



# Conceptual Framework for Integrating Real-Time Control and Source Control Solutions for CSO Frequency Control

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**Abstract.** Combined sewer overflows (CSO) are associated with water quality degradation and health risks, but limited knowledge exists on the optimal solutions applicable to reach maximal overflow frequency targets as specified by some regulatory agencies. This study assesses the potential benefit of integrating source control with real-time control solutions based on hydrological/hydraulic modelling of urban catchments of the Province of Québec (Canada). Firstly, modelling procedures for volume sizing of CSO solutions are improved by determining the proper rainfall input among the three most common types of rainfall data (continuous simulation, historical rainstorms and IDF-derived storms) excluding winter months in the analysis to be aligned with Quebec legislation. Secondly, a methodological framework is developed to integrate source control and optimal real-time control solutions based on a cost-efficiency performance objective. Thirdly, two optimization software are coupled to iteratively solve for the best flow management strategy according to physical and operating constraints; iPOP for source control design and CSoft for dynamic control. Preliminary results showed that simulation of continuous rainfall series results in the most accurate volume estimations for sizing CSO solutions and IDF-derived design storms could serve as input data for initial optimization runs. Based on the determined appropriate rainfall data, source control optimization showed considerable solutions implementation cost reduction for acceptable runoff reduction. Future work includes refining the integrated solution framework and comparative analysis of modelling results under optimal implementation of source control and real-time control solutions.

**Keywords:** Combined sewer overflows · Source control · Real-time control  
Rainfall data

## 1 Introduction

For many cities over the world, sanitary sewage and stormwater runoff are intercepted and transported together in a combined network toward a wastewater treatment plant. Per design, the capacity of this system will be surpassed during some wet weather events or thawing periods, causing discharge of untreated waters into receiving waters. These combined sewer overflows (CSOs) are one of the major causes of degraded water quality in urban rivers (Madoux-Humery et al. 2015) and the impact of climate change and urban land development are expected to exacerbate CSO-related problems (Yazdanfar and Sharma 2015).

In the Province of Quebec (Canada), many municipalities are not achieving governmental overflow frequency targets to mitigate CSO impacts. For example, in the year 2013, a total of 36 565 CSO events caused by rainfall or snowmelt events were recorded (MAMOT 2014) contributing to aquatic life and environmental degradation, drinking water supply contamination and primary contact recreation restrictions. Municipalities are now required to demonstrate compensatory actions to avoid increasing the annual frequency of CSO under land development projects (MDDELCC 2014).

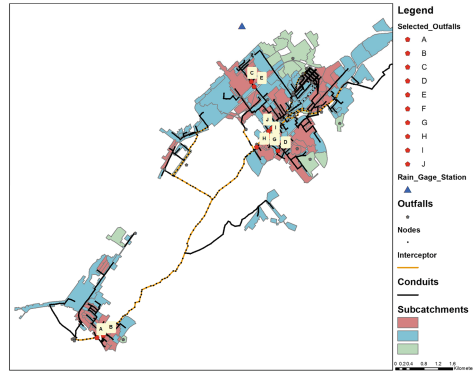
Implementation of CSO control measures presents significant challenges as only little knowledge exists on the adequate use of rainfall data for CSO analysis and the optimal choice of solutions to reach maximal annual overflow targets. To narrow these knowledge gaps, this research project aims at: (1) analysing the impact of rainfall inputs for sizing CSO mitigation measures; (2) elaborate an innovative methodological framework for integrating real-time and source control solutions optimization for CSO frequency reduction; and ultimately (3) evaluating how real-time control of the drainage network influences the design of source control practices at the watershed scale.

## 2 Materials and Methods

### 2.1 Study Area

The first case study is a 400 ha combined sewer catchment located in the southern part of Québec Province, Canada. The network was modelled using the hydrologic/hydraulic PCSWMM software (Computational Hydraulics International 2016) and is schematised in Fig. 1 with the ten overflow structures for which CSO frequencies and volumes were analysed (outfalls A to J). For this municipality, the provincial legislation imposes a maximum of seven CSOs during the wet weather season comprising May to November months.

The second case study is a smaller combined sewer catchment of 102 ha located further south in Québec Province, Canada. The network comprises a deep tunnel of 2.1 m of diameter with one overflow structure located downstream.



**Fig. 1.** Combined sewer network and selected CSO structures

## 2.2 Rainfall Data

Different rainfall inputs were simulated to determine resulting impact on retention volume estimations for CSO frequency control.

*Continuous Simulation.* Nine years of seasonal 5-min rainfall data (May to November 2006–2009 and 2011–2015; since winter months are excluded from Quebec legislation).

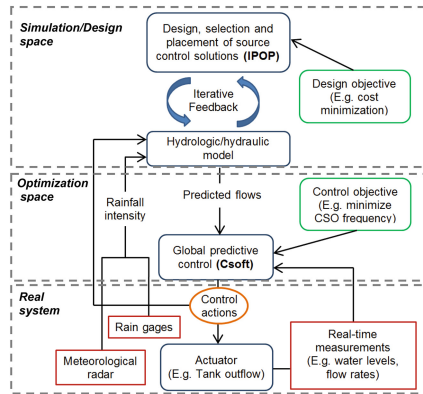
*Historical Rainstorm Events.* A minimum inter-event time (MIT) criteria varying from 3, 6, 12 to 24 h was applied to the observed rainfall record. Historical design rainstorms were further selected among the MIT-separated series by frequency analysis, based on two rainfall event selection criteria: (1) total depth; and (2) maximal intensities over durations of 30, 60, 120 and 180 min. The selected events are exceeded, in depth or intensity, seven times a year maximum in order to achieve the annual CSO frequency target applicable at the case study location.

*Intensity Duration-Frequency (IDF) Derived Storms.* IDF curves were constructed from daily maximum intensity values determined for durations varying from 5 to 1440 min. From the IDF curves, the following synthetic storms were derived for a return period of seven times a year: (1) 1 h, 3 h and 6 h Chicago storms (Keifer and Chu 1957); (2) 1 h Hydrotek storm (Watt et al. 1986); (3) 1 h AES type 2 (Rousselle et al. 1990); and (4) 3 h symmetrical triangular distribution.

## 2.3 Conceptual Framework for Integrating Solutions for CSO Frequency Control

In order to assess the combined impact of applying real-time control and implementing source control practices, Fig. 2 illustrates how the simulation, optimization and real system interact and the feedback loop linking global predictive real-time control of the network and source control solutions design. The methodology will further rely on the integration of two optimization software: Integrated Planning and Optimization Program (iPOP) and the Control of Sewer Overflow SOFTWARE (Csoft). iPOP is a software

for optimizing the design of green and grey solutions for CSO abatement. It relies on SWMM 5 for sewer simulation and on a particle swarm optimization (PSO) or genetic algorithm (GA) for determining the optimal design (i.e. the alternative that enables to achieve the design objective(s) at the lowest cost or the most efficient options determined from Pareto front analysis). On the other hand, Csoft is a software dedicated to the operation of sewer systems. It enables to find the optimum setting of gates and pumps in order to minimize CSO frequencies and volumes. The optimal set points are determined using a Mix Integer Linear Programming algorithm.



**Fig. 2.** Optimization feedback loop between source control solutions and global predictive control

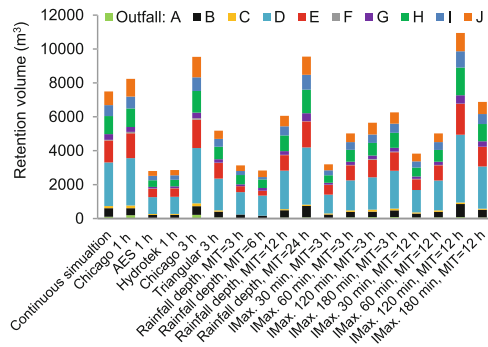
The first step of the global methodology, is to apply iPOP and Csoft alone, which would provide comparison results for further assessing the combined benefit of integrating both design tools. In the case of source control optimization, the following procedure was followed for running iPOP: (1) Identification of land suitability for source control approaches based on detailed data on land uses, surface elevations, hydraulic soil conductivity and other geographical information, (2) Determination of the running parameters of SWMM (design rainfall event and simulation options), (3) Development of the optimization objective penalties and source control implementation cost functions, and (4) Selection of the iPOP optimization parameters including the optimization algorithm, population size, objective method (cost minimization or cost-efficiency curve), present worth analysis period and other economic considerations.

### 3 Results and Discussion

#### 3.1 Rainfall Input Impact on the Volume of CSO Control Solutions

Figure 3 compares the design volume estimated with the different rainfall inputs for the study catchment. Volume determination is used as a point of comparison for rainfall

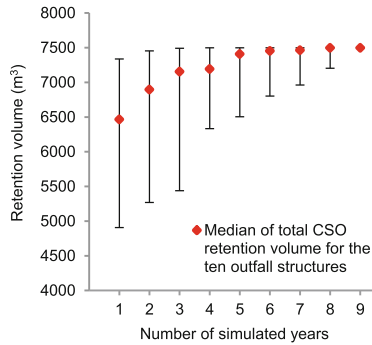
data assessment, whereas the next research steps will include solution type, placement and operation. Continuous simulation of rainfall records led to solution sizing specific to each outfall structures. However, reducing the number of years in the analysis rapidly impacted the estimated volumes (see Fig. 4) as a consequence of inter-annual variability of rainfall data. For the historical design rainstorms based on total depth or maximal intensity, retention volume estimations demonstrated high inter-event variability, which is disputably applicable as design criteria for CSO control. Finally, event-based simulation of synthetic design storms derived from multiple IDF values such as Chicago storms should be prioritized over other standard storms as they resulted in volume estimations closer to those of continuous simulation. Synthetic design storms should serve as preliminary assessment of CSO control solutions and optimization runs, whereas continuous simulation for the final design and validation.



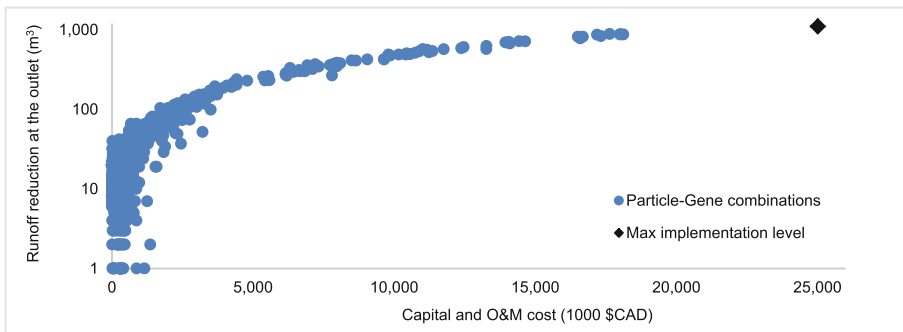
**Fig. 3.** Retention volumes estimated to achieve a maximum of 7 CSOs per year under continuous simulation and event-based simulation

### 3.2 Source Control Optimization

Preliminary optimization results of bioretention cells quantity and placement at the watershed scale was conducted for the second case study under PSO. Figure 5 presents efficiency-cost results based on a runoff reduction objective. The design rainfall event is selected according to the above analysis (Chicago storm of 3 h and a return period of 7 times a year) and has a frequency which corresponds to typical CSO frequency targets. Compare to the maximum implantation level, results demonstrated considerable capital, operation and maintenance cost reduction over the analysis period of 20 years for acceptable runoff reduction. Interestingly, the highest level of bioretention cells implementation is usually not located in the sub-catchments having the greatest impervious surfaces. Further work will permit to determine optimal combination of multiple source control technologies (bioretention cells, permeable pavements, infiltration trench, etc.) to achieve CSO frequency targets in particular rather than only overall runoff reduction.



**Fig. 4.** Sensitivity to the number of years of the total retention volumes computed for the 10 outfall structures to achieve a maximum of 7 CSOs per year



**Fig. 5.** Cost-efficiency results for bioretention cells implementation

## 4 Conclusions

This study addresses the knowledge gaps of CSO frequency control. A better understanding of the impact of rainfall data on solution design is a prerequisite for improving modelling procedures for CSO analysis. Simulation of a continuous rainfall record results in the most accurate volume estimations for refining CSO solutions sizing, whereas IDF-derived design storms provide acceptable results for initiating optimization design. Based on adequate rainfall data selection method, the impact of integrating source control with online real-time control solutions can further be assessed. Preliminary results for source control quantity and placement optimization showed iPOP potential for reducing overall runoff while limiting investments. Future work will permit to apply both source control and real-time control optimization tools in integration to achieve CSO frequency targets. The research findings contribute to the advancement of knowledge concerning urban drainage system modelling for optimal solutions development for CSO control.

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