# Evaluation of the impact of Low Impact development measures on the Sewer system of the Räcknitz district (in Dresden)

**Scientific Report - MHSE 22 Urban Water II**

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## List of Abbreviations

| | |
|---|---|
| DWA | Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall |
| DWF | Dry weather flow |
| EPA | Environmental Protection Agency |
| GOF | Goodness of Fit |
| ha | hectare |
| hr | Hour |
| IDs | Identification numbers |
| LID | Low impact development |
| LPS | Liters per second |
| m | Meter |
| m3/d | Cubic meter per day |
| mm | Millimeter |
| NSE | Nash Sutcliffe efficiency |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PFE | Peak flow error |
| QGIS | Quantum Geographic Information System |
| SWMM | Storm Water Management Model |

# 1 Introduction

Urban stormwater networks have an important role in urban water management in preventing pluvial flooding in urban areas (Hesarkazzazi et al., 2022). To reduce the impact, it is essential to understand how to adapt and change our infrastructures and surrounding areas in these extraordinary situations. Recent studies have emphasized the effectiveness of decentralized stormwater management as a solution to this problem. Decentralized stormwater management refers to a broad range of technical and non-technical activities ((Sieker, n.d.). The main essential components of a stormwater management model are Usage, Infiltration, Evaporation, Retention, Drainage and Treatment. For an ideal overall system, these separate components should be merged following regional circumstances. Like, for evaporation purposes, it may be helpful to seep in places with sandy soils and hold runoff in areas with loamy-clayey soils. The system's ability to adapt to different conditions and requirements is endless (Sieker et al., 2007). As a result, the idea of decentralized rainwater management is distinct from the traditional stormwater drainage concepts. A portion of rainwater runoff is released locally to the water cycle under the decentralized system. In contrast to conventional methods, this can also be seen as a replication of the natural system where water balance is maintained. In this study, the impact of decentralized rainwater management measures on the water budget of the Räcknitz district will be analyzed.

The process of urban development, as well as the growth of impermeable surfaces and urban areas, is ongoing. Urban areas' traditional infrastructure is built to capture rainwater and transport it into surface water channels and sewers as it exists in the watershed. In terms of the quantity and quality of discharge, urban runoff has a significant impact on watercourses (*The Pollution Conveyed by Urban Runoff: A Review of Sources - ScienceDirect*, n.d.). Numerous studies have emphasized the harm that stormwater runoff causes to receiving watercourses and found that urban stormwater runoff contains a significant quantity of contaminants that come from sewers and sewer overflows as well as sealed surfaces like roadways, rooftops, and backyards (Keßler, n.d.). Depending on how they are used, various compounds enter receiving water in various ways. Heavy metals and polycyclic aromatic hydrocarbons (PAH) are mobilized from surfaces and carried by rainwater into sewage systems and rivers. While pesticides, fertilizers, and pharmaceuticals from livestock farms are conveyed with surface water and groundwater runoff in the watercourses, drugs are delivered there by combined sewer overflows (Burant et al., 2018).

## 1.1 Low-impact development (LID)

Nowadays, Decentralized stormwater management uses Low impact development (LID) in Urban water management. Low impact development (LID) is a word used to describe methods and systems that employ or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater to safeguard water quality and associated aquatic habitat ("Low Impact Development," n.d.). LID's approaches use soils, vegetation, and rainfall harvesting techniques to protect, restore, and generate green space at both the site and regional scales. LID is a method of land development (or re-development) that collaborates with the environment to control stormwater as close to its source as is practical. To construct an effective and aesthetically appealing site drainage system that treats stormwater as a resource rather than a waste product, LID uses principles including maintaining and recreating natural landscape elements.

Numerous techniques, including Vegetated swales, Infiltration Trenches, rain gardens, vegetated rooftops (Green roofs), rain barrels, and permeable pavements, have been employed to adhere to these principles (O. US EPA, 2015). Let us discuss and understand some of these LIDs which will be later used in this study for evaluation of the given system: -

**Permeable Pavements -** These are alternatives to typical pavements and can significantly reduce runoff by letting rainwater and snowmelt infiltrate through its pervious surface. Such alternative materials include pervious asphalt, pervious concrete, interlocking pavers, and plastic grid pavers which allow rain and snowmelt to permeate through the top layer and reach the gravel and soil layer below. Permeable pavements can help filter out contaminants that cause water pollution in addition to lowering the runoff from the rain that falls on them. By eliminating the requirement for some conventional drainage measures, permeable pavements can also lower the demand for road salt and construction expenses for residential and commercial developments (R. 01 US EPA, 2015b).

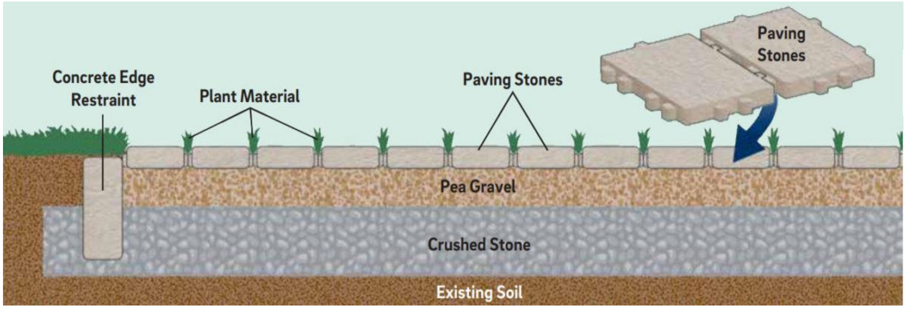


Figure 1:Diagram of permeable pavement with vegetation (Permeable Paving – Green Stormwater Infrastructure, n.d.)

**Rain Gardens -** A rain garden is a small depression that is usually created on a natural slope and is planted with native shrubs, perennials, and flowers. It is designed to capture and soak up rainwater runoff that comes from roofs, roads, patios, or lawns for a short period. Up to 90% of nutrients, pollutants and up to 80% of sediment can be effectively removed from rainwater flow using rain gardens. Rain gardens allow approximately 30% more water to percolate into the soil than a typical grass does (*All About Rain Gardens – What They Are & How to Build One*, n.d.).

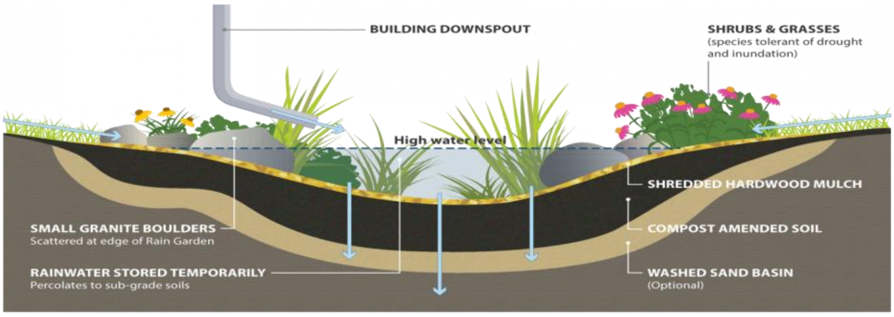


Figure 2: Components of a Rain Garden (Todd, 2018)

**Rain Barrels -** Rain barrels collect water from a roof and store it for use on lawns, gardens, or indoor plants in the future. Rain barrel collection minimizes the amount of water that drains from our land. It is a terrific technique to save water and we can use it for our landscaping for free. Rain barrels are provided to people in many cities and municipalities through yearly sales. Online merchants and neighborhood hardware and gardening supply stores are further possibilities. Rainwater is also "harvested" using cisterns. They can be placed above or below the ground, and they can have a bigger storage capacity (R. 01 US EPA, 2015a).

Figure 3: Rain Barrel connected to a rooftop rainwater harvesting (How to Keep Pesky Mosquitoes out of Your Rain Barrel | Take Care of Texas, n.d.)

**Green Roof -** A green roof is a building's roof that has a waterproofing membrane that is partially or entirely covered with plants and a growing medium (Rodriguez Droguett, 2011). Additionally, it could have root barriers, drainage and irrigation systems as additional layers. A green roof system is an addition to the current roof that includes good quality waterproofing, a root repellant system, a drainage system, filter cloth, a lightweight growing medium, and plants (*About Green Roofs*, n.d.). A building can benefit from a green roof in several ways, including water absorption, insulation, creation of a habitat for wildlife, a reduction in stress for those living nearby, a reduction in the temperature of the surrounding air and a reduction in the heat island effect (Vandermeulen et al., 2011).


Figure 4: Different layers of a green roof (Green Roofs - Neptune Coatings, n.d.)

**Vegetative swales -** are also known as bioswales, are plant-covered contoured land areas or ditches. They are made to collect rainwater runoff and transport it away from surfaces like roads, parking lots, and rooftops where it can't be absorbed by the soil. While some swales resemble meandering natural streams, some appear to be straight rivers. Native plants are often used to fill in vegetated swales, but occasionally turfgrass is used instead. They are frequently built using specialized soils that can naturally treat runoff from storms. In addition to being functional, bioswales can be placed in place of or in addition to underground storm sewers (*Roadside Guide to Clean Water*, n.d.).

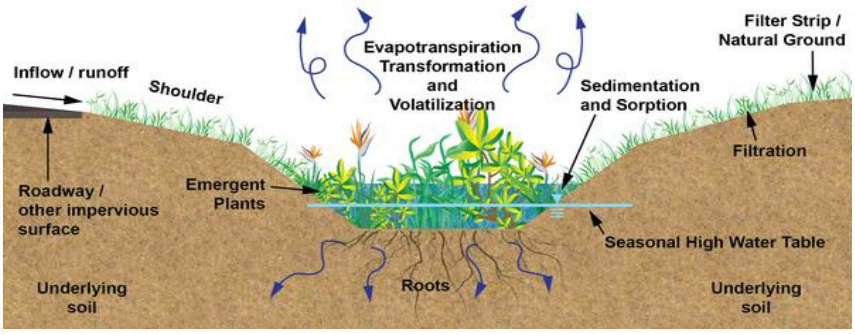


Figure 5: Cross section of a vegetative swale (Swale Terminology for Urban Stormwater Treatment | NC State Extension Publications, n.d.)

**Infiltration Trenches -** They are straight ditches that collect rainwater from nearby surfaces and allow it to quickly soak into the ground due to the presence of extremely permeable soils. Infiltration trenches are mostly used to treat stormwater. When rain falls on impervious surfaces, it collects contaminants from the surface as it runs downhill across the area. In places where they can restrict this surface flow, infiltration trenches are dug. They are linear ditches, making it relatively easy to place them parallel to roadside medians or around parking lots (*Infiltration Trenches*, n.d.).

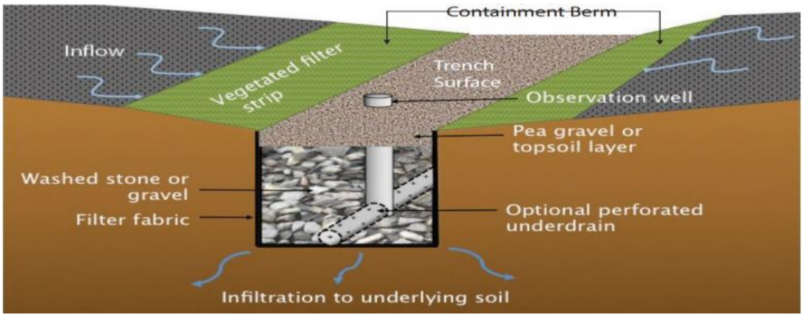


Figure 6: A cross-section of an Infiltration Trench (Infiltration-Trench-Inspection-Checklist.Pdf, n.d.)

Water can be managed in a way that reduces the impact on urban areas and encourages the natural circulation of water within an ecosystem or watershed, by establishing LID concepts and techniques into practice. When used extensively, LID can sustain or restore the hydrologic and ecological functions of a watershed.

## 1.2 Objective

The goal is to implement Low impact development (LID) in each catchment and then analyze the impact of LIDs in Decentralized stormwater management. The main objective is to see how the implementation of LIDs can improve stormwater management of the system. This evaluation will be done by comparing the current water management system (without LIDs) with the same area after introducing LID in each catchment by comparing the flooding in the sewer network and runoff generated. The second objective is to develop a new area of 3 hectares (ha) as the extension of the existing university campus and then analyze the impact of this new development on overall stormwater management. The overall objective is to reduce flooding, runoff and promote groundwater recharge.

# 2 Material and methods

## 2.1 Modelling Software

To create a model of the catchment, an integrated approach to urban drainage was adopted using the software program known as the EPA Storm Water Management Model (SWMM). This model was developed to analyze stormwater management techniques for grey infrastructure, such as pipes and storm drains, combined and sanitary sewers, and any other drainage systems. EPA SWMM is an excellent tool for planning and policy analysis because it can simulate a wide variety of engineered and natural components of systems for stormwater control, to lessen runoff through infiltration & retention and aid to reduce discharges that disrupt water bodies. (EPA, 2021)

## 2.2 Sewer Network Construction

As an initial step for the model development, the sewer network must be incorporated into the model. Then the information about nodes and conduits was added to the EPA SWMM model. The node data includes the elevation, manhole depth, and X and Y coordinates. The conduit data includes information about the conduit's length, roughness, material composition, and shape. The study area, which is situated on the Technical University of Dresden campus, has 73 nodes (which can be seen in figure 7). Table 1 shows the water consumption of each street in the study area.

Table 1:Water Consumption in the study area

| Street | Water Consumption (m3/d) | Water Consumption (LPS) |
|---|---|---|
| Haeckelstraße | 9.425 | 0.10909 |
| Zeunerstraße_east Bergstr. | 32.424 | 0.375278 |
| Zeunerstraße_west Bergstr. | 128.833 | 1.4911257 |
| Bergstraße | 462.328 | 5.3510192 |
| Mommsenstraße | 3.516 | 0.04069 |

## 2.3 Dry Weather Flow Implementation

Once the sewer network was established, the dry weather flow was incorporated into the model. Also, Dry Weather Flow (DWF) is the term used to describe the typical daily flow to a wastewater treatment plant during a dry period (For more information, the DWF pattern is displayed in Appendix I). The flow was split into an hourly pattern based on the hourly characteristics that were discovered for the area. Due to the variance in water usage during the week, the components were then further split into weekdays and weekends.

## 2.4 Sub Catchment Delineation

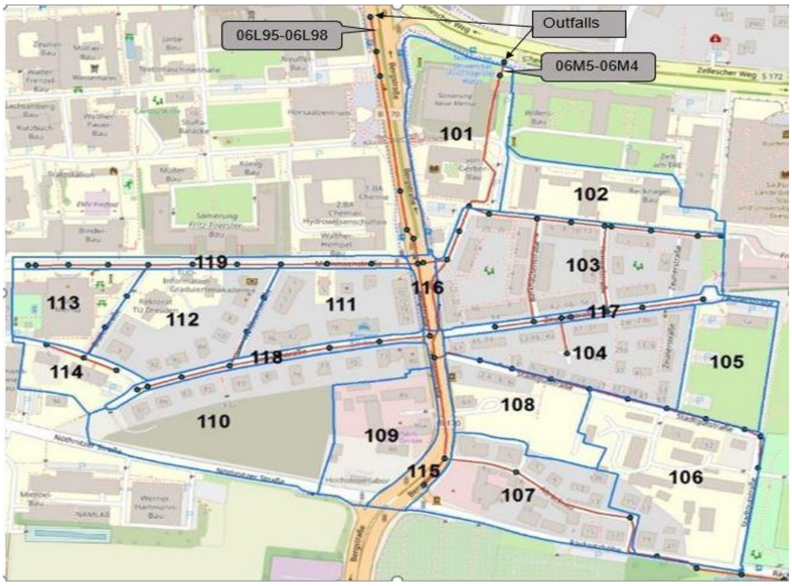


Figure 7:Arrangement of Links, Nodes and Subcatchments

The area under consideration includes 19 sub-catchments starting from 101 to 119 (Figure 7). They are made using the EPA SWMM model's sub-catchment tool. The sub-catchment was sketched over a Google image (in png. format) that served as the background. The entire sub-catchments flow is assumed to proceed to a single node (This assumption is a part of the software SWMM). The node near sub-catchment 101, to the north of the study area, was designated as the outfall as shown in figure 7. The area, width, impervious area, slope, and infiltration were defined as parameters of these sub-catchments. The infiltration rate was determined using the Horton infiltration method. The current land use classification was used to estimate other metrics, such as impervious areas, Street area, flat roof area, gable roof area, and sidewalk space. These were all considered to be impermeable areas for determining land-use requirements. A rain gauge was included in the model, and rainfall data from 1996 to 2015 was added to it. This input data consisted of five-minute intervals of rainfall data. This rainfall data from the rain gauge was shared by the entire catchment. Data on evaporation was also incorporated into the model which was added at an interval of every month.

## 2.5 New Development

The university campus was expanded into a new location to the south of the Volkspark Racknitz (Figure 11). In this new area of 3 ha, there will be 0.6 ha of building space (0.3 ha flat and 0.3 ha gable roofs) with 100 population equivalents and 0.25 ha of traffic space (0.05 ha sidewalk, 0.2 ha street). It is assumed that the remaining portion of the region, apart from any structures or vehicles, is made up of the green area. By determining the frequency of overflows that must be permitted concerning DWA A-118, it will be determined whether the current sewer network is suitable for the connection of a new settlement.

## 2.6 Low impact development (LID)

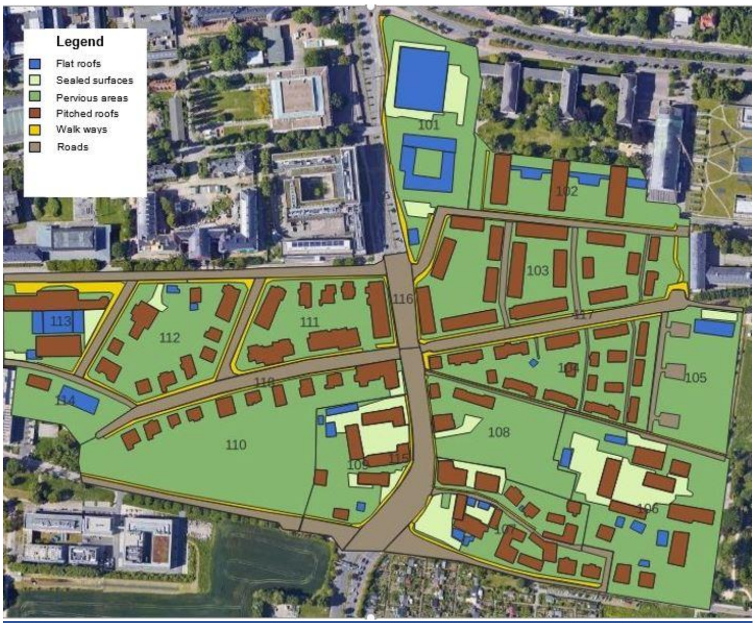


Figure 8: Digitized map using QGIS to extract the relevant data for LIDs

In this study first, short-term LIDs and a combination of short-term and long-term LIDs were implemented into the EPA SWMM software to evaluate the effect on flooding in the research area. First of all, based on the sub-catchment characteristics and land use types of each sub-catchment, suitable LIDs were identified. Using the polygon feature of QGIS software, all the LID areas were digitized. Figure 8 shows the digitized map of the area using QGIs. Then with the help of this digitized map and attribute tables from QGIS the area of each specific LID was estimated. Then finally, percentage of pervious or impervious area treated by different LIDs was calculated. Also, wherever required, the LIDs were divided into a certain number of units (can be seen in table 2) so that they can effectively cover each part of the sub-catchment. At last different LIDs were assigned for each sub-catchment which can be seen in table 2 and table 3.

To precisely estimate and compare the effectiveness of LIDs in the research area, the entire catchment was divided into three scenarios: -

**Scenario 1**: The reference scenario (with new development) and without any LIDs.

**Scenario 2**: Only short-term LIDs (LIDs that can be used from 0 and 5 years after establishment and have no major impact on existing structures) were used. Mainly Vegetative swales, Infiltration Trenches, Rain Barrels and permeable pavement were the practical choices when it came to land-use conditions for short-term application. As it can be seen in Table 2**,** which shows the amount and type of short-term LIDs implemented.

Table 2: Sub-catchment and LID Implementation for Short-Term

| Catchment | Total impervious Area (ha) | Total pervious area (ha) | Area of each unit of LIDs (m2) | No. of units | Short-term LID Area m2 | % of total pervious areas or impervious areas | Remarks |
|---|---|---|---|---|---|---|---|
| **101** | 1.13 | 0.81 | 5681.45 | 1 | 5681.45 | 50 | for permeable pavement |
| **102** | 0.38 | 0.85 | 1500 | 1 | 1500 | 18 | Along the road vegetative swale |
| **103** | 1.26 | 1.62 | 1 | 16 | 16 | 0.1 | 16 barrels for 16 houses |
| | | | 300 | 6 | 1800 | 11 | 6 units of the infiltration trench |
| **104** | 0.52 | 1.14 | 1 | 17 | 17 | 0.2 | 17 barrels for 17 houses |
| | | | 300 | 6 | 1800 | 16 | 6 units of the infiltration trench |
| **105** | 0.22 | 0.91 | 320 | 3 | 960 | 43 | Permeable pavement for each of the 3 car parks |
| | | | 1010 | 1 | 1010 | 11 | Vegetative swale on two sides |
| **106** | 0.77 | 1.73 | 1400 | 3 | 4200 | 55 | Permeable pavement for each of the 3 yards |
| | | | 375 | 6 | 2250 | 13 | Vegetative swale |
| **107** | 0.81 | 0.99 | 800 | 2 | 1600 | 20 | Permeable pavement in 2 car parks |
| | | | 185 | 2 | 370 | 4 | Vegetative swale on the boundary of the catchment |
| **108** | 0.2 | 1.03 | 500 | 4 | 2000 | 19 | Infiltration trench surrounding the catchment |
| **109** | 0.46 | 0.83 | 765 | 3 | 2300 | 50 | The permeable pavement on the yard of the catchment |
| | | | 260 | 5 | 1300 | 16 | Vegetative swale |
| **110** | 0.89 | 2.04 | 300 | 9 | 2700 | 13 | Vegetative swale boundary of the catchment |
| | | | 1 | 11 | 11 | 0.1 | 11 barrels for 10 houses |
| **111** | 0.55 | 0.81 | 617 | 3 | 1851 | 23 | Vegetative swale on 3 sides of the boundary |
| | | | 1 | 12 | 12 | 0.2 | 12 barrels for 7 houses |
| **112** | 0.53 | 1.09 | 420 | 4 | 1680 | 15 | Vegetative swale on the 3 sides of the catchment |
| | | | 1 | 10 | 10 | 0.2 | 10 barrels for the 10 houses |
| **113** | 0.61 | 0.31 | 475 | 4 | 1900 | 31 | The permeable pavement on 3 yards |
| **114** | 0.19 | 0.42 | 200 | 5 | 1000 | 24 | Infiltration trench surrounding the catchment |

**Scenario 3**: Long-term LIDs (LIDs that can be used from 5 and 20 years after establishment but require substantial adaptation changes on existing structures) were used in combination with short-term LIDs. The long-term LIDs used in this study were mainly green roofs and rain gardens. It is understandable that green roofs can only be implemented on buildings with flat roofs and that rain gardens can only be established in available green areas near the building. This implementation of long-term LIDs with their respective area and type can be seen in table 3.

Table 3: Sub-catchments and The Long-term LID

| Catchment | Total impervious Area (ha) | Total pervious area (ha) | Area of each unit of LIDs | No. of units | Long-term LID Area (m2) | % of total pervious or impervious areas | Remarks |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **101** | 1.13 | 0.81 | 2665 | 2 | 5330 | 47.07 | 2 Green roofs over the top of two buildings |
| **102** | 0.38 | 0.85 | 280 | 2 | 560 | 14.87 | 2 Green roofs over the two connecting structures between the three buildings |
| | | | 400 | 3 | 1200 | 14.16 | 3 Rain gardens in the central courtyards of each adjoining buildings |
| **103** | 1.26 | 1.62 | 550 | 5 | 2750 | 16.99 | 5 Rain gardens in the 3 central courtyards surrounded by buildings |
| **104** | 0.52 | 1.14 | 150 | 6 | 900 | 7.90 | 6 Rain gardens in the central green space areas between the buildings |
| **105** | 0.22 | 0.91 | 3150 | 1 | 3150 | 34.65 | 1 big Rain Garden on the side of the pavement on the permeable area in the catchment |
| **106** | 0.77 | 1.73 | 500 | 2 | 1000 | 5.78 | 2 Rain gardens in the green areas between the buildings |
| **107** | 0.81 | 0.99 | - | - | - | 0.00 | No long-term LIDs due to limited space (space occupied by other LIDs) |
| **108** | 0.2 | 1.03 | 1750 | 1 | 1750 | 17.05 | 1 big Rain Garden on the eastern side of this sub-catchment |
| **109** | 0.46 | 0.83 | 560 | 1 | 560 | 6.72 | 1 Rain Garden in the center of the sub-catchment |
| **110** | 0.89 | 2.04 | 150 | 6 | 900 | 5.00 | 6 small Rain gardens behind each house (Excluding the demolished area under reconstruction) |
| **111** | 0.55 | 0.81 | 450 | 2 | 900 | 11.07 | 2 Rain gardens in the central area enclosed by all the buildings |
| **112** | 0.53 | 1.09 | 250 | 4 | 1000 | 9.21 | 4 Rain gardens in the central courtyard |
| **113** | 0.61 | 0.31 | 250 | 3 | 750 | 12.22 | A green roof over the Alte Mensa and 1 other building in the sub-catchment |
| | | | 250 | 1 | 250 | 7.94 | A rain garden on the western side of the catchment |
| **114** | 0.19 | 0.42 | 580 | 1 | 580 | 30.01 | A green roof over the only flat roof available |
| | | | 250 | 3 | 750 | 18.02 | 3 Rain gardens in the backyard |

The catchments 115, 116, 117, 118 and 119 are completely covered with the impermeable area which are either streets or main roads. Hence, none of the above-discussed LIDs can be provided in these sub-catchments.

# 3 Results

## 3.1 Calibration

To calibrate the model, first, those rain events were selected which will be used in the calibration and validation process. To do this, we selected six different rain events with various characteristics for calibration & three different events for validation to test the network's behaviour under various rain event characteristics. Based on the intensity and duration of the rain, these rain events were chosen, with each event representing conditions of low, medium, or high rain intensity. Suggested dates of rain and event numbers can be seen in table 4.

Table 4: Different rain events suggested for the model

| Event | Date (dd/mm/yyyy) | Event | Date (dd/mm/yyyy) | Event | Date (dd/mm/yyyy) |
|---|---|---|---|---|---|
| 1 | 04/05/1996 | 17 | 07/07/2001 | 33 | 29/09/2009 |
| 2 | 03/06/1996 | 18 | 05/09/2002 | 34 | 02/06/2010 |
| 3 | 08/07/1996 | 19 | 30/11/2002 | 35 | 02/08/2010 |
| 4 | 11/08/1996 | 20 | 09/05/2003 | 36 | 03/07/2011 |
| 5 | 11/08/1996 | 21 | 10/05/2004 | 37 | 04/07/2011 |
| 6 | 22/08/1996 | 22 | 12/09/2004 | 38 | 10/10/2013 |
| 7 | 18/07/1997 | 23 | 12/09/2004 | 39 | 01/05/2014 |
| 8 | 25/07/1997 | 24 | 09/11/2004 | 40 | 18/05/2014 |
| 9 | 03/06/1998 | 25 | 07/07/2005 | 41 | 26/05/2014 |
| 10 | 21/07/1998 | 26 | 22/08/2005 | 42 | 30/05/2014 |
| 11 | 12/09/1998 | 27 | 21/01/2006 | 43 | 08/07/2014 |
| 12 | 09/07/1999 | 28 | 12/05/2006 | 44 | 19/09/2014 |
| 13 | 14/07/1999 | 29 | 19/06/2006 | 45 | 21/10/2014 |
| 14 | 18/09/1999 | 30 | 16/06/2007 | 46 | 17/08/2015 |
| 15 | 09/10/1999 | 31 | 24/06/2007 | 47 | 30/11/2015 |
| 16 | 15/04/2000 | 32 | 08/08/2008 | | |

For each sub-catchment, the recommended calibration values and their respective variation ranges were given (for more information on these ranges see Appendix II). Manual calibration was used to calibrate the model. Only the imperviousness, slope, and width of each sub-catchment will be modified as calibration parameters for this model. This is because these three EPA SWMM characteristics are among the most sensitive parameters. Other surface parameters can be assumed to be constants because they are not as sensitive. Two calibration points will be used, which are the links 06M5-06M4 and 06L95-06L98. These links are situated directly downstream of each of the two outfalls of the model (figure 07). For the calibration, we'll use discharge time series (in LPS). The goodness of fit (GOF) will be evaluated using Nash-Sutcliffe Efficiency (NSE) and Peak Flow Error (PFE) performance indicators.

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## 3.2 Validation

The comparison of observed and simulated data is the main emphasis of the validation methods, just like the calibration procedures. The distinction is based on the fact that the model was used with the best set of parameters during the validation process. The best outcomes for all the validation events are produced by this ideal set of parameters. To evaluate the outcomes of the validation procedure, the same GOF parameter that was used in the calibration phase must be employed.

## 3.3 Calibration results

The selected rain events were 3,7,13,19,22 and 26 which can be seen in table 4. After selecting the events, the dates were determined and put in their respective model scenarios in EPA SWMM with the simulation starting one day before and ending one day after the selected event. For each event, the values of parameters like width, imperviousness and slope were changed and added to the model as shown in Table 5, Table 6 & Table 7.

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| Sub catchment | Width | | | | | | |
|---|---|---|---|---|---|---|---|
| | Event 3 | Event 7 | Event 13 | Event 19 | Event 22 | Event 26 | Average |
| **101** | 190 | 190 | 190 | 190 | 196 | 200 | **192.67** |
| **102** | 167 | 167 | 167 | 167 | 165 | 165 | **166.33** |
| **103** | 209 | 209 | 209 | 209 | 207 | 205 | **208.00** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **104** | 170 | 170 | 170 | 170 | 172 | 178 | **171.67** |
| **105** | 81 | 81 | 81 | 81 | 79 | 91 | **82.33** |
| **106** | 130 | 110 | 130 | 130 | 140 | 135 | **129.17** |
| **107** | 116 | 80 | 116 | 116 | 114.5 | 114.5 | **109.50** |
| **108** | 151 | 120 | 151 | 151 | 79 | 151 | **133.83** |
| **109** | 102 | 80 | 102 | 102 | 168 | 103 | **109.50** |
| **110** | 136 | 102 | 136 | 136 | 142 | 137 | **131.50** |
| **111** | 110 | 88 | 127 | 110 | 43.5 | 126 | **100.75** |
| **112** | 117 | 117 | 117 | 117 | 118 | 120 | **117.67** |
| **113** | 70 | 67 | 91 | 70 | 80 | 95 | **78.83** |
| **114** | 70 | 30 | 89 | 70 | 89 | 85 | **72.17** |
| **115** | 157 | 157 | 157 | 157 | 157 | 160 | **157.50** |
| **116** | 75 | 75 | 75 | 75 | 75 | 100 | **79.17** |
| **117** | 27 | 27 | 27 | 27 | 25 | 26.5 | **26.58** |
| **118** | 27 | 12 | 35 | 27 | 34 | 33.5 | **28.08** |
| **119** | 14 | 6 | 18 | 14 | 17 | 17 | **14.33** |

Table 5: Width values after the calibration

Table 6: Imperviousness values after the calibration

| **Sub catchment** | **Imperviousness %** | | | | | |
|---|---|---|---|---|---|---|
| | Event 3 | Event 7 | Event 13 | Event 19 | Event 22 | Event 26 | Average |
| **101** | 58 | 50 | 58 | 58 | 52 | 54 | **55.00** |
| **102** | 30 | 25 | 30 | 30 | 24 | 26 | **27.50** |
| **103** | 43 | 38 | 43 | 43 | 37 | 39 | **40.50** |
| **104** | 31 | 26 | 31 | 31 | 25 | 27 | **28.50** |
| **105** | 19 | 14 | 19 | 19 | 13 | 15 | **16.50** |
| **106** | 30 | 36 | 30 | 30 | 24 | 26 | **29.33** |
| **107** | 45 | 46 | 45 | 45 | 39 | 41 | **43.50** |
| **108** | 12 | 12 | 16 | 12 | 10 | 8 | **11.67** |
| **109** | 35 | 42 | 35 | 35 | 29 | 31 | **34.50** |
| **110** | 28 | 28 | 35 | 28 | 29 | 24 | **28.67** |
| **111** | 23 | 23 | 45 | 23 | 39 | 19 | **28.67** |
| **112** | 30 | 30 | 35 | 30 | 25 | 26 | **29.33** |
| **113** | 70 | 90 | 70 | 90 | 64 | 66 | **75.00** |
| **114** | 26 | 26 | 33 | 26 | 21 | 22 | **25.67** |
| **115** | 100 | 100 | 100 | 100 | 59 | 65 | **87.33** |
| **116** | 100 | 100 | 100 | 100 | 59 | 65 | **87.33** |
| **117** | 100 | 100 | 100 | 100 | 59 | 65 | **87.33** |
| **118** | 100 | 100 | 100 | 100 | 59 | 65 | **87.33** |
| **119** | 46 | 46 | 46 | 46 | 39 | 42 | **44.17** |

Table 7: Slope values after the calibration

| **Sub catchment** | **Slope %** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Event 3 | Event 7 | Event 13 | Event 19 | Event 22 | Event 26 | Average |
| **101** | 1 | 1 | 1 | 1 | 1.3 | 1.4 | **1.12** |
| **102** | 1 | 1 | 1 | 1 | 1.3 | 1.4 | **1.12** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **103** | 3 | 3 | 3 | 3 | 3.3 | 3.4 | **3.12** |
| **104** | 2 | 2 | 2 | 2 | 2.3 | 2.4 | **2.12** |
| **105** | 3 | 3 | 3 | 3 | 3.3 | 3.4 | **3.12** |
| **106** | 2 | 4 | 2 | 2 | 2.3 | 2.4 | **2.45** |
| **107** | 2 | 4 | 2 | 2 | 2.3 | 2.4 | **2.45** |
| **108** | 1 | 4 | 1 | 1 | 1.3 | 1.4 | **1.62** |
| **109** | 2 | 4 | 2 | 2 | 2.3 | 2.4 | **2.45** |
| **110** | 2 | 6 | 2 | 2 | 2.3 | 2.4 | **2.78** |
| **111** | 1.5 | 3 | 1.5 | 1.5 | 1.8 | 1.9 | **1.87** |
| **112** | 2.5 | 6 | 2.5 | 2.5 | 2.8 | 2.9 | **3.20** |
| **113** | 2.5 | 6 | 2.5 | 2.5 | 2.8 | 2.9 | **3.20** |
| **114** | 0.5 | 1 | 0.5 | 0.5 | 0.8 | 0.9 | **0.70** |
| **115** | 0 | 1 | 0 | 0 | 0.3 | 0.4 | **0.28** |
| **116** | 4 | 5 | 4 | 4 | 4.3 | 4.4 | **4.28** |
| **117** | 3 | 5 | 3 | 3 | 3.3 | 3.4 | **3.45** |
| **118** | 1 | 1 | 1 | 1 | 0.5 | 0.5 | **0.83** |
| **119** | 2 | 2 | 2 | 2 | 1.3 | 1.3 | **1.77** |

The simulated flow values for links 06L95-06L98 and 06M5-06M4 were exported to excel and compared with the observed flow values for the respective events. The corresponding values of Nash-Sutcliffe Efficiency (NSE) and Peak Flow Error (PFE) were calculated. The calibration of events by changing parameters was performed again and again until satisfactory values of NSE and PFE were found as shown in Table 8 (satisfactory values for NSE reflect a value as close to 1 while for PFE reflect a value as close to 0). After getting satisfactory values for each event, six sets of values of parameters were obtained for each respective event which produced optimal results. To determine the best possible combination, validation was performed.

Table 8: NSE and PFE values for selected events with event intensity

| Event no | Link: 06L95-06L97 | | Link: 06M5-06M10 | | Event intensity |
|---|---|---|---|---|---|
| | NSE | PFE | NSE | PFE | |
| **3** | 0.926 | 0.158 | 0.987 | 0.032 | High |
| **7** | 0.895 | 0.153 | 0.991 | 0.063 | Low |
| **13** | 0.845 | 0.263 | 0.979 | 0.018 | Medium |
| **19** | 0.733 | 0.133 | 0.950 | 0.018 | High |
| **22** | 0.916 | 0.207 | 0.967 | 0.187 | Low |
| **26** | 0.887 | 0.052 | 0.968 | 0.211 | Medium |

## 3.4 Validation results

Validation was performed to find the optimal set of parameters that can be considered as the one which yields the best results for all the validation events. To do this first three different rain events were selected based on their intensities, which were events 16,17 and 24 from table 4. Now an average of each parameter obtained from six different calibration events was calculated to obtain one set of values for width, imperviousness and slope. Table 9 shows the averaged calibrated values of Width, Slope and imperviousness for each catchment. These values were used to run the analysis for each validation event to validate the obtained values of NSE and PFE. As the values produced were still in the satisfactory range, it was concluded that our model had been calibrated.

Table 9: Validation results for Events 16,17 & 24

| Event | Intensity | Link: 06L95-06L98 | | Link: 06M5-06M4 | |
|---|---|---|---|---|---|
| | | NSE | PFE | NSE | PFE |
| **16** | Medium | 0.851 | 0.140719 | 0.972 | 0.155766 |
| **17** | Low | 0.785 | 0.334022 | 0.973 | 0.046378 |
| **24** | High | 0.721 | 0.012339 | 0.943 | 0.037862 |

## 3.5 Precipitation

Figure 9 shows the precipitation events from 1995 to 2015. The highest peak can be seen on 1$^{st}$ February 2010 with more than 400 mm/hr of rainfall, which can be considered as an outlier because this is a very unusual event (an outlier is an extraordinarily high or very low data point relative to the nearest data point and the rest of the nearby co-existing values in a data graph). Now, the second highest event can be observed in august 2002 which will be selected as the rain event for the calculation of results in this study. While all the other rain events are in a average range of precipitation recived by the region.

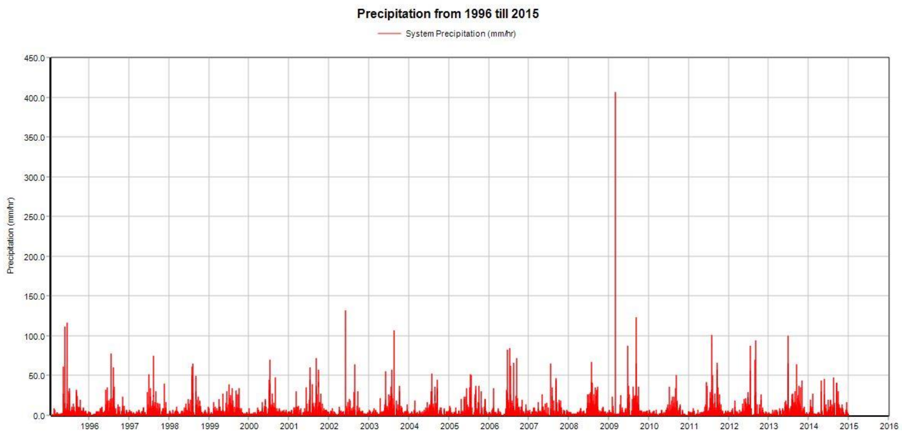


Figure 9: Precipitation in the entire catchment from 1995 to 2015

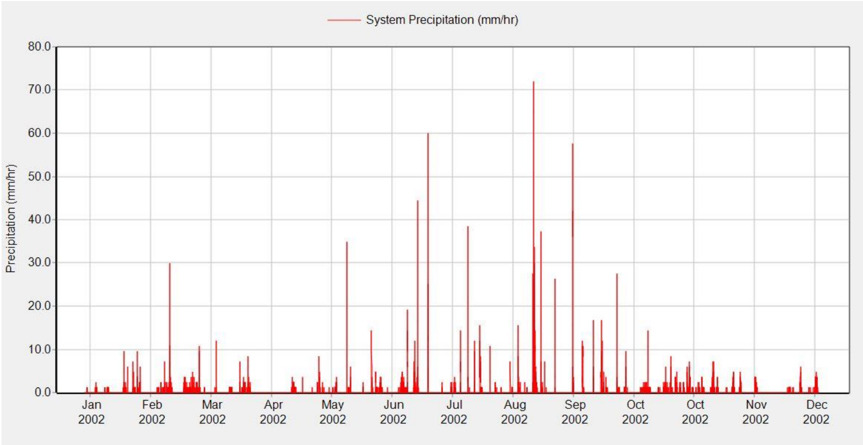


Figure 10: Precipitation in the year 2002

To find the exact date of this 2nd highest rainfall event, Figure 10 was plotted which shows the precipitation in the year 2002. As it can be observed in the graph, we have several rainfall events in the year 2002, but the biggest one can be seen on 12th august 2002 with more than 70 mm/hr. Also, it should be noted that the majority of the rain events in 2002 occurred in summer between may to September 2002. Interstingly, the study area which is a part of Dresden also received extreme flooding on the same day on 12th august, 2002. Hence, it can be said that rain events discussed in this year are correct and not a outlier.

## 3.6 Comparison between reference scenarios with and without new development

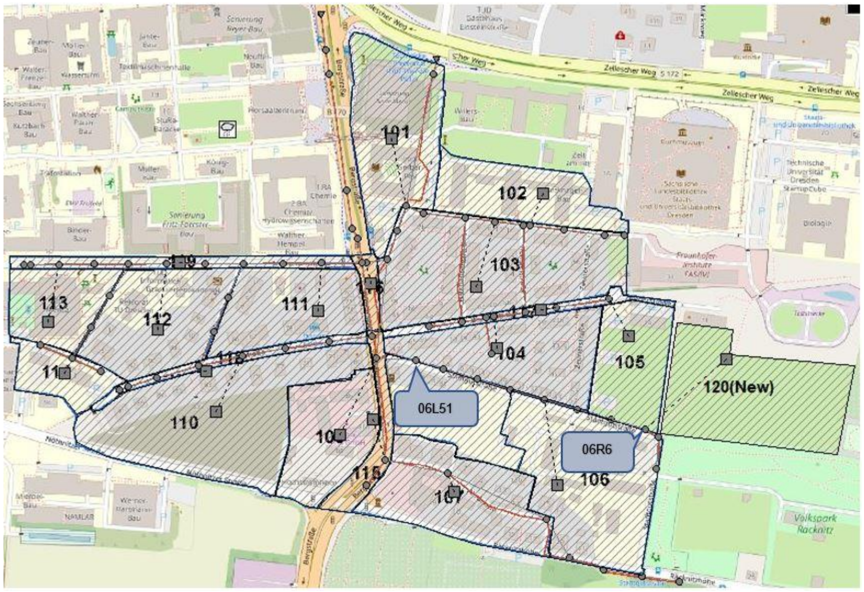


Figure 11: Subcatchment areas after adding New development area

The first objective of this study is to establish a new development towards the east of the seminar buildings Zeunerstraße and south of the Volkspark Räcknitz as an extension of the university campus (can be seen in Figure 11 as sub catchment 120(New)). After the establishment of new development in the model it will be compared with the initial sewer network to see if it is suitable for a connection to this existing settlement or not.

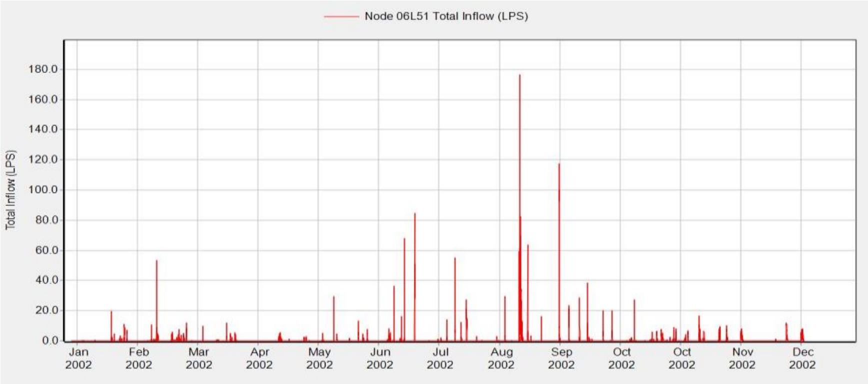


Figure 12: Total Inflow of node 06L51 without New development in the year 2002

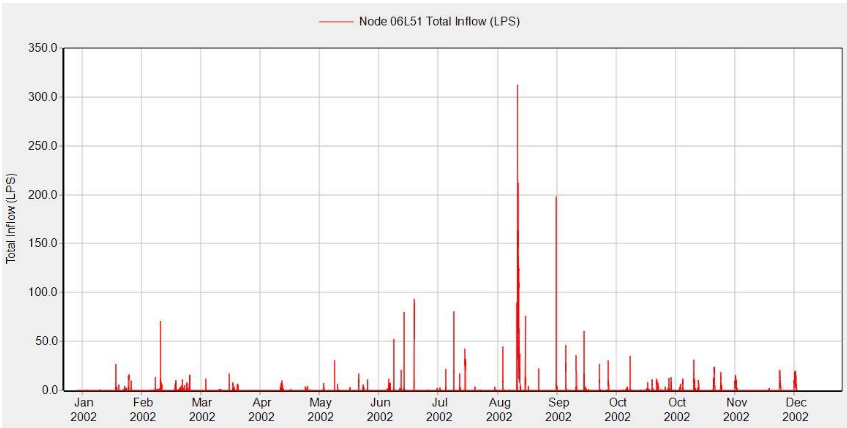


Figure 13: Total inflow of node 06L51 with New Development in the year 2002

As we can see from Figures 12 & 13 that the inflow volume on node 06L51 (which is a node just after a few nodes to where our new development is connected and can be seen in Figure 11) considerably increased after adding the new development in the same network. Particularly, if we see the values on 12th august 2002 we find that the inflow volume increases from 175 LPS (without new development) to 310 LPS (after adding new development), which is a very high jump in inflow of water.

Figure 14 shows the flooding in the same branch of the sewer network discussed above (from node 06R2 to 06L51) where our new development is connected. The figure was analyzed for a specific time of 4:40 AM on 12th august 2002 which shows highest precipitation in the area. As it can be seen from the graph that the overall quantity of water increases but still the initial sewer system is easily able to contain this extra inflow of water from the new development.

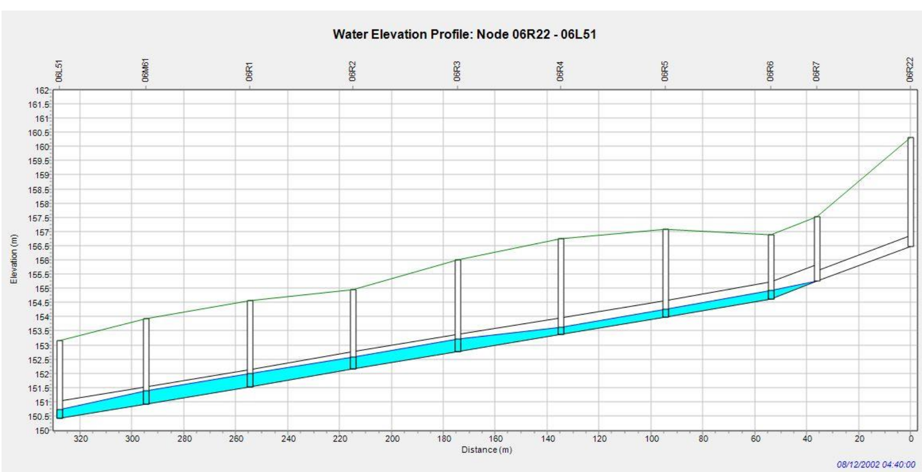


Figure 14: Water elevation of Node 06R22 to 06L51

## 3.7 Effect of LIDs

To show the effect of LIDs in the catchment the study will compare three different scenarios: -

1. Scenario 1 - Reference scenario (with new development) without any LIDs
2. Scenario 2 - Reference scenario with short-term LIDs
3. Scenario 3 - Reference scenario with short-term and long-term LIDs

Each of these cases will be compared to each other based on flooding in the area. The study expects the flooding (if any) would decrease or can be avoided in the sewer system after the establishment of LIDs in the catchment. As we already saw in the previous graph that the highest rainfall occurred on 12th august 2002. So, for discussion of the results of these LIDs, we will focus on this specific event.

### 3.7.1 Scenario 1 - System flooding in the reference scenario without any LIDs

From Figure 15 we can see that there was only one flooding event in the year 2002 on 12th august. The flooding was observed to be 139.40 LPS on the same day when no LIDs were installed in the area.

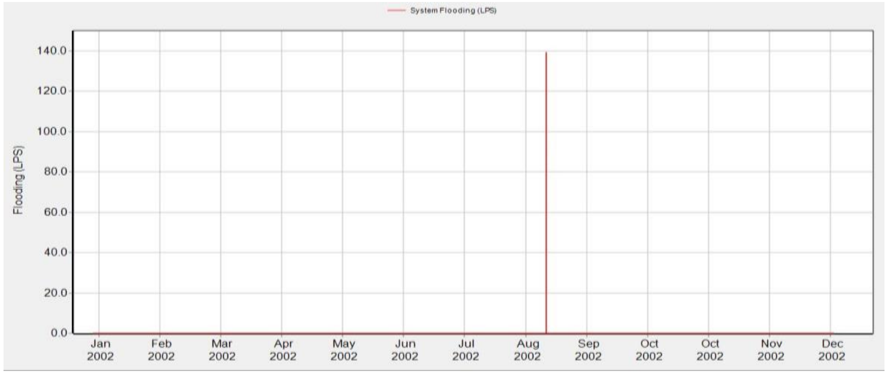


Figure 15: System flooding in the year 2002 without any LIDs

### 3.7.2 Scenario 2 - System flooding in reference scenario with short-term LIDs

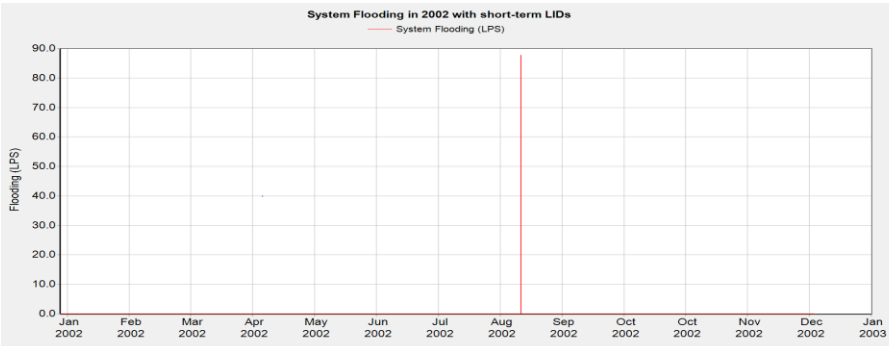


Figure 16: System flooding in the year 2002 with short-term LIDs

Figure 16 represents the flooding in the area after the establishment of short-term LIDs. As it can be seen in the graph that the flooding on 12th august 2002 was reduced to 87.8 LPS, which is a 37 % reduction in flood discharge. This reduction can be explained by the fact that the LIDs increased the percentage of the total pervious area in the catchment which led to less stormwater discharged into the sewer network, hence reducing the flooding.

### 3.7.3 Scenario 3 - System flooding in Reference scenario with short-term and long-term LIDs

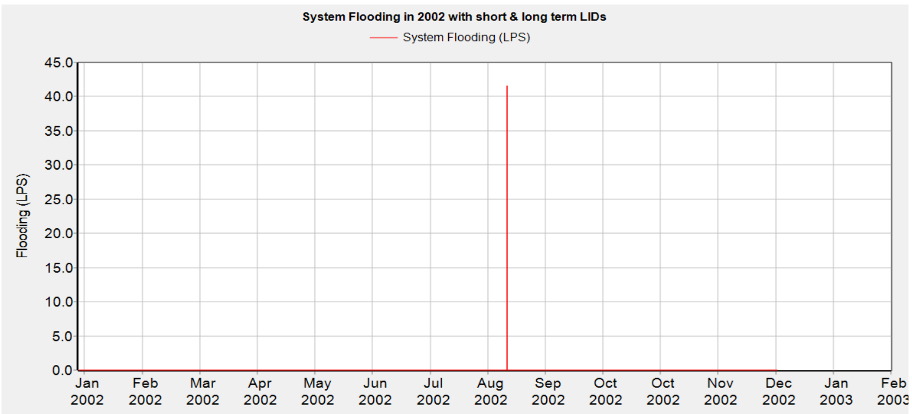


Figure 17: System flooding in the year 2002 with short-term & long-term LIDs

Now, Figure 17 reflects the flooding in the area after the addition of both short and long-term LIDs in the catchment. As a result, the flooding was further reduced to 41.6 LPS which is a 70 % reduction in overall flooding. So, we can see that the LIDs have a very important role in reducing the overall load on the sewer network and treatment plants. Now to find the exact location and time of flooding in the catchment, we can plot the time elevation profile of the given branch of the sewer network.

## 3.8 Flooding of Node 06M41

After analysing the node system, it was found that only one node (06M41) is flooded in all of the above three discussed senarios, but with different floodwater levels. The flood occurs at 04:40 hours on 12$^{th}$ august 2002, and it lasts for 5 minutes. In the following Figure 18, the flooded node (06M41) in this specific event is shown in the given branch of the sewer network from node 06R22 to 06M47 in a water elevation profile graph. The first part of the given branch has decreasing slope till node 06L44 after which the slope changes and it starts increasing. The nodes which are flooded or are almost full during this event lie on this part of the branch were topography is an upward slope.

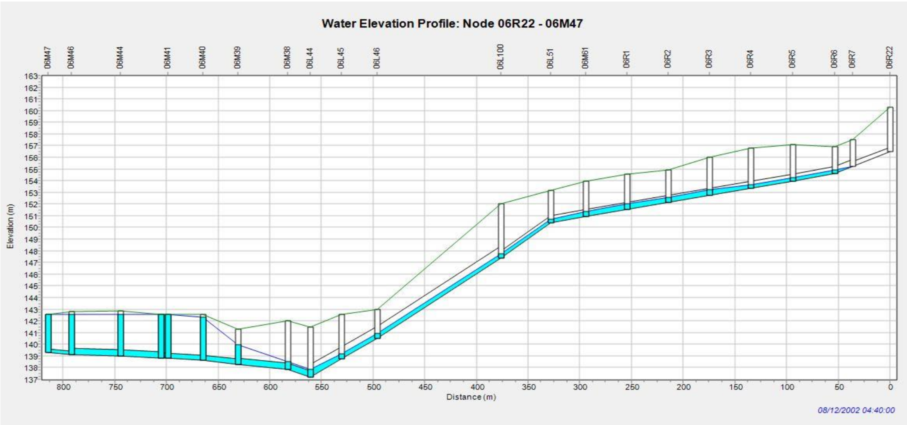


Figure 18: Elevation profile of the system from node 06M47 till 06R22 on 12th of August 2002 at 04.40 a.m

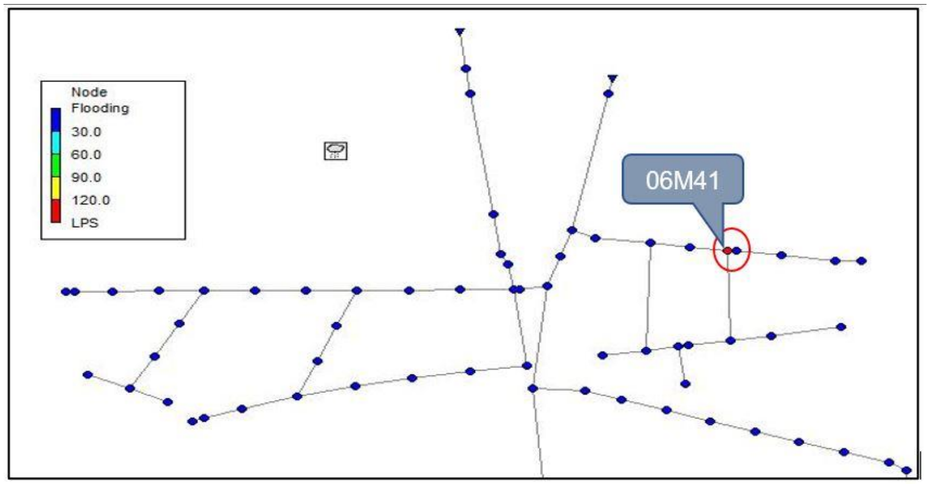


Figure 19: System flooding on 12th of August 2002 at 04.40 A.M. without LIDs

When we look at the node flooding network (Figure 19), it shows a node flooding of 139.5 LPS at node 06M41 on a branch (Haeckelstrasse), which is unusual as the expected flooding should have been in a branch (Stadtgutstrasse) where the new development area was connected. As we already saw that this development area considerably increases the inflow volume (by 135 LPS at node 06L51) in the given network (Figure 12 & Figure 13). This can be explained by the water elevation profile in (figure 18) which shows that the elevation of nodes decreases from 06R22 to 06L44 but then again increases from 06L44 to 06M47. Due to this elevation change our node 06M41 lies on this upward slope of the sewer branch which makes it prone to backwater effects from the main sewer line. The sewer branch of Haeckelstrasse acts as a storage tank for excess water till the quantity of water is reduced in the main sewer discharge line.

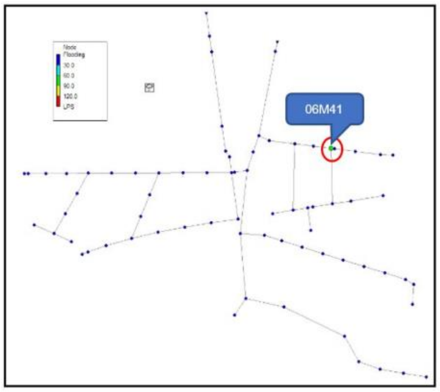


Figure 20: Node flooding of reference scenario with short-term LIDs

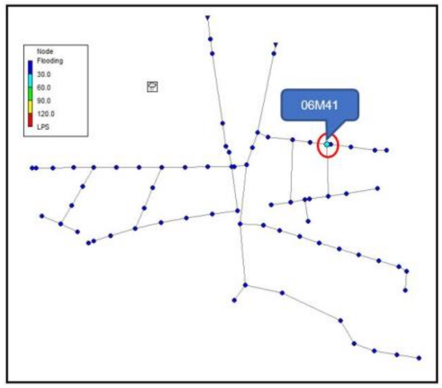


Figure 21: Node flooding with Short term + long-term scenarios

If we compare figure 19, 20 and 21 which reflects Scenario 1, 2 and 3 respectively. We see that the flooded node 06M41 changes its colour from red to green to finally blue which means that the flooding discharge gets reduced from 139.5 LPS (for scenario 1 without LIDs) to 87.8 LPS (for scenario 2 with short-term LIDs) to finally 41.6 LPS (for scenario 3 with the combination of short-term & long-term LIDs). Hence, reflecting the effectiveness of LIDs in reducing floodwater discharge in the given catchment.

## 4 Discussion

As discussed in the methodology, mainly permeable pavements and vegetative swales were used as short-term LIDs and long-term LIDs were mainly green roofs and rain gardens. Besides the fact that the green roof can only be implemented on flat roofs which is a disadvantage for the given study area as it has lots of pitched roofs, there are some other issues with the implementation of green roofs. According to some of the literature, the risk associated with the installation of green roofs can be divided into three main categories: -

- building's structure deterioration such as roof leakage due to root penetration, and erosion stemming from clogged drainage) (Chen, 2013; Mahdiyar et al., 2018)
- environmental problems like water contamination by organic constituents (Bianchini & Hewage, 2012)
- material-related issues (Tabatabaee et al., 2019)

The modern solution to these problems is the blue roof or green-blue roof which can be used as an alternative to the green roof. The main objective of this blue roof technology is to both increase the volume of water stored and regulate the amount of water released. ("The Blue Green Roof – Helping Cities Cope with Stormwater," 2018)

Manual calibration of the model was a very tedious and long procedure. To arrive at a precise calibrated value, after every calibration run, the variation between the original discharge and simulated discharge values at the 06L95-06L98 links was noted. Then from the variation graph, the sub-catchments which had the highest impact on this variation in discharge were found. Then the values of imperviousness, slope and width values of only these sub-catchments were changed. For example, to adjust the outflow values of link 06L95-06L98, we change the parameters on sub-catchments 110,111,112,113 and 114. As these sub-catchments give a large contribution in terms of discharge to the link 06L95-06L98. Also, it was noticed that changing the imperviousness values had a larger impact on the calibration results compared to slope and width. Hence, it was concluded that imperviousness was a very sensitive parameter compared to the slope. As slope values were too small to significantly affect the calibration results. Finally, this study would suggest finding a way of automatic calibration utilizing new software and programming which can save a lot of time and effort while also increasing accuracy.

With increasing population and urbanization, the load on the existing sewer network will go on increasing to a point where it will no longer be able to hold the increased water quantity and may result in flooding at nodes. This might also lead to increased load at wastewater treatment plants as a plant can only treat a given amount of water at a time. The best solution to this growing problem is the Decentralized management of water with the help of LIDs. This study shows that the establishment of LIDs leads to a considerable decrease in flooding by reducing the total amount of water produced by each catchment individually. LIDs increase the overall pervious area in the catchment leading to more groundwater infiltration and less stormwater discharge to sewers. The three different scenarios discussed in this study show how effectively short-term and short & long-term combined LIDs can reduce the total floodwater generated. In comparison to a catchment with no LIDs, it was found that the same catchment with short-term LIDs can reduce total flooding by 37% while the combined system of LIDs can reduce it to 70%. Also, we see the efficiency of the existing sewer system in successfully accommodating the extra wastewater (of 135 LPS at node 06L51) generated from the new development.

The system receives a sewer flooding in august 2002 during the second highest precipitation (the first one was an outlier) between 1995 to 2015. Surprisingly, this flooding is observed at only a single node at 06M41 for five minutes at 04:40 in the morning. As none of the other nodes was flooded during this entire year of 2002, this node (06M41) becomes a critical node in our study report. The reason why only this node is flooded might depend on the topography as already discussed in this study. Also, the flooding shouldn't relate to the effectiveness of LIDs, since flooding was already observed in the current system without any LIDs. Hence, the LIDs were not able to completely prevent the flooding of the given node but were able to reduce the flood discharge by 70%. However, this study doesn't focus on the reasons for flooding but on the fact that how this flooding can be effectively reduced. So, finally, we can say that the LIDs measures are very helpful in reducing the total amount of stormwater generated by the system. Also, the economic, socio-economic, and political consequences, in addition to environmental benefits need to be considered while implementing LIDs in the real world.

**Commented [aa3]:** Add a paragraph discussing about calibration and validation

# 5 Conclusions

The main purpose of this study was to see the effectiveness of LIDs in decentralized stormwater management in the Räcknitz district. The effects of LIDs in the short-term, and short-term plus long-term were discussed along with their effects. LIDs implementation has shown to be a more effective method of reducing flooding and runoff compared to any other available methods. The fact that it is also environmentally friendly is one of its added benefits. The municipality in various cities could use the findings of this study to control flooding and improve water availability by increasing recharge into the aquifer. Moreover, it's possible to say that in most cases, there isn't just one right technique or most appropriate method that can be used to implement LIDs. Instead, the integration of several methods that approach the issue from various angles will result in the best-fitting and most relevant outcome.

Additionally, If there is a requirement of replacing a certain impervious area with a pervious area for the construction of a given LID, then it should be done in such a way that the efficiency and the effectiveness of infiltration increases in the given area. For example, replacing the sealed surface of the car park with pervious blocks has to be done after changing the subsoil to some other type of soil which has more water retention and bearing capacity with a large void ratio. This can be done by performing research on several types of soils which are available in the given locality. Hence, now the soil might easily bear the weight of the vehicles as well as it could also retain water which is being infiltrated through pervious pavement during rainfall, increasing the efficiency of LID. Another suggestion would be to loosen the soil in the backyards of the houses so that it helps to increase the infiltration by increasing the porosity of the pervious layer. This can be done using the deep tillage method which can increase the void ratio of the soil significantly.

The slope, imperviousness, and width values of sub-catchments in urban areas are important parameters that have a significant impact on the hydrological response of the area. These parameters influence the runoff generation and transport processes, as well as the performance of stormwater management practices. Moreover, A steeper slope leads to faster and more concentrated runoff, which can increase the risk of flooding and erosion. Similarly, a higher imperviousness level reduces the infiltration capacity of the soil, increasing the volume and velocity of runoff. These factors can be mitigated through the use of green infrastructure and low-impact development practices, which are designed to reduce the runoff volume and improve water quality. The width of sub-catchments also plays a role in the hydrological response of the area. Narrow sub-catchments may experience higher velocities of runoff due to the limited surface area available for infiltration, while wider sub-catchments may experience longer detention times and greater potential for infiltration. Overall, considering the slope, imperviousness, and width values of sub-catchments is essential in urban stormwater management planning and design.

The main problems with LID implementation can be that its importance might not be recognized by the general public and they would not want to give any part of their land for the construction of LIDs. Also, there might be conflicts with people if they would want a different LID to be installed at their property which might not be the optimum LID for that particular sub-catchment. The solution to this problem can be given by making people aware of the increasing problems of urban water management due to the increasing rate of urbanization. They should be made aware of the benefits of LIDs in decentralized stormwater management. The government could also provide some awards or benefits if people adopt LIDs in their surroundings.

# 6 Acknowledgement

We would like to express our sincere gratitude to Professor **Peter Krebs**, **Julian David Reyes Silva** and **Bjorn Helm** for introducing us to the EPA SWMM software and providing us with an opportunity to apply it in a real-world project. Your guidance and expertise have been invaluable in enhancing our understanding and practical skills in the field of water resources engineering. Your dedication and enthusiasm for teaching have been evident throughout the course, and we greatly appreciate the effort you have put into making the material accessible and engaging. The project you assigned, allowed us to work with the software and apply the concepts we learned in class to practical problems, which was an extremely valuable experience.

A big appreciation to the management team of EPA-SWMM for giving us the platform to carry out our project using the SWMM software without any limitations.

Once again, thank you for your exceptional teaching and mentorship. Your contributions have had a significant impact on our education and professional development, and we are truly grateful for your support.

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# 8 Appendix

## Appendix I: 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 |

## Appendix II: Recommended calibration values and their respective variation

| 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 |