck, F., Nopens, I., De Baets, B., Vanrolleghem, P.A., Mikkelsen, P.S., Benedetti, L., 2010. Combining multimedia models with integrated urban water system models for micropollutants. Water Sci. Technol., 62, 1614–1622. doi: 10.2166/wst.2010.475

Delli Compagni, R., Polesel, F., von Borries, K.J.F., Zhang, Z., Turolla, A., Antonelli, M., Vezzaro, L., 2020. Modelling the fate of micropollutants in integrated urban wastewater systems: Extending the applicability to pharmaceuticals. Water Res., 116097. doi: 10.1016/j.watres.2020.116097

Lützhøft, H.-C.H., Donner, E., Wickman, T., Eriksson, E., Banovec, P., Mikkelsen, P.S., Ledin, A., 2012. A source classification framework supporting pollutant source mapping, pollutant release prediction, transport and load forecasting, and source control planning for urban environments. Environ. Sci. Pollut. R., 19, 1119–1130. doi: 10.1007/s11356-011-0627-9

Vezzaro, L., Benedetti, L., Gevaert, V., De Keyser, W., Verdonck, F., De Baets, B., Nopens, I., Cloutier, F., Vanrolleghem, P.A., Mikkelsen, P.S., 2014. A model library for dynamic transport and fate of micropollutants in integrated urban wastewater and stormwater systems. Environ. Modell. Softw. 53., Doi: 10.1016/j.envsoft.2013.11.010