



# **Combat of Retrofitting Urban Drainage Networks with Nature-Based Solutions**

***Cite as:***

Oberascher, Martin; Funke, Fabian; Satish; Rahul; Rajabi, Mohammad; Dastgir, Aun; Minaei, Amin; Back, Yannick; Chen, Shiyang; Hauser, Martina; Hajibabaei, Mohsen; Huynh Thi Ngoc, Chau; Leitao, Joao Paulo; Rauch, Wolfgang; Kleidorfer, Manfred; and Sitzenfrei, Robert. “*Combat of Retrofitting Urban Drainage Networks with Nature-Based Solutions*” 2024. In Proc., 13th Urban Drainage Modelling Conference (UDM). Innsbruck, Austria.

# 1. Introduction

Urban drainage systems are increasingly challenged by external factors that can negatively impact their performance. These factors include changing rainfall patterns and more extreme weather events due to climate change (Hosseinzadehtalaei et al., 2020), as well as an increase in sealed surfaces resulting from urbanization (Tscheikner-Gratl et al., 2019). These changes lead to more pressure on sewer networks, which exacerbates urban pluvial flooding and contributes to combined sewer overflows, negatively affecting receiving water bodies. In response to these challenges, some cities and municipalities have adopted decentralized strategies for managing rainwater, including Nature-based Solutions (NBS) (Voskamp et al., 2021; Fang et al., 2023). By reducing and delaying the runoff into sewer systems, NBS help to mitigate urban flooding and alleviate stress on receiving water bodies. Moreover, in comparison to “grey” underground urban drainage infrastructures, NBS have multiple co-benefits, including cooling of urban areas through shading and evapotranspiration, increasing biodiversity, improving air quality and overall quality of day-to-day life (Ruangpan et al., 2020). However, knowing how to maximise and assess the (co-)benefits of NBS measures while improving the drainage performance of sewer systems is a difficult challenge. Therefore, the “*Combat of Retrofitting Urban Drainage Networks with Nature-Based Solutions*” aims to compare the solutions produced by different integration methods to investigate the potential of NBS in enhancing the performance of the benefits and various co-benefits of urban drainage systems, and establish a benchmark case for future developments.

## 2. Aim of the combat, materials and rules

The aim of the “Combat” is to retrofit an existing urban drainage network with different types of nature-based solutions to achieve an optimal system’s performance. The performance of the system is described based on various indicators, as described in Section 3. The provided materials are:

- Calibrated SWMM input file of the case study with rain and temperature data
- Structure of the different types of NBS considered (predefined in the input file)
- Excel file with allowed implementation degree of different NBS in the subcatchments

- Excel file for inputting the solutions
- The files can be downloaded in this link: <https://www.uibk.ac.at/en/congress/udm2025/>

## 2.1. Calibrated SWMM input file

The urban drainage network of the case study is designed as a combined sewer network for the handling of both stormwater and wastewater in SWMM 5.2. The total length of the network is 12.4 km, having pipe sizes between 150 and 1400 mm. As outlined in Figure 1, there is one combined sewer overflow (CSO) at the catchment outlet (storage size of 154.5 m<sup>3</sup>, throttle flow of 30 l/s to the wastewater treatment plant (WWTP)), including an overflow to the receiving water body.

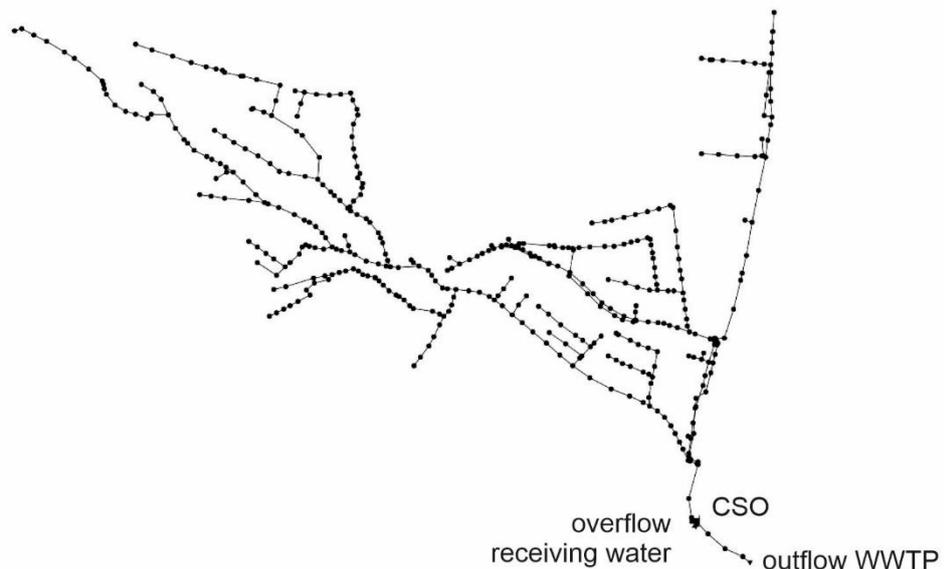


Figure 1: Case study overview

The case study consists of 805 sub-catchments at property level, while streets are further subdivided using the junctions of the combined sewer network as separation criterion. The network and sub catchment characteristics are implemented into a input file, using SWMM 5 (Rossman, 2015) for the hydrodynamic simulations. For this combat, timeseries of precipitation (1 min resolution) and temperature (10 min resolution) are provided over one year.

## **2.2. Available nature-based solutions**

In total, seven types of NBS are available for the combat, differing in their structure and surfaces, into which they can be installed. For the combat, three different types of surfaces are considered, namely NBS installed at green areas, NBS installed at house areas, and NBS installed at traffic areas. The seven types of NBS are already predefined under 'LID Controls' in the provided SWMM input file and cannot be changed.

- NBS for green areas: soakaway, bio retention systems, and dry swales
- NBS for roof areas: Extensive and intensive green roof, cistern
- NBS for traffic areas: Permeable pavement

### **2.2.1. NBS for green areas**

NBS for green areas include soakaway, bio retention systems, and dry swales. Soakaway and bio retention system have the SWMM LID Type Bio-Retention Cell and the dry swale has the LID Type raingarden. The SWMM LID Control parameters used for the implementation are summarised in Table 1.

Table 1: Overview of the NBS for green areas with their structures for SWMM5  
(already implemented in the provided input file).

Layer	Parameter	Soakaway	Bio retention system	Dry swale	
Surface	Berm Height (mm)	2500	300	300	
	Vegetation Volume Fraction (-)	0.0	0	0	
	Surface Roughness (n)	0.1	0.1	0.1	
	Surface Slope (%)	0	0.1	0.1	
Soil	Thickness (mm)	500	300	300	
	Porosity (-)	0.437	0.437	0.453	
	Field Capacity (-)	0.06	0.105	0.19	
	Wilting Point (-)	0.02	0.047	0.085	
	Conductivity (mm/h)	360	30	7	
	Conductivity slope (-)	10	30	30	
	Suction Head (mm)	3.5	61	110	
	Storage	Thickness (mm)	500	500	-
		Void ratio (-)	0.25	0.35	-
Seepage Rate (mm/h)		36	7	7	
Clogging Factor (-)		0	0	-	
Drainage	Thickness (mm)	-	-	-	
Mat	Void Fraction (-)	-	-	-	
	Roughness (n)	-	-	-	
Drain	Flow Coefficient (-)	0	0	0	
	Flow Exponent (-)	-	-	-	
	Offset (mm)	-	-	-	
	Drain delay (h)	-	-	-	

### 2.2.2. NBS for roof areas

NBS for roof areas include extensive and intensive green roof and cisterns. Extensive and intensive green roof have the SWMM LID Type Green roof and the cistern has the LID Type rain barrel. The SWMM LID Control parameters used for the implementation are summarised in Table 2.

Table 2: Overview of the NBS for house areas with their structures for SWMM5  
(already implemented in the provided input file).

Layer	Parameter	Extensive Green roof	Intensive Green roof	Cistern	
Surface	Berm Height (mm)	5	10	-	
	Vegetation Volume Fraction (-)	0.0	0	-	
	Surface Roughness (n)	0.1	0.1	-	
	Surface Slope (%)	2	0.5	-	
Soil	Thickness (mm)	100	250	-	
	Porosity (-)	0.56	0.56	-	
	Field Capacity (-)	0.35	0.35	-	
	Wilting Point (-)	0.02	0.02	-	
	Conductivity (mm/h)	73.71	73.71	-	
	Conductivity slope (-)	18.33	18.33	-	
	Suction Head (mm)	34.45	34.45	-	
	Storage	Thickness (mm)	-	-	1000
		Void ratio (-)	-	-	-
Seepage Rate (mm/h)		-	-	-	
Clogging Factor (-)		-	-	-	
Drainage	Thickness (mm)	9.97	9.97	-	
Mat	Void Fraction (-)	0.55	0.55	-	
	Roughness (n)	0.1	0.1	-	
Drain	Flow Coefficient (-)	0	0	156	
	Flow Exponent (-)	-	-	0.5	
	Offset (mm)	-	-	6	
	Drain delay (h)	-	-	6	

### 2.2.3. NBS for traffic areas

NBS for traffic areas include only permeable pavement, which has the SWMM LID Type Bio-retention cell. The SWMM LID Control parameters used for the implementation are summarised in Table 3.

Table 3: LID control parameters  
(already implemented in the provided input file).

Layer	Parameter	Permeable pavement	
Surface	Berm Height (mm)	1	
	Vegetation Volume Fraction (-)	0.0	
	Surface Roughness (n)	0.1	
	Surface Slope (%)	1	
Soil	Thickness (mm)	100	
	Porosity (-)	0.3	
	Field Capacity (-)	0.2	
	Wilting Point (-)	0.15	
	Conductivity (mm/h)	360	
	Conductivity slope (-)	10	
	Suction Head (mm)	3.5	
	Storage	Thickness (mm)	100
		Void ratio (-)	0.633
Seepage Rate (mm/h)		7	
Clogging Factor (-)		-	
Drainage	Thickness (mm)	-	
Mat	Void Fraction (-)	-	
	Roughness (n)	-	
Drain	Flow Coefficient (-)	-	
	Flow Exponent (-)	-	
	Offset (mm)	-	
	Drain delay (h)	-	

## 2.3. Allowed implementation of NBS

### 2.3.1. Implementation degree of NBS

The case study was extended with information about land usage from previous work (Oberascher et al., 2021) to determine the proportion of house and traffic areas in the impervious surfaces for every subcatchment defined in the case study. Also, the green areas were estimated for each subcatchment. Furthermore, each subcatchment was assigned a land-use classification, since according to the legal requirements in the case region, the selection of NBS depends on the degree of pollution of the runoff of the connected areas. Based on these information, an excel file is provided

(implementation\_details.xlsx), summarising the allowed implementation degree of NBS as percentage of impervious area that can be treated by the three different groups of NBS (see also Table 5).

**Allowed\_imperviousness\_area (%)** in the excel spreadsheet:

- NBS for traffic areas (permeable pavement) can only treat runoff from access roads in the subcatchments
- NBS for roof areas (cistern, extensive and intensive green roofs) can only treat runoff from the roof areas in the subcatchment
- NBS for green areas (soakaway, bioretention cell, dry swale) can treat runoff from all imperviousness areas

Table 4: Examples for allowed maximum % impervious area connected to a NBS for five sub catchment

Subcatchment	Green LID (%)			Roof LID (%)			Access road LID (%)
	Soakaway	Bio retention system	Dry swale	Extensive green roof	Intensive green roof	Cistern	Permeable pavement
.384	100	100	100	100	100	100	0
.385	100	100	100	52.4	52.4	52.4	47.5
.388	100	100	100	90.6	90.6	90.6	9.3
.389	100	100	100	100	100	100	0
.415	100	100	100	53.1	53.1	53.1	46.8

The area of each NBS type is subdivided into the three groups for every subcatchment (Table 6). In any particular subcatchment, contestants are allowed to implement different NBS, following the rules below.

**Allowed\_NBS (m<sup>2</sup>)** in the excel spreadsheet:

- For each sub catchment, a green LID, roof LID and a access road LID can be implemented in parallel
- only one Green LID can be implemented in a subcatchment (e.g., only soakaway or bioretention system or dry swale)

- for green LIDs any area in the range of zero and maximum value mentioned for each subcatchment can be implemented. For example, for “Dry\_swale” in subcatchment “.384”, contestants can implement any area between 0 and 930 m<sup>2</sup>.
- only one Roof LID can be implemented in a subcatchment (e.g., only extensive green roof or intensive green roof or cistern)
- for Roof LIDs only the maximum area (Table 5 and Allowed\_imperviousness\_area (%) in the excel spreadsheet) for each subcatchment or 0 can be implemented. this means if there is a roof, it can only be fully equipped with either an extensive green roof or intensive green roof or a cistern. For example according to Table 6, for subcatchment “.384” and for LID type “Extensive\_green\_roof”, contestants can either implement 153 m<sup>2</sup> or 0 m<sup>2</sup>).

Table 5: Example of allowed maximum NBS implementation in (m<sup>2</sup>) for each LID type and for each sub catchment

Subcatchments	Green LID(m <sup>2</sup> )			Roof LID (m <sup>2</sup> )			Access road (m <sup>2</sup> )
	Soakaway	Bio retention system	Dry swale	Extensive green roof	Intensive green roof	Cistern	Permeable pavement
.384	0	930	930	153	153	1	0
.385	20	40	40	75	75	0.7	68
.388	0	10	10	58	58	0.5	6
.389	0	10	10	65	65	0.6	0
.415	200	400	400	716	716	5	631

### 2.3.2. Implementation in the SWMM input file

The implementation of the NBS is carried out by using the LID Controls (Figure 2) and the LID Usage Editor (Figure 3) in SWMM5.

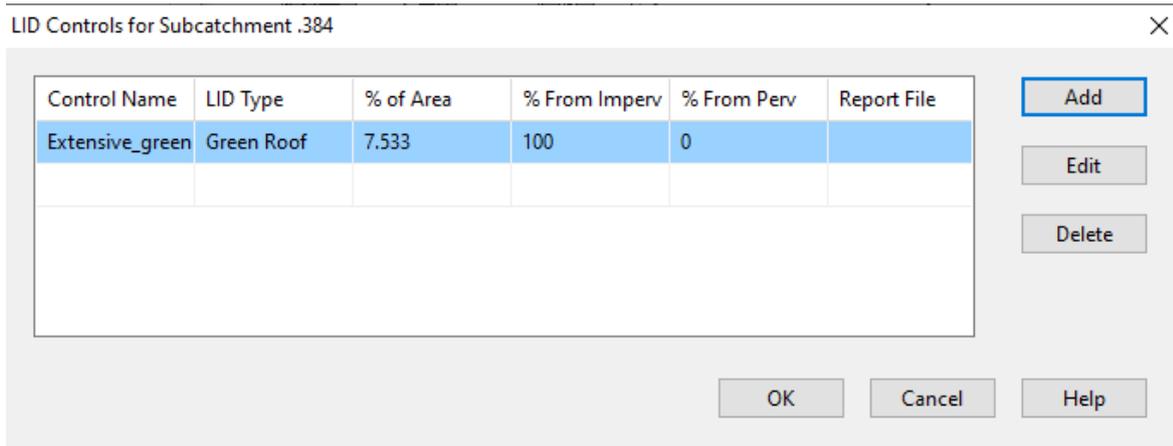


Figure 2: LID controls (example for Subcatchment .384 with an extensive green roof)

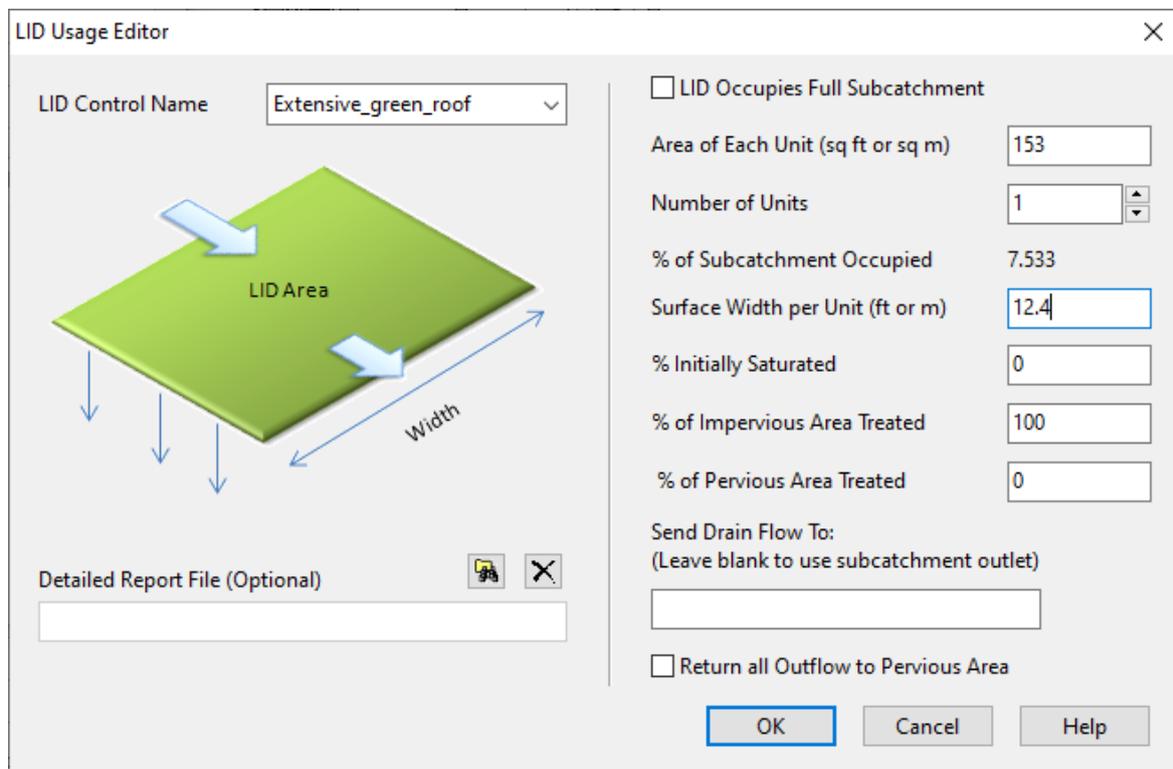


Figure 3: LID usage editor (example for Subcatchment .384 with an extensive green roof)

NBS can be implemented in all subcatchments, however, they are subject to the following boundary conditions:

- The “*Area of Each Unit*” is in  $m^2$  and can be extracted from the spreadsheet “Allowed\_NBS ( $m^2$ )”.
- The “*Number of Units*” is 1 for every implemented NBS.

- The “*Surface Width per Unit*” is in m, calculated as the square root of the “*Area of Each Unit*”.
- The “*% of Impervious Area Treated*” can be set between 0 and the value specified in the spreadsheet “Allowed\_imperviousness\_area (%)” for each subcatchment and LID group.
- All other values are 0 or blank.

## 2.4. Excel spreadsheet for the solutions

All the teams participating in the combat are required to provide an excel file (solutions.xlsx) to be evaluated by the “Combat” organizing team. From the provided excel sheet, the solution of each team will be automatically implemented in the SWMM input file, and the different performance indicators will be assessed by the organizing team.

The first sheet must contain the area of each NBS implemented in each subcatchment. All the NBS implemented in a particular subcatchment will have the value of the area of the NBS implemented while the other NBS which are not implemented in that sub catchment will show a value of 0. An example of the first excel spreadsheet is shown in Table 7.

Table 6: Example for area of each LID implemented in every sub catchment of the case study

Subcatchments	Green (m <sup>2</sup> )			Roof (m <sup>2</sup> )			Access road (m <sup>2</sup> )
	Soakaway	Bio retention system	Dry swale	Extensive green roof	Intensive green roof	Cistern	Permeable pavement
.384	0	0	0	0	153	0	0
.385	0	0	0	0	0	0	0
.388	0	0	0	0	58	0	0
.389	0	0	0	65	0	0	0
.415	0	200	0	0	0	0	0

It can be seen that in “.384” subcatchment, only Intensive\_green\_roof is implemented and the whole roof area is used. In “.389”, Extensive\_green\_roof is implemented on the whole roof area. While

in subcatchment “.415”, Bio\_retention\_system is implemented with 250m<sup>2</sup>, not exceeding the maximum allowed value of 400 m<sup>2</sup> (see Table 6). The second sheet should contain the values of percentage impervious area that is used for each of the NBS implemented in all the subcatchments. An example of such an excel sheet is shown in Table 8.

Table 7: Percentage Impervious area for each LID implemented in every subcatchment

Subcatchments	Green (%)			Roof (%)			Access road (%)
	Soakaway	Bio retention system	Dry swale	Extensive green roof	Intensive green roof	Cistern	Permeable pavement
.384	0	0	0	0	100	0	0
.385	0	0	0	0	0	0	0
.388	0	0	0	0	90.6	0	0
.389	0	0	0	100	0	0	0
.415	0	78	0	0	0	0	0

## 2.5. Competition rules

- The maximum budget allocated for the implementation of NBS in the case study is **€650,000** (the budget must not be spent fully)
- the maximum allowable implementation degree of NBS in every subcatchment must not be violated.
- Each participating team must submit a Microsoft Excel file detailing the implemented NBS, adhering to the provided template, by the deadline of **30.06.2025**.
- Submission of an abstract by **15.01.2025** is mandatory for participation in the 1<sup>st</sup> UDM Combat. The abstract should outline the main methods that will be used.
- Changes to results after 30.06.2025, the final submission date, are not permitted; all results submitted must be presented during the UDM Combat session.

- At least one member from each team must be registered for the UDM 2025 Conference and present the results. Participants must not belong to more than one team and teams are not allowed to submit more than one solution.
- The SWMM parameters are to be considered fixed, and only the implementation of LIDs according to the specified rules is allowed. The evaluation of the solutions will be done by the organizing team with SWMM 5.2 according to the performance evaluation and ranking described in the following section.

### 3. Performance evaluation and ranking

Performance evaluation for each team is based on seven indicators, each contributing to a ranking system. The indicators are designed to assess various aspects of NBS implementation across different subcatchments. Below is a detailed explanation of each indicator.

**Total Cost:** This indicator evaluates the financial investment required for NBS implementation by calculating the total cost, which includes both base costs and variable costs. Table 8 below presents the base price and the price per square meter (unit price) for each NBS type. The base price applies uniformly to any size of NBS implemented. The element costs  $EC_i$  for each implemented NBS  $i$  in Equation (1) is calculated by summing up the base costs  $BC_i$  with the unit costs  $UC_i$  multiplied with the square meter implemented  $A_{ij}$  of NBS type  $i$  in catchment  $j$ .

$$EC_i(\text{€}) = BC_i(\text{€}) + UC_i(\text{€/m}^2) * A_{ij}(\text{m}^2) \quad (1)$$

Table 8: Base and unit costs for NBS's implemented in the combat

NBS type (i=1 to 7)	Base cost (€)	Unit cost (€/m <sup>2</sup> )
Soakaway	608	1000
Bio-retention-system	608	200
Dry swale	103	177
Extensive green roof	486	25
Intensive green roof	486	46
Permeable pavement	344	70
Cistern (1m height)	161	100

The total cost is determined by Equation (2) where  $NS$  is the number available NBS which is in this problem  $i=1$  to 7, and the total number of implemented type  $i$  over catchments  $j$  ( $m^2$ ) for all catchments  $j=1$  to the number of catchments  $noC$

$$Total\ Cost = \sum_{i=1}^{NS} \sum_{j=1}^{noC} (BC_i(\text{€}) + UC_i(\text{€/m}^2) * A_{ij}(\text{m}^2)) \quad (2)$$

**Biodiversity:** This indicator assesses the biodiversity of NBS implemented in subcatchments by summing up the implemented areas in all catchments for the NBS Bio retention systems ( $i=2$ ), dry swale ( $i=3$ ), extensive green roof ( $i=4$ ) and intensive green roof ( $i=5$ ). The indicator is then the minimum value of the different Green LID type, ensuring a wide range of different green LID types implemented.

$$Biodiversity = \text{Min}(\sum_{j=1}^{noC} A_{i=2,j}, \sum_{j=1}^{noC} A_{i=3,j}, \sum_{j=1}^{noC} A_{i=4,j}, \sum_{j=1}^{noC} A_{i=5,j}) \quad (3)$$

**Flood Volume Reduction:** This indicator measures the reduction  $\Delta V_F$  in flood volume achieved through NBS implementation by comparing the total flood volume in the base scenario  $V_{F,base\ scenario}$  to the flood volume when NBS measures are in place ( $V_{F,NBS}$ ):

$$\Delta V_F = V_{F,base\ scenario} - V_{F,NBS} \quad (4)$$

**Evaporation Enhancement:** This index evaluates the improvement in evaporation losses  $\Delta E$  resulting from NBS practices by comparing the evaporation losses in the base scenario  $E_{base\ scenario}$  with those in the NBS-implemented scenario  $E_{NBS}$ :

$$\Delta E = E_{NBS} - E_{base\ scenario} \quad (5)$$

**Inflow Increase to Wastewater Treatment Plant:** This metric assesses the change in inflow  $\Delta V_{WWTP}$  to the waste water treatment plant following NBS implementation  $V_{WWTP,NBS}$  compared to the base scenario  $V_{WWTP,base\ scenario}$ .

$$\Delta V_{WWTP} = V_{WWTP,NBS} - V_{WWTP,base\ scenario} \quad (6)$$

**CSO (River) Reduction:** This indicator measures the reduction in Combined Sewer Overflow volume discharging into rivers  $\Delta V_{CSO}$  by comparing the total CSO volume in the base scenario  $V_{CSO,base\ scenario}$  with that in the NBS-implemented scenario  $V_{CSO,NBS}$

$$\Delta V_{CSO} = V_{CSO,base\ scenario} - V_{CSO,NBS} \quad (7)$$

**Water Quality Enhancement:** Total Suspended Solids (TSS) for rain and dry weather flow are considered 70 Mg/L and 200 Mg/L. This metric evaluates the improvement in water quality by assessing the reduction in TSS mass (kg)  $\Delta M_{TSS}$  in CSO discharges with implementing NBS measures  $M_{TSS,NBS}$  compared to the base scenario  $M_{TSS,base\ scenario}$ :

$$\Delta M_{TSS} = M_{TSS,base\ scenario} - M_{TSS,NBS} \quad (8)$$

Table 9 provides a mapping of the ranking indicators to the corresponding sections and parameter names in the SWMM report file. The performance evaluation is done based on the provided time series for precipitation and temperature. Therefore, the simulation results for the entire period (1 year) are considered for the performance evaluation in equation 4 to equation 8. Each team is assigned a rank for each indicator, and the overall performance ranking is determined based on these individual scores.

Table 9: Correspond sections and names to the ranking indicators in SWMM rpt file

<b>Ranking Indicator</b>	<b>Section in SWMM rpt file</b>	<b>Assigned name in the section</b>
$\Delta V_F$	Flow Routing Continuity	Flooding Loss
$\Delta E$	Flow Routing Continuity	Evaporation Loss
$\Delta V_{WWTP}$	Outfall Loading Summary	Total Volume (WWTP)
$\Delta V_{CSO}$	Outfall Loading Summary	Total Volume (CSO_river)
$\Delta M_{TSS}$	Outfall Loading Summary	Total TSS (CSO_river)

## 4. Timetable with corresponding tasks

- 15.01.2025      Submission of a short abstract:
- Description of the intended approach (max. 200 words)
  - Team name
- 30.06.2025      Conference registration of at least one team member
- 30.06.2025      Submission of the solutions:
- Filled out excel spreadsheets with the solutions to [contact@udm2025.org](mailto:contact@udm2025.org)
  - Description of the approach for optimal placement of NBS (max. 1 page) used by the organiser to prepare the joint journal publication with all teams as co-authors
- 15-19.09.2025    Presentation at the conference in the combat session, announcing of the winners during the closing ceremony

## 5. References

- Fang, X., Li, J., & Ma, Q. (2023). Integrating green infrastructure, ecosystem services and nature-based solutions for urban sustainability: A comprehensive literature review. *Sustainable Cities and Society*, 98. <https://doi.org/10.1016/j.scs.2023.104843>
- Hosseinzadehtalaei, P., Tabari, H., & Willems, P. (2020). Climate change impact on short-duration extreme precipitation and intensity–duration–frequency curves over Europe. *Journal of Hydrology*, 590(March), 125249. <https://doi.org/10.1016/j.jhydrol.2020.125249>
- Oberascher, M., Kinzel, C., Kastlunger, U., Kleidorfer, M., Zingerle, C., Rauch, W., and Sitzenfrie, R. (2021). "Integrated urban water management with micro storages developed as an IoT-based solution – The smart rain barrel." *Environ Model Softw* 139. <https://doi.org/10.1016/j.envsoft.2021.105028>
- Rossman, L.A. (2015). User's Manual Version 5.2 Manual Storm Water Management Model (SWMM) User's Manual Version 5 .2.1. U.S. Environmental Protection Agency (EPA), September, 1–353. <https://www.epa.gov/system/files/documents/2022-04/swmm-users-manual-version-5.2.pdf>

- Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M. P., McClain, M. E., & Lopez-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Nat. Hazards Earth Syst. Sci.*, 20(1), 243-270. <https://doi.org/https://doi.org/10.5194/nhess-20-243-2020>
- Tscheikner-Gratl, F., Caradot, N., Cherqui, F., Leitão, J. P., Ahmadi, M., Langeveld, J. G., Le Gat, Y., Scholten, L., Roghani, B., Rodríguez, J. P., Lepot, M., Stegeman, B., Heinrichsen, A., Kropp, I., Kerres, K., Almeida, M. do C., Bach, P. M., Moy de Vitry, M., Sá Marques, A., ... Clemens, F. (2019). Sewer asset management—state of the art and research needs. *Urban Water Journal*, 16(9), 662–675. <https://doi.org/10.1080/1573062X.2020.1713382>
- Voskamp, I. M., de Luca, C., Polo-Ballinas, M. B., Hulsman, H., & Brolsma, R. (2021). Nature-Based Solutions Tools for Planning Urban Climate Adaptation: State of the Art. *Sustainability*, 13(11). <https://doi.org/https://doi.org/10.3390/su13116381>