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

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## Abstract

The existing urban drainage infrastructure, which mainly consists of central solutions, has been extended in the last decades by decentralised system applications such as nature-based solutions (NBS) and is currently an area of greatest interest of the research community.

To further expand the knowledge on this topic, the "Combat of retrofitting Urban Drainage Networks with NBS" is organised at the UDM 2025. The aim of the combat is to optimise the retrofitting of an existing urban drainage network with seven different types of nature-based solutions. Therefore, a calibrated combined sewer network of an Alpine municipality in Austria is provided as an SWMM5 input file, together with implementation rules (e.g., type of nature-based solution is depending on land classification).

The submitted solutions will be evaluated based on seven performance indicators, including costs, biodiversity and metrics related to system performance improvements. The best teams are honoured during the closing ceremony, and the submitted solutions and the task will be published in a joint publication of all participants of the combat to support the dissemination of the case study as a benchmark network in future.

## Highlights

- Description of the participating rules for the combat of retrofitting urban drainage networks with nature-based solutions.
- Dissemination of the presented case study as benchmark network for future research.

## 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 at., 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.

## 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/

### 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 m³, throttle flow of 30 l/s to the wastewater treatment plant (WWTP)), including an overflow to the receiving water body.

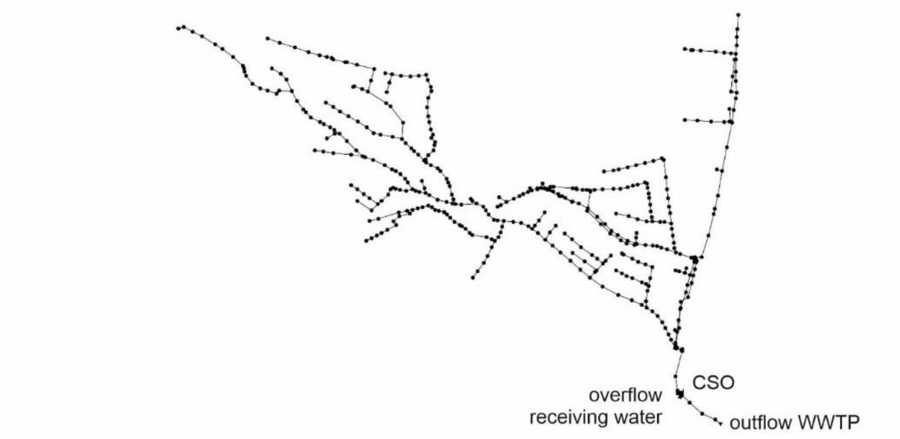


**Figure 1.** Case study overview

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.

## 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

## 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 Mat | Thickness (mm) | - | - | - |
| | Void Fraction (-) | - | - | - |
| | Roughness (n) | - | - | - |
| Drain | Flow Coefficient (-) | 0 | 0 | 0 |
| | Flow Exponent (-) | - | - | - |
| | Offset (mm) | - | - | - |
| | Drain delay (h) | - | - | - |

## 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 |

## NBS for roof 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.** Overview of the NBS for traffic areas with their structures for SWMM5 (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) | - |

## Allowed implementation of NBS

### 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 this 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 subcatchment, contestants are allowed to implement different NBS, following the rules below.

**Allowed_NBS (m²)** 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 and access road 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 $m^2$.
- 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 m² or 0 m²).

**Table 5.** Examples of allowed maximum NBS implementation in (m2) for each LID type and for each sub catchment.

| Subcatchments | Green LID(m²) | | | Roof LID (m²) | | | Access road LID (m²) |
|---|---|---|---|---|---|---|---|
| | 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 |

## 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.

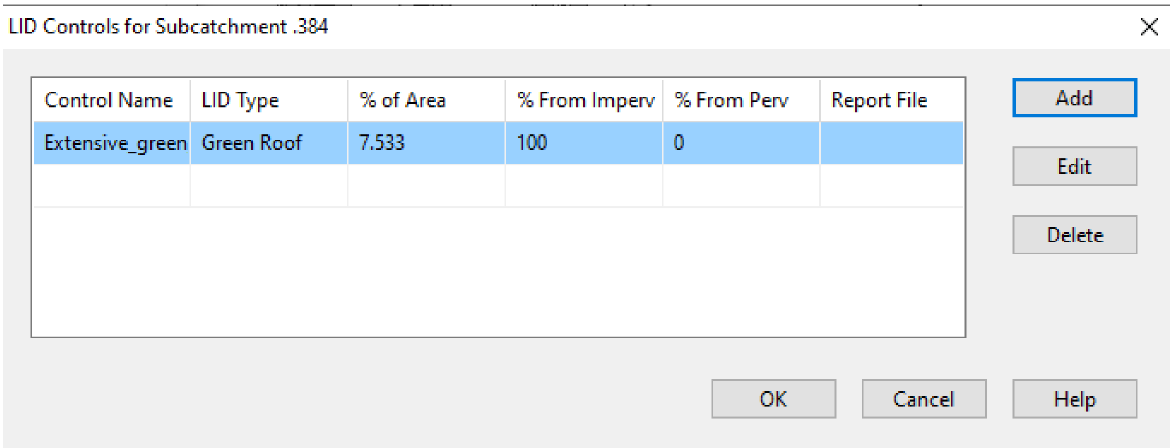


**Figure 2.** LID controls (example for Subcatchment .384 with an extensive green roof).

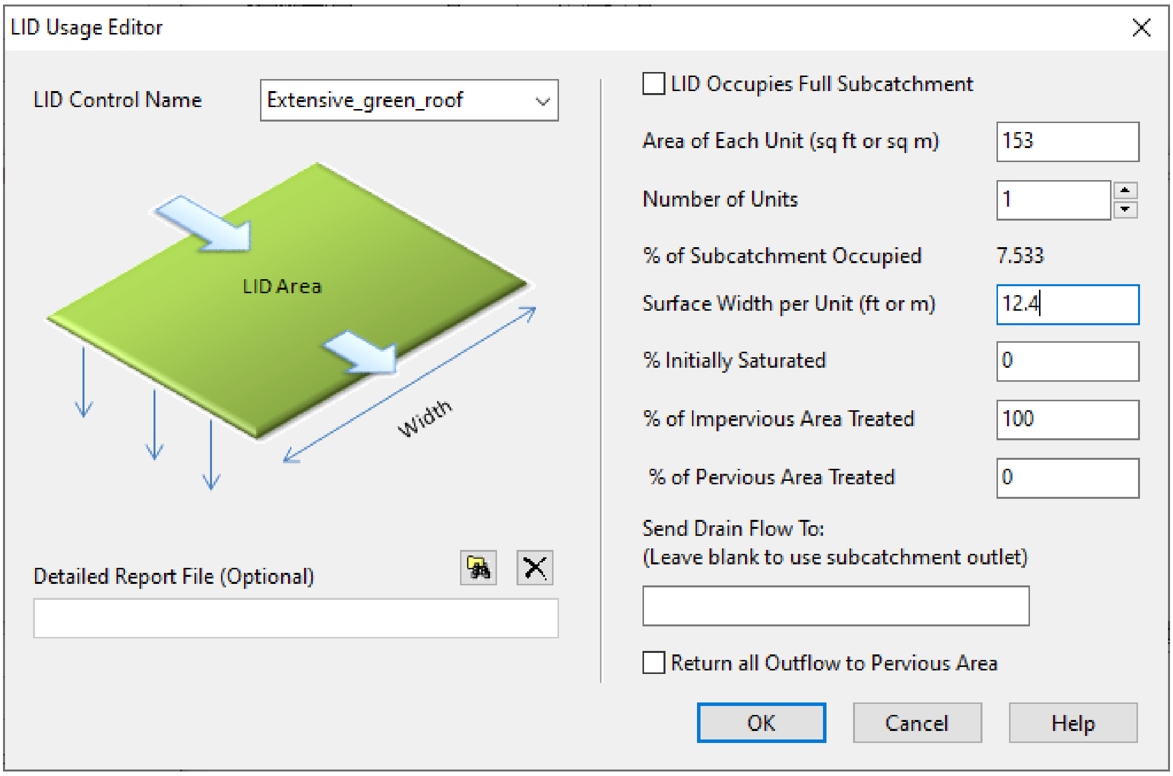


**Figure 3.** LID usage editor (example for Subcatchment .384 with an extensive green roof).

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

- The *"Area of Each Unit"* is in m² and can be extracted from the spreadsheet "Allowed_NBS (m²)".
- 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.

### 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 (m²) | | | Roof (m²) | | | Access road (m²) |
|---|---|---|---|---|---|---|---|
| | 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 250m², not exceeding the maximum allowed value of 400 m² (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 |

## 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.
- The SWMM parameters are to be considered fixed, and only the implementation of LIDs according to the specified rules is allowed. For the combat, changes in the subcatchment characteristics due to the implementation of LIDs are neglected. 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.

# 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:

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

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

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

| NBS type (i=1 to 7) | Base cost (€) | Unit cost (€/m²) |
|---|---|---|
| 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 (m²) for all catchments j=1 to the number of catchments noC

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

**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.

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

**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 simulations result of 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 through the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (for more information, refer to Chakraborty (2022)) based on these individual scores.

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

| Ranking Indicator | Section in SWMM rpt file | Assigned name in the section |
|---|---|---|
| $\Delta V_F$ | Flow Routing Continuity | Flooding Loss |
| $\Delta E$ | Runoff Quantity Continuity | Evaporation Loss |
| $\Delta V_{WWTP}$ | Outfall Loading Summary | Total Volume (WWTP) |
| $\Delta \mathbf{V_{CSO}}$ | Outfall Loading Summary | Total Volume (CSO_overflow) |
| $\Delta M_{TSS}$ | Outfall Loading Summary | Total TSS (CSO_overflow) |

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