MULTISOURCE

Hydraulic disconnection module – Characterization of disconnected regions

Deliverable D5.2

This project has received funding from the European Union's Horizon H2020 innovation action programme under grant agreement 101003527.

Deliverable Number and Name	D5.2 – Hydraulic disconnection model - Characteristics of urban regions disconnected from combined sewers
Work Package	WP5 – Multisource Platform
Dissemination Level	
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Date Due	May 27th 2024
Date Submitted	May 31 2024
File Name	
Status	
Reviewed by (if applicable)	Jaime Nivala
Suggested citation	Lipeme Kouyi *et al.* (2024). Hydraulic disconnection module – characterization of disconnected regions. MULTISOURCE Deliverable D5.2, H2020 grant no. 101003527

This document has been prepared in the framework of the European project MULTISOURCE. This project has received funding from the European Union’s Horizon 2020 innovation action programme under grant agreement no. 101003527.

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EXECUTIVE SUMMARY

The objective of this investigation is to reveal the characteristics of the disconnected regions that enable to mitigate combined sewer overflows (CSO). Two stormwater management strategies were simulated: the disconnection strategy, which involves directing runoff from impermeable areas to a facility other than the sewer system, and the desealing strategy, which aims to restore permeability to urban impervious surfaces. In this deliverable, only the disconnection strategy is presented. Different levels of deployment of the disconnection strategy were simulated for each sub-watershed of the city of Figeac. The results allowed to describe, capture, and characterize the hydrological response of the various sub-watersheds in order to identify where hydraulic disconnection actions would be most effective and to assess the effort required to reduce overflows. Initially, the results showed that peripheral watersheds with large impervious areas contribute little to the outflow (either because the impervious surfaces are not all directly connected to the combined sewer network, or because they inherently have a lower runoff coefficient). Additionally, the implementation of NBS on a small, highly urbanized sub-watershed has a greater capacity to reduce overflows than that of a peripheral sub-watershed with a large impermeable area but low runoff capacity. Subsequently, territorial characteristics and proximity to the targeted combined sewer overflow structures play a key role in contributing to overflows. Sub-watersheds with features (impermeable surface area, runoff coefficient, slope) that tend to increase runoff volume and/or velocity during the transfer process have a more significant contribution to overflows. Therefore, these areas present greater potential for effective hydraulic disconnection and desealing actions to help addressing the issue of CSO mitigation. Furthermore, the model allowed to quantify the impact of implementing these strategies on the performance criteria typically used to assess the regulatory compliance of CSO (annual overflow frequency and overflow ratio).

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1.0 INTRODUCTION

Combined Sewer Overflows (CSO) represent a major source of pollution for receiving water bodies and their impacts on aquatic ecosystems are well recognized. Several studies have highlighted the significant role of CSO as pathways to reach urban receiving waters for various contaminants, such as organic micropollutants (Launay et al., 2016), especially those highly removed by wastewater treatment plants (WWTPs) (e.g. Weyrauch et al., 2010), inorganic micropollutants (Weyrauch et al., 2010), nutrients (Viviano et al., 2017), hormones (Phillips et al., 2012) or bacteria (Passerat et al., 2011; Weyrauch et al., 2010) among others. These studies show the importance of CSO contribution to both, the annual pollutant loads on the receiving waters and their peak pollutant concentrations during storm events. For example, Launay et al. (2016) showed that despite the relatively low contribution of CSO to the total annual water discharge (18%), CSO discharges contributed up to 95% of the annual pollutants loads. Recovery of receiving water body quality requires strategies to mitigate these impacts. Some of the strategies involve reducing the number of overflows, for example by increasing the urban catchment permeability and thereby reducing stormwater runoff volume (Maté Marin et al., 2018). Such strategy requires a better understanding of flow dynamics in the related drainage systems as well as continuous control and reliable monitoring of CSO volumes and pollutant loads. Two stormwater management strategies, disconnection and desealing, are applied at the city of Figeac in France. The semi-distributed model developed as part of this project (see Montoya-Coronado et al., 2024a) is used, and continuous simulations over 5 years were conducted to test the performance of different scenarios. The analysis of the results allowed for the estimation of the performance of NBS in reducing overflows, both in volume and frequency, particularly under the disconnection scenarios.

1.0 MATERIAL AND METHODS

1.1 Site presentation

In addition to the case study of Ecully (Montoya-Coronado et al., 2024), the city of Figeac, located in the Lot department in France, is the second pilot study site for the development and the test of the hydraulic disconnection model. The city of Figeac has a population of 10,524 inhabitants spread over 513 hectares. An urban area of 330 hectares is drained by a combined sewer system. The sewer network of Figeac is characterized by 44 km of combined sewers and is equipped with 17 combined sewer overflow structures (CSOs). The pipe diameters are ranging from 120 mm to 150 mm. The oldest pipes, with a rectangular or ovoid geometry, account for 2.3 km of the 44 km of combined sewer network. The watershed selected for this study is equipped with six instrumented CSOs including one main CSOs, the Pont de la Gua. This watershed was selected notably because, in 2012, its main CSOs accounted for one-third of the city's total annual overflow volume. Figure 1 indicates the details of the selected site.

Figure 1 Presentation of Figeac site

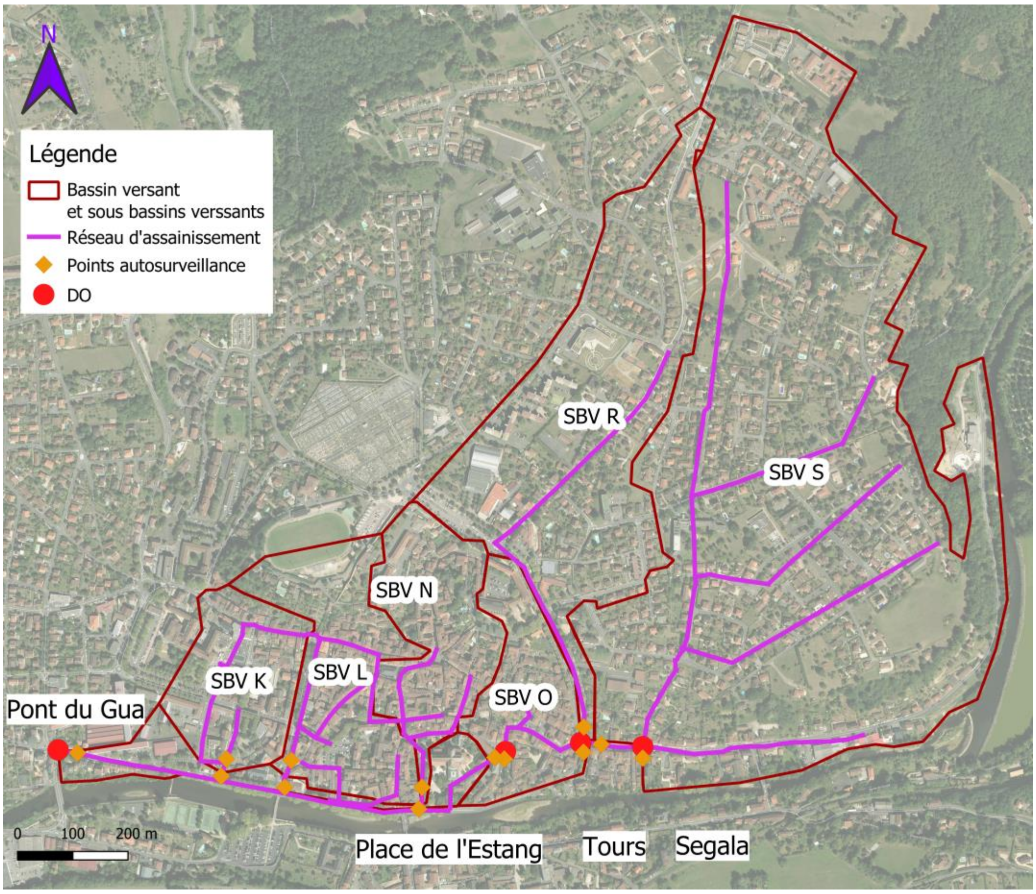


Table 1 Key characteristics of Figeac sub-catchments

	Sub-catchment (SC) S	SC R	SC O	SC N	SC L	SC K
Total surface [ha]	63	22	4.2	7.4	6.2	6.2
Impervious surface [ha]	34	13	3	5	3.6	3.8
Impervious rate [%]	54	59	71	68	58	61
Pervious surface [ha]	29	9	1.2	2.4	2.6	2.4
Pervious rate [%]	46	41	29	32	42	39

The areas of six sub-watersheds were calculated using QGIS (Table 1). Among them, the "S" sub-watershed stands out with a large area of 62 hectares. In contrast, the "O" sub-watershed, with an area of only 4.2 hectares, represents the smallest sub-watershed studied. The "O" sub-watershed, located in the heart of the city, has the highest impervious rate (71%); conversely, the "S" sub-watershed has the lowest one with 54%.

1.2 Model calibration and accuracy evaluation

The model requires ten input data to be estimated (see Montoya-Coronado et al., 2024a for details). For nine of them, this is achieved through the analysis of observed data and the last one (lag-time) is estimated via an empirical equation. In addition, six other parameters describe the characteristics of the catchment. The detailed list of all parameters used in the model is presented by Montoya-Coronado et al. (2024). The daily wastewater flow patterns (*WW(t)*) were derived from the observed data collected during 5 years. All the patterns obtained during the study period were examined and the median hourly flow rate was retained to reconstruct a median daily wastewater flow pattern with hourly time step. In the same way, permanent inflow infiltration (PII) has been identified through the observations of the minimum night time flow during all dry periods. An inter-seasonal minimum night-time flow comparison, corresponding to the four typical European weather seasons, was carried out to observe a potential seasonal variation of PII, i.e., due to differences in the groundwater level or in the soil moisture, but there was no significant difference between the estimated PII between seasons, thus, the base flow was considered to be the same throughout the year.

For all selected events, the equivalent depth of wet-weather flow was calculated and plotted against the rainfall depth. The resulting scatterplot shows three distinct groups of points, each having its own slope. This differentiation supports the assumption that depending on the rainfall depth, different hydrological processes are present based on the rainfall depth (i.e., runoff on impervious surfaces, rain-induced infiltration after a rain event, and runoff on permeable surfaces). This process enables to get runoff coefficients according to the type of drained surface. The model's accuracy was evaluated by means of the Kling-Gupta Efficiency (KGE) as a goodness of fit criteria (Gupta et al., 2009).

1.3 Disconnection strategy

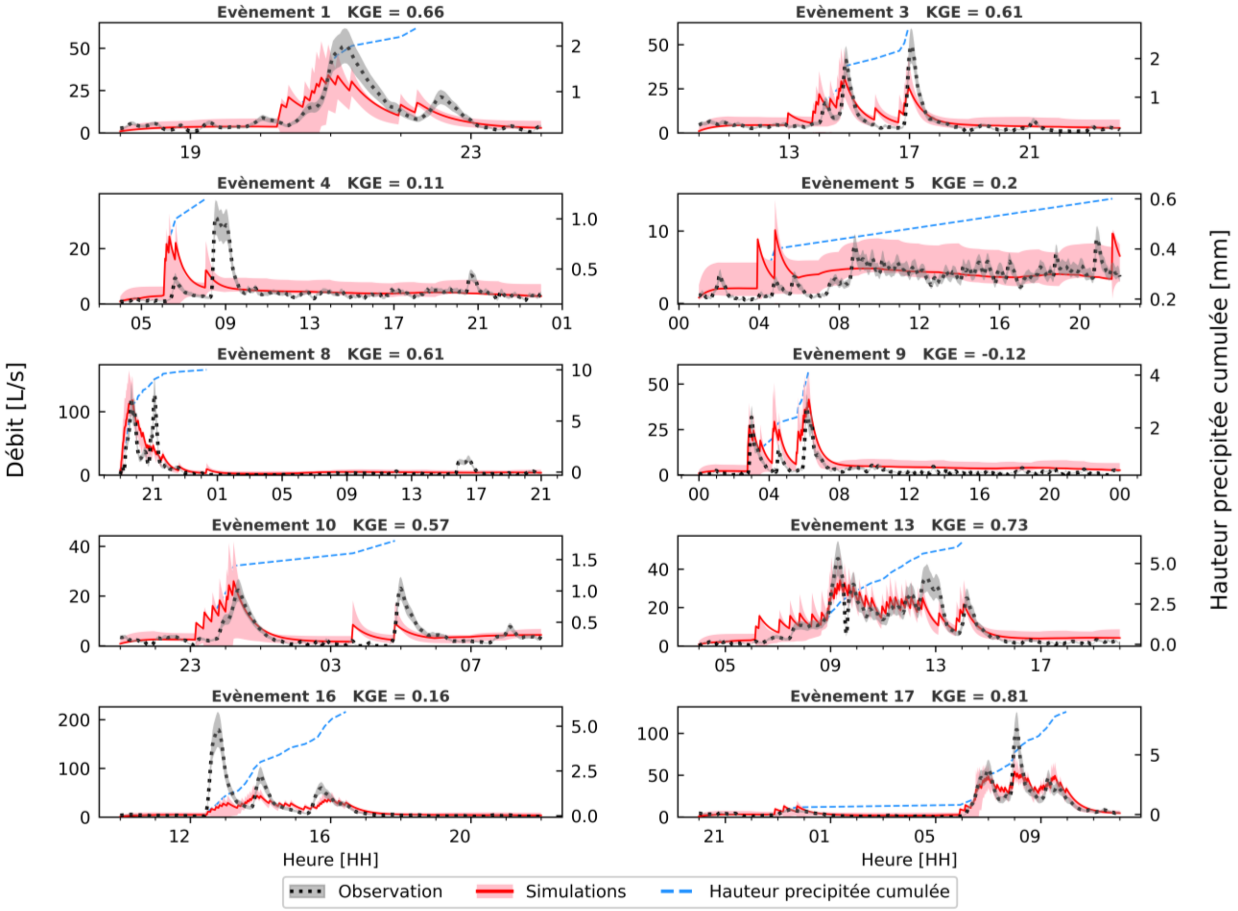
The elaborated scenarios aim to disconnect stormwater from the combined sewer system by implementing source control structures for stormwater management such as green roofs, rain gardens and swales that collect water from nearby roofs and pavements. These infrastructures capture and infiltrate rainwater, reducing a fraction of surface runoff. To model stormwater disconnection scenarios, the initial loss values of the surfaces on which these structures could be implemented were increased to conceptualize the capacity of the structures to store and infiltrate the first millimeters of rainfall. There is a possibility that water infiltrating through the NBS could reach the sewer system. However, in the absence of experimental data to parameterize this phenomenon, it will not be considered. Basically, no systematic approach exists to elaborate disconnection scenarios through NBS (Montoya-Coronado et al., 2024b). Two scenarios were conducted, increasing initial losses by 5 and 10 mm. The CSO volume reduction as well as the decreasing of CSO frequency were used to compare the disconnection scenarios through five years of simulations.

2.0 RESULTS

2.1 Model calibration and accuracy evaluation

Initially, the model evaluation was based on a comparison of the observed and simulated hydrographs upstream of the Ségala CSOs (SC "S", Figure 1). For this purpose, we had a series of 10 rainfall events exceeding 0.6 mm, with the hydrographs represented in Figure 2. The uncertainty associated with the simulated flows is the result of 104 possible parameter set combinations generated using MCM (Monte Carlo Method). KGE values greater than 0.62 were obtained for 90% of the parameter sets, with the remaining 10% ranging from 0.3 to 0.62.

Figure 2 Accuracy evaluation of the model (SC « S »)

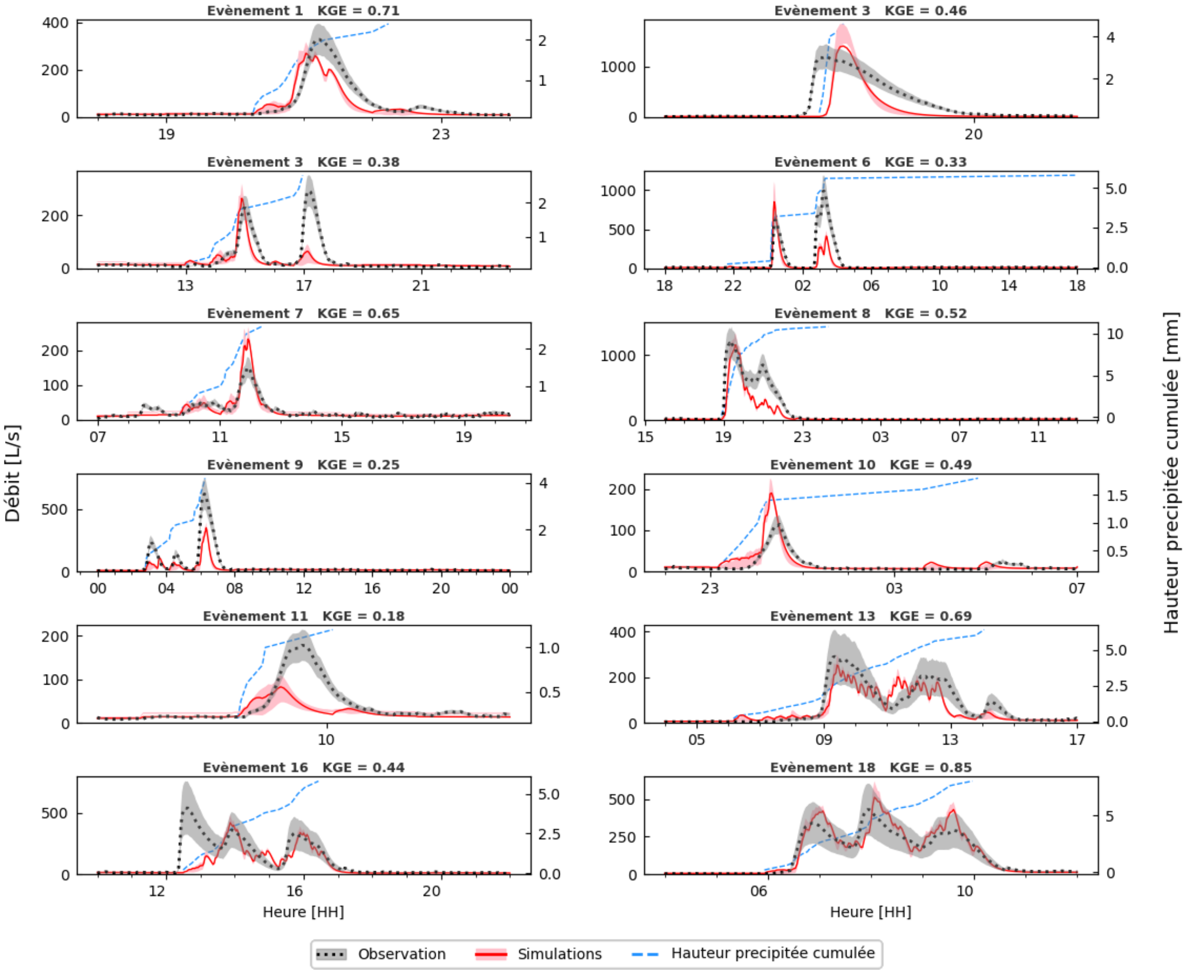


The model demonstrates its ability to reproduce the complex dynamics of the observed hydrograph, as shown by events No. 3, 9, and 13, despite some underestimations of peak flow for event No. 3 at 5 p.m. and event No. 16 at 1 p.m. Some events, such as event No. 4 and event No. 5, are not well reproduced, but these events are very small, with precipitation less than 1 mm. Overall, the events provide a satisfactory KGE value, and the hydrograph upstream of the Ségala CSOs has a relevant shape (Figure 2).

In addition, the semi-distributed model of Figeac was evaluated on 12 rainfall events by comparing the observed and simulated data at the watershed outlet, which includes the six sub-watersheds mentioned previously (Table 1, Figure 1). Figure 3 shows the measured and simulated hydrographs for each event. For all events, the simulated flow begins to increase a few minutes after the start of the rain. The events are categorized into three groups according to the model's performance based on the KGE criterion.

The first group, comprising events No. 1, 7, 13, and 18, stands out with a KGE greater than 0.55, indicating fair performance. The second group includes events No. 3, 6, 8, and 16, for which the model partially reproduces hydrological and hydraulic processes. In these cases, although multiple peaks are observed, the model does not correctly simulate all of them. For instance, for events 3, 6, and 8, the second peak of the hydrograph is not reproduced by the model, while for event 16, the first peak is not simulated.

Figure 3 Accuracy evaluation of the model for the catchment of Figeac

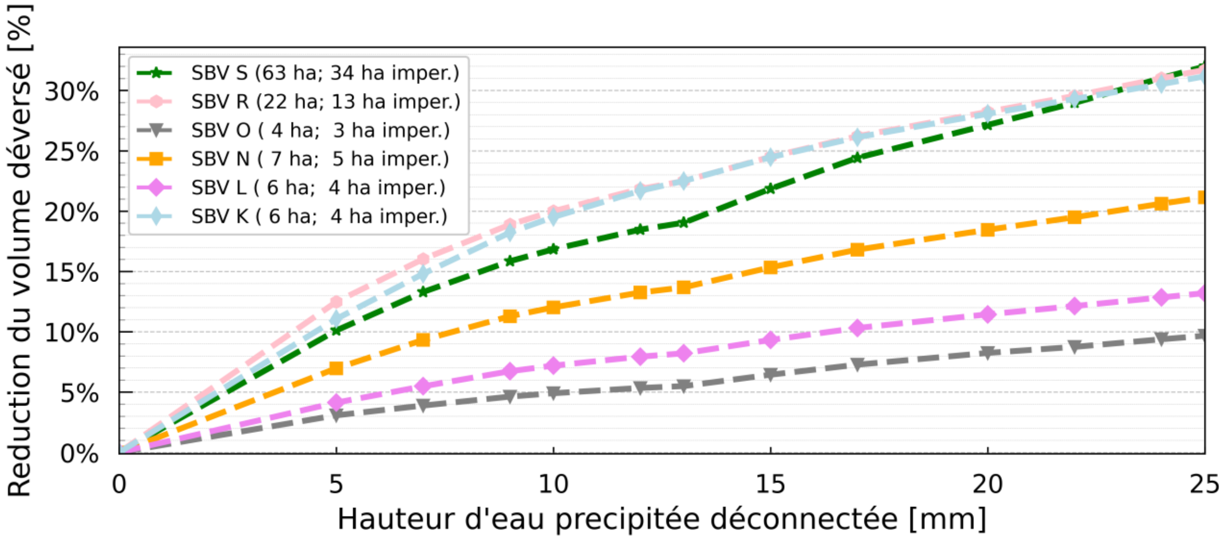


The model evaluation resulted in KGE values greater than 0.57 for 90% of the parameter sets, with the remaining 10% ranging from 0.52 to 0.57.

2.2 Performances of disconnection strategy

Figure 4 shows the reduction rate of the CSO volume in the watershed according to the rainfall depth removed in each sub-catchment (to mimic the operation of implemented NBS).

Figure 4 Reduction rate of CSO volume according to the removed rainfall depth in each sub-catchment for simulated period (2015-2020)



The "S" sub-watershed (34 ha impermeable and runoff coefficient of CRimp = 0.17) in Figeac performs worse than the "R" sub-watershed (13 ha impermeable and CRimp = 0.37) despite its larger impermeable surface area. This is due to "R" having a runoff coefficient approximately two times higher than that of "S". Similarly, the "K" sub-watershed, with only 4 ha of impermeable surface but a CRimp = 0.62, performs better than the "S" sub-watershed (with a larger impermeable area) and the "L" sub-watershed (which has very similar characteristics: same area, slope, and located in the city center near the CSOs). This is explained by "K" having a runoff coefficient four times higher than that of "S" and twice as high as that of "L", as well as its proximity to the CSOs.

Another example illustrating the impact of hydrological characteristics of sub-catchments is the "O" sub-watershed, the least efficient. This sub-watershed has a low runoff coefficient (CRimp = 0.13), a small impermeable area (4 ha), and is not located near the CSOs. These results show that a detailed description of the sub-watersheds (runoff coefficient, slope, lag-time) plays an important role in the hydrological response at the watershed scale and, consequently, in the identification of the most effective mitigation actions to reduce CSO.

3.0 CONCLUSIONS

Different levels of deployment of disconnection strategies were simulated for each sub-watershed of Figeac. The results allowed to describe, understand, and characterize the hydrological response of the various sub-watersheds. This enabled to identify where actions would be most effective and to assess the effort required to reduce overflows in order to meet regulatory objectives. The following can be pinpoint out:

- For the period from 2015 to 2020, the simulations highlighted greater improvement in reducing overflow due to targeted source control measures.
- Sub-watersheds like "S" with large impervious surfaces but lower runoff coefficients required more extensive measures to achieve the desired results compared to smaller but more responsive sub-watersheds like "K".
- Proximity to CSOs and specific hydrological characteristics such as slope and lag-time played crucial roles in the effectiveness of the interventions.

Hydrological Characterization:

- Detailed analysis of each sub-watershed's response helped in prioritizing areas where source control measures would yield the highest benefits.
- Characterization involved assessing impervious surface percentage, runoff coefficients, slope, and proximity to CSOs.

The study demonstrates that a detailed understanding of sub-watershed characteristics is essential for effective stormwater management. By simulating different deployment levels of disconnection and de-impermeabilization strategies, we could identify the most impactful interventions and required efforts to meet regulatory standards and significantly reduce overflow volumes.

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The overall goal of MULTISOURCE is to, together with local, national, and international stakeholders, demonstrate a variety of about Enhanced Natural Treatment Solutions (ENTS) treating a wide range of urban waters and to develop innovative tools, methods, and business models that support citywide planning and long-term operations and maintenance of nature-based solutions for water treatment, storage, and reuse in urban areas worldwide. The project includes seven pilots treating a wide range of urban waters. Two individual municipalities (Girona, Spain; Oslo, Norway), two metropolitan municipalities (Lyon, France; Milan, Italy), and international partners in Brazil, Vietnam, and the USA will contribute to each of the main project activities: ENTS pilots, risk assessment, business models, technology selection, and the MULTISOURCE Planning Platform. The use of urban archetypes in the Planning Platform will enable users to quickly classify regions (in both developed or developing countries) suitable for the application of nature-based solutions for water treatment (NBSWT) and compare scenarios both with and without NBSWT.

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enhanced natural treatment solutions

This project has received funding from the European Union’s Horizon H2020 innovation action programme under grant agreement 101003527.