Project Proposal Form

Understanding the transport and fate of ejected sewer sediments during urban flood events

A/B FLUME [Above/Below Ground Urban Drainage Scale Model]

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Abstract

This research project presents a comprehensive investigation into sediment transport dynamics during flood events within urban drainage systems. A meticulously designed physical model, featuring a scaled "floodplain" with dimensions akin to real-world scenarios, linked to a sewer system via a manhole, serves as the experimental platform. Sediments representative of road runoff (d_{50} between 63 and 300 µm) are introduced into the drainage system via controlled injection. The study will focus on the transport of these sediments in flood conditions, and specifically the propensity of sediments to be transported from sewers to surface flows during sewer surcharge events. This type of events are expected to become more frequent and severe in the future due to climate change, urbanization, and degraded existing sewer systems.

A range of experiments, totalling 45, systematically vary pipe flow rates, surface flow conditions, and granulometries to examine their impact on sediment behaviour will be performed. Advanced particle tracking techniques, including 3D Particle Tracking Velocimetry (PTV) and overhead camera observations, will provide granular insights into sediment dynamics. To complement the physical experiments, numerical simulations will be conducted employing 3D Computational Fluid Dynamics (CFD) models. This comparison between experimental data and simulations enhances our understanding of urban drainage processes. Subsequently, simplified 1D/2D urban flood models are developed and calibrated, incorporating sediment and pollutant transport modules.

The project's results are anticipated to yield a deep and sound knowledge into sediment transport mechanisms during flood events, with applications related to the understanding of public health risks from exposure to contaminated sediments. The combination of detailed experiments and advanced modelling approaches is expected to advance our ability to simulate real-world scenarios accurately. This research contributes to sustainable urban planning and water management practices, with potential implications for enhancing flood resilience in urban areas and it is in line with Sustainable Development Goal 11 (Make cities and human settlements inclusive, safe, resilient and sustainable) and 13 (Take urgent action to combat climate change and its impacts).

KEYWORDS | Urban flooding, Sediment transport, Coupled modelling, Shallow water hydro-sediment-morphodynamic model .

EXCELLENCE OF THE PROPOSAL

State-of-the-Art

Urban floods pose a significant public health risk, impacting communities on multiple fronts (Rubinato et al. 2022). They can lead to waterborne disease outbreaks due to contamination of water sources (Rocha et al. 2022) and create perfect breeding grounds for disease-carrying vectors like mosquitoes, increasing the risk of vector-borne diseases (Usman Qamar and Aatika 2023). The physical dangers of urban floods, including injuries and drownings, are well-documented (Agonafir et al. 2023), and stagnant floodwater can promote mould growth, exacerbating respiratory problems (Toda et al. 2023). Furthermore, flooding can disrupt food supply chains, leading to food shortages and malnutrition (Mirzabaev et al. 2023), while vulnerable populations, such as the elderly, face heightened risks due to limited mobility and healthcare access (Ward 2023). Moreover, the transport of

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contaminated materials from drainage/sewer networks caused by sewer blockages, or insufficient capacity under heavy rainfall leading to sewer surcharge (Addison-Atkinson et al. 2023) into urban floodwaters poses a public health risk. Environmental pollutants are likely to be associated closely with the colloid elements and fine-grained particulates, at the bottom sediment, and the intensity of the flow velocity and the amount of the overflow volume during heavy rainfall events affect the distribution and contamination over urban areas. These combined health impacts underscore the urgent need for comprehensive flood management strategies to protect public health.

Understanding the process of sediment transport during flood events in urban areas presents several critical challenges. Urban settings are inherently complex, characterized by diverse infrastructure, land use, and environmental conditions, including factors such as topography and weather patterns (Li et al. 2023). This complexity poses a formidable obstacle to the creation of universally applicable models or guidelines. A significant hindrance to progress is the scarcity of real-time data from sewer systems and urban surfaces during flood events (Lin et al. 2023). This scarcity of information severely limits our ability to develop precise models and predictions. Moreover, the sources of sediment and pollutants within urban areas exhibit significant variability (Chang et al. 2022), encompassing diverse contributors like road runoff, industrial discharges, and combined sewer overflows, making their accurate identification and quantification pivotal for effective management. Additionally, emerging pollutants, such as pharmaceuticals and microplastics (Bolognesi et al. 2022), further complicate these processes, calling for ongoing research to comprehend their transport and long-term environmental impacts. Finally, existing hydrodynamic and risk modelling tools, while useful, are hampered by simplifications and assumptions due to computational constraints, emphasizing the need for more comprehensive data and a deeper understanding of the underlying physical processes. Addressing these challenges requires experimental data to further improve and validate the numerical models.

The mitigation of flood risk is currently built on modelling tools which aim to simulate both overland and drainage networks flows (Martins et al. 2017). Although commercially available, the accuracy and utility of such models is dependent on understanding the interaction between surface and drainage flows at gullies and inlets (Kitsikoudis et al. 2021; Lopes et al. 2015; Martins et al. 2017, 2018b) and validation with experimental data (Martins et al. 2015, 2017, 2018a; b). This drainage system is usually divided into three sub-models that describe the flow in the drainage system, the surface system, and the linking elements. As current modelling tools are limited to 1D/2D, they are inherently limited in understanding sewer ejections including sediments into surface flows (Mignot et al. 2019).

Project

The project's fundamental premise lies in answering two research questions: (1) can we develop some evidence-based relationships suitable for models based on measurement of the sediment transport processes? (2) can we advance the validation, calibration, and utilization of physically-based numerical flood models when representing sediment transport, using experimental data obtained from a state-of-the-art above/below ground urban drainage experimental facility?

The project is therefore split in two clear aims:

1. Physical modelling to understand the transport and fate of sediments in surcharging urban drainage networks under flood conditions.
2. Developing simple modelling based approaches to represent the fraction of sediment transported to surface flow as a function of the flow/velocity.

With two distinct interconnected approaches:

1. We employ a state-of-the-art experimental facility featuring a meticulously designed physical model, mirroring real-world urban drainage scenarios. This model comprises a floodplain with dimensions reflecting urban areas, including a manhole structure and controlled inflow conditions (Rubinato et al. 2013, 2017). Sediments, representing road runoff, are introduced at steady rates. Through a combination of advanced techniques such as 3D Particle Tracking Velocimetry (PTV) and overhead camera observations, individual sediment grains and velocity vectors can be meticulously tracked. These experiments systematically vary pipe flow rates, surface flow conditions, and granulometries.
2. We leverage state-of-the-art open-source 3D Computational Fluid Dynamics (CFD) models, including OpenFOAM, to simulate urban drainage scenarios. These models incorporate sediment behavior through the Multiphase Particle-in-Cell (MPPIC) model. By systematically comparing our experimental data with numerical simulations, we aim to

refine and validate our numerical 3D models. Subsequently, we transition to simplified 1D/2D urban flood models, using sediment and pollutant modules. The linkage between the 1D and 2D components will be facilitated by time-integrated weir and orifice equations.

IMPACT OF THE EXPECTED RESULTS

The research project focuses on providing a comprehensive understanding of flow and particle transport dynamics within stormwater inlets and manholes, encompassing a range of granulometries. The expected outcomes will significantly contribute to the field of urban drainage, offering valuable insights into the intricate dynamics of stormwater management systems.

This research involves a detailed characterization of flow dynamics using existing instrumentation and state-of-the-art computational fluid dynamics software. It includes examining flow patterns, velocities, and particle transport dynamics in stormwater inlets and manholes under various conditions and granulometries. This analysis aims to improve the design and management of interface hydraulic equipment in urban drainage systems, and to develop efficient sedimentation and filtration strategies, enhancing the sustainability and effectiveness of stormwater infrastructure.

Furthermore, the project will lead to the formulation of practical recommendations and guidelines for optimizing the design and maintenance of stormwater infrastructures, ultimately streamlining the functionality of urban drainage systems.

To maximize the impact of these findings, the user group has devised a comprehensive dissemination plan. This plan includes publishing research findings in reputable journals (e.g., Journal of Hydrology, Water Resources) and international conferences [Urban Drainage Modelling (UDM) or International Conference on Urban Drainage (ICUD) or International Conference on Hydroinformatics (HIC)] to reach a broad audience, including academics, researchers, and industry professionals. Additionally, the user group will facilitate engagement through meetings, webinars, and workshops, providing platforms for stakeholders to discuss and exchange knowledge based on the research outcomes. The establishment of a dedicated online repository will offer easy access to research papers, reports, and datasets for the research and innovation community. Collaborative partnerships with relevant organizations and networks will further expand the reach of these findings.

In line with a commitment to transparency and innovation, the research data and findings will be openly shared with the broader research and innovation community through open-access platforms and repositories. This approach includes the creation of open data repositories for the secure storage and accessibility of research data, such as flow and particle transport measurements. The user group is actively involved in formulating data sharing policies to ensure responsible and ethical data use, ensuring its availability for future research and innovation initiatives.

The dissemination of these research results is expected to have a profound and lasting impact on the European Urban Drainage community. It can enhance the resilience of urban drainage infrastructures, optimize design and maintenance practices, reduce pollution, and stimulate innovation and collaboration within the research and innovation community. In summary, the research project's dissemination plan and open data policies will ensure that the anticipated results benefit infrastructure management, sustainability, and environmental stewardship within the European Urban Drainage community.

POTENTIAL FOR ACADEMIC OR INDUSTRIAL INNOVATION

The potential for academic and industrial innovation within this research project is substantial and is primarily driven by several key objectives. Firstly, the calibration of new models is essential, as it lays the foundation for more accurate predictions in the field of urban drainage. By fine-tuning these models to experimental conditions, their predictive capabilities can be significantly improved. Secondly, the optimization of manholes and inlets geometries and configurations is crucial, as it can lead to more efficient stormwater management systems. This optimization aims to enhance the functionality of these critical elements in urban drainage, contributing to better flow control. Therefore, the information that will be gathered in this study could be used to prioritize efforts to invest in failing sewer infrastructure and create appropriate goals to address the health concerns posed by sewage contamination from urban areas. Thirdly, the project offers an opportunity for issuing guidance to local authorities regarding remediation of pollution during/after flood events. These objectives collectively contribute to the potential for academic and industrial innovation in the realm of urban drainage and stormwater management.

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