Real-time pollution-based control of urban drainage and sanitation systems for protection of receiving waters

LIFE RUBIES is co-funded by the European LIFE programme (https://cinea.ec.europa.eu/life). It is a trans-European project that includes eight members, four of whom are Spanish and four others are French. LIFE RUBIES started in late 2021 and is due to conclude by the end of 2025.

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Figure 1: LIFE RUBIES concept schematics.

The project aims to decrease surface water pollution from sewerage system discharges during storm events. It adopts an alternative approach to concrete-based solutions, complying with the upcoming new European Water Framework Directive, which addresses the issue of sewer direct discharges into natural bodies of water. The objective is to improve the existing volume-based approach by deploying real-time model predictive control (MPC) tools to optimise the sewage system. This approach aims to reduce overflow in terms of volumes discharged and pollutant loads, drawing from the works of Ly *et al.*, (2019) and Sun *et al.*, (2021). The solution includes rainfall forecasts, quality sensor installation in sewerages and receiving waters, and the development of algorithms to identify the best network management solution (Figure 1). These components are deployed and integrated into the digital solution for task scheduling, with results displayed on the SUEZ expert dashboard AQUADVANCED Urban Drainage. The solution is implemented in two pilot locations: Madrid, Spain, and Metropole Européenne de Lille (MEL), France).

The project is innovative not only for its quality-based optimisation approach but also for the methodology applied to assess the impact of the urban drainage system on natural bodies, thanks to the PhD work performed at CNRS (Ali Said *et al.*, 2024). Additionally, it examines the potential benefits resulting from the improved network control thanks to LIFE RUBIES concepts. The initial findings presented in this paper show the project's progress through quality monitoring and its ability to demonstrate the impact of human activities on the receiving aquatic system, the Deûle River (northern France).

Methods

The pilot sites

The chemical and ecological status of receiving rivers in Spain and France are poor partly due to the effect of spills that adversely impact tens of kilometres downstream. Combined sewer overflow (CSO) volumes in MEL remain higher than the regulation threshold. For instance, in 2018, 8.5% of the total wastewater volume was spilt through CSOs, corresponding to 4.6 Mm^3, 837 tons of total mass and 181 mg/L total suspended solids (TSS), whereas 5% is considered the maximum according to the French regulation. For the Madrid pilot, the CSOs represent 4.5 Mm^3/year and 1318 ton/year of suspended solids.

Network and river quality monitoring in the Deûle River

The CSO pilots and the storage units are equipped with hydraulics and quality sensors, making it possible to calculate pollutant fluxes for classical parameters (TSS, COD, Nitrogen), according to Patris *et al.*, (2020). The data are used for pollution fluxes emission calculation and model quality calibration. The rivers are equipped with high-frequency online quality monitoring stations, including turbidity, conductivity, ammonia and oxygen sensors (Ali Said *et al.*, 2022). Three monitoring stations are installed along the river: one before the urban area, another after the combined sewer infrastructures, and the third following the wastewater treatment plant (WWTP) discharge point.

Quality-based MPC solutions

LIFE RUBIES integrates LIFE EFFIDRAIN methods in an advanced hypervision platform, the AQUADVANCED® Urban Drainage, dedicated to real-time data management, system monitoring and remote control in connection with a supervisory control and data acquisition (SCADA). It can also manage hydraulic simulator runs using real-time weather forecasts to anticipate the system's behaviour, see figure 2 below.

Two MPC strategies will be applied and integrated into AQUADVANCED® Urban Drainage:

- **Mass-volume-based controller**—the algorithm follows a multiple local system approach using an improved hydraulic model that provides spatial and temporal evolution of TSS.
- **Model-predictive controller**—the algorithm follows a global system approach using a model with linearised hydraulic and quality equations.

River quality monitoring for solution impact assessment

Multiparameter probes were deployed throughout the project to allow high-frequency measurements of physicochemical parameters. Ammonium analysers were also installed in prototype mobile stations, including a smart sampling system controlled by a new algorithm that triggers sampling of quality variation.

LIFE RUBIES solution deployment steps

The project is split into three main phases over its three-year duration. The first phase was dedicated to site understanding, data gathering, global pilot preparation, and monitoring the environment quality to draw the rivers' quality baseline, which will be further used as a reference to compute the LIFE RUBIES benefits. The second phase, the one currently running, is dedicated to the activation of the hydraulics-based controller of the sewer as it is a more known/mature solution. The third and last phase is dedicated to the activation of the pollution-based controller and represents the most innovative part of the project. In the end, the results monitored in the natural bodies will allow us to assess the impact of each strategy on the environment.

Figure 2: Lille AQUADVANCED® Urban Drainage screen shot.

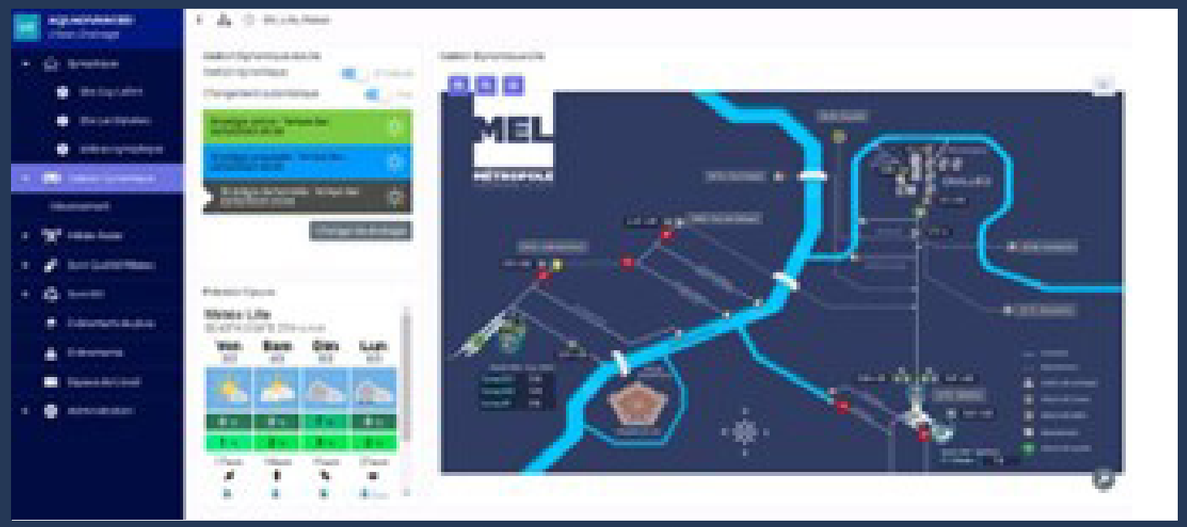

Figure 3. Hydraulics and quality data collected in a CSO at Bateliers monitoring station (Lille).

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Results and discussion

Sewer quality monitoring strategy

Figure 3 reports results obtained during a storm event from one high-frequency monitoring station on the MEL pilot. It illustrates the transport of solid and soluble pollutants in combined sewers, which will be used to monitor classical parameters continuously. It is worth noting that soluble and particulate pollutants react in very different ways, illustrating the complementarity of the information reported by these two types of sensors. Indeed, turbidity increases from about 250 NTU up to 1500 NTU during the storm, while the conductivity drops from 1800 µS/cm down to 1000 µS/cm. This information is extracted and used following the methodology suggested by Patris *et al.*, (2020), which adds a mathematical layer to convert sensor signals into pollutants' concentrations.

Natural body quality monitoring

Figure 4 presents results collected during the event of 9 March 2023 in Lille (France) at two locations in the river (left) and the Batelier CSO (right). In the river, station D1 is located upstream of the CSO, and D2 is located downstream. For the three parameters (temperature, dissolved oxygen and ammonia), station D1 does not show any signal change, while sharp variations occur at D2. Indeed, ammonia presents a value multiplied by more than 2 (0.5 mg_{NH4}/L up to 1.2 mg_{NH4}/L). In the meantime, when looking at CSO discharges, an important ammonia peak happens during the CSO spillage with mass fluxes reaching 250 mg_{NH4}/L. These observations suggest that sewers are the primary, and possibly the sole, contributors to river pollution by ammonia.

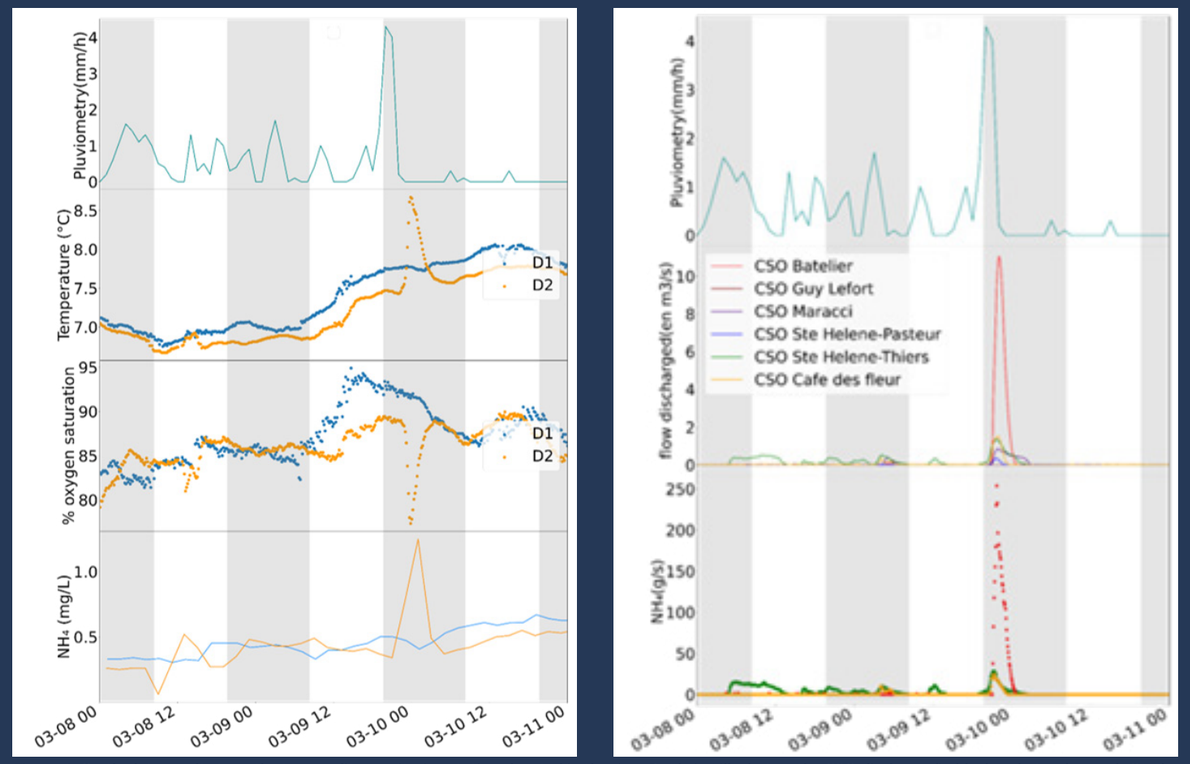

Figure 4: On the left, results from the two quality monitoring stations located in the river Deûle in Lille, before the CSO discharge (in blue) and after (orange). On the right are results from the monitoring stations located in the sewer at various CSOs.

Sewer discharge assessment of LIFE RUBIES hydraulics-based controller activation

The first results obtained within phase two of LIFE RUBIES (hydraulics-based control) have shown an overall discharge mitigation of around 20% over 18 events from May to August. It is estimated that CSOs would have been around 180 000 m^3 without LIFE RUBIES and around 140 000 m^3 with LIFE RUBIES running.

Figure 5 illustrates the controller behaviour during the rain event of 1 August 2024 that cumulated 40mm of rain over 8h. The first graph displays the discharge flow forecasted before the event occurs. During the event, it was anticipated that CSO would occur, the purple line displaying the real observed discharged flow that highlights a reduced CSO volume spillage. The second plot shows that the tank begins to store the stormwater volume around 2h30, reaching the maximum tank storage capacity and beginning the CSO. It is estimated that a total of 20 000 m^3 has been saved from spillage.

Natural receiving body impact analysis

By mixing observed data from the monitoring stations with a one-dimensional hydraulic model built using the Storm Water Management Model (SWMM, US EPA), the project authors were able to quantify the contribution of each CSO to the river pollution. Figure 6 results have been obtained after iterative simulations, revealing that over the same event: (*i*) the quantity of ions monitored in the river (red dots on top figure) is very similar to the quantity of ions simulated (zones sum on top plot), and (*ii*) even if over the whole event the major source of ions is the natural body itself, the spike of ions corresponding to the river response to the rain event is mainly originated from the Batelier CSO. The same conclusion can be made when looking at ammonia on the bottom plot of Figure 6.

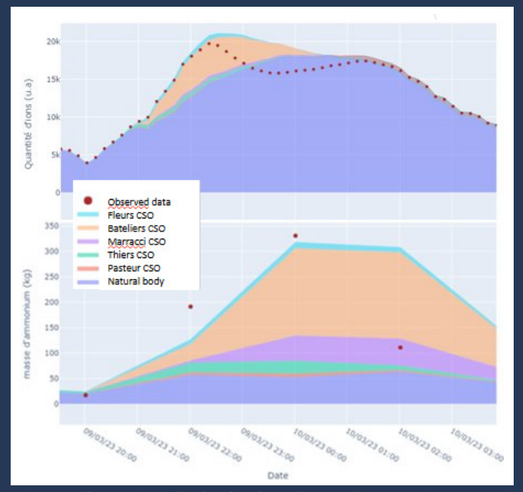

Figure 5: Illustration of hydraulics-based controller operation on a real storm event.

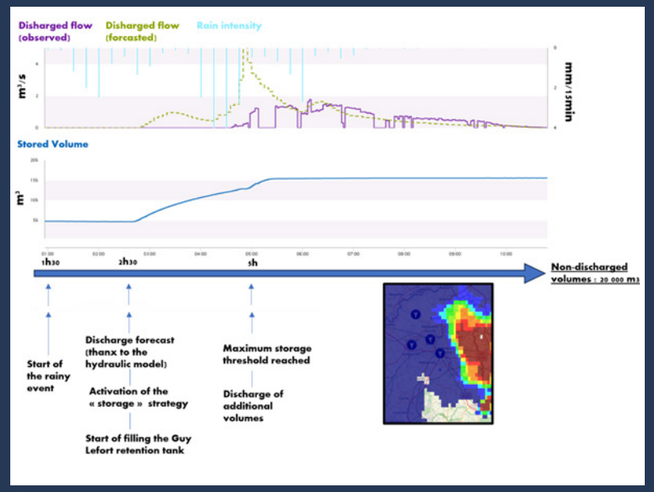

Figure 6: Comparison between observed and simulated data of conductivity and ammonia in the Deûle river detailing the contribution of each CSO.

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Conclusion

The implementation of LIFE RUBIES, which is a quality-based MPC of wastewater systems, is ongoing in two large European cities in France and Spain. The results collected through the sensor system illustrate the wastewater quality-based methodology and the capacity to monitor the impact of the urban drainage system on the receiving rivers and the potential future benefits of LIFE RUBIES operation. The activation of the hydraulics-based controller has shown discharge volume mitigation by around 20% over 18 events. The natural body monitoring strategy mixed with hydraulics modelling has enabled the capacity to understand each CSO's distinguished contribution to the river's pollution due to combined sewer overflows.

Now, the overall quality strategy is ready (sensors, data treatment, algorithms, weather observations and forecasts, models, optimisers, etc.). Under the final testing steps, the quality-based controller will be activated by early 2025. Final results are expected to be computed and published by the end of 2025.

Home - LIFE RUBIES

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PROJECT NAME
LIFE RUBIES

PROJECT SUMMARY

The LIFE RUBIES project aims to develop an operational tool to reduce urban wastewater's impact on the natural environment by controlling water pollution in real time and deploying that tool in two cities. Real-time control will make it possible to direct and store urban wastewater to avoid pollution by relying on the coupling of sensors, models and controllers.

PROJECT PARTNERS

The consortium has eight partners in France and Spain, including private companies, public research centres and metropolitan areas. Solutions will be deployed on two pilot sites: the Metropolis of Lille (France) and its canalised river (La Deûle), as well as the city of Madrid (Spain). Suez provides data collection solutions (sensors, probes), providing digital models and real-time applications. 3S owns AQDV UD and will have a key role as project coordinator and integrator. Also assisting are : AQUATEC, (Spain), CSIC, (Spain),CETAQUA, (Spain), Canal de Isabel II, (Spain), Métropole européenne de Lille (France), SUEZ EAU FRANCE (France) and Université de Lille, LASIRE (France).

PROJECT LEAD

SUEZ takes the lead in managing the LIFE Rubies project, overseeing its various components and ensuring smooth implementation.

AQUADVANCED technology: SUEZ leverages its AQUADVANCED Urban Drainage technology, which provides advanced digital modelling tools for urban drainage systems, to analyse and optimise water management within the project.

Focus on urban drainage: The LIFE Rubies project primarily focuses on improving urban drainage systems, making SUEZ's expertise in this area particularly relevant.

CONTACT

Martin VUILLAUME
SUEZ Smart Solutions, 38 Rue du President Wilson, 78230, Le Pecq
martin.vuillaume@suez.com
https://www.suez.fr/fr-fr
life-rubies.eu

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