2024 European Control Conference (ECC)
June 25-28, 2024. Stockholm, Sweden

Minimization of CSOs through real-time valves control: Exploring Optimal Valves Numbers, Placement and Control to Improve Water Storage and Minimize Residence Time

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***Abstract*— Urban combined sewer overflow (CSO) events represent a major risk to surface water quality. This study develops and evaluates an optimal dynamic management strategy for CSO reduction in Dunkirk, France. The studied Dunkirk's catchment relies on ten spillways to manage excess stormwater. Nine spillways have real-time water level sensors and eight have calibrated discharge laws. The average annual CSO volume and frequency is 250,000 m^3 and 50 events, respectively. To solve the CSO issue and avoid costly detention ponds, a dynamic network control strategy was designed using InfoWorks ICM software. The network was divided into six autonomous zones. While the zones are distinct during dry weather, interconnection points in the network can allow for water transfer during heavy rainfall events. Five criteria guided the selection of the optimal dynamic management strategy: number and location of valves, valve type and dimensions, operating mode, and flood safety considerations. Several scenarios were tested via numerical simulation. The optimal approach involved dynamic control of two strategically positioned valves that achieved a 40% reduction in annual CSO volume, primarily targeting low-intensity rainfall events associated with higher pollutant concentrations. Increasing the number of valves was inefficient due to limited storage gains and potential overflow risks. Valve location and operation mode were key to maximizing storage, minimizing spillage, and ensuring flood safety. This study proves the success of dynamic sewer network control for CSO reduction and represents a promising approach for selecting the optimal strategy to adopt.**

I. Introduction

Combined Sewer Overflow (CSO) events from urban drainage systems pose significant threats to receiving water bodies, impacting environmental quality and public health. This study investigates the development and evaluation of an optimal dynamic management strategy to reduce CSO discharges in Dunkirk, France, while considering cost-effectiveness and network flood safety.

Manuscript received Mars 15, 2024. This work was supported by the French Water Agency Artois Picardie as part of the DK'Eau project in partnership with the Dunkirk Urban Community (CUD), the University of the Littoral Opal Coast, Deltares, and Ixsane.

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II. Study Site

The studied section of the Dunkirk combined sewer system (CSS) serves a 400-ha catchment area with 40,000 equivalent inhabitants. During heavy rainfall, the network's ten spillways are activated to discharge excess water, which may contain fecal bacteria such as *Escherichia coli*. The discharge of polluted water into the Veurne and Exutoire canals can ultimately affect bathing water quality and pose a danger to tourism in the city. (Figure 1). Nine spillways have real-time water level radar sensors, and eight possess calibrated spill laws for discharge measurement in function of the water level. The average annual volume and frequency are 250,000 m^3 and 50 CSOs respectively.

III. Methodology

To address the CSO challenges and avoid the high costs of retention basins, a dynamic network management strategy was developed to optimize storage capacity within the existing network. The InfoWorks ICM software was chosen to build the dynamic hydraulic model of the CSS due to its capabilities in simulating valve control phenomena and handling transient events. Calibration involved four rainfall events with varying return periods, considering both water level (nine points) and volume data (eight points) obtained from spillway sensors and specific spill laws (Figure 2). The network was divided into six sub-CSS autonomous zones using the flow labeling method, representing catchment areas drained by individual outlets. While these zones remain distinct during dry weather, the network's interconnections enable water transfer during rainfall (Figure 1). Topological analysis identified interconnection points, crucial for the chosen strategy. Zone areas range from 18 to 108 ha and have a maximum CSS storage capacity between 400 to 3000 m^3. The maximum storage capacity is determined through hydraulic modeling, ensuring network safety and flood prevention by limiting water levels to 1.5 m below the minimum ground level of each zone.

For the dynamic management strategy definition, five key criteria guided the selection of the optimal one: (1) Number of valves, determined by cost-effectiveness and maximum storage capacity; (2) Valve location, strategically chosen to maximize storage potential; (3) Valve type and dimensions, selected for optimal operation and network adaptation; (4) Valve operating mode, defined by precise control rules, including opening levels, opening percentages, and speeds; (5) Safety considerations, ensuring flood prevention and the ability to revert to normal operation during heavy rainfall exceeding storage capacity.

IV. Results

Ten numerical simulations using the hydraulic model assessed the impact of different dynamic management strategies. The optimal strategy involved dynamically managing two controlled valves installed in strategic and optimal locations. This approach achieved a 40% reduction in annual CSO volume, primarily targeting low-intensity rainfall events with higher pollutant concentrations. Increasing the valve number proved inefficient due to limited storage gains and potential increased spillage risks in some cases. Valve location and operation mode (opening percentage and speed) emerged as critical factors for maximizing storage, minimizing spillage, and guaranteeing flood safety. This study demonstrates the efficacy of dynamic management strategies for CSO reduction in urban drainage systems. The developed methodology is applicable to any other CSS, offering a promising approach for identifying optimal solutions and contributing to improved water quality and environmental protection.

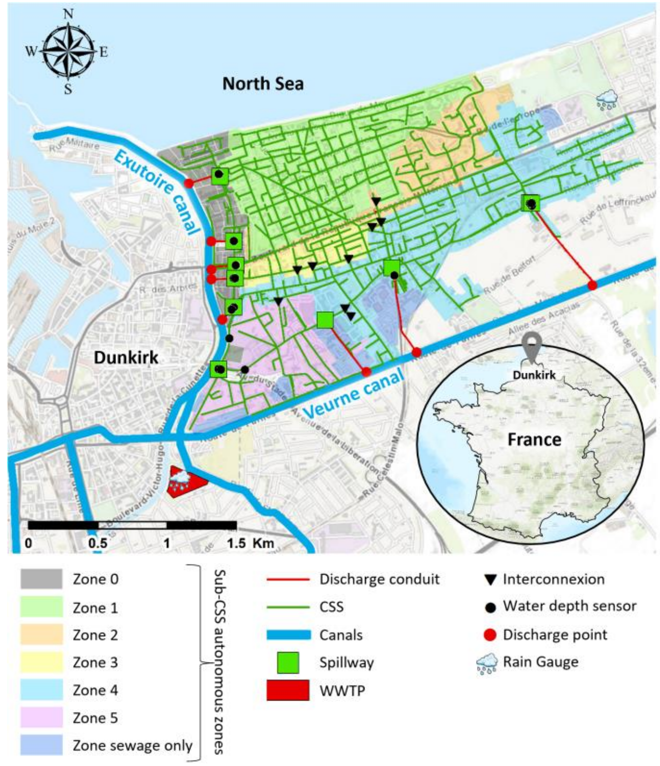

Figure 1. Combined Sewer System and Catchment Area within the "Communauté urbaine de Dunkerque" (CUD) (Data source: CUD; Base map: World Topographic Map).

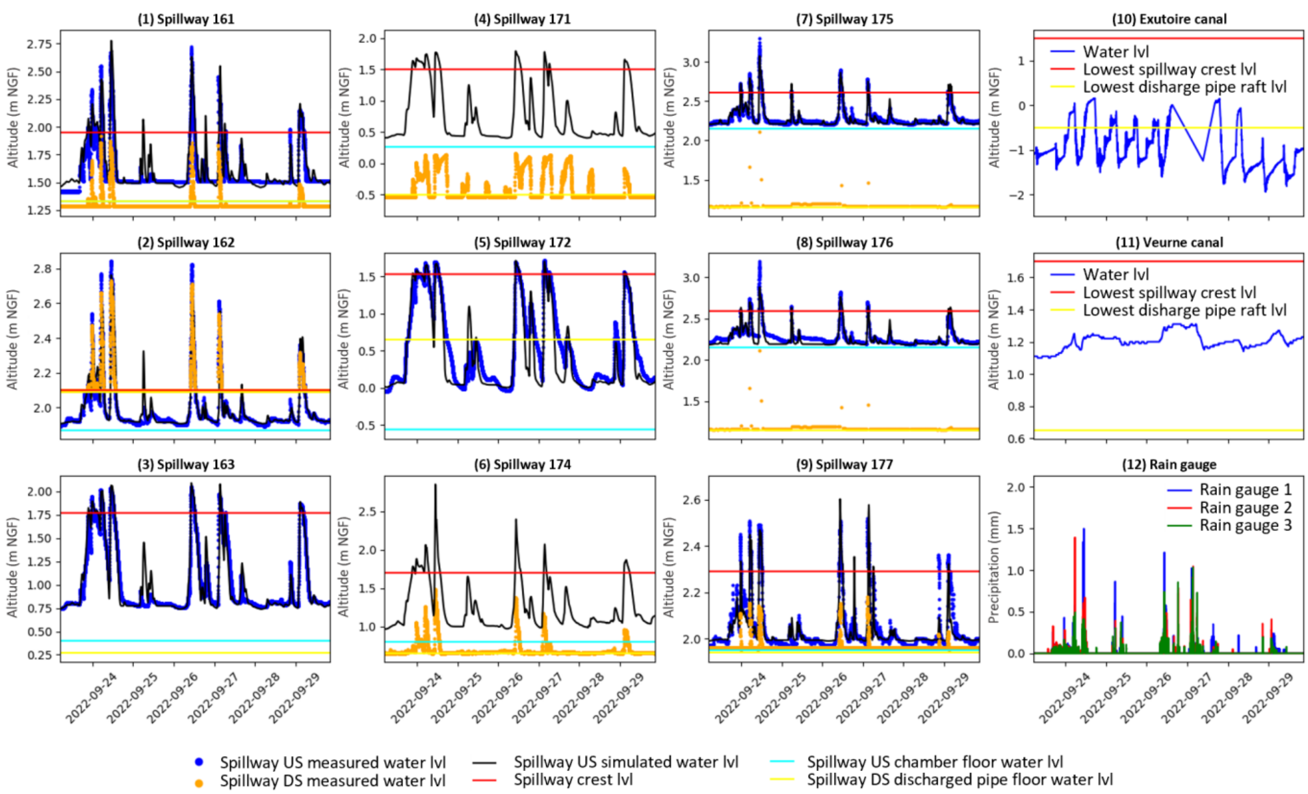

Figure 2. Spillway Water Level Calibration: Measured vs. Simulated Values ((1) to (9)). Measured water level in Exutoire and Veurne canals ((10) and (11)). Precipitation from 3 Rain Gauges (12). *(US = Upstream, DS = Downstream, NGF = Nivellement Général de la France)*