

# The ENVISION Project: Integrating Nature-Based Solutions in Urban Areas for Lake Pollution Mitigation <sup>†</sup>

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<sup>†</sup> Presented at II International Conference on Challenges and Perspectives in Urban Water Management Systems (CSDU-CSSI DAYS 25), Trieste, Italy, 18–19 November 2025.

## Abstract

Traditional urban drainage systems face increasing pressures due to growing urbanization and climate change, which amplify stormwater volumes beyond the design capacity of sewer networks. These conditions often result in combined sewer overflows (CSOs) and wastewater treatment plant (WWTP) bypasses, discharging untreated, nutrient-laden effluents into receiving water bodies. Elevated nitrogen (N) and phosphorus (P) loads from these events exacerbate eutrophication and harmful algal blooms in lakes. The ENVISION project (Lake Pollution: Integrating Nature-Based Solutions Into Environmental Urban Planning for Risk Mitigation) addresses the impact of urban discharges on lakes and evaluates the potential of Nature-Based Solutions (NBSs) to mitigate N and P releases from CSOs. A coupled hydrological–hydraulic and probabilistic modeling framework is applied to the Lake Maggiore (Northern Italy) catchment as a case study, to assess the potential of NBSs in reducing CSO events and, consequently, the N and P loads discharged into the lake. Preliminary results from the hydrological–hydraulic approach are presented.

**Keywords:** nature-based solutions (NBSs); lake pollution mitigation; analytical probabilistic modeling

## 1. Introduction

Urban drainage systems (UDSs) are increasingly challenged by urbanization and climate change, which generate stormwater volumes that exceed the capacity of conventional sewer networks and wastewater treatment plants (WWTPs) [1,2]. During intense rainfall events, combined sewer overflows (CSOs) and WWTP bypasses release untreated water into receiving water bodies, introducing pollutants and nutrients [3]. Among these urban inputs, nitrogen (N) and phosphorus (P) are of particular concern for eutrophication processes in lakes, as they interact with natural sources such as soil weathering, organic matter decomposition, groundwater inflows, and atmospheric deposition, promoting harmful algal blooms [4].

Nature-Based Solutions (NBSs) have been extensively investigated and demonstrated to effectively attenuate stormwater runoff peaks and volumes [5–7]. However, their efficiency in reducing pollutant loads, and specifically in lowering nutrient discharges from



Academic Editors: Patrizia Piro,  
Bruno Brunone, Federico Roman and  
Michele Turco

Published: 21 July 2026

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urban areas, remains poorly understood. To address this knowledge gap, the ENVISION project has been designed to assess the potential of NBSs in mitigating N and P loads from CSOs and to evaluate their implications for lake water quality, with Lake Maggiore (Northern Italy) serving as a case study. The methodological framework adopted for this purpose combines hydrological modeling with a probabilistic approach. The preliminary results from the application of this framework are presented and discussed.

## 2. Materials and Methods

### 2.1. Study Area and Data Collection

The dataset employed originates from the Italian National Research Council—Water Research Institute (CNR-IRSA) and comprises daily discharge measurements for 13 tributaries at their outlets into Lake Maggiore, along with daily total nitrogen (TN) and total phosphorus (TP) concentrations measured once a month. The study period spans 1996–2015, selected to ensure the most consistent overlap between hydrological and water quality records. Precipitation data were obtained from the ERA5-Land reanalysis (ECMWF), which provides global coverage at  $0.1^\circ \times 0.1^\circ$  spatial resolution (around 9 km) and hourly temporal resolution.

### 2.2. Simulation Approach

The simulation methodology estimated TN and TP loads on a daily scale, considering three components: natural load, build-up and wash-off (BU-WO) load, and wastewater load. The natural load was calculated using the Event Mean Concentration (EMC) method [8], assuming constant daily concentrations. The BU-WO component, representing diffuse pollution coming only from impervious surfaces, was modeled with exponential build-up and wash-off functions at an hourly time step [8], while the urban runoff flow rate was derived exploiting the linear reservoir model.

Finally, the wastewater load component was considered active only when the combined wastewater flow and urban runoff exceeded a predefined threshold; specifically, five times the constant base wastewater flow for the activation of sewer system flow diverters. When the flow diverter is inactive, the load is treated by wastewater treatment plants, hence their load contribution to the lake can be assumed negligible. Both wash-off and wastewater contributions were assumed to be perfectly mixed within the diverted flow.

To assess the impact of NBSs, one specific scenario was simulated. In this scenario, it was assumed that 20% [9] of the total contributing urban area was treated by NBSs. The effect of NBSs was modeled by applying a modified Curve Number (CN) of 50 to the treated areas.

The selection of model parameters was guided by values reported in the scientific literature, with particular reference to [10,11], in order to ensure consistency with established practices and comparability with previous studies.

### 2.3. Analytical Probabilistic Approach

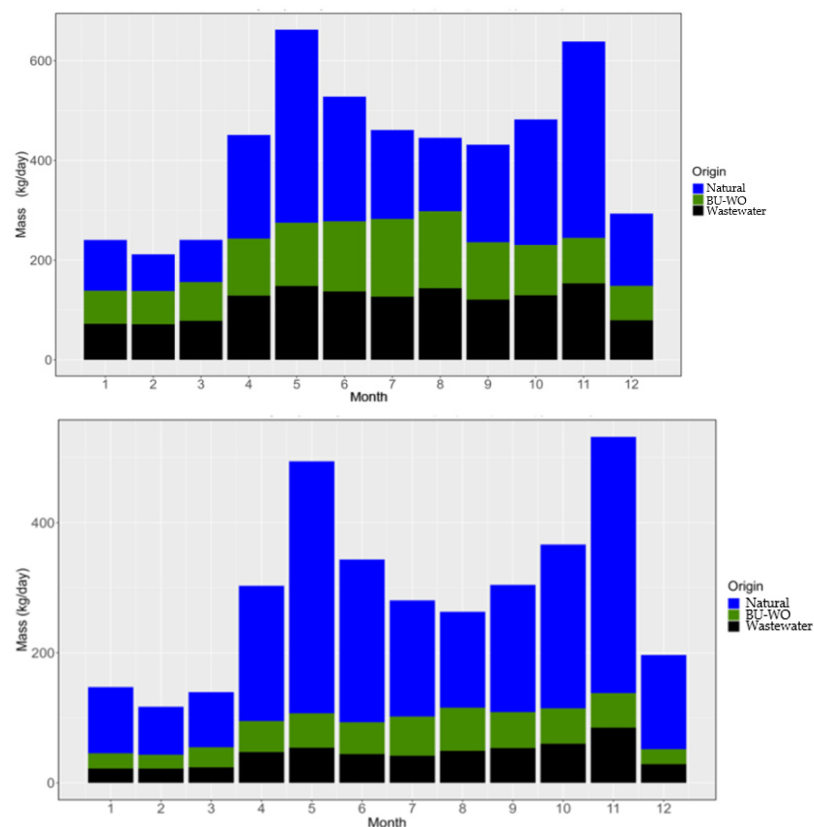
The analytical probabilistic approach relates the probability density functions (PDFs) of meteorological inputs—such as rainfall volumes, durations, and inter-event times—to the PDFs of catchment outputs through hydrological and hydraulic transformation functions. This framework accounts for antecedent conditions from previous rainfall events, which can be significant under low-release scenarios, as in the case of NBSs, and allows the derivation of analytical expressions for the distributions of runoff volumes and pollutant concentrations. The model is currently under development and aims to generate synthetic scenarios to evaluate system behavior under varying hydrological conditions, without relying on long-term observational data.

### 3. Results and Discussion

Preliminary analyses confirmed the validity of representing TN and TP concentrations using the EMC approach. The observations indicated that the EMCs remained relatively constant across varying runoff conditions in each catchment: single linear regressions for each of the 13 river tributaries were fitted on specific load data [ $\text{kg}/\text{km}^2$ ] against natural runoff [8], depicting high  $R^2$  both for the TN component ( $>0.9$ ) and for the TP ( $>0.7$ ). This result denotes the robustness of constant EMC assumption to model natural load. The EMCs vary between 0.79 and 3.36 mg/L for TN and between 7.95 and 169  $\mu\text{g}/\text{L}$  for TP.

The simulation of NBSs under a scenario where 20% of the total contributing urban area was treated by NBSs [9] demonstrated a significant impact on urban pollution dynamics. A primary effect of the NBSs was the reduction in total runoff volume, which, in turn, decreased the frequency of sewer overflow activations. Specifically, the simulations indicated an average reduction in the frequency of overflow activations in the order of 60% across the monitored catchments.

Furthermore, the implementation of NBSs led to tangible reductions in the overall nutrient loads discharged into Lake Maggiore. The estimated reduction in nutrient loads was approximately 8% for TN and 33% for TP. These reductions are attributed solely to the decreased frequency of sewer overflows due to enhanced infiltration and reduced run-off. The average daily monthly contributions of TN and TP for all tributaries, disaggregated into natural, build-up and wash-off, and wastewater components, under both pre-NBS and post-NBS conditions, are visually presented in Figure 1 (for TP), highlighting the overall impact of NBSs on nutrient discharge.



**Figure 1.** The monthly average daily loads of TP [ $\text{kg}/\text{day}$ ] separated into natural, build-up/wash-off, and wastewater contributions. Results are shown for the baseline scenario (upper panel) and for the scenario with 20% urban area treated by NBSs (lower panel).

These preliminary results underscore the significant potential of NBSs in mitigating lake pollution and enhancing urban resilience to climate change, aligning with the ENVISION project objectives. The greater reduction observed for phosphorus suggests its stronger susceptibility to urban diffuse pollution and sewer overflow events, making it a key target for NBS interventions.

#### 4. Conclusions

This study introduced a methodological framework to estimate the reductions in nitrogen and phosphorus loads achieved through Nature-Based Solutions (NBSs) in lake catchments, exemplified by a case study of Lake Maggiore. The preliminary results from the continuous simulations indicate that implementing NBSs on approximately 20% of urban surfaces can reduce nutrient loads by about 8% for total nitrogen and 33% for total phosphorus, primarily through an average 60% decrease in sewer overflow events.

Future work will build on this approach by integrating it into an analytical–probabilistic modeling framework to explicitly account for uncertainties in hydrological variability and pollutant transport. Moreover, assessing climate change scenarios will be essential to evaluate the long-term effectiveness and resilience of NBSs under altered precipitation patterns.

**Author Contributions:** Conceptualization, M.G.D.C. and E.G.; methodology, M.G.D.C., E.G. and C.C.; software, M.G.D.C. and E.G.; validation, M.G.D.C. and C.D.; formal analysis, M.G.D.C. and E.G.; investigation, M.G.D.C. and C.C.; resources, M.G.D.C. and C.D.; data curation, M.G.D.C. and E.G.; writing—original draft preparation, M.G.D.C. and E.G.; writing—review and editing, M.G.D.C., U.S., G.B. and C.C.; visualization, M.G.D.C. and E.G.; supervision, C.C. and C.D.; project administration, C.C. and C.D.; funding acquisition, C.C., C.D. and G.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The present research was carried out within the project PRIN (Research Projects of National Relevance) “Lake pollution: Integrating nature-based solutions into environmental urban planning for risk mitigation” (ENVISION) founded by the Italian Ministry of University and Research (MUR).

**Data Availability Statement:** The data presented in this study are available from the corresponding author upon reasonable request.

**Conflicts of Interest:** The authors declare no conflict of interest.

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