



HAL
open science

Un modèle hydrologique semi-distribué pour la réduction des déversements par des stratégies de déconnexion des eaux pluviales.

Violeta Montoya, Pascal Molle, Helene Castebrunet, Damien Tedoldi, Gislain Lipeme Kouyi

► To cite this version:

Violeta Montoya, Pascal Molle, Helene Castebrunet, Damien Tedoldi, Gislain Lipeme Kouyi. Un modèle hydrologique semi-distribué pour la réduction des déversements par des stratégies de déconnexion des eaux pluviales.. Novatech 2023, Graie, Jul 2023, Lyon, France. hal-04186331

HAL Id: hal-04186331

<https://hal.science/hal-04186331v1>

Submitted on 18 Sep 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Un modèle hydrologique semi-distribué pour la réduction des déversements par des stratégies de déconnexion des eaux pluviales.

A semi-distributed hydrological model for CSO mitigation through stormwater disconnection strategies

V. A. Montoya-Coronado¹, P. Molle², H. Castebrunet³, D. Tedoldi¹, G. Lipeme Kouyi¹

¹Univ Lyon, INSA Lyon, DEEP, EA7429, 69621 Villeurbanne, France – violeta-alexandra.montoya-coronado@insa-lyon.fr, damien.tedoldi@insa-lyon.fr, gislain.lipeme-kouyi@insa-lyon.fr ;

²INRAE, Research Unit REVERSAAL, Lyon, France - pascal.molle@inrae.fr

³IGE, Grenoble, France - helene.castebrunet@univ-grenoble-alpes.fr

RÉSUMÉ

La gestion à la source des eaux pluviales est de plus en plus utilisée pour soulager le réseau unitaire et contribuer à réduire les déversements vers les milieux naturels. Cependant, cette approche soulève plusieurs questions sur le nombre minimal d'infrastructures, leurs types et leurs emplacements optimaux pour obtenir une réduction significative des déversements à l'échelle du bassin versant. Ces questions sont souvent évaluées par des approches de modélisation et des analyses de scénarios. Pour faciliter la formulation de scénarios de déconnexion qui atteignent directement les objectifs de réduction des volumes déversés, un modèle semi-distribué est proposé dans cette étude. Le modèle permet de simuler les différentes composantes de débit du bassin versant (débits des eaux usées, eaux de ruissellement et eaux claires parasites) et les déversements. L'exploitation des résultats des simulations permet ensuite d'identifier les composantes à déconnecter et l'emplacement prioritaire des ouvrages à la source dédiés à cette déconnexion. Le modèle a été appliqué au bassin versant d'Ecully sur une année de simulation. Pour illustrer la méthodologie, un événement pluvieux typique a été analysé. Les résultats obtenus montrent que pour respecter la limite réglementaire de 5% en volume annuel déversé, il est nécessaire de déconnecter de 3% les eaux de ruissellement produites dans le sous-bassin versant identifié. Par la suite une analyse à long terme des déversements sera effectuée pour déterminer les scénarios de déconnexion potentiels afin d'atteindre les objectifs d'autosurveillance réglementaire notamment concernant le nombre de déversements et le volume déversé sur une année.

ABSTRACT

Sustainable Urban Drainage Systems (SUDs) are increasingly used to alleviate the sewer system and thus contribute to reduce combined sewer overflows (CSO). However, this approach raises several questions about the minimal number of SUDs, their types, and optimal locations to achieve a significant decrease of CSO at the catchment scale. Those questions are often appraised through modelling approaches and scenario analyses. To facilitate the formulation of disconnection scenarios that directly achieve the objectives of spill reduction a semi-distribute model is proposed in this study. The model simulates the different components of the catchment (wastewater, runoff and rain infiltration and inflow water) and the CSO volume discharges. The results of the simulations can then be used to identify the components to be disconnected and the priority location of the structures at the source dedicated to this disconnection. The model was applied to the Ecully catchment to one simulation year. To illustrate the methodology, a typical rainfall event has been analyzed. Results show that in order to respect the regulatory limit of 5% in annual volume discharged, it is necessary to disconnect 3% of the runoff produced in the identified sub-watershed. A long-term analysis of the discharges will then be carried out to determine potential disconnection scenarios in order to achieve the regulatory self-monitoring objectives, particularly with regard to the number of discharges and the volume discharged over a year.

MOTS CLÉS

Combined sewer overflow, Disconnection, Integrated Stormwater Management, Modeling, Urban Planning

1 INTRODUCTION

Combined sewer overflows (CSO), consisting of untreated spills of storm- and wastewater caused by heavy rains, are one of significant source of pollution towards surface waters (Botturi et al., 2021). Nowadays, different stormwater management strategies are increasingly applied to relieve the traditional combined sewer system and thus, avoid CSO (Fan et al., 2022). In order to mitigate CSO volumes and frequencies, the implementation of sustainable urban drainage systems (SUDS) upstream seems appropriate. However, such implementation across a territory raises several questions about the optimal location, type, number and size of SUDS (Ferrans et al., 2022; Lerer et al., 2015; Torres et al., 2016). Hydrological and Hydraulic models are used to explore a diversity of configurations (also called scenarios) and determine their performance according to the targeted objectives. A large variety of approaches exist and can be found in the literature for SUDS scenario implementation. For example, Bach et al. (2013) developed an integrated tool for SUDS placement selection based on urban land use characteristics, Alves et al. (2016) used a decision tool based on local constraints (area, drainage area, slope, soil type, groundwater) and Torres et al. (2021) used an piece-wise linear interpolation method for SUDS placement.

However, even if the placement choice respects engineering constraints (slope, soil type, among others...), it is still not focused on its performance in terms of reduction of spilled volumes. In addition, many investigations are based on the trial-and-error method, changing one parameter prior to each simulation and evaluating if the performance is enough for the desired objectives. This type of approach may be a considerable computational time and input data demanding.

This study aims to consider the aspects that are lacking in existing SUDS planning studies for CSO mitigation: how to identify the most suitable placement(s) for implementing SUDS according to their contribution to CSO volumes and how to quantify the effort needed for a disconnection strategy according to the quantitative objective to be reached (e.g. volume reduction).

These two questions have been investigated in this article using a specifically designed semi-distributed hydrological-hydraulic model. The latter simulates flow dynamics (runoff water, wastewater, rainfall-induced infiltration inflow and overflow water) in the combined sewer system, under the current configuration and accounting for scenarios with SUDS. Finally, based on the quantitative outputs of the model (with a particular focus on CSO frequency and volume), a prioritization method selects the sub-catchments where SUDS implementation would be most effective to fulfil the selected criteria.

2 MATERIALS AND METHODS

2.1 Case study

The methodology was applied to the 245-ha catchment of Ecully (Lyon, France), which is drained by a combined sewer system with an average slope of 2%. The catchment is urbanized with 42% of impervious surface. The main CSO structure of the catchment was monitored by the Field Observatory for Urban Water Management (OTHU - <http://othu.graie.org>) from 2004 to 2013. Water levels and flow velocities were continuously measured upstream and downstream of the CSO with a 2-min time step. Rainfall was also measured with a 1-min time step.

2.2 Data-driven hydrological model

The aim of the model was to simulate each component of the flow monitored upstream of the CSO (wastewater, groundwater infiltration, surface runoff, rainfall-induced infiltration inflow). To avoid the discrepancy between the use of empirical input parameters and the behavior of the catchment, the model has been developed to use parameters that can be extracted from observations and data treatment analysis (i.e. runoff coefficient, initial losses, wastewater inflow pattern, groundwater inflow pattern). As shown in Figure 1, the model is based on (i) the rational method for surface runoff production, with a runoff coefficient calculated from the observations over the observed period, (ii) a linear reservoir as a transfer function for surface runoff and as a soil reservoir for the slow infiltration and inflow into the network. Both are implemented with a respective lag time determined from the rainfall observations over the same period (iii) an injection of wastewater pattern and groundwater infiltration based on monitoring surveys and (iv) a discharge equation, obtained by means of 3-D numerical simulations of the CSOs proposed by Momplot (2014). The outputs of the model are: the volume and frequency of CSO and the water balance of each sub-catchment. These output criteria were selected to allow to compare the initial state of the catchment to the legislative objectives as the annual exceedance

of discharge volume in accordance with the local legislation (in France the discharge volume is limited to 5% of the volume produced per year by the WWTP).

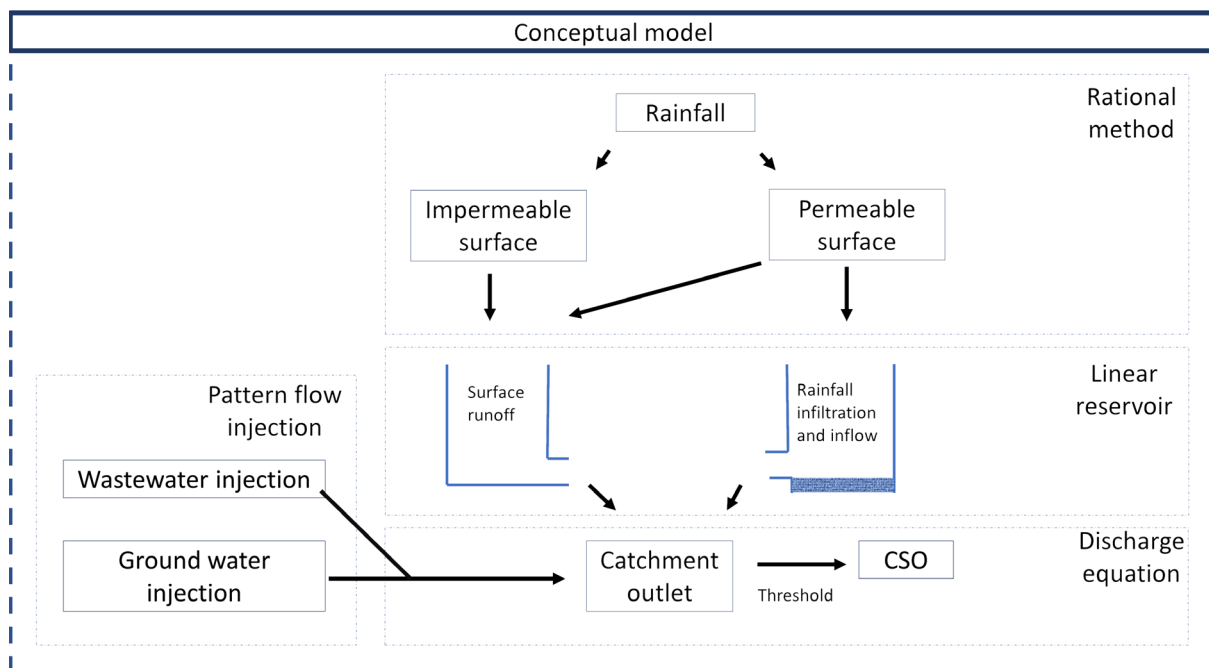


Figure 1 Conceptual model of surface, sub-surface and network processes per sub-catchment.

2.3 Disconnection methodology

The disconnection methodology is a three-step approach: (i) rank the sub-catchments according to their water balance (ii) identify the water component that contributes the most to the sub-catchment(s) water balance and (iii) correlate the required volume to be reduced annually to the component identified previously. The remaining volume will be first removed in the main contributing sub-catchment and if necessary, the volume is removed from the next sub-catchment in the ranking.

3 PRELIMINARY RESULTS

The catchment was divided in 6 sub-catchments with different sizes and land use characteristics (Figure 2, a). The treatment analysis of 2007 observed data allowed to obtain the input parameters for calibrating the model. One rainfall year was simulated and rainfall events with CSO were studied. The model proved to simulate 75% of the 26 overflow events in 2007 with a NASH criterion better than 0.6 compared to the discharge flow measured. To illustrate the disconnection methodology, one rainfall event characterized by a return period of 2 months (data from Lyon Metropole) is taken as an example. Figure 2, b) show the different component simulated: wastewater, groundwater, surface run-off and rainfall infiltration and inflow and the CSO threshold. Results show that 8% of the total volume produced in the catchment is discharged through the CSO for the present rainfall event. According to the water balance of each catchment (Figure 2, c), the major volume could come from the sub-catchment D, A and C and the main component is runoff water. To reduce, at least, to 5% the fraction of the spilled volume (threshold proposed by the French regulation policies), the proposed disconnection methodology suggests to reduce at least 3% of run-off volume coming from sub-catchment D.

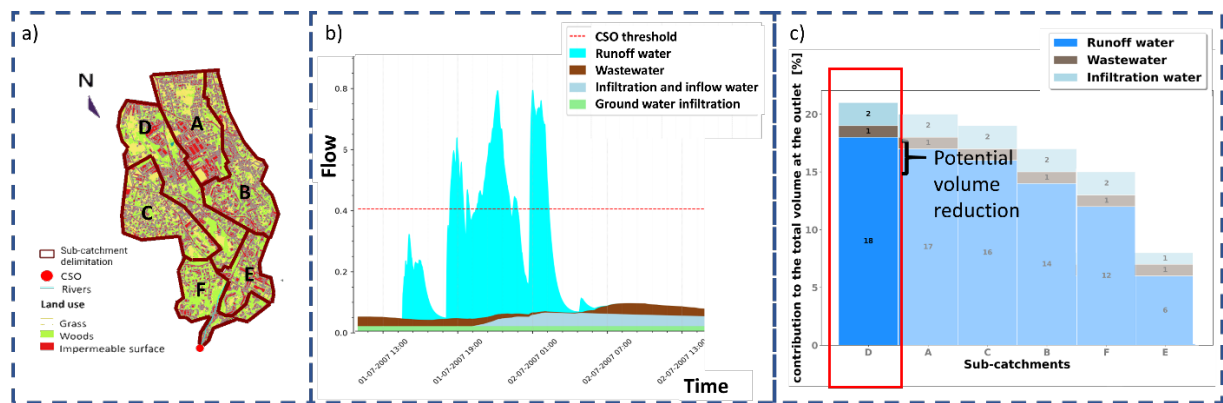


Figure 2 a) catchment and sub-catchments land use of Ecully b) example of hydrograph simulated with the model showing the different urban water components c) classification of sub-catchments according to their contributions to the catchment outlet. The contribution is described according to the volume produced by each component per sub-catchment.

4 CONCLUSION

This study explores a direct method for identifying where to implement disconnection strategies to achieve CSO volume reduction goals. In addition to identify priority areas to be disconnected, this study will also drive the scenario proposal by helping to optimize the selection and sizing of SUDS technologies guided directly by a volume to be disconnected.

Results of one-year simulation show a good performance of the model to reproduce the different components of urban flows and CSO events. Moreover, the direct method seems to be promising for identifying the volume to be disconnected.

Upcoming results will apply the disconnection methodology to long-term annual simulations to formulate disconnection scenarios that directly achieve the annual spill volume reduction objectives. In order to verify the direct disconnection method's efficacy, the placement and feasibility of the selected scenarios will be simulated.

BIBLIOGRAPHIE

- Alves, A., Sanchez, A., Vojinovic, Z., Seyoum, S., Babel, M., Brdjanovic, D., (2016). *Evolutionary and Holistic Assessment of Green-Grey Infrastructure for CSO Reduction*. Water 8, 402.
- Botturi, A., Ozbayram, E.G., Tondera, K., Gilbert, N.I., Rouault, P., Caradot, N., Gutierrez, O., Daneshgar, S., Frison, N., Akyol, Ç., Foglia, A., Eusebi, A.L., Fatone, F., (2021). *Combined sewer overflows: A critical review on best practice and innovative solutions to mitigate impacts on environment and human health*. Critical Reviews in Environmental Science and Technology 51, 1585–1618.
- Fan, G., Lin, R., Wei, Z., Xiao, Y., Shangguan, H., Song, Y., (2022). *Effects of low impact development on the stormwater runoff and pollution control*. Science of The Total Environment 805, 150404.
- Ferrans, P., Torres, M.N., Temprano, J., Rodríguez Sánchez, J.P., (2022). *Sustainable Urban Drainage System (SUDS) modeling supporting decision-making: A systematic quantitative review*. Science of The Total Environment 806, 150447.
- Lerer, S., Arnbjerg-Nielsen, K., Mikkelsen, P., (2015). *A Mapping of Tools for Informing Water Sensitive Urban Design Planning Decisions—Questions, Aspects and Context Sensitivity*. Water 7, 993–1012. <https://doi.org/10.3390/w7030993>
- Momplot, A. (2014) : *Modélisation tridimensionnelle des écoulements en réseau d'assainissement : évaluation des modèles RANS à travers l'étude des écoulements au droit d'ouvrages spéciaux* (Thèse). Lyon : INSA
- Torres, M.N., Fontecha, J.E., Walteros, J.L., Zhu, Z., Ahmed, Z., Rodríguez, J.P., Rabideau, A.J., (2021). *City-scale optimal location planning of Green Infrastructure using piece-wise linear interpolation and exact optimization methods*. Journal of Hydrology 601, 126540.
- Torres, M.N., Sánchez, J.P.R., de, N., Nascimento, O., Leitão, J.P., Granceri, M., (2016). *Decision support tools for sustainable urban drainage systems: a systematic quantitative review* .