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Real-time hydrological-hydraulic hybrid modelling to inform smart management of urban flow regimes

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Abstract: The flow regime describes the characteristic pattern of a waterway's flow quantity, timing and variability. Flow regimes are significantly changed by urbanisation and climate change, causing floods and increased peak flows, loss of baseflow, habitat degradation, ultimately threatening the survival of aquatic plant and animal species (Poff et al., 1997). In recent years, stormwater control measures (SCMs) have been applied to deliver more natural flow regimes. More recently, real-time control technology (RTC), allowing systems to be operated in response to live monitoring data, has been applied to improve the performance of SCMs in regulating flow regimes (Xu et al., 2022). Model Predictive Control (MPC) is often used in the control of RTC systems, but the process is computationally intensive. Real-time operation for multiple flow targets is technically challenging, even more so in the context of changing climate conditions. Meeting such requirements will rely on hydrological-hydraulic models to provide rapid, accurate and adaptive flow predictions.

The hydrological-hydraulic model can not only help provide flow predictions as input for real-time controlled SCMs systems, but also generate dynamic flow processes under control actions, allowing the impact of SCMs on the flow regime to be understood. These models can be mainly divided into physical models and data-driven models. The former are labour-intensive and costly, while the latter show high efficiency in computational speed, but lack transparency and interpretability. Current research has shown that hybrid models integrating deep learning techniques with physical models significantly enhance the accuracy and interpretability of flow process predictions with comparable computational speed (Zhong et al., 2024). Therefore, hybrid modelling shows potential benefits in informing better flow regime predictions and management in real-time, providing adaptability to respond to climate change and rapid urbanisation.

This study will propose a hybrid structure to model complex urban stormwater networks and predict the flow regime in real-time. The hybrid model will be constructed by combining an LSTM model with the water balance equation. The water balance equation will be used as part of the loss term in the LSTM, penalising prediction results that violate the law of water balance. Along with the hybrid model, a separate physically-based model (SWMM) and a deep learning model (LSTM) will also be constructed to verify if the hybrid model can make more accurate and adaptive predictions. Key drivers of the flow regimes will be found by quantifying the contribution of each input factor in the proposed hybrid model via the SHAP method.

The benefit of conducting hybrid modelling will then be investigated to answer whether the hybrid model can inform real-time adaptive control of distributed SCMs. The MPC method will be used, and the hybrid model in MPC will learn the response relationship between input features (including weather information, control actions and overflow from SCMs) and simulated flow from SWMM under the impact of SCMs. The hypothesis of this study is that the proposed hybrid model will show great promise to benefit flow prediction and management of SCMs, providing in-time, accurate and interpretable predictions of multiple flow targets, adapted to changing weather and operation conditions.

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