Large-Scale Assessment and Prioritization of Combined Sewer Overflows in Flanders

Évaluation et priorisation à grande échelle des déversoirs d’eaux usées unitaires en Flandre

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RÉSUMÉ

Cette étude présente une analyse à grande échelle des déversoirs d’orage (DO) en Flandre, réalisée à partir de simulations hydrodynamiques InfoWorks ICM® pour l’année 2021 et de calculs de charges polluantes avec le logiciel propriétaire Cockle®. Environ 8 300 déversoirs ont été modélisés, couvrant 85 % de la population raccordée, révélant une forte variabilité des émissions. Les charges équivalentes atteignent ~400 000 habitants (≈7 % de l’entrée du système). À l’échelle des agglomérations, 54 % respectent la règle des 2 % de la directive européenne. Les CSO dominent les émissions de DBO et de MES, tandis que les effluents des stations d’épuration dominent l’azote total (TN) et le phosphore total (TP). Cockle® combine des statistiques de concentration issues de DO échantillonnés à haute fréquence avec les débits simulés (corrigés pour les eaux parasites) afin d’estimer les charges annuelles. Des cartes synthétiques ont été produites par zone de traitement et masse d’eau, localisant les points d’impact (stations, raccordements en attente, systèmes individuels appropriés prévues et DO), ces derniers étant représentés par des cercles proportionnels à leur émission. Ces résultats soutiennent une priorisation ciblée et fournissent un cadre pour la mise en conformité avec la directive européenne et les impacts attendus du changement climatique.

ABSTRACT

We present a large-scale assessment of combined sewer overflow (CSO) emissions across Flanders based on InfoWorks ICM® hydrodynamic simulations for 2021 and proprietary software Cockle® pollutant-load calculations. Approximately 8 300 CSOs were modelled, covering 85% of connected inhabitants, revealing substantial variability in overflow behaviour. Total CSO emissions amount to ~400,000 equivalent inhabitants (IE), ≈7% of system input. At the agglomeration level, 54% comply with the EU Urban Wastewater Directive’s 2% rule. CSOs dominate emissions of BOD and suspended solids, whereas WWTP effluents dominate TN and TP. Cockle® applies concentration statistics from multiple pre-registered, high-frequency sampled CSOs and combines them with simulated spill flows (corrected for infiltration and inflow) to estimate annual pollutant loads consistently. Comprehensive maps were produced for each drainage area and surface water body, showing all impact points—including WWTPs, pending connections, planned individual treatment systems, and CSOs—with circles scaled to discharge magnitude. Findings support targeted prioritization under evolving climate and regulatory constraints and provide actionable insights for compliance planning.

KEYWORDS

agglomerations, combined sewer overflow, pollutant loads, urban wastewater treatment directive, Cockle ®

1 INTRODUCTION

Combined Sewer Overflows (CSOs) are a major source of intermittent pollutant discharges during wet weather events in urban drainage systems (Botturi *et al.*, 2021). This study focuses on conventional parameters—COD, BOD, TSS, TP, and TN—that remain central to regulatory compliance and design. These pollutants are critical for assessing the UWWTD 2% rule and prioritizing CSO remediation strategies. The revised UWWTD (EC, 2024)indeed imposes stricter CSO control, notably limiting annual CSO loads relative to dry-weather inputs at agglomeration scale. Flanders offers a unique testbed due to extensive sewer modelling and coherent monitoring infrastructure. This work quantifies CSO emissions, evaluates compliance at multiple scales, and proposes a prioritization framework based on equivalent inhabitant loads.

2 MATERIALS AND METHODS

2.1 Cockle® Calculation Framework

Cockle® is a specialized computational tool designed to estimate pollutant loads from combined sewer overflows using a hybrid approach that combines hydraulic outputs with statistical concentration models. The core principle is straightforward: for each time step, overflow discharge volumes are multiplied by pollutant concentrations to derive instantaneous loads, which are then aggregated to daily and annual totals. This methodology ensures consistency across large datasets, accounts for uncertainty through stochastic modelling, and supports strategic decision-making for CSO management under regulatory constraints (Dirckx *et al.*, 2022).

2.1.1 Data Inputs and Processing

- **Hydraulic Component:** CSO spill flows are obtained from long-term hydrodynamic simulations in InfoWorks ICM®, driven by local rainfall time series and corrected for infiltration and inflow (I&I). This ensures realistic representation of wet-weather behaviour across sewer systems.
- **Concentration Component:** Pollutant concentrations are drawn from a stochastic database built from multiple pre-registered CSOs sampled at high frequency (time-proportional). This statistical approach captures variability in first-flush dynamics and seasonal patterns.

2.1.2 Outputs and Applications

- **Annual pollutant loads** also expressed in equivalent inhabitants (IE) using COD = 123 gCOD/d·IE for comparability with continuous discharge points, and **GIS-ready datasets** for visualization at drainage area or surface water body level.
- **Compliance indicators** (e.g., UWWTD 2% rule) and prioritization metrics for remediation planning.
- **High-resolution pollutant load time series**, aligned with hydraulic simulation time steps, which can be used in river water quality models to assess short-term (instantaneous) impacts.

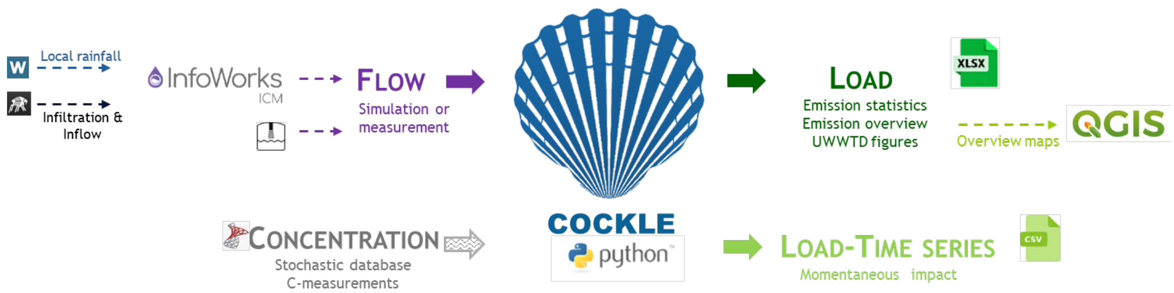

Figure 1: Cockle scheme

3 RESULTS AND DISCUSSION

3.1 Emission properties

3.1.1 Combined Sewer Overflows

Approximately 8,300 CSOs were modelled (Figure 1), representing around 85% of the Flemish sewer network. This extensive coverage provides a unique regional perspective on overflow behaviour. The results reveal marked heterogeneity: whilst around one in four CSOs (≈26%) remained inactive throughout 2021, others discharged pollutant loads equivalent to hundreds or even thousands of inhabitants. This variability reflects differences in catchment size, sewer configuration, and rainfall response. Applying a 50 IE threshold - a practical benchmark for significant impact - shows that approximately 18% of CSOs qualify as priority sites. Within this group, a small but important subset (≈1%) exceeds 500 IE, and the most extreme cases surpass several thousands of IE, indicating localised hotspots with disproportionate environmental pressure (Figure 2). These findings underscore the need for targeted interventions rather than uniform measures.

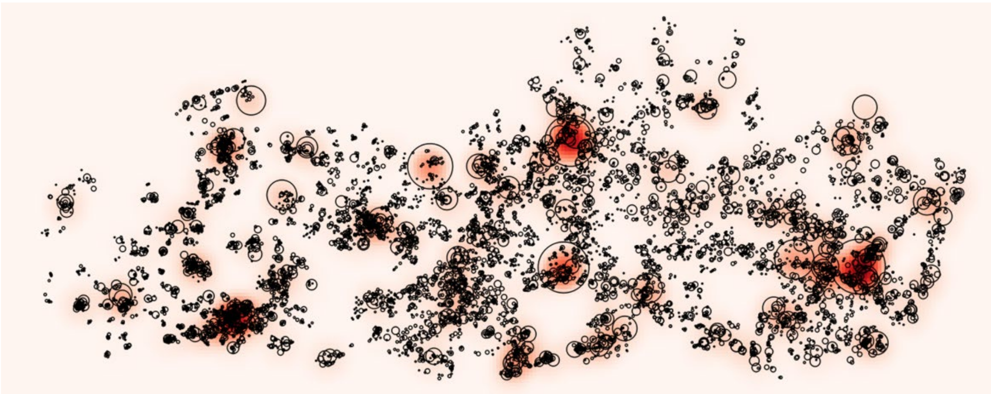

Figure 1. Heatmap of Flemish CSO emissions

3.1.2 Detention and Stormwater tanks

In addition to CSOs, emissions from detention tanks and stormwater tanks located at WWTP premises were assessed (Cockle® incorporates separate stochastic dataset for these). These structures are designed to retain stormwater and promote sedimentation, thereby reducing pollutant loads. Nevertheless, results show that stormwater tanks can still exhibit significant emissions, with several ranking among the highest discharge points in the dataset. Detention tanks generally perform better, yet approximately 22% of the modelled basins still exceed the 50 IE threshold. Although their contribution is smaller than that of CSOs, these assets require attention in prioritisation strategies, particularly where sensitive receiving waters are concerned.

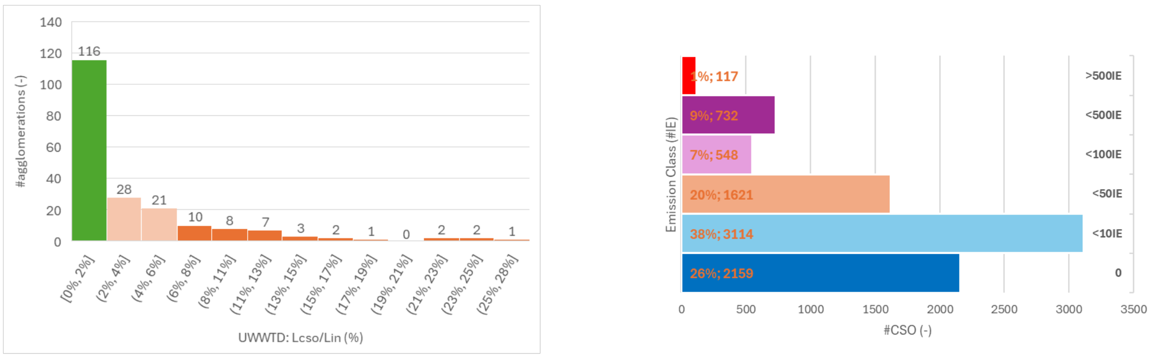

Figure 2: (left): UWWTD compliance check representing bins of 2% (green: compliant – light orange: not compliant – orange: significantly not compliant) – (right): division in emission classes (expressed as IE)

3.1.3 WWTP effluent

In addition to CSO emissions, the analysis also considers discharges from wastewater treatment plants (WWTPs). For this purpose, a 'sister' application, Cockle4F, was employed. Cockle4F applies the same stochastic percentile-based principle as Cockle®, but instead of CSO concentration statistics, it uses multiple high-frequency measurements collected directly from WWTP effluents. This approach ensures consistency across all discharge points and enables a robust comparison between intermittent CSO loads and continuous WWTP emissions. Results indicate that for parameters such as BOD and suspended solids, CSOs tend to dominate, whereas for nutrients (TN and TP), WWTP effluents represent the larger share of annual loads.

3.2 Mapping for prioritization

Comprehensive maps were produced per treatment area and per surface water body to support decision-making, showing WWTPs, pending connections, planned IAS (individual appropriate systems), and CSOs; the latter are represented by circles scaled to discharge magnitude.

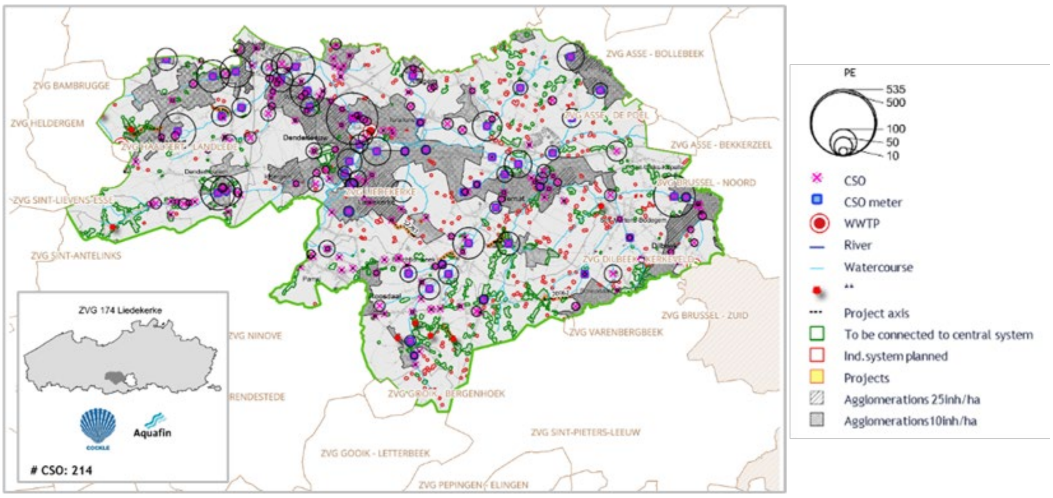

Figure 3. Example of Cockle ® output map showing agglomerations, remaining outlets and all CSO with circles indicating the magnitude of the emission (yearly load 2021 converted to equivalent PE) for the drainage area of Liedekerke

3.3 UWWTD

The Urban Wastewater Treatment Directive (UWWTD) sets performance standards for agglomerations, including the 2% rule that limits CSO emissions relative to dry-weather loads. Our analysis reveals that approximately 54% of agglomerations comply with the 2% rule, while about 26% exceed the threshold moderately (balance > 6%), and nearly 20% fall significantly short of compliance (see Figure 2). These findings highlight the importance of scale in regulatory reporting and investment planning

4 CONCLUSIONS

CSO emissions in Flanders are non-negligible, with ~7% pollutant-loss equivalents and pronounced heterogeneity across assets. Hydrodynamic–statistical coupling (ICM + Cockle®) enables consistent, scalable estimation of annual loads and defensible prioritization. Under the UWD 2% rule, compliance is substantially higher at agglomeration scale than at treatment area scale, guiding both reporting and investment planning. Future work will extend coverage (~95%), and further operationalize impact-based prioritization to accelerate CSO remediation. This will include emission, water quality and environmental (ecological) aspects. We will also look into Cockle® time-series outputs with dynamic water quality models, enabling impact-based management strategies at catchment scale.

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