A report on

Impact of decentralized rainwater management measures on the water budget of the Räcknitz district, Dresden

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ABSTRACT

Urban water management is facing increasing challenges due to rapid urbanization and climate change, necessitating the adoption of sustainable stormwater management solutions. This study evaluates the impact of decentralized rainwater management measures on the water budget of the Räcknitz district in Dresden, focusing on the role of Low Impact Development (LID) techniques. Using the Environmental Protection Agency's Storm Water Management Model (EPA SWMM), the study analyses stormwater runoff behaviour under different rainfall return periods and assesses the effectiveness of various LID implementations, including Green Roofs (GR), Permeable Pavements (PP), and Infiltration Trenches (IT). The model was calibrated and validated using historical rainfall data, employing Nash-Sutcliffe Efficiency (NSE) and Peak Flow Error (PFE) as performance indicators. Results indicate that LID measures significantly reduce peak runoff and enhance infiltration, with Green Roofs demonstrating the highest efficiency in mitigating stormwater discharge. While Permeable Pavements and Infiltration Trenches also contribute to runoff reduction, their effectiveness varies depending on rainfall intensity. The study further examines the feasibility of integrating LID into new developments, with Vegetative Swales as a recommended measure for enhanced infiltration and urban resilience. The findings highlight the potential of decentralized stormwater management strategies in reducing flood risks, improving groundwater recharge, and ensuring sustainable urban drainage.

Keywords: LID, EPA SWMM, Wastewater Modelling, Permeable pavement, Green Roof

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DWF	Dry weather flow
EPA	Environmental Protection Agency
LID	Low Impact Development
PFE	Peak Flow Error
NSE	Nash-Sutcliffe Efficiency
SWMM	Storm Water Management Model
WWTP	Wastewater Treatment Plant
PP	Permeable Pavement
IT	Infiltration Trench
GR	Green Roof
VS	Vegetative Swale
LID	Low Impact Development

1 Introduction

Urban water management is facing unprecedented challenges due to rapid urbanization and the growing impacts of climate change. As cities expand, natural surfaces that once allowed rainwater to infiltrate are being replaced by impervious structures such as roads, buildings, and parking lots. This shift disrupts the natural hydrological cycle, increasing surface runoff, reducing groundwater recharge, and exacerbating the risk of urban flooding. At the same time, climate change is intensifying rainfall variability, making extreme weather events more frequent and unpredictable, further straining existing water infrastructure.

Traditional centralized drainage and stormwater management systems, which were designed to quickly channel excess water away from urban areas, are often ill-equipped to handle these evolving conditions. They frequently lead to overwhelmed sewer networks, increased pollution in water bodies, and deteriorating water quality due to the rapid conveyance of untreated runoff mixed with contaminants from urban surfaces. As a result, many cities are now experiencing a heightened risk of waterlogging, erosion, and degradation of aquatic ecosystems.

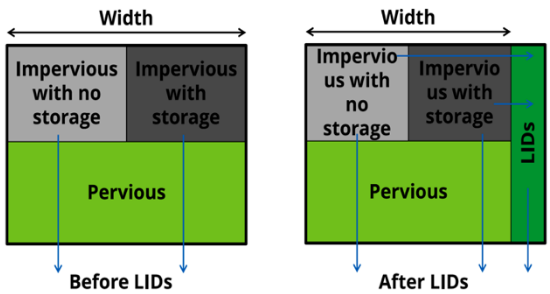


Figure 1 Conceptual diagram showing working of LID (Reyes-Silva, Low Impact Development (LID) structures , 2024)

To address these challenges, Low Impact Development (LID) has gained significant attention as an effective and sustainable approach to stormwater management. Unlike conventional systems that focus solely on diverting runoff, LID aims to mimic natural hydrological processes by promoting infiltration, evapotranspiration, and water storage at the source. This decentralized strategy helps mitigate flooding, improve water quality, and enhance urban resilience.

LID encompasses a range of innovative practices designed to manage stormwater more effectively while integrating green infrastructure into urban landscapes. Some of the most widely used LID techniques include.

Rainwater Harvesting Systems: These systems collect and store rainwater from rooftops or other surfaces, offering a sustainable water source for non-potable applications such as irrigation. By capturing rainfall, they contribute to reducing stormwater runoff and enhancing urban water security (Addo-Bankas et al. 2024).

Vertical Gardens/Living Walls: Vertical gardens are an innovative form of green infrastructure designed to enhance air quality, mitigate urban heat, and manage stormwater. In addition to their functional benefits, they improve the visual appeal of urban environments and support sustainable urban ecosystems (Ibrahim Momtaz 2018).

Green Roofs: Vegetated rooftops that absorb rainwater, provide thermal insulation, reduce urban temperatures, and minimize stormwater runoff (Jeffers et al. 2022).

Rain Gardens: Shallow, vegetated depressions that capture and absorb runoff from impervious surfaces, help recharge groundwater, and filter pollutants (Ishimatsu et al. 2017).

Permeable Pavements: Specially designed surfaces that facilitate water infiltration, reduce surface runoff, and improve water quality by filtering contaminants before reaching the subsurface (Scholz and Grabowiecki 2007)

Bioretention Cells: Engineered systems that use soil and vegetation to collect, filter, and treat stormwater runoff, promoting infiltration and reducing pollutant loads in receiving water bodies (Davis, 2008).

Low Impact Development (LID) measures play a key role in sustainable urban water management by improving resilience against climate change and reducing stormwater impacts. Integrating LID into urban planning enhances water security, minimizes runoff, and supports long-term environmental sustainability.

This study examines decentralized stormwater management in the Räcknitz district of Dresden, focusing on its combined sewer system. Using the Environmental Protection Agency’s Storm Water Management Model (EPA SWMM), long-term simulations assess the impact of LID techniques on runoff dynamics across different rainfall return periods. The study also evaluates whether the existing sewer network can accommodate planned developments near the Zeunerstraße seminar building and Volkspark Räcknitz. A decentralized stormwater management model tailored to the Räcknitz district is proposed, ensuring compliance with the overflow frequency guidelines of DWA A-118. The findings offer insights into how LID measures enhance urban resilience, improve water management, and support ecological sustainability.

1.1 Presentation of the Study Area

The Räcknitz district in Dresden lies within the Dresden Basin and is bordered by notable natural features such as the East Ore Mountains, the Elbe Sandstone Mountains, and the Lusatian Granite Crust. Characterized by a mild climate and diverse topography, the region combines urbanized areas with green spaces. The Elbe River significantly impacts the area’s hydrology and plays a crucial role in flood management strategies. The development of Räcknitz and Dresden reflects a blend of historical and contemporary influences, with a strong emphasis on integrating green infrastructure and sustainable urban planning.

Figure 2 Urban Land Use and Infrastructure Map including New Development Area (Reyes-Silva, 2024)

The designated study area within the Räcknitz district spans three hectares and includes 6,000 m² allocated for residential use and 2,500 m² designated for transportation infrastructure, accommodating around 100 inhabitants. Additionally, there are ongoing plans to extend the university campus towards the eastern section of the study area.

2 Materials and Methods

To evaluate decentralized rainwater management in the Racknitz district, the Storm Water Management Model (EPA SWMM) is used to simulate various rainfall events across different return periods. The study examines both the existing drainage system and the effects of implementing LID measures. This approach involves setting up a reference scenario, integrating LID techniques, and conducting hydrological simulations to analyse runoff behaviour, infiltration rates, and sewer system performance in compliance with DWA A-118 guidelines.

The results provide a comparative insight into the efficiency of traditional and decentralized stormwater management solutions in enhancing urban resilience.

The model setup in EPA SWMM follows a structured process, which includes the following steps:

1. **Sewer Network Modelling:** Establishing the layout and hydraulic properties of the existing drainage infrastructure.
2. **Sub-Catchment Definition:** Segmenting the study area into hydrological units based on land use, surface properties, and topography.
3. **Incorporating Dry and Wet Weather Flow:** Accounting for base flow contributions and precipitation-induced runoff.
4. **Configuring Model Parameters:** Setting up key inputs such as rainfall data, infiltration characteristics, and flow routing methods.
5. **Calibration and Validation:** Refining the model parameters to ensure consistency with observed or literature-based data.
6. **Scenario Simulations:** Running multiple simulations to compare the impacts of LID interventions on the stormwater system.

2.1 Modeling Approach

2.1.1 Overview of EPA SWMM

The Storm Water Management Model (SWMM) is a dynamic computational tool designed for simulating rainfall-runoff processes. It can be applied to both individual storm events and long-term hydrological assessments to evaluate runoff quantity and quality (Hossain et al. 2019). Developed by the U.S. Environmental Protection Agency (EPA), SWMM serves as a robust modelling framework for analysing stormwater behaviour, particularly in urban settings.

The model enables detailed simulations of precipitation patterns, surface runoff generation, and the movement of water through drainage infrastructure, including pipes, channels, and storage or treatment facilities. A key feature of

SWMM is its ability to assess green infrastructure solutions, also referred to as Low Impact Development (LID) strategies, which aim to manage stormwater close to its source. These strategies include green roofs, rain gardens, permeable pavements, and rainwater harvesting systems, all of which can be incorporated into SWMM simulations to analyse their effectiveness in reducing runoff, enhancing infiltration, and minimizing flood risks.

By utilizing SWMM's advanced modelling capabilities, urban planners and engineers can systematically evaluate the effectiveness of various stormwater management approaches. The insights gained from these simulations support the development of resilient and sustainable urban environments, ensuring that stormwater infrastructure is better equipped to handle extreme weather conditions.

2.1.2 Sewer Network Model

The sewer network in the Räcknitz district extends approximately 3.44 km and exhibits variability in both cross-sectional shapes and material composition. However, for modelling purposes, all conduits are assumed to be circular and composed of concrete, ensuring consistent application of Manning's roughness coefficient.

To develop the model, the sewer conduits and corresponding manholes were imported into SWMM. The attribute tables associated with these elements contain key spatial and hydraulic properties, including pipe length, roughness coefficients, cross-sectional geometry, diameter, invert elevations, material type, and manhole depths. Additionally, the geographic coordinates of network components are defined using the EPSG 3857 coordinate system to maintain spatial consistency in the study.

2.1.3 Dry Weather Flow

Dry weather flow (DWF) refers to the average daily flow directed to a wastewater treatment plant (WWTP) under conditions without rainfall. In a combined sewer system, this flow typically increases during wet weather due to additional inflow and infiltration. Seasonal variations in DWF can occur due to changes in sewer infiltration rates and fluctuations in population size. Accurate estimation of dry weather flow is essential in sewer system design and maintenance, as it directly impacts network capacity and performance. Proper consideration of both sewage flow and extraneous flow during dry periods ensures that the sewer system is appropriately dimensioned to manage anticipated loads without the risk of overflows or blockages. Therefore, incorporating DWF into the model was crucial for improving simulation accuracy.

The total dry weather flow (Q_{dw}) is calculated using the following equations:

$$Q_{dw} = Q_s + Q_{extraneous}$$

where:

$$Q_s = Q_{dom} + Q_{ind}$$

Q_s represents the total sewage flow, consisting of domestic sewage flow Q_{dom} and industrial sewage flow Q_{ind}. $Q_{extraneous}$ accounts for additional inflows such as groundwater infiltration and unintended stormwater entry into the system.

Q_{dw} = Dry weather flow (DWF)

Q_s = Sewage flow

$Q_{extraneous}$ = Extraneous flow (typically 30% to 50% of Q_s

Q_{dom} = Domestic sewage flow

Q_{ind} = Industrial sewage flow

The domestic sewage flow is generally estimated based on water consumption and is assumed to range between 0.8 to 1.0 times the total water usage. The water consumption values for the study area are summarized in Table 1. The dry weather flow exhibits temporal variations throughout the day, with noticeable differences between weekdays and weekends. These fluctuations closely align with the typical water consumption patterns observed in the study area Annex A

Table 1 Water Consumption data of the study area (Reyes-Silva, Water consumption, 2024)

Location	Water Consumption (m^3/day)
Haeckelstraße	9,425
Zeunerstraße (East of Bergstraße)	32,424
Zeunerstraße (West of Bergstraße)	128,833
Bergstraße	462,328
Mommsenstraße	3,516

The dry weather flow exhibits temporal variations throughout the day, with noticeable differences between weekdays and weekends. These fluctuations closely align with the typical water consumption patterns observed in the study area.

2.1.4 Sub catchment Delineation

The study area is divided into 19 sub-catchments for preliminary later new development catchment was added, which were delineated and spatially integrated with the existing sewer network for accurate modelling. Key hydrological parameters of these sub-catchments were carefully analysed and utilized for model calibration to enhance simulation accuracy. These parameters include: Area, Width, Impervious Area Percentage, Slope Percentage and Infiltration etc whose values are presented in Annex A.

Annex A. By incorporating these parameters into the model, the hydrological response of the study area was refined, improving the reliability of runoff and infiltration simulations.

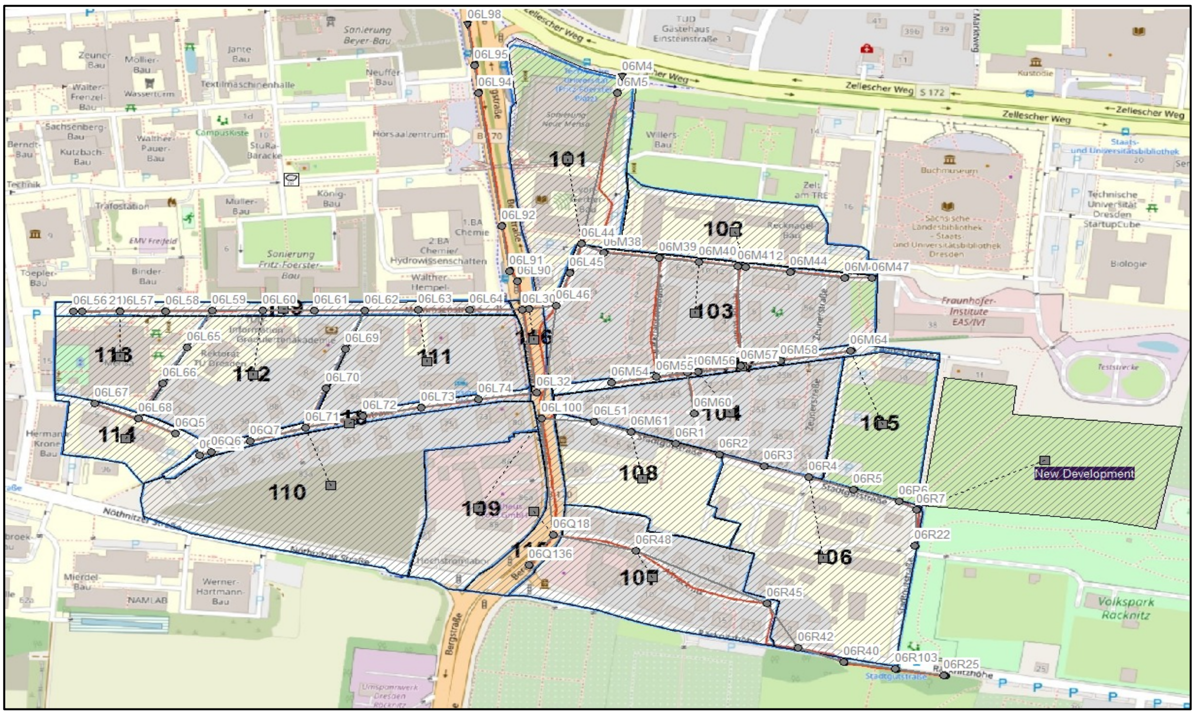


Figure 3 Delineated sewer network model with the inclusion of new development area

2.2 Calibration and Validation

2.2.1 Calibration

Classification of Rain Events

Based on return period values, the selected rain events were categorized into three intensity levels. Events with a return period less than 1.0 years (Z < 1.0) were classified as low intensity, representing frequent minor rain events. Medium-intensity events were those with a return period between 1.0 and 4.0 years (1.0 ≤ Z ≤ 4.0), corresponding to moderate rainfall scenarios. Lastly, high-intensity events were defined as those with a return period greater than 4.0 years (Z > 4.0), representing extreme rainfall conditions.

Selection of Rain Events

For model calibration, rainfall data spanning from May 4, 1996, to November 30, 2015, was analysed (Reyes-Silva, Rain.CO, 2024). The dataset contained 5-minute interval rainfall depths (in mm), providing a detailed record for evaluating storm events. Following established calibration methodologies, 43 specific rain events were initially identified for assessment. For validation, three events (Table 3) were selected in such a way that it describes different rainfall characteristics and return period, where each event represented each intensity level.

From this dataset, 6 representative events Table 2 were selected for calibration process based on their return periods Annex B. The return periods were determined using Reinhold's formula for rainfall events lasting less than 90 minutes.

Reinhold's Formula

For short-duration rain events, the return period (Z) is computed using the equation:

$$Z = (\frac{I(t_R)(z)}{I_{15}(1)} \cdot \frac{t_R + 9(min)}{38(\mathrm{min})} + 0.369)^4$$

where:

Z = Return period of the rain event

I_{15} (1) = Rain intensity (mm/h) for a 15-minute event with a 1-year return period

t_R = Duration of the rain event (minutes)

$I(t_R)(z)$ = Rain intensity as a function of the return period Z and duration t_R

Table 2 Characteristics of the selected rain events for calibration process

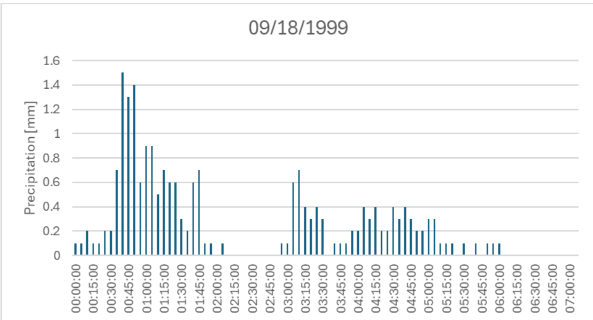
Rain Event	Precipitation (mm)	Duration (min)	Return Period (years)
12 May 06	3.6	245	0.08
03 Jun 98	6.4	130	0.19
18 Sep 99	21.2	695	2.79
08 Jul 14	24.9	1225	4.39
08 Jul 96	43.2	1385	25.12
17 Jun 15	50.6	800	43.57

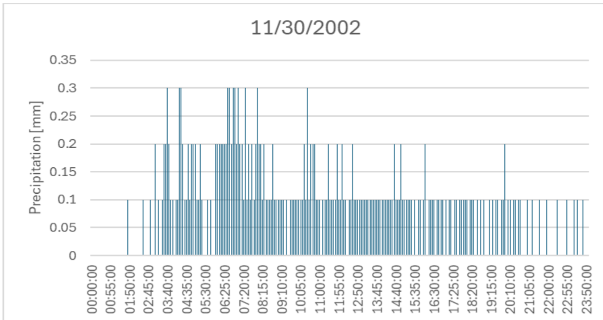
2.2.2 Validation

To validate the model, three rain events with different characteristics are selected based on their return period Table 3. The selection aimed to ensure that the chosen events represent a range of hydrological conditions while maintaining strong model performance.

Table 3 Summary of Selected rain event characteristics for validation process

Rain Event	Cumulative Precipitation (mm)	Duration (min)	Return Period (years)
18 Sep 1999	21.2	695	2.5
30 Nov 2002	25.3	1320	5
08 Aug 2008	37.5	325	17





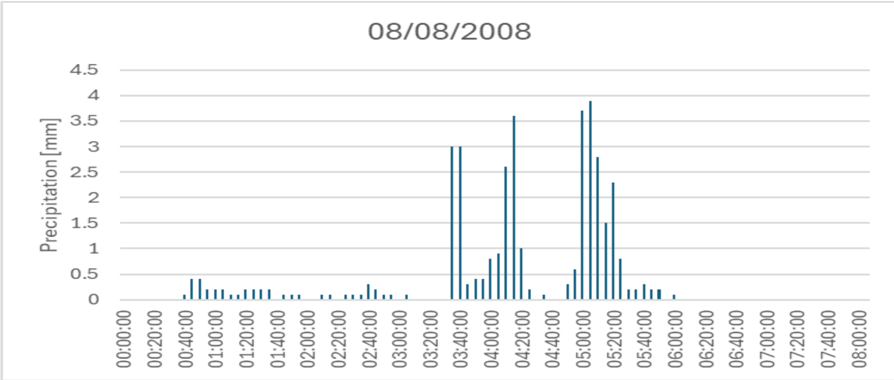


Figure 4 Precipitation distribution on Validation Events (09/18/1999 (top left), 11/30/2002 (top right) & 08/08/2008 (lower))

2.2.3 Performance Indicators

The accuracy of the model calibration was assessed using two key performance indicators: the Nash-Sutcliffe Efficiency (NSE) and the Peak Flow Error (PFE). These indicators help evaluate how well the simulated values match the observed data.

The Nash-Sutcliffe Efficiency (NSE) quantifies the goodness of fit by comparing the sum of squared differences between observed and simulated values to the variance of the observed data. A value close to 1 indicates a strong correlation between the simulated and observed values, signifying a well-calibrated model.

$$NSE = 1 - \frac{\sum(obs_i - sim_i)^2}{\sum(obs_i - \overline{obs_i})^2}$$

For an ideal calibration, NSE = 1, meaning the model perfectly replicates observed values.

PFE measures the relative difference between the peak observed flow and the peak simulated flow. This indicator is particularly useful for assessing whether the model accurately captures peak discharges, which are critical for flood risk analysis.

$$PFE = \frac{|max(obs) - max(sim)|}{max(obs)}$$

For an ideal calibration, PFE = 0, indicating that the model perfectly matches the peak observed flow.

2.3 Implementation of LID on the Existing Network

2.3.1 Characteristics of the selected catchment

This study focuses on sub-catchment 101 Figure 5 situated opposite to the Hörsaalzentrum of TU Dresden. The sub-catchment spans an area of 19,400 m² and is particularly well-suited for the implementation of LID measures. The details of the structures present in the catchment are presented in Table 4. The area has Gerber Bau and the neu Mensa which is temporarily closed. This catchment is particularly selected for the application of LID because, the flow of the sub catchment is the highest among the 19 sub-catchments. The highest is selected, because, if we reduce the peak flow for the highest flow, it will reduce significantly the load on the sewer network.

The site survey identified three potential LIDs measures suitable for implementation: Pervious Pavements (PP) in the sidewalks, Infiltration Trench (IT) near Gerber Bau and Green Roofs (GR) on the flat roofs.

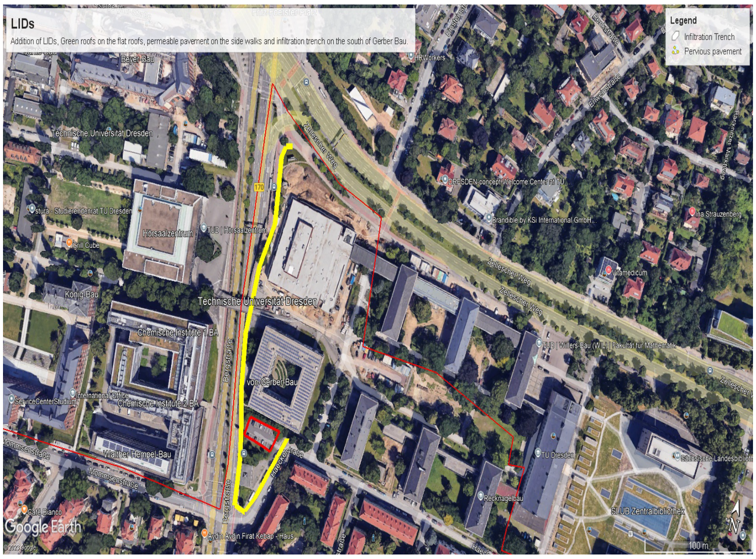


Figure 5 Details as seen in the sub-catchment 101, with yellow and red dashed line representing application of LID measures: permeable pavement and infiltration trench respectively. The flat roofs will be replaced by green roofs

Table 4 Characteristics of sub-catchment 101

Parameter	Value
ID Subcatchment	101
Total Area (Ha)	1.94
Street Area (Ha)	0.41
Yard Area (Ha)	0
Flat Roofs Area (Ha)	0.56
Sidewalks Area (Ha)	0.16
Green Areas (Ha)	0.54
Gable Roofs Area (Ha)	0
Others Area (Ha)	0.27
Surface Length (m)	260.58
Width (m)	74.63
Impervious Area (Ha)	1.13

2.3.2 Selection and Justification of LID Measures

Pervious Pavements

Pervious pavements replace impervious pedestrian pathways, enabling direct infiltration and reducing surface runoff. Turfstone pavers are selected for their structural integrity and permeability, allowing rainwater to pass through voids filled with gravel. The catchment has sidewalks area of 1600 m^2, which is 8.24 % of the total area. As per site inspection, the sidewalk slopes mildly to the north, so using of pervious pavements minimizes localized flooding, decreases peak discharge, and enhances groundwater recharge. The system is particularly effective in managing low-intensity runoff from walkways while maintaining pedestrian accessibility. The design values used are listed in Table 5 for the conceptual layers as shown in Figure 6.

Table 5 Characteristics of pervious pavement (Reyes-Silva, Low Impact Development (LID) structures , 2024)

Layer	Parameter	Value
Surface	Berm Height (mm)	0
	Vegetation Volume	0.1
	Manning's n	0.1
	Surface Slope (%)	1
Soil	Thickness (mm)	200
	Porosity	0.4
	Field Capacity	0.2
	Permanent Wilting Point (PWP)	0.1
	Hydraulic Conductivity (mm/h)	50
	Conductivity Slope	15
	Suction Head (mm)	80
Storage	Thickness (mm)	150
	Void Ratio	0.25
	Seepage Rate (mm/h)	50
	Clogging Factor	0
	Drain	No
Pavement	Thickness (mm)	80
	Void Ratio	0.2
	Impervious Surface Fraction	0.2
	Permeability (mm/h)	50
	Clogging Factor	0
	Regeneration Intervals (days)	365
	Regeneration Factor	0.5

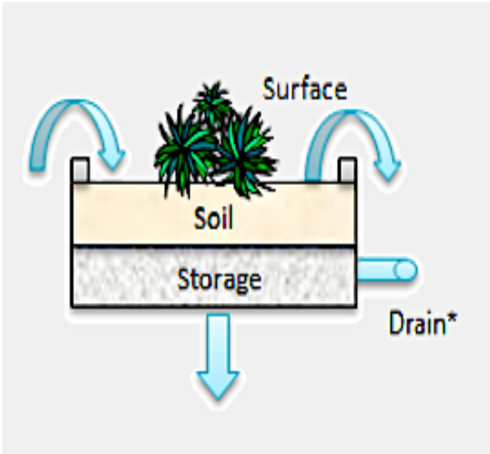


Figure 6 Conceptual design layers of Permeable Pavement (EPA SWMM)

Infiltration Trenches

Infiltration trenches are implemented along street edges to capture and store roadway runoff. These trenches consist of a gravel-filled subsurface layer that allows stormwater to percolate, reducing the burden on drainage infrastructure. They are ideal for managing concentrated runoff from roads, preventing drainage system overload, and enhancing groundwater recharge. Their underground placement ensures efficient space utilization in an urban setting. In our catchment, an infiltration trench of rectangular size 10m x 30m is proposed near at the intersection of Mommsenstraße and Haeckelstraße, close to the Gerber Bau. More details can be found from Table 6.

Table 6 Specifications of Infiltration Trench (DWA-A 138)

Category	Parameter	Value
Surface	Dimensions (m)	30 x 10
Surface	Berm Height (mm)	3000
Surface	Vegetation Volume Fraction	0
Surface	Surface Roughness (Manning's n)	0.1
Surface	Surface Slope (\%)	0
Storage	Thickness (mm)	500
Storage	Void Ratio	0.75
Storage	Seepage Rate (mm/h)	180
Storage	Clogging Factor	0
Drain	Type	No drain

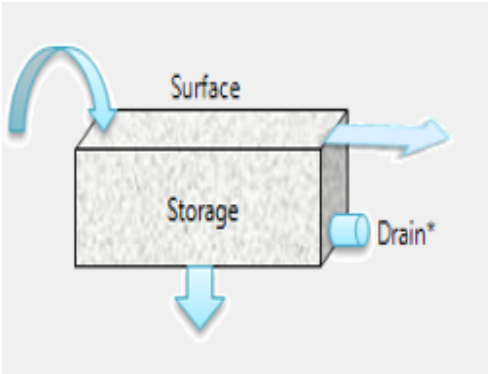


Figure 7 Conceptual drawing of Infiltration Trench (IT) layer

Green Roofs

Green roofs are introduced on flat rooftops (Table 7) to retain and delay stormwater runoff. The vegetative layer absorbs rainfall, reducing the volume and peak discharge of rooftop runoff. This measure improves water retention, mitigates urban heat island effects, and enhances energy efficiency by providing thermal insulation. Green roofs contribute to stormwater management by flattening peak runoff curves and reducing pressure on storm sewers.

Table 7 Specifications of Green Roof (acc. FLL Dachbegrünung)

Category	Parameter	Value
Surface	Berm Height (mm)	20
	Vegetative Volume Fraction	0.35
	Surface Roughness (Manning's n)	0.3
	Surface Slope (\%)	2
Soil	Surface Thickness (mm)	300
	Porosity (Volume Fraction)	0.5
	Field Capacity	0.2
	Wilting Point	0.05
	Hydraulic Conductivity (mm/h)	180
	Conductivity Slope	30
	Suction Head (mm)	100
Drainage	Thickness (mm)	50
	Void Fraction	0.5
	Roughness (Manning's n)	0.1

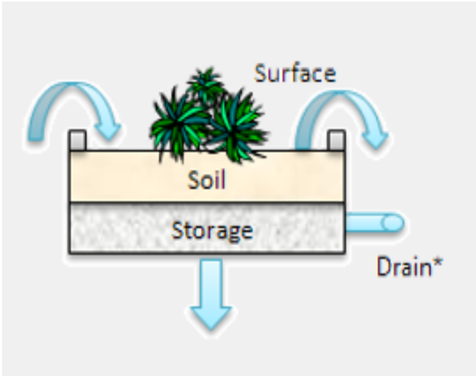


Figure 8 Conceptual drawing showing design layers of Green Roof (GR)

2.3.3 Integrated LID Strategy

The combination of pervious pavements, infiltration trenches, and green roofs creates a synergistic approach to stormwater management. Pervious pavements manage pathway runoff, infiltration trenches handle road drainage, and green roofs reduce rooftop discharge. Together, these measures enhance infiltration, decrease flood risks, and support a resilient urban drainage system.

2.4 Implementation of LID Measures in a New Development

This section discusses the suitability and effectiveness of the Low Impact Development (LID) measures implemented in the new development area. Additionally, it provides the technical specifications of the adopted measures.

2.4.1 Characteristics of the New Development

The proposed development site is anticipated to generate domestic wastewater at a rate of 150 Liters per person per day, in accordance with DWA guidelines. It is assumed that the wastewater discharge patterns will be like those already observed in the surrounding study area. In terms of land use classification, the site is divided into impervious and pervious surfaces. The residential and traffic areas are categorized as impervious, while the remaining sections are considered fully pervious. Based on this classification, the average imperviousness of the site is determined as $\frac{8500\ m^2}{30000\ m^2} = 28.33\ \%$. The slope of the area is fixed at 2 %, determined based on the profile plot. The width parameter is derived from the length measured in EPA SWMM, calculated as the watershed area divided by the measured length.

2.4.2 Characteristics of LID Measures in the New Development

The objective of this study is to implement a decentralized rainwater management system that optimizes stormwater infiltration and reduces runoff in the Räcknitz district of Dresden. To achieve this, vegetative swale will be implemented.

Vegetative Swales

Vegetative swales will be implemented on the northern side of the new development to enhance stormwater infiltration and reduce peak runoff. Spanning 200 m × 10 m, these swales slow water flow, promote sediment deposition, and facilitate natural filtration. They provide a low-maintenance, cost-effective solution for managing large runoff volumes while improving biodiversity and aesthetics Table 8. Additionally, infiltration trenches along streets will enhance groundwater recharge, while pervious pavements will replace impervious pathways, allowing direct infiltration. Together, these LID measures will improve stormwater retention, infiltration, and urban drainage sustainability.

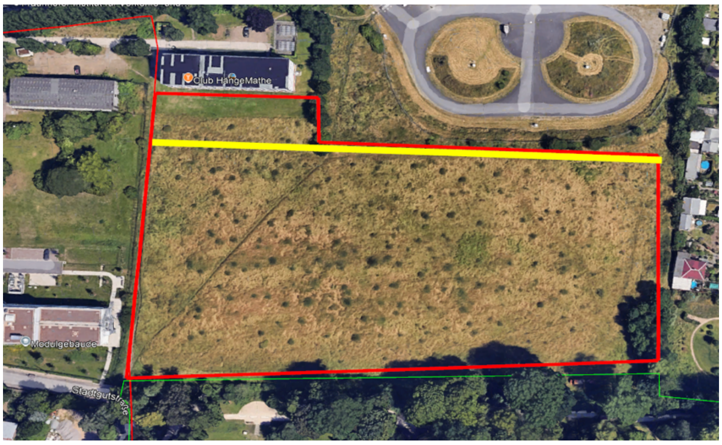


Figure 9 Implementation of Vegetative Swale (VS) in the new development, represented by yellow line

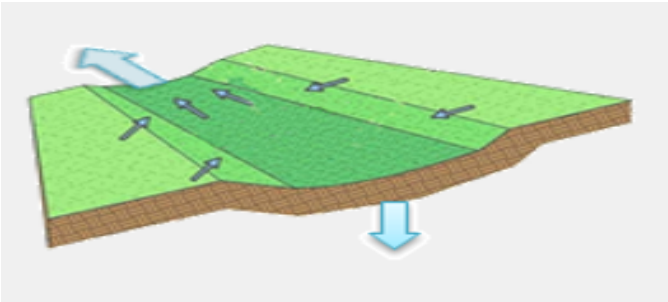


Table 8 Specifications of Vegetative Swale (DWA-A 138, AG Boden)

Layer	Parameter	Value
Surface	Dimensions (m)	200x10
	Berm Height (mm)	300
	Vegetation Volume Fraction	0.2
	Surface Roughness (Manning’s n)	0.2
	Surface Slope (%)	0.5
	Swale Side Slope (Run/Rise)	10:1

3 Results

3.1 Calibration and validation

The Nash-Sutcliffe Efficiency (NSE) and the Peak Flow Error (PFE) values obtained for the selected calibration and validation events are presented in Table 9.

Table 9 Model performance indicators for calibration and validation events

Events	LINK	NSE (%)	PFE (%)	Return period (years)
Calibration Events				
08/11/1996	06L95-06L98	96.90	11.90	12
	06M5-06M4	95.42	18.51	
07/18/1997	06L95-06L98	95.10	17.77	12
	06M5-06M4	95.19	19.32	

07/21/1998	06L95-06L98	96.46	14.88	4.5
	06M5-06M4	96.52	15.70	
07/08/2014	06L95-06L98	95.66	14.06	4.4
	06M5-06M4	94.87	19.38	
05/30/2014	06L95-06L98	94.95	12.93	0.5
	06M5-06M4	94.90	8.10	
05/09/2003	06L95-06L98	83.59	12.46	0.25
	06M5-06M4	85.51	16.55	
		Validation Events		
09/18/1999	06L95-06L98	94.83	9.1972	2.5
	06M5-06M4	85.05	19.80	
08/08/2008	06L95-06L98	96.70	19.45	17
	06M5-06M4	96.23	17.65	
11/30/2002	06L95-06L98	94.83	9.19	5
	06M5-06M4	85.05	19.80	

3.2 Effect of LID on existing Network

To assess the effectiveness of LID implementation, simulations were conducted for both the pre-implementation (baseline) and post-implementation (LID scenario) conditions. The analysis focused on sub catchment 101 and considered the flow at conduit 06M5-06M4 from three flood events with return periods of 2.5, 5, and 17 years. Three types of LIDs: Permeable Pavement (PP), Green Roof (GR), and Infiltration Trenches (IT), were evaluated individually and in combination. Figure 10, Figure 11 and Figure 12 (detail as shown in Annex C) illustrate the effectiveness of GRs in mitigating precipitation runoff. For lower return period floods, GR consistently reduced runoff throughout the event. However, for higher return period floods, its effectiveness was limited to shorter durations, primarily during peak runoff. GR successfully reduced the peak runoff from 235 l/s to 209 l/s for the 5-year return period flood and from 718 l/s to 645 l/s for the 17-year return period flood, demonstrating its potential to alleviate peak flow impacts.

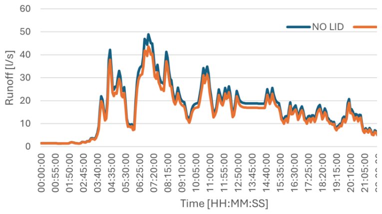


Figure 10 Comparison between baseline and after GR implementation for 2.5 Year return period

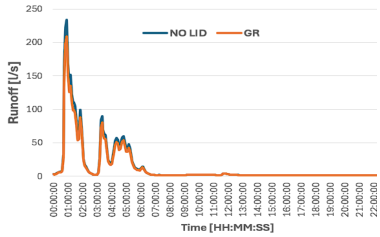


Figure 11 Comparison between baseline and after GR implementation for 5 Year return period flood

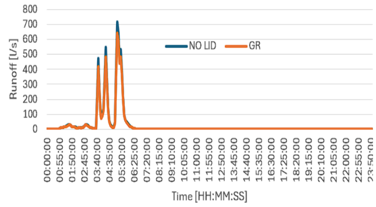


Figure 12 Comparison between baseline and after GR implementation for 17 Year return period

The implementation of PP as LID also shows a similar trend as before. While PP shows consistent albeit low reduction in runoff rate for longer duration of low return period floods, it proves more effective in reducing runoff during peak flow periods for higher return period floods. PP reduced peak runoff flow from 718 l/s to 708 l/s for the 17-year return period flood and from 234 l/s to 226 l/s for the 5-year return period flood. Although there is a reduction in peak runoff flow, it is not as pronounced as seen before with GR implementation.

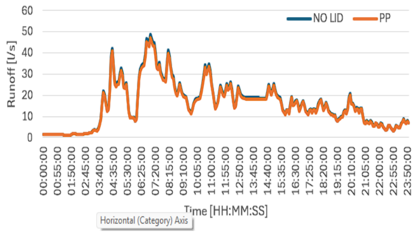


Figure 13 Comparison between baseline and after PP implementation for 2.5 Year return period flood

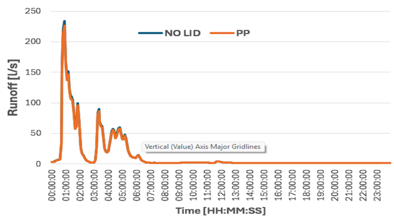


Figure 14 Comparison between baseline and after PP implementation for 5 Year return period flood

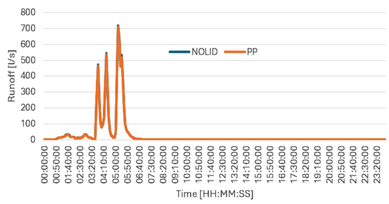


Figure 15 Comparison between baseline and after PP implementation for 17 Year return period flood

A similar trend is observed with the implementation of Infiltration Trenches (IT) though, the reduction in runoff flow rate is miniscule. This suggests that IT alone is not highly effective in significantly reducing runoff but may perform better when combined with other LID systems as shown in Figure 16, Figure 17 and Figure 18.

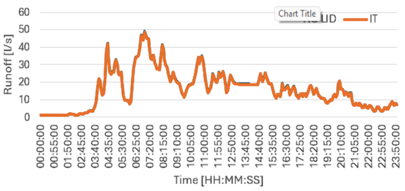


Figure 16 Comparison between baseline and after IT implementation for 2.5 Year return period flood

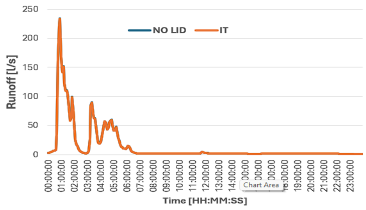


Figure 17 Comparison between baseline and after IT implementation for 5 Year return period flood

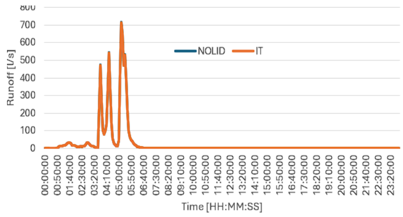


Figure 18 Comparison between baseline and after IT implementation for 17 Year return period flood

A final simulation was conducted using a combination of all three types of LIDs to assess their impact on runoff rates compared to the baseline. As shown in Figure 19, Figure 20 and Figure 21 (for clear graphs refer Annex C) the runoff reduction follows a similar trend as observed in all previous cases. The ALL LIDs performed consistently during the 2.5-year return period flood, maintaining a lower runoff rate throughout the rainfall event and even successfully reducing the peak runoff flowrate from 47 l/s to 41 l/s. The reduction in peak runoff became even more pronounced for the higher return period floods. During the 5-year return period flood, the peak runoff flowrate dropped from 235 l/s (baseline) to 202 l/s after ALL LIDs implementation. Likewise, for the 17-year return period flood, the peak runoff flowrate was reduced from 718 l/s (baseline) to 635 l/s, demonstrating the effectiveness of LIDs implementation in mitigating runoff during higher intensities rainfall events.

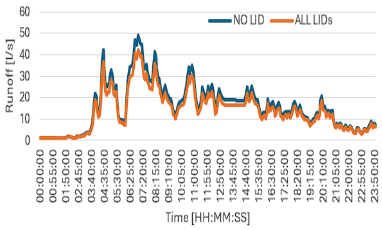


Figure 19 Comparison between baseline and after ALL LIDs implementation for 2.5 Year return period flood

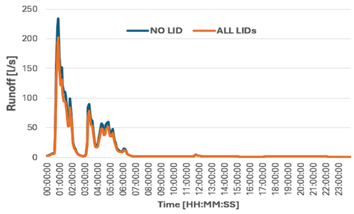


Figure 20 Comparison between baseline and after ALL LIDs implementation for 2.5 Year return period flood

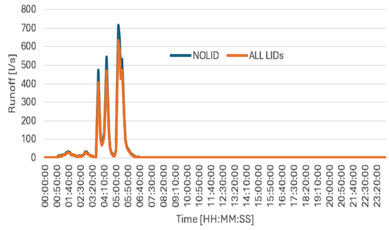


Figure 21 Comparison between baseline and after ALL LIDs implementation for 2.5

The overall reduction in the runoff rate is summarized below:

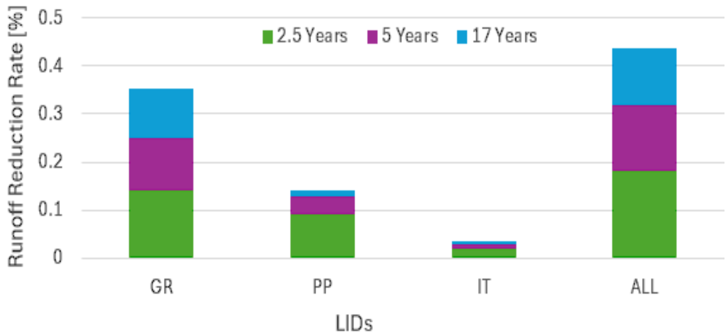


Figure 22 Comparison of peak runoff reduction rate across all LID types and return period floods

Table 10 Peak runoff reduction rate in % for all LIDs type across all return period floods

LIDS	Return Period [year]		
	2.5	**5**	**17**
GR	18%	11%	10%
PP	9%	4%	1.4%
IT	2%	1%	0.7%
ALL	18%	14%	12%

3.3 Effect of New Development Area into Existing Sewer Network

For the new development, simulations were conducted to determine the runoff at conduit 06R7-06R6 and find out about any additional pressure the existing sewer network might have to address from the assimilation of new development area into the sewer system. The runoff flow rates were recorded at conduit 06R7-06R6, which connects the new development to the existing sewer system. Additionally, flooding was analysed at two key nodes:

- Node 06R7, where the new development area connects to the existing system.

- Node 06R4, which links sub catchment 106 to the sewer network and is located downstream of Node 06R7.

According to DWA A-118 guidelines, the overflow frequency for a residential zone should not exceed once every 3 years. To assess potential flooding risks, simulations were performed for two rainfall events with return periods of 2.5 years and 5 years.

As shown in Figure 23 and Figure 24 (for clear graphs refer Annex C) the simulations indicate an additional inflow of approximately 17 l/s and 52 l/s into the existing sewer system from the new development during the 2.5-year and 5-year return period rainfall events, respectively.

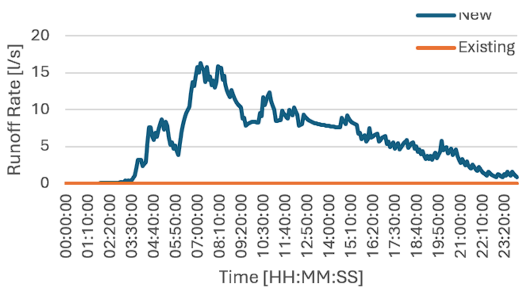


Figure 23 Additional runoff into existing sewer system during 2.5-year return period rainfall event

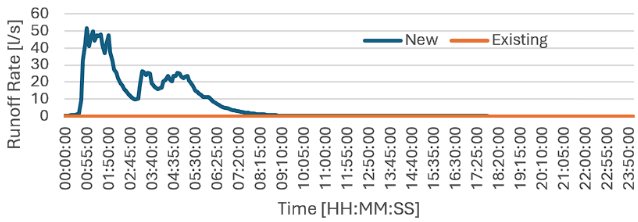


Figure 24 Additional runoff into existing sewer system during 5-year return period rainfall event

Whereas, as shown in Figure 25 (for clear graphs refer Annex C), there is no flooding at the node 06R4 downstream during rainfall event of 17-year return period. This indicates that the existing sewer system can effectively accommodate the additional inflow from the new development without exceeding its capacity.

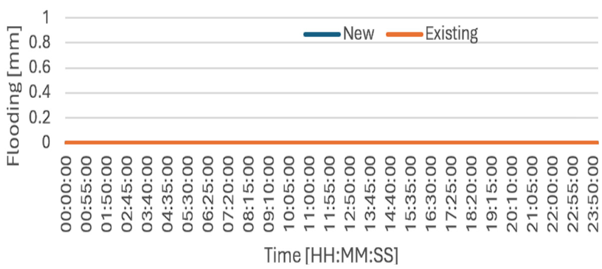


Figure 25 Flooding at Node 06R4 before and after assimilation of New Development (Z = 17 years)

3.4 Effect of LID Measure on the New Development Area

For the new development, simulations were conducted to determine the effectiveness of introducing VS as a LID measure for runoff rate mitigation. The runoff rates were measured at the conduit, 06R7-06R6, that connects the new development area into the existing network before and after the implementation of LID measure during the three rainfall events with return periods of 2.5, 5 and 17 years.

As seen from the Figure 26, Figure 27 and Figure 28 (for clear graphs refer Annex C), VS follows a similar pattern to all the LID measures used previously. For lower return period flood, the effect is relatively lower but persistence throughout the duration, whereas for higher return period flood the effect is mostly pronounced during the peak flooding and less visible elsewhere.

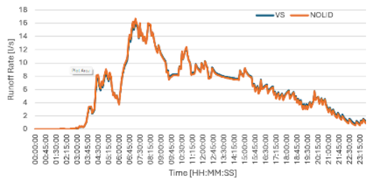


Figure 26 Flooding at node 06R4 during 2.5-year return period rainfall event

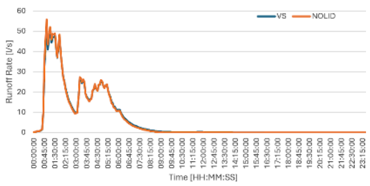


Figure 27 Flooding at node 06R4 during 5-year return period rainfall event

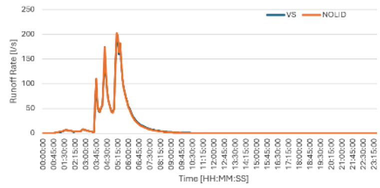


Figure 28 Flooding at node 06R4 during 17-year return period rainfall event

4 Discussion

Several significant insights can be drawn from the results of the case study of Räcknitzdistrict, especially regarding the implementation of decentralized rainwater management measures such as LID to enhance the resilience of the existing system.

Two long term LID, Green Roof (GR) and Pervious Pavement (PP) and one short term LID, Infiltration Trench (IT) that were used in the simulations showed a noticeable reduction in runoff volumes across various storm recurrence intervals. From the summary table in the results section, GR showed the most efficacy in dealing with runoff rate across all recurrence periods. As a long-term LID measure, the widespread implementation of GR would significantly enhance resilience of urban catchments to flooding. By increasing surface retention capacity, GR help reduce peak runoff volumes, delay stormwater discharge, and mitigate the impacts of intense rainfall events. Additionally, their ability to improve insulation, reduce the urban heat island effect, and enhance biodiversity further strengthens their role as a sustainable and decentralized stormwater management solution. The other long-term LID measure, PP, proved highly effective in mitigating runoff overflow during short-recurrence flooding. However, its effectiveness waned sharply with increasing rainfall intensity, limiting its performance under extreme storm conditions. Conversely, the short-term LID measure, infiltration trenches (IT), did not demonstrate strong individual efficiency but could serve as a valuable component when integrated with other LID measures to manage stormwater more effectively. While LID strategies offer considerable benefits for runoff control, their efficiency tends to diminish during high-intensity, low-recurrence storm events. This underscores the need for a more holistic approach to rainwater management system that combines LID techniques with broader urban infrastructure and planning strategies. Nevertheless, despite certain limitations, LID measures remain crucial for urban runoff management. Their widespread implementation can significantly enhance the sustainability and resilience of decentralized stormwater management systems, contributing to climate adaptation efforts in urban environments.

5 Conclusion

The study evaluates the impact of decentralized rainwater management strategies on the water budget of the Räcknitz district in Dresden, focusing on Low Impact Development (LID) measures such as Green Roofs (GR), Permeable Pavements (PP), and Infiltration Trenches (IT). Using EPA SWMM modelling, the research analysed stormwater runoff dynamics under different rainfall return periods and assessed how LID implementations influence runoff reduction, peak flow mitigation, and overall system resilience.

Simulation results demonstrate that LID strategies significantly reduce surface runoff and mitigate peak discharge across multiple rainfall intensities. Green Roofs were the most effective in peak runoff reduction, particularly for lower return periods, while Permeable Pavements performed well in reducing runoff over extended durations. Infiltration Trenches, although less effective in isolation, complemented other LID measures when combined, enhancing overall system performance. A hybrid LID approach, integrating multiple techniques, yielded the highest reduction in flood risks, particularly for extreme rainfall events (return periods of 5 and 17 years).

Despite the positive outcomes, LID efficiency declines for extreme storm events, indicating the need for complementary stormwater management strategies in high-intensity rainfall conditions. Nevertheless, LID measures offer a sustainable, cost-effective approach to decentralized stormwater management, helping to enhance urban flood resilience, improve groundwater recharge, and align with DWA A-118 overflow guidelines. Future research should focus on long-term performance assessment of LID measures and their scalability in urban environments to optimize their hydrological and infrastructural benefits

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Annex A

Dry Weather Flow Pattern

Hour of day	Hourly_pattern_weekdays	Hourly_pattern_weekend
0:00	0.7549	0.8787
1:00	0.6616	0.825
2:00	0.5668	0.759
3:00	0.5197	0.6152
4:00	0.5465	0.498
5:00	0.7362	0.5831
6:00	1.0463	0.8693
7:00	1.2694	1.0798
8:00	1.3027	1.2212
9:00	1.2621	1.3105
10:00	1.2282	1.3155
11:00	1.2061	1.2144
12:00	1.191	1.1366
13:00	1.1667	1.0956
14:00	1.1358	1.0364
15:00	1.1061	1.0023
16:00	1.0817	1.0265
17:00	1.0646	1.1003
18:00	1.0554	1.1665
19:00	1.0497	1.1632
20:00	1.0612	1.1032
21:00	1.0822	1.0502
22:00	1.0236	1.0067
23:00	0.8815	0.9427

Input Parameter of the Sub-catchment (Reyes-Silva, Report description, 2024)

Subcatchment	Imperviousness (%)		Width (m)		Slope (%)	
101	33	100	190	570	1	4
102	20	65	56	167	1	2
103	18	57	70	209	3	8
104	17	54	77	230	2	5
105	7	22	71	212	3	10
106	11	36	102	306	2	7
107	14	46	39	116	2	5
108	4	12	72	216	1	4
109	13	42	102	306	2	5
110	9	28	88	263	2	6
111	7	23	43	129	1	3
112	9	30	117	351	2	6
113	32	100	67	201	2	6
114	8	26	30	89	0	1
115	45	100	157	470	0	1
116	32	100	75	225	4	11
117	45	100	9	27	3	9
118	38	100	12	35	0	1
119	14	46	6	18	1	2

Evaporation data (Reyes-Silva, Report description, 2024):

Month	**Evaporation (mm/day)**
January	0.47
February	0.82
March	1.42
April	3.14
May	4.77
June	5.13
July	5.14
August	4.78
September	3.15
October	2.44
November	1.81
December	0.46

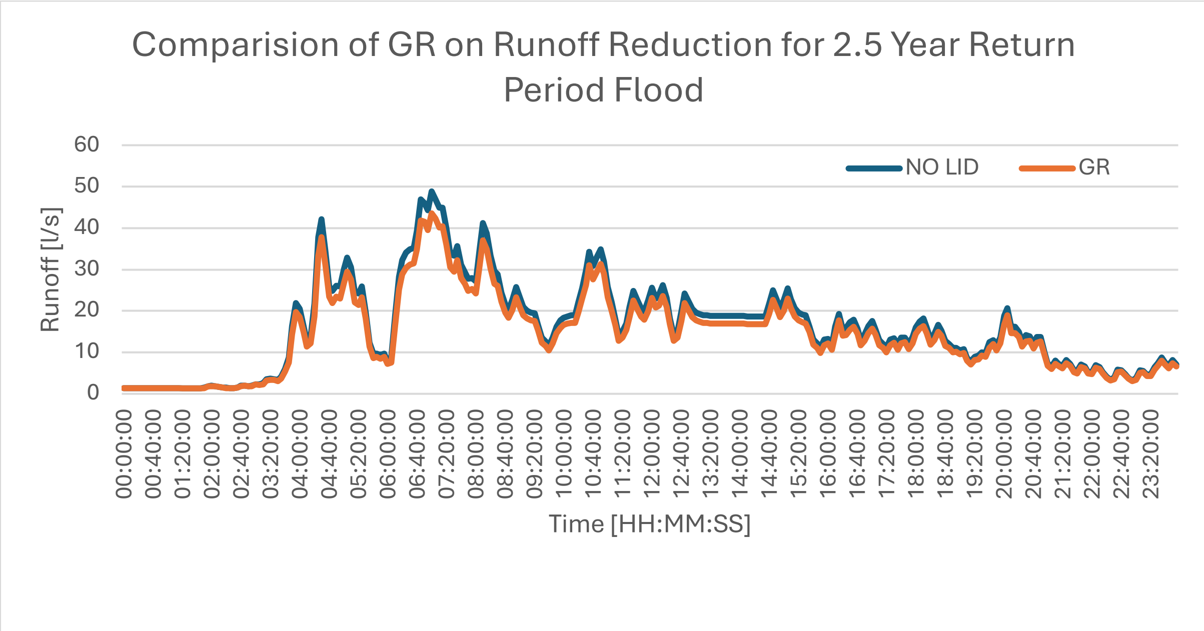
Annex B

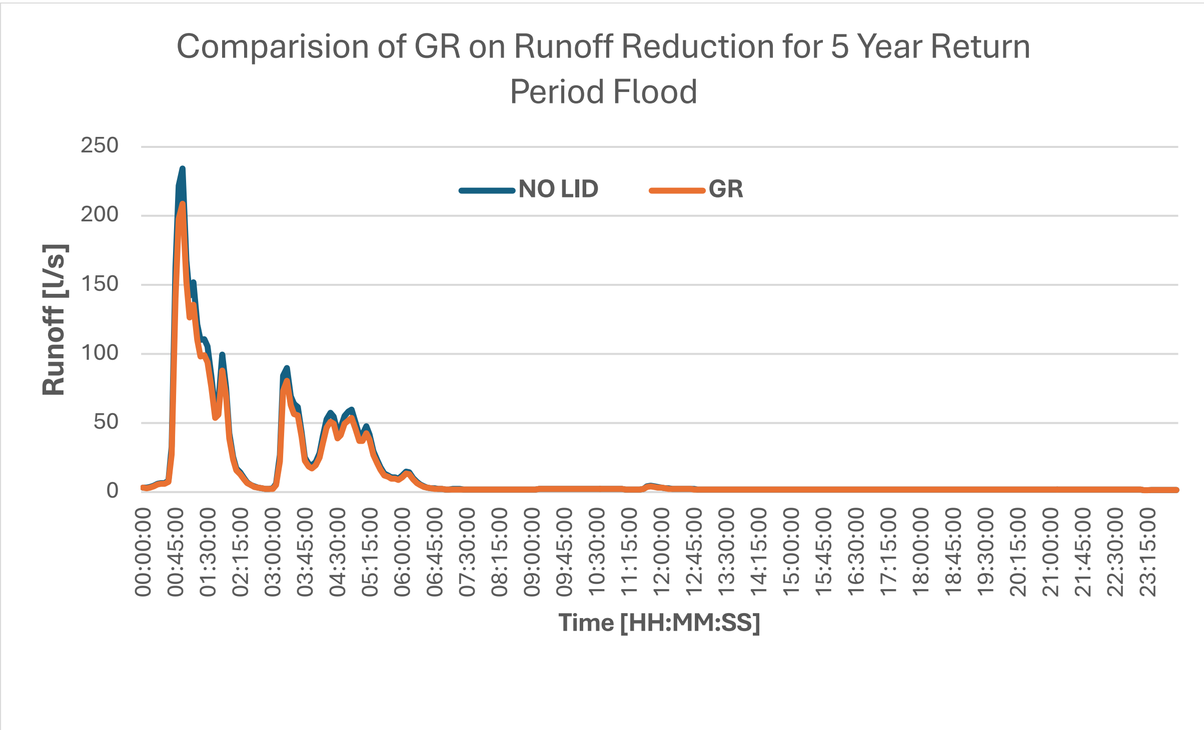
Calculation for selection of events using Reinhold's Intensity-Duration-Frequency equation, keeping in mind that the r15,1 for Dresden is 102 L/s*Ha (Reyes-Silva, Report description, 2024)

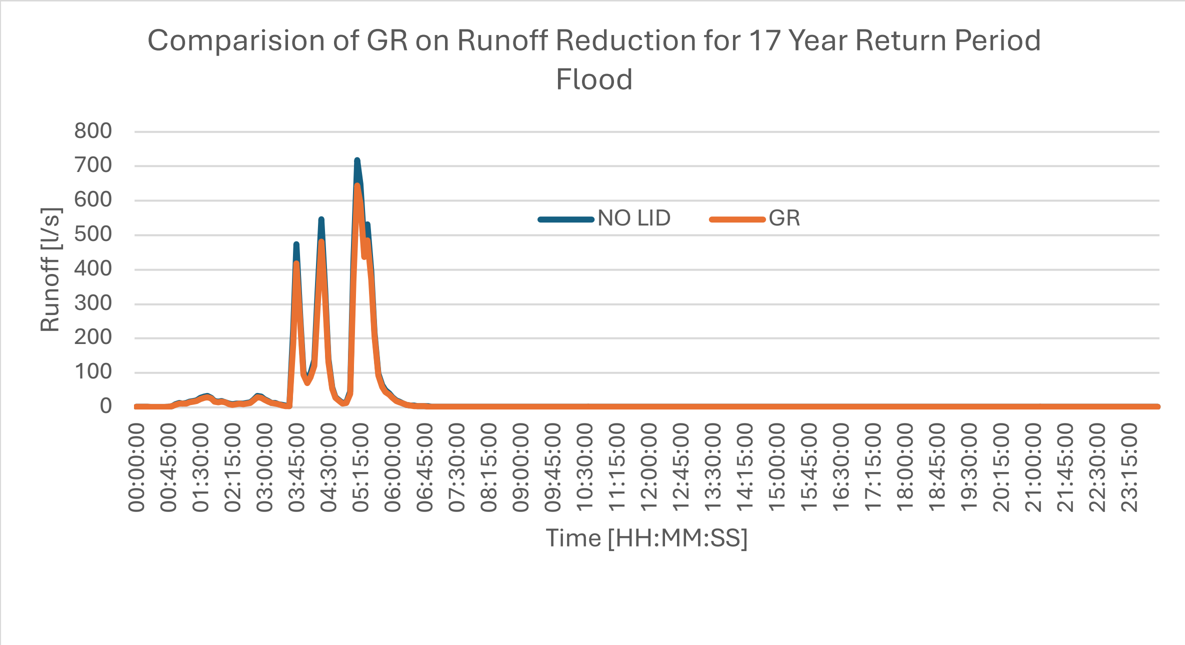
S.N	Date	tR (min)	rtR,z	Z (year)	Cumulative rain (mm)
1	04.05.96	1440	1.019	0.32	8.8
2	03.06.96	390	3.162	0.23	7.4
3	08.07.96	1385	5.199	25.12	43.2
4	11.08.96	520	10.929	11.99	34.1
5	22.08.96	50	13.667	0.11	4.1
6	18.07.97	1385	4.067	11.26	33.8
7	25.07.97	435	7.203	2.03	18.8
8	03.06.98	130	8.205	0.19	6.4
9	21.07.98	145	27.356	4.49	23.8
10	12.09.98	1045	3.174	2.30	19.9
11	09.07.99	115	0.725	0.02	0.5
12	14.07.99	485	5.773	1.49	16.8
13	18.09.99	695	5.084	2.79	21.2
14	09.10.99	890	1.217	0.18	6.5
15	15.04.00	900	2.537	0.86	13.7
16	07.07.01	195	9.231	0.53	10.8
17	05.09.02	580	3.046	0.48	10.6
18	30.11.02	1320	3.194	4.60	25.3
19	09.05.03	990	1.296	0.24	7.7
20	10-15-2004	1430	1.434	0.66	12.3
21	12.09.04	390	7.009	1.41	16.4
22	09.11.04	1015	3.432	2.65	20.9
23	07.07.05	395	6.540	1.22	15.5
24	22.08.05	515	5.016	1.20	15.5
25	21.01.06	1120	1.027	0.20	6.9
26	12.05.06	245	2.449	0.08	3.6
27	19.06.06	410	4.593	0.56	11.3
28	16.06.07	735	5.079	3.26	22.4
29	08.08.08	325	19.231	16.85	37.5
30	29.09.09	1440	0.926	0.26	8
31	02.06.10	1375	1.733	0.95	14.3
32	02.08.10	1440	1.412	0.65	12.2
33	03.07.11	1390	1.223	0.43	10.2
34	04.07.11	1440	1.181	0.43	10.2
35	10.10.13	1275	2.641	2.39	20.2
36	01.05.14	675	2.099	0.30	8.5
37	18.05.14	345	9.614	2.42	19.9
38	30.05.14	1065	1.706	0.50	10.9

39	08.07.14	1225	3.388	4.39	24.9
40	19.09.14	375	5.822	0.80	13.1
41	21.10.14	475	1.579	0.10	4.5
42	17.08.15	800	10.542	43.57	50.6
43	30.11.15	1275	1.908	1.00	14.6

Annex C







Comparision of GR on Runoff Reduction for 17 Year Return Period Flood
Runoff [l/s]
800
700
600
500
400
300
200
100
0
NO LID
GR
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
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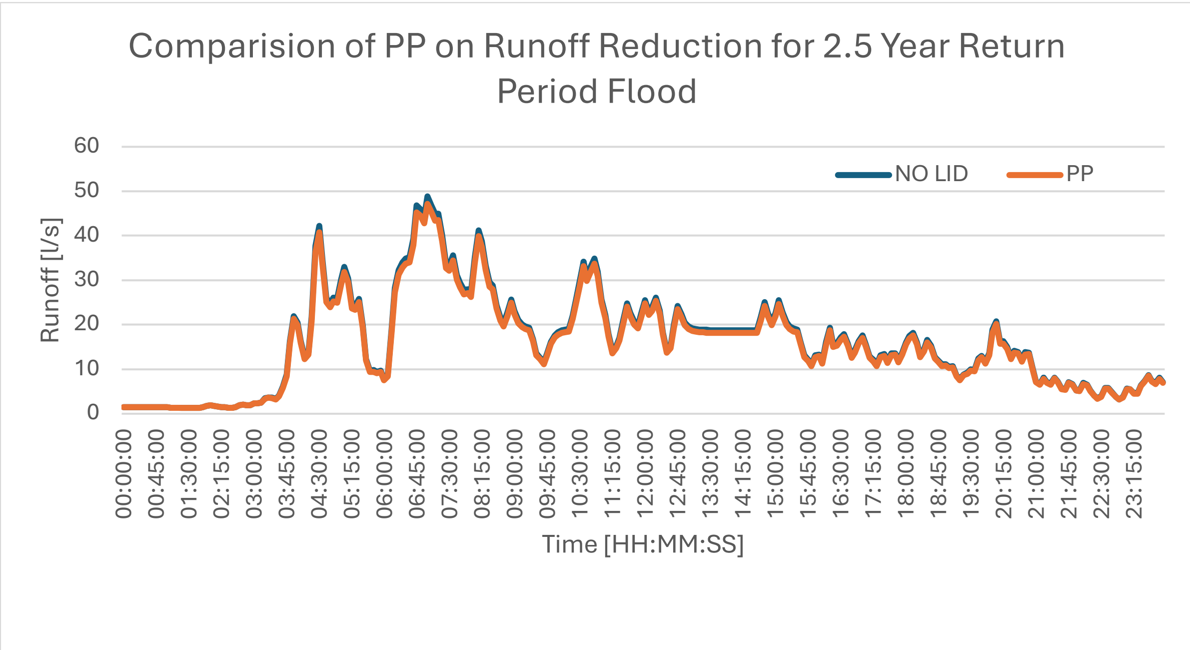
21:00:00
21:45:00
22:30:00
23:15:00
Time [HH:MM:SS]



Comparision of PP on Runoff Reduction for 2.5 Year Return Period Flood
Runoff [l/s]
60
50
40
30
20
10
0
NO LID
PP
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
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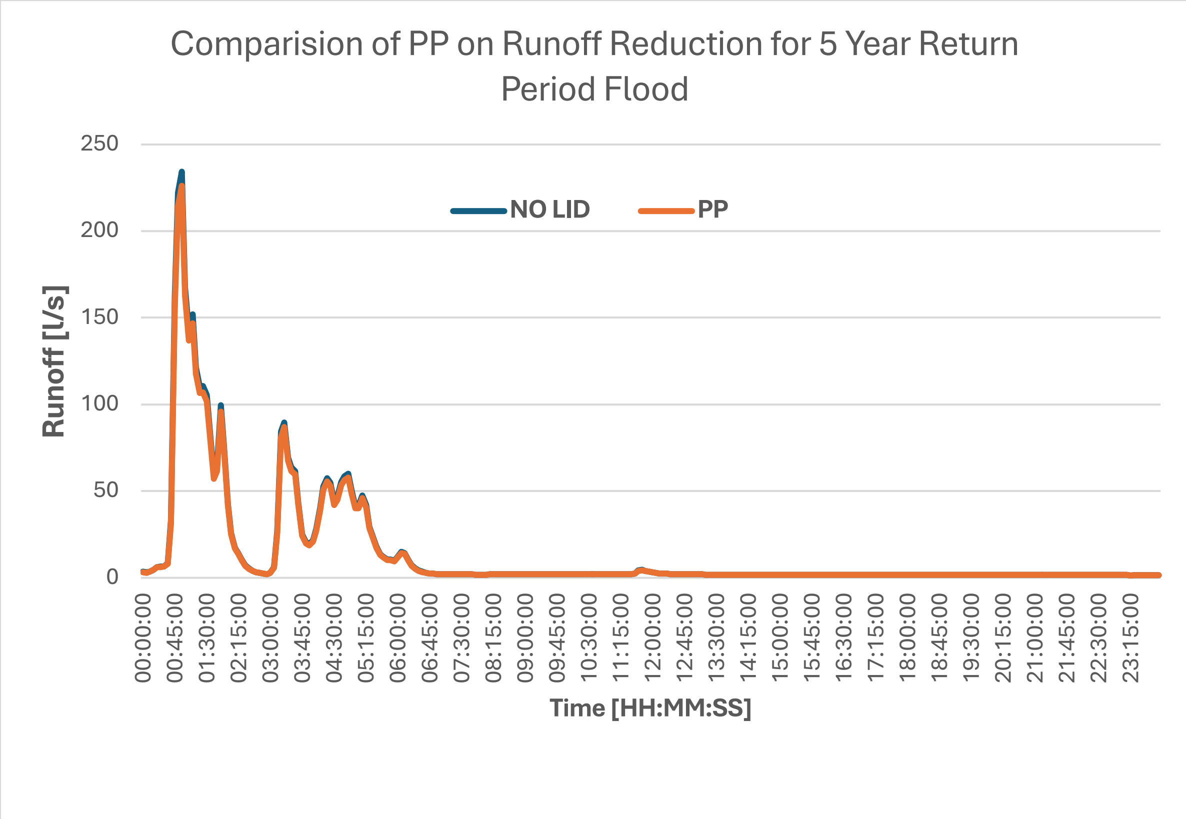
23:15:00
Time [HH:MM:SS]


Comparision of PP on Runoff Reduction for 5 Year Return Period Flood
Runoff [l/s]
250
200
150
100
50
0
NO LID
PP
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
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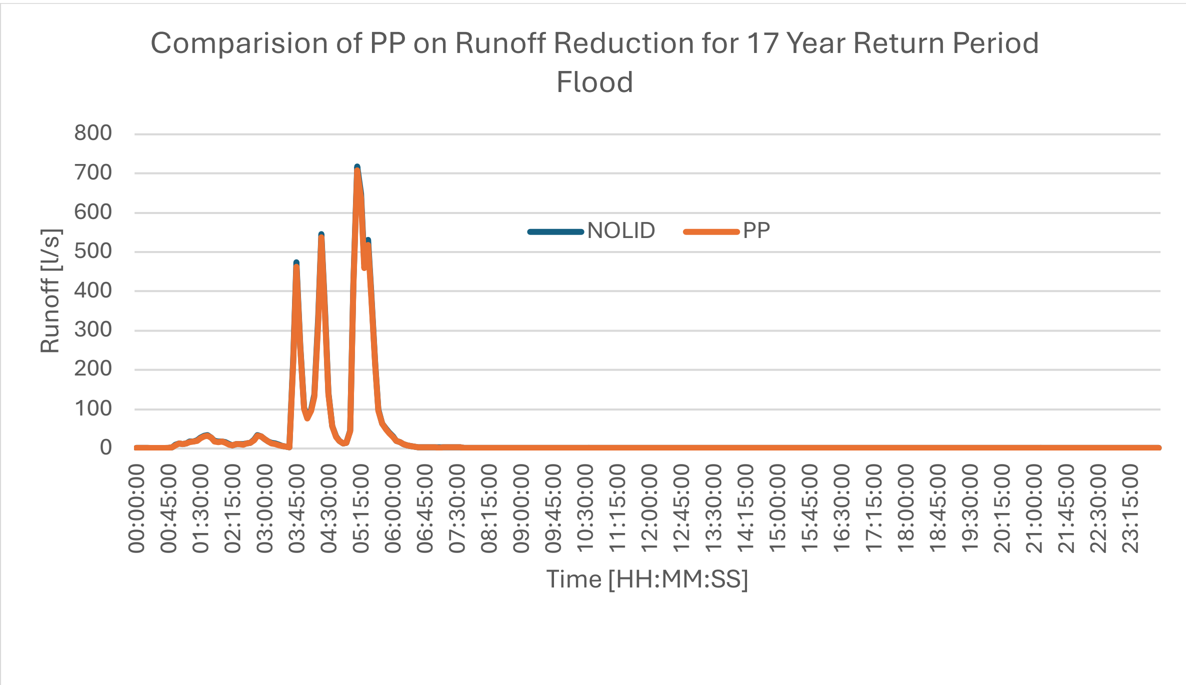
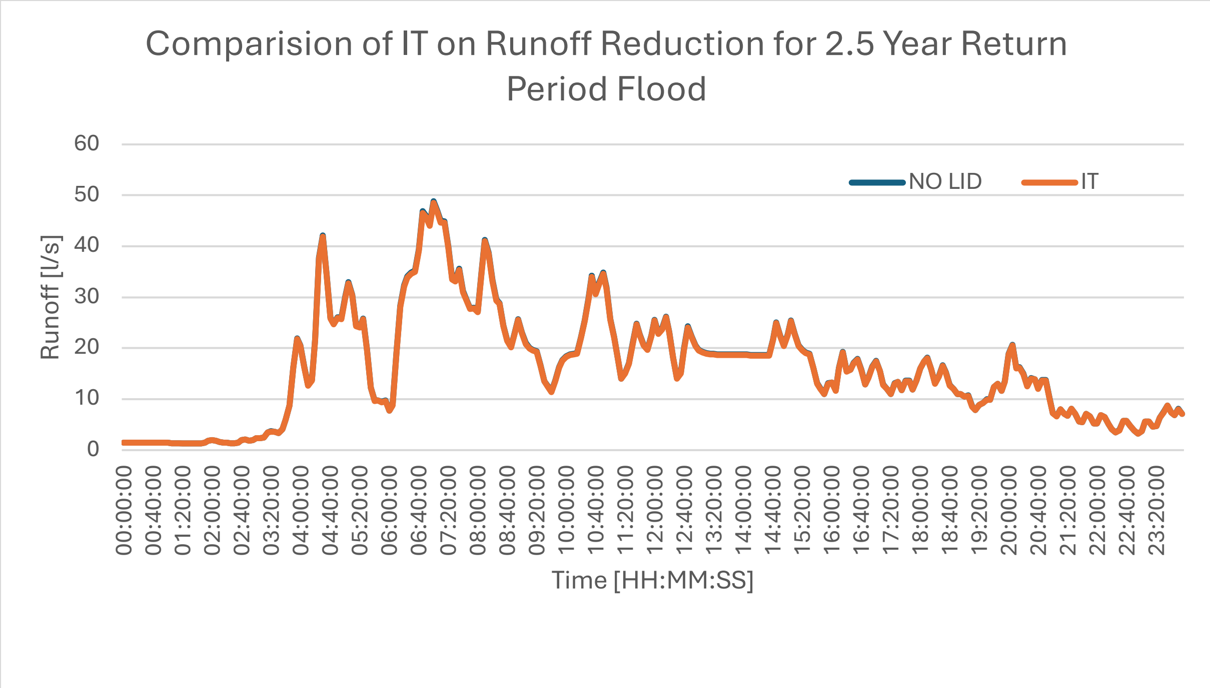
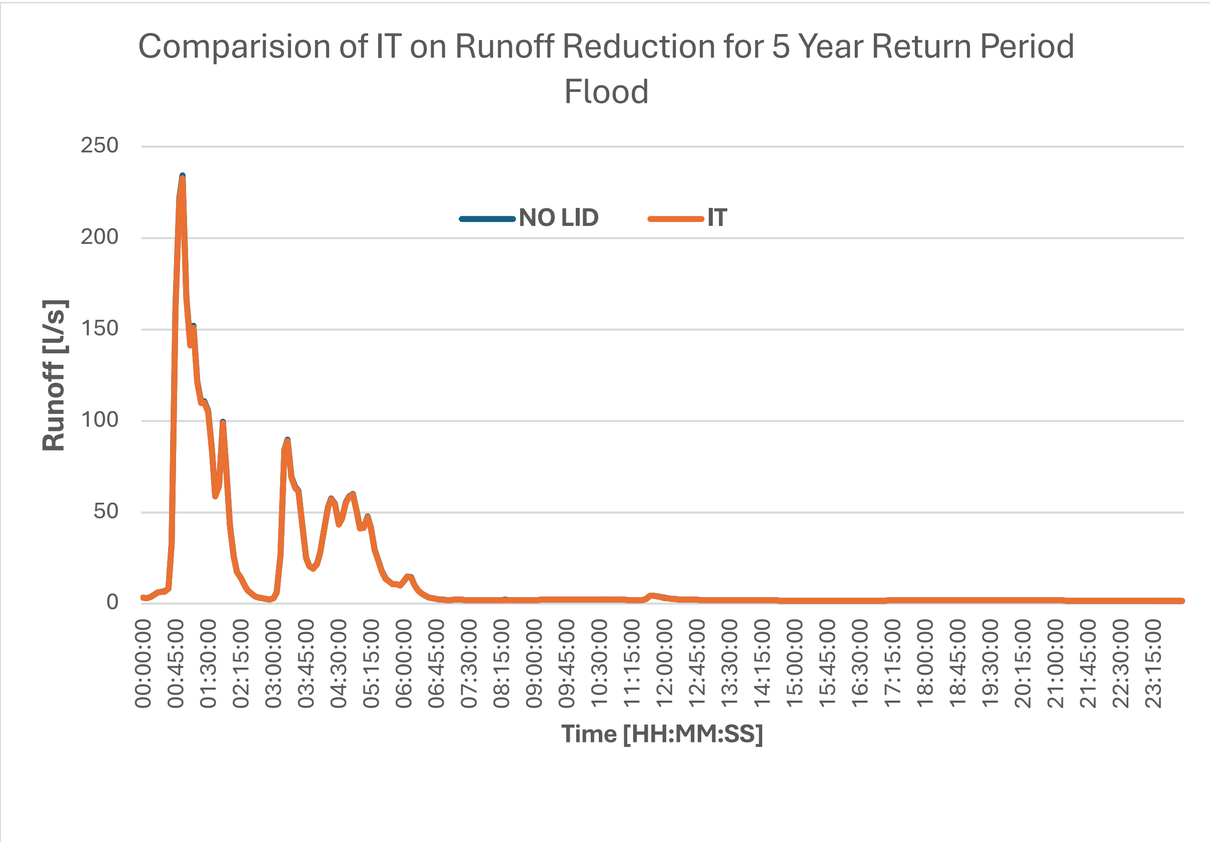
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
Time [HH:MM:SS]

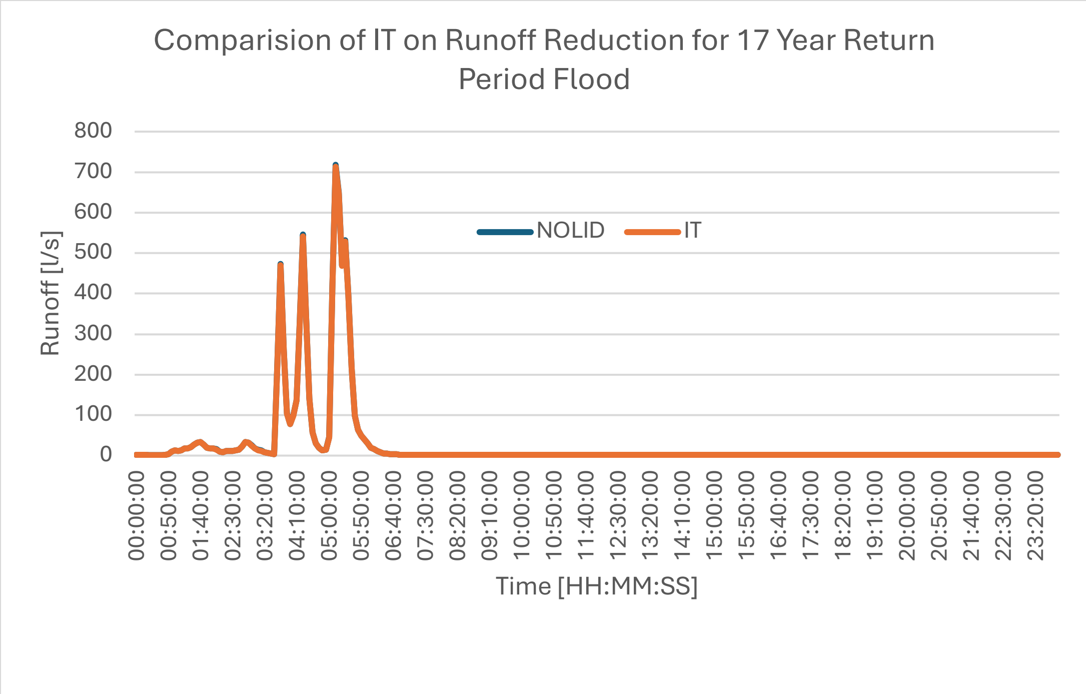

Comparision of PP on Runoff Reduction for 17 Year Return Period Flood
Runoff [l/s]
800
700
600
500
400
300
200
100
0
NOLID
PP
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
Time [HH:MM:SS]

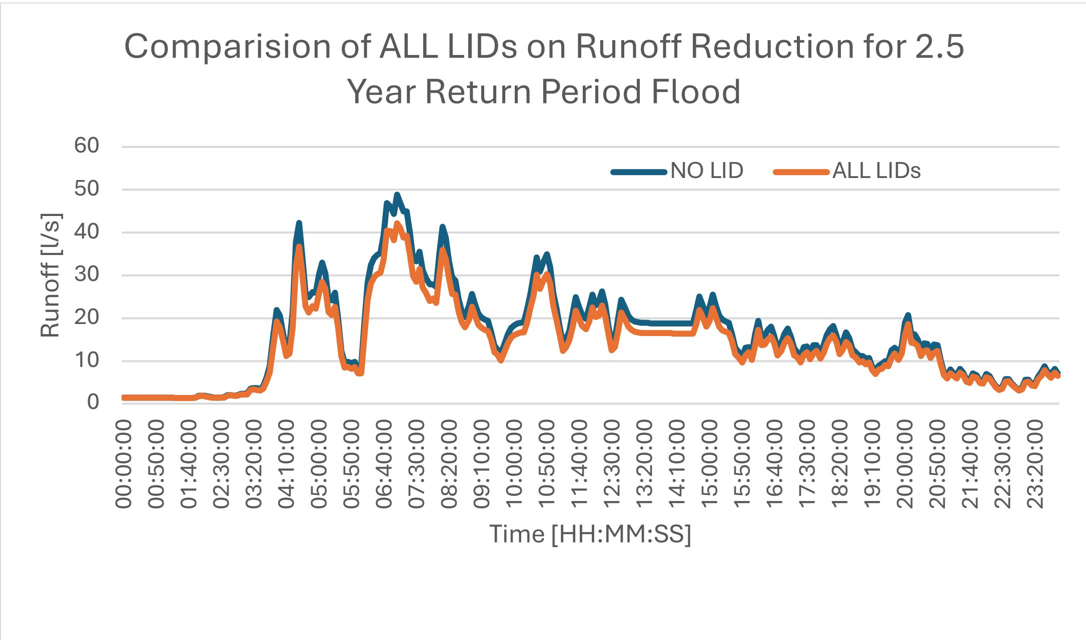


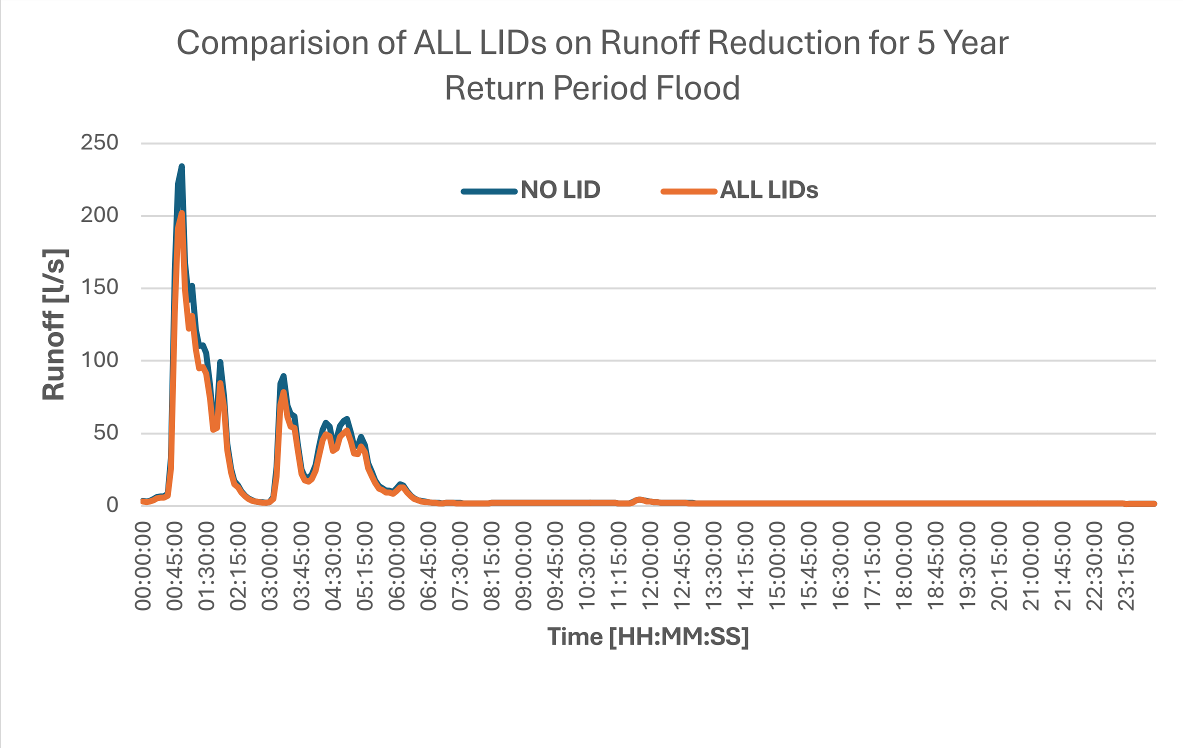
Comparision of IT on Runoff Reduction for 2.5 Year Return Period Flood
NO LID
IT
Runoff [l/s]
60
50
40
30
20
10
0
Time [HH:MM:SS]

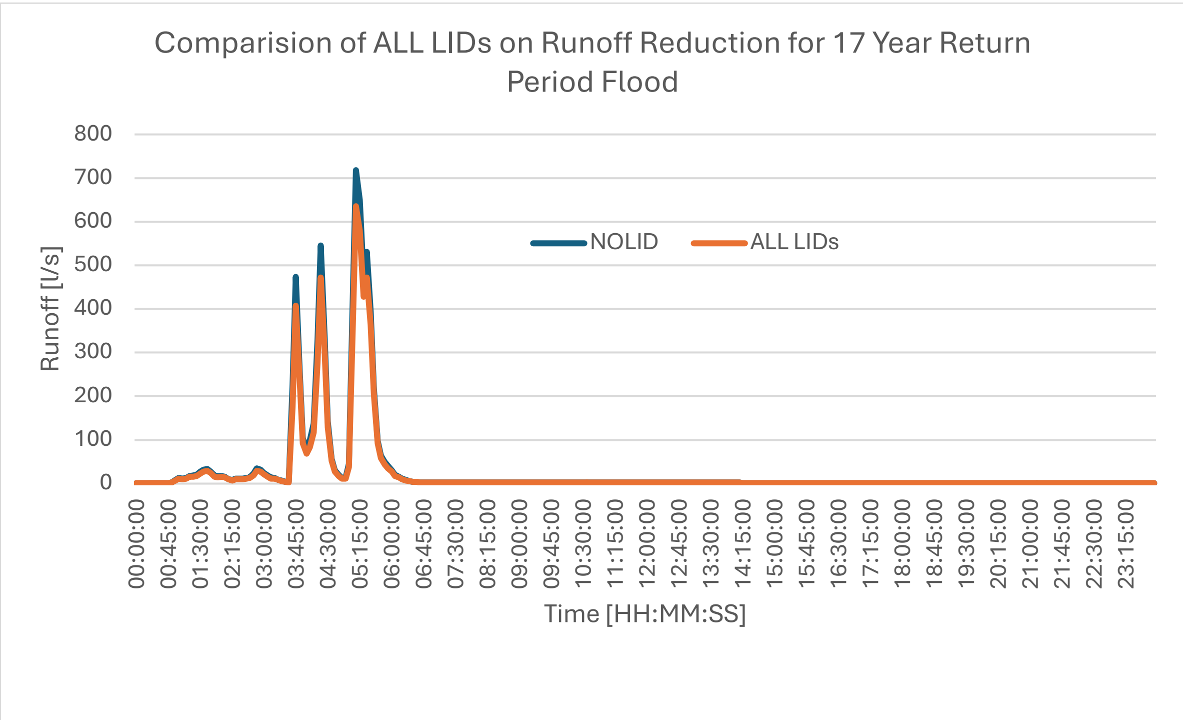


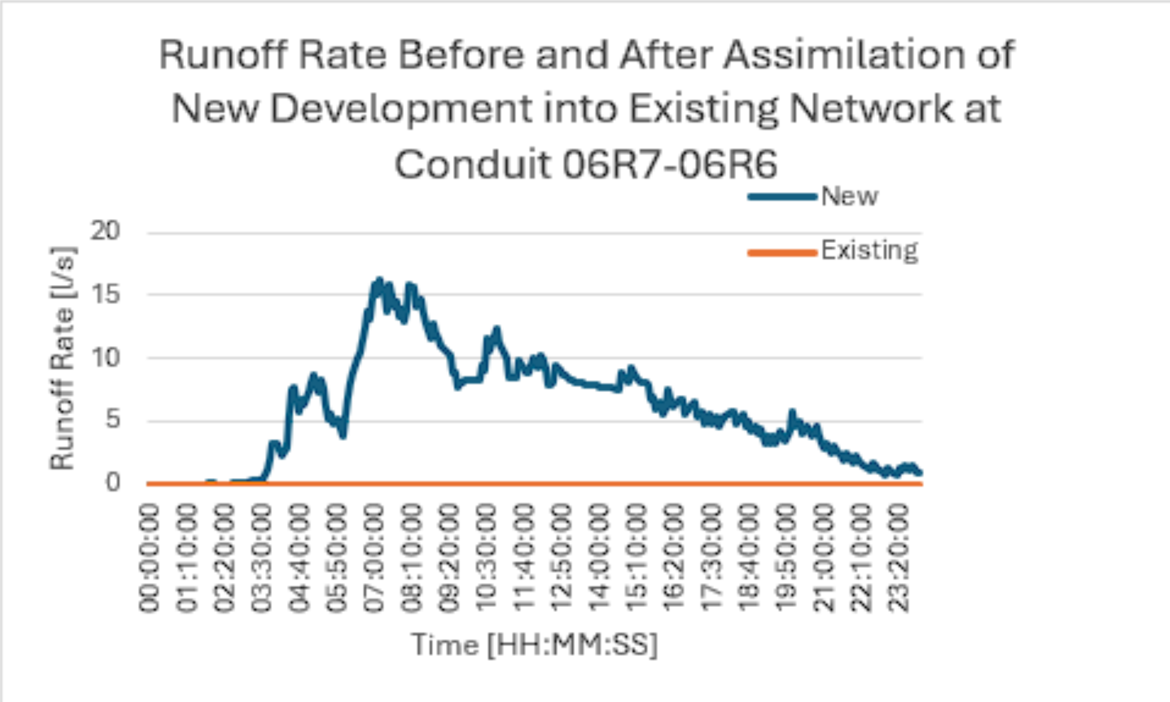
Comparision of IT on Runoff Reduction for 5 Year Return Period Flood
NO LID
IT
Runoff [l/s]
250
200
150
100
50
0
Time [HH:MM:SS]

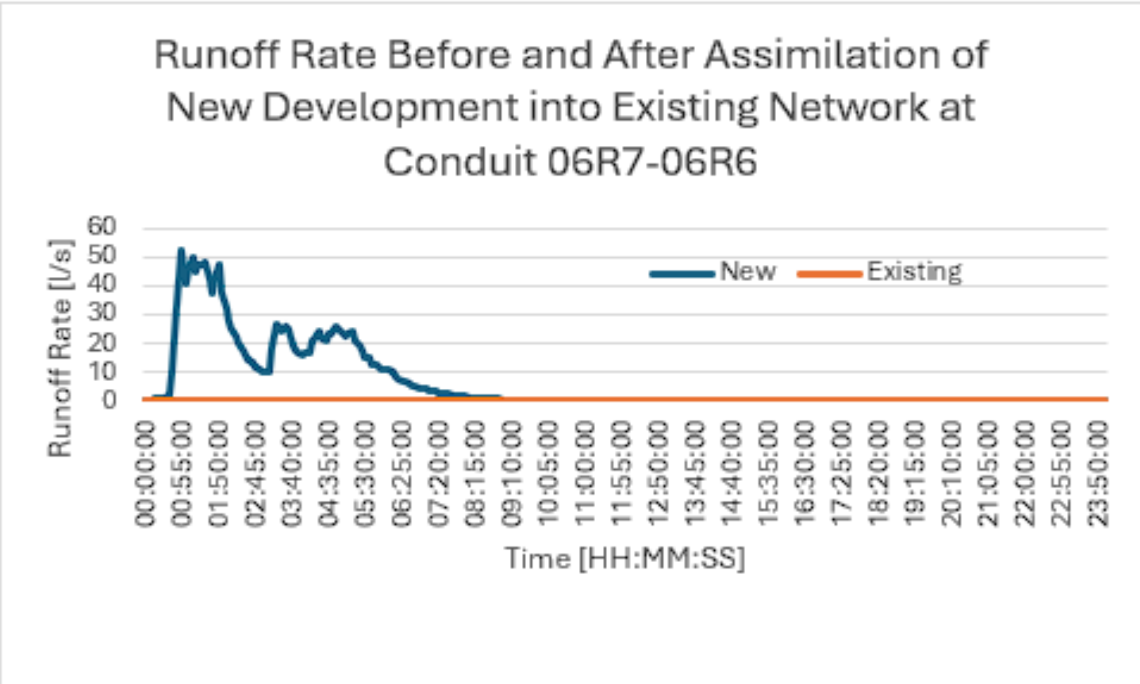

Comparision of IT on Runoff Reduction for 17 Year Return Period Flood
NOLID
IT
Runoff [l/s]
800
700
600
500
400
300
200
100
0
00:00:00
00:50:00
01:40:00
02:30:00
03:20:00
04:10:00
05:00:00
05:50:00
06:40:00
07:30:00
08:20:00
09:10:00
10:00:00
10:50:00
11:40:00
12:30:00
13:20:00
14:10:00
15:00:00
15:50:00
16:40:00
17:30:00
18:20:00
19:10:00
20:00:00
20:50:00
21:40:00
22:30:00
23:20:00
Time [HH:MM:SS]

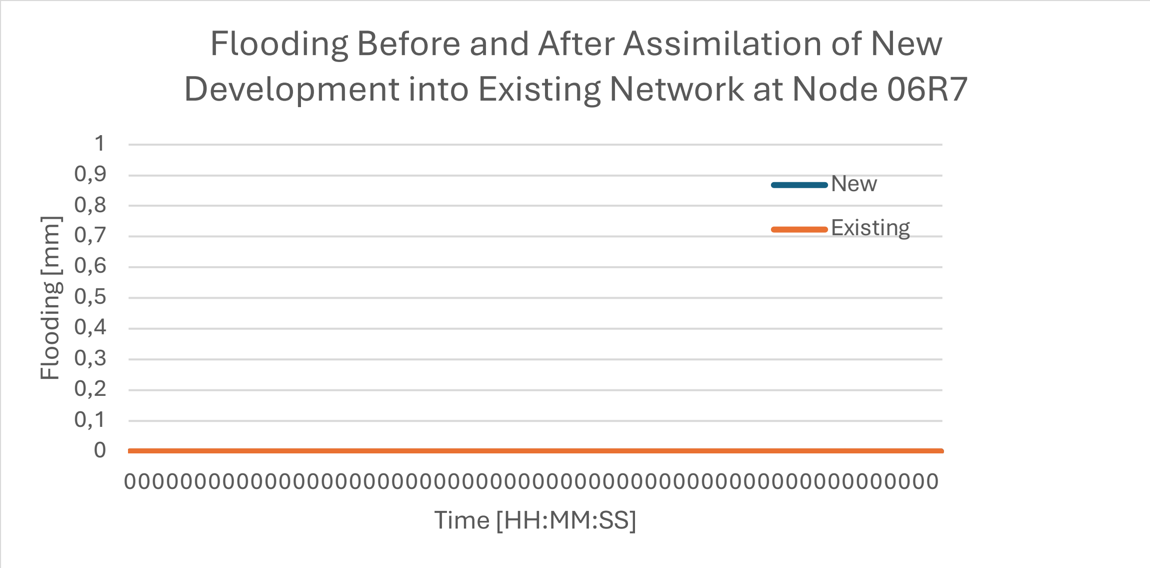

Comparision of ALL LIDs on Runoff Reduction for 2.5 Year Return Period Flood
NO LID
ALL LIDs
Runoff [l/s]
60
50
40
30
20
10
0
00:00:00
00:50:00
01:40:00
02:30:00
03:20:00
04:10:00
05:00:00
05:50:00
06:40:00
07:30:00
08:20:00
09:10:00
10:00:00
10:50:00
11:40:00
12:30:00
13:20:00
14:10:00
15:00:00
15:50:00
16:40:00
17:30:00
18:20:00
19:10:00
20:00:00
20:50:00
21:40:00
22:30:00
23:20:00
Time [HH:MM:SS]

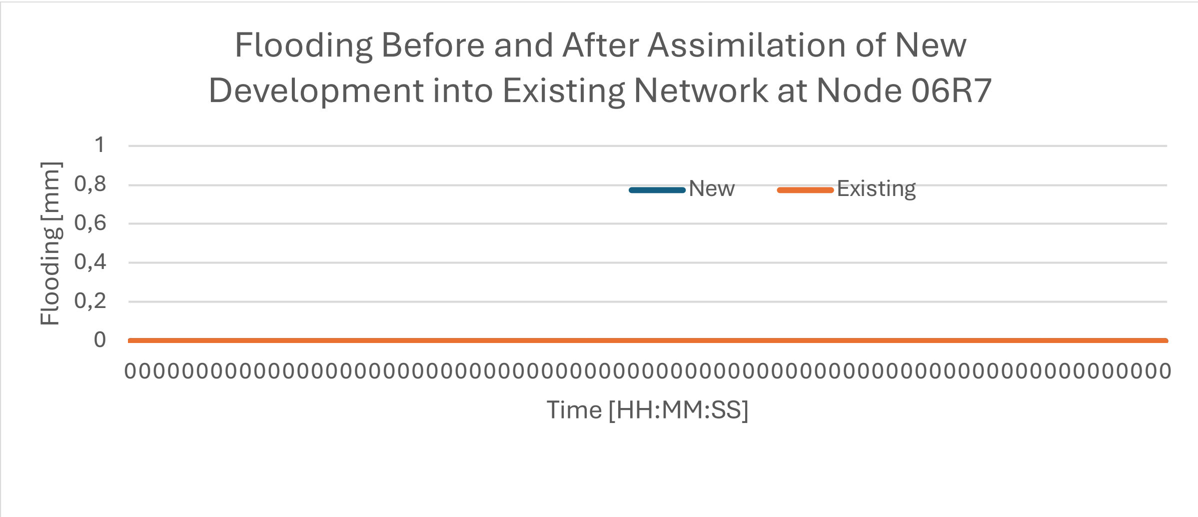

Comparision of ALL LIDs on Runoff Reduction for 5 Year Return Period Flood
NO LID
ALL LIDs
Runoff [l/s]
250
200
150
100
50
0
Time [HH:MM:SS]

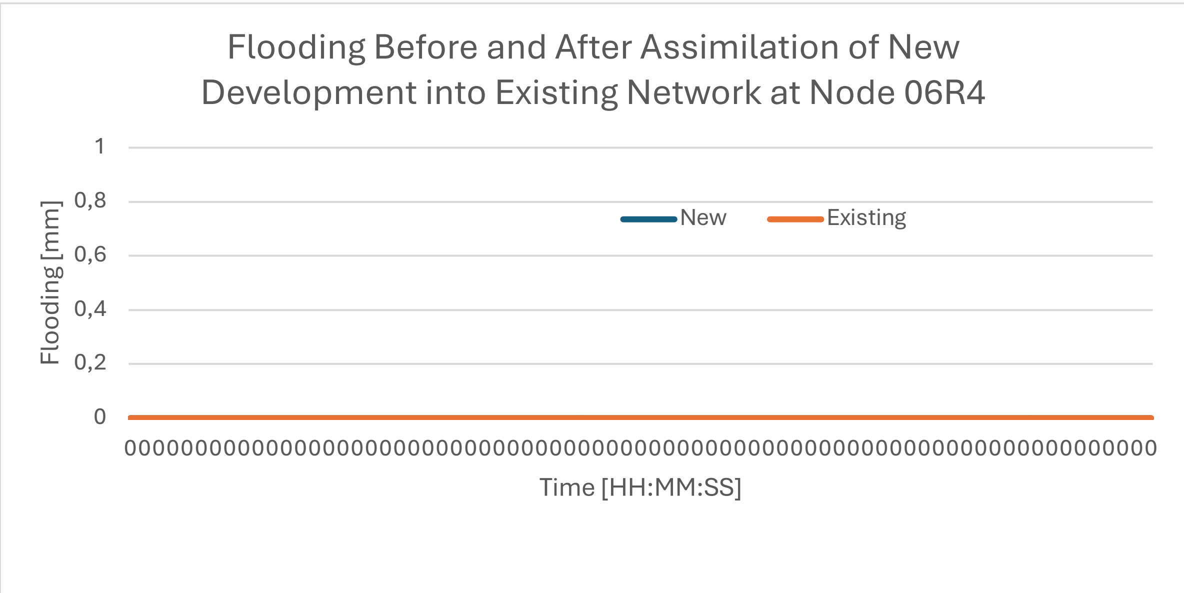

Comparision of ALL LIDs on Runoff Reduction for 17 Year Return Period Flood
NOLID
ALL LIDs
Runoff [l/s]
800
700
600
500
400
300
200
100
0
Time [HH:MM:SS]


Runoff Rate Before and After Assimilation of New Development into Existing Network at Conduit 06R7-06R6
New
Existing
Runoff Rate [l/s]
20
15
10
5
0
00:00:00
01:10:00
02:20:00
03:30:00
04:40:00
05:50:00
07:00:00
08:10:00
09:20:00
10:30:00
11:40:00
12:50:00
14:00:00
15:10:00
16:20:00
17:30:00
18:40:00
19:50:00
21:00:00
22:10:00
23:20:00
Time [HH:MM:SS]


Runoff Rate Before and After Assimilation of New Development into Existing Network at Conduit 06R7-06R6
New
Existing
Runoff Rate [l/s]
60
50
40
30
20
10
0
00:00:00
00:55:00
01:50:00
02:45:00
03:40:00
04:35:00
05:30:00
06:25:00
07:20:00
08:15:00
09:10:00
10:05:00
11:00:00
11:55:00
12:50:00
13:45:00
14:40:00
15:35:00
16:30:00
17:25:00
18:20:00
19:15:00
20:10:00
21:05:00
22:00:00
22:55:00
23:50:00
Time [HH:MM:SS]


Flooding Before and After Assimilation of New Development into Existing Network at Node 06R7
Flooding [mm]
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
New
Existing
Time [HH:MM:SS]


Flooding Before and After Assimilation of New Development into Existing Network at Node 06R7
Flooding [mm]
1
0,8
0,6
0,4
0,2
0
New
Existing
Time [HH:MM:SS]


Flooding Before and After Assimilation of New Development into Existing Network at Node 06R4
Flooding [mm]
1
0,8
0,6
0,4
0,2
0
New
Existing
Time [HH:MM:SS]

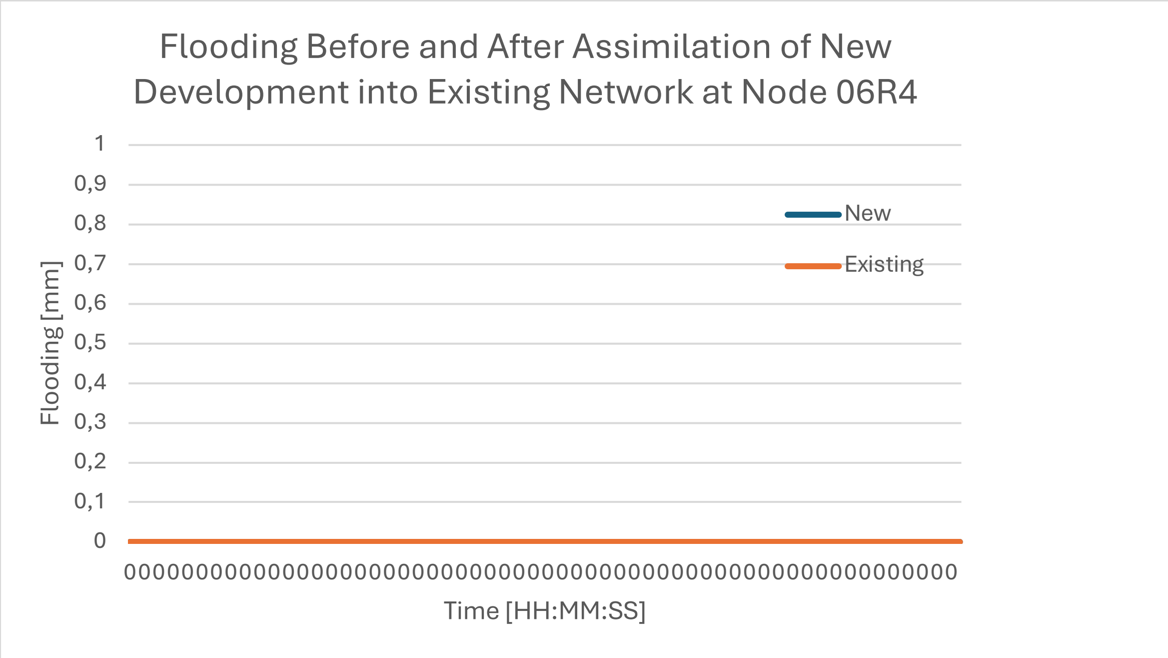
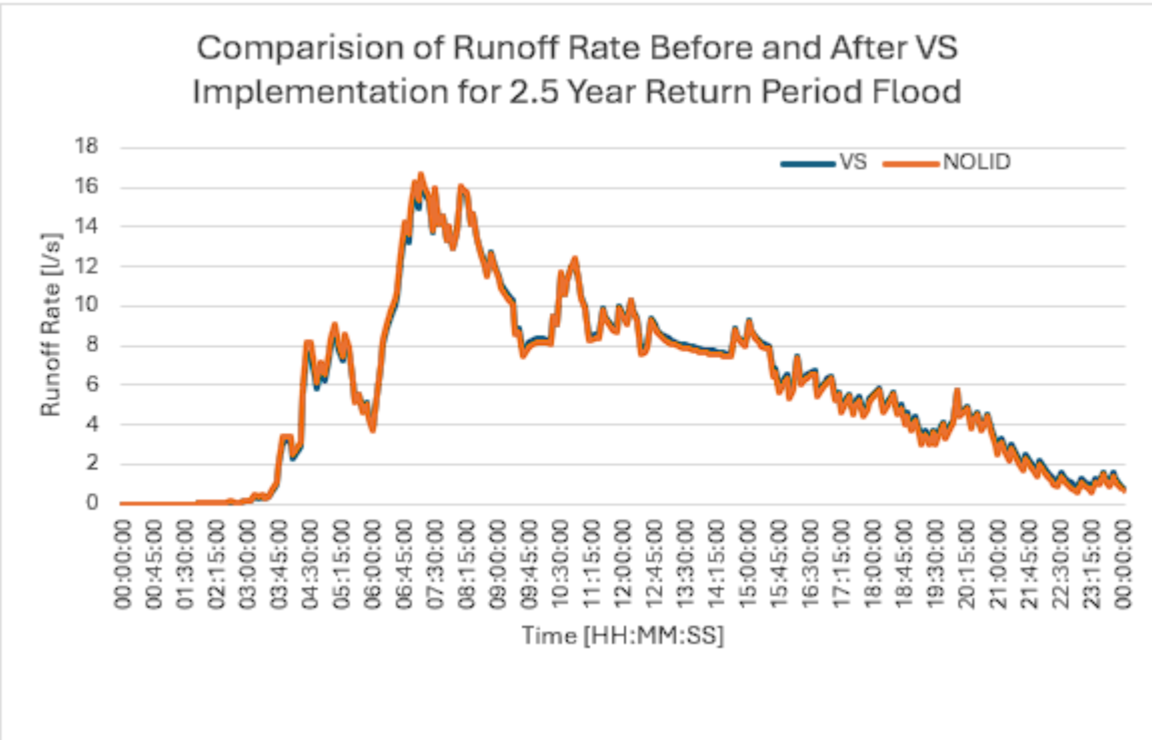
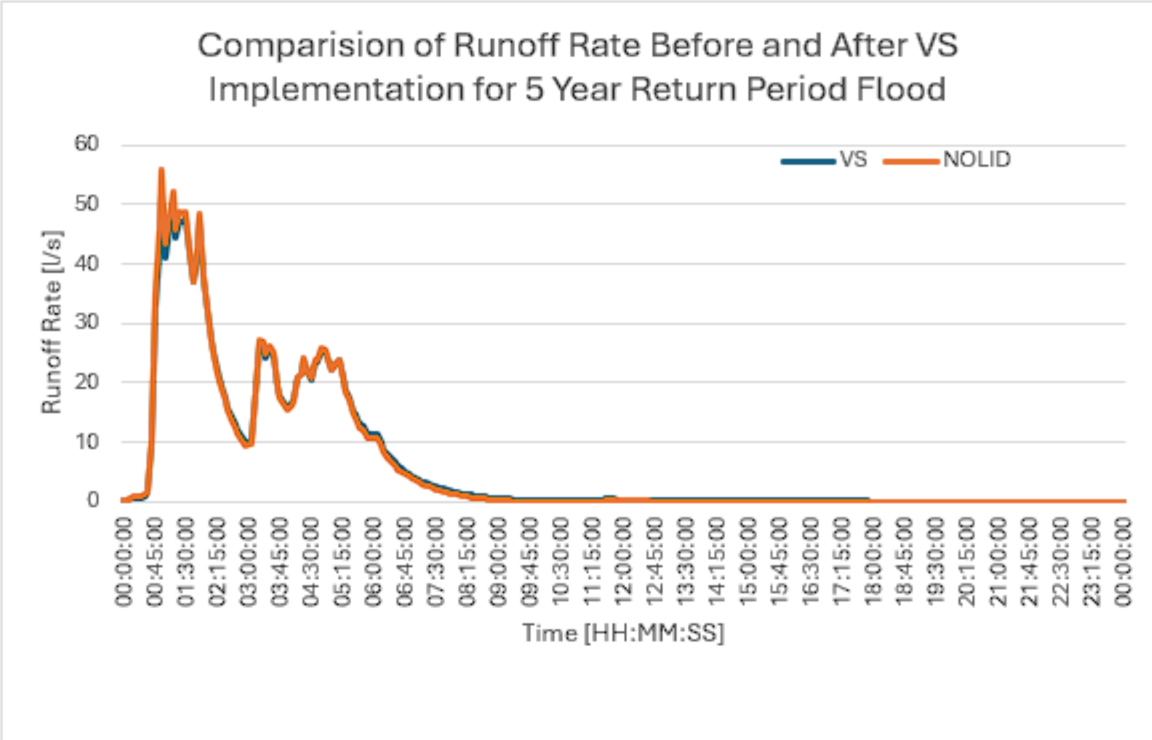
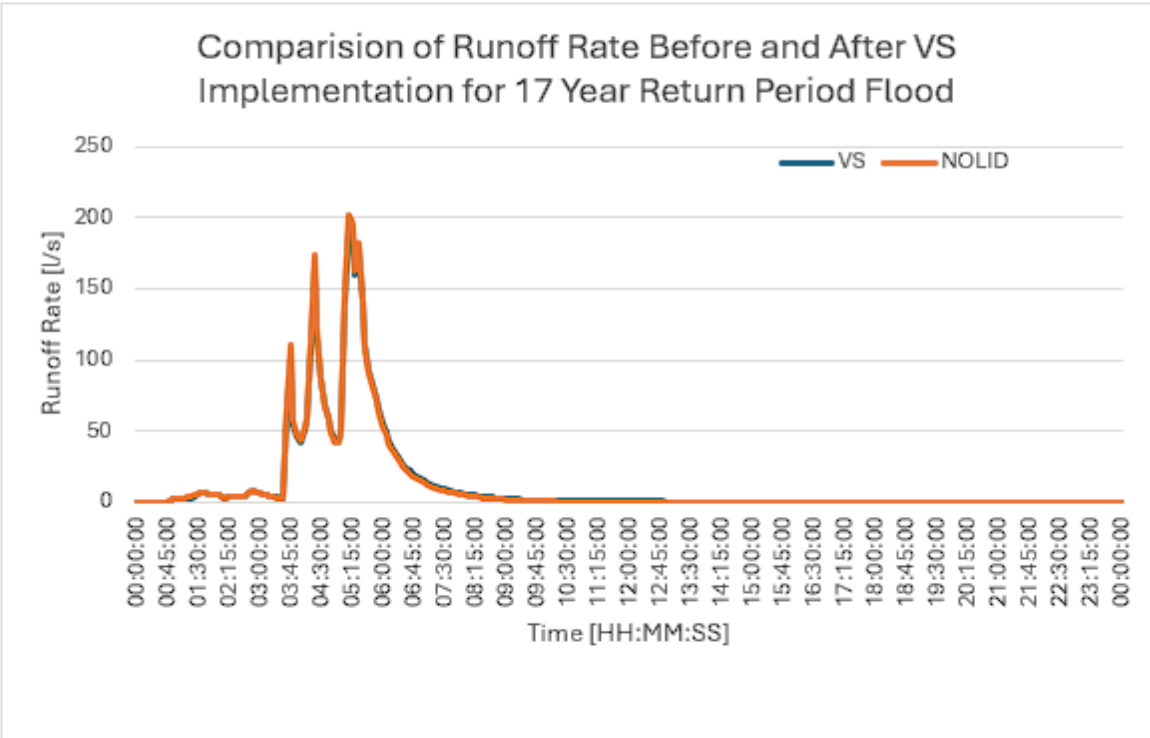

Flooding Before and After Assimilation of New Development into Existing Network at Node 06R4
Flooding [mm]
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
New
Existing
Time [HH:MM:SS]

Figure 28


Comparision of Runoff Rate Before and After VS Implementation for 2.5 Year Return Period Flood
Runoff Rate [l/s]
18
16
14
12
10
8
6
4
2
0
VS
NOLID
Time [HH:MM:SS]


Comparision of Runoff Rate Before and After VS Implementation for 5 Year Return Period Flood
VS
NOLID
Runoff Rate [l/s]
60
50
40
30
20
10
0
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
Time [HH:MM:SS]


Comparision of Runoff Rate Before and After VS Implementation for 17 Year Return Period Flood
VS
NOLID
Runoff Rate [l/s]
250
200
150
100
50
0
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
Time [HH:MM:SS]