TECHNISCHE UNIVERSITÄT DRESDEN

Module MHSE22

Urban Water II- Modelling of Wastewater Systems WiSe 2022/23

Project Report on

Evaluate the impact of decentralized rainwater management measures on the Räcknitz district (TUD Campus)

Submitted to:

Technische Universität Dresden

Faculty of Environmental Sciences

Submitted by:
Nandhini Suthesh
Priyadarsini Manikandan
Vibhu Batheja

Supervisors:
Julian David Reyes Silva
Peter Krebs
Björn Helm

Date of submission
Dresden - 15.03.2023

Abstract

The increasing frequency of rainfall events must be overlooked into having an up-to-date storm-water management system. Urbanization drives to follow decentralized measures and choosing low-impact development (LID) helps maintain the watershed functions close to intact.

Starting with analysing the existing sewer system of the Räcknitz district (Dresden), could be the base model to compare with additional changes. Looking into the future for new development area, the additional 3 ha to the existing 25 ha could cause failure of the sewer system making the decision of installing LIDs significant. Choosing LIDs over other measures makes it easier on the environment and the stakeholders by being cost-effective.

Calibrating with several rainfall events and validating against half its count makes the model a decent performing one besides the uncertainties. Long term LIDs and short-term LIDs, both provided a remarkable change in the water budget and the additional load from the new development area was handled with safe flow in the outlets.

The performance of the model is discussed with different scenarios. LIDs are highly preferred for installing in highly developed region, making it more feasible. One of the scenarios include planning LIDs in an undeveloped area which happens to be planned for expansion. Studying scenarios, were beneficial in identifying the influencing parameters for the performance of the sewer system and the new measures too. The influencing parameters came to be the characteristics of the sewers, conduits and the characteristic of each LID and their position accounting for the slope of the topography affects the how the run-off flows.

The overall picture of maintaining the water balance was the most influencing goal of this study, besides performance and feasibility.

Table of Contents

List of Figures

List of Tables

Introduction

Urbanization has been a global trend for several decades and is expected to continue in the years to come. According to the United Nations, the global urban population is expected to reach 68% by 2050, up from 55% in 2018 (World Urbanization Prospect UN 2018 n.d.). Rapid urbanization has resulted in fundamental changes in urban runoff processes due to rapid changes to underlying surfaces. Urban flooding is becoming more common because of these changes, which are heavily influenced by climate and land use change specifically an increase in impervious areas. Waterlogging in cities causes a slew of socioeconomic losses, including traffic disruption, property loss, and even human casualties (Luan et al. 2017).

The increased urbanization of the land cause increased stress on the existing sewer system, resulting in more frequent flooding events (Ghafghazi n.d.).

Even though the traditional, centralized approach to water service provides clean drinking water, sanitation, and protection from urban flooding with little apparent risk of failure, this approach may be failing to adequately address the complexities of urban water management, human liveability, and ecological health. Decentralized storm water planning integrated into spatial planning and urban design can reduce urban floods and enhance freshwater availability (Schuetze, 2013). In already developed areas, decentralized measures become possible with the help of experts and interested citizens. Rather than having run-off in the form of disorderly stagnant water, certain decentralized measures could encourage efficient evaporation. Some decentralized measures may also allow rainwater to infiltrate aquifers. Instead of water flowing into sewage for further treatment, improving the drainage system design can result in a well-balanced water budget.

Low impact development (LIDs) tools for storm water management have been introduced in recent years. They work close to the source. Even though not financially viable, these measures are increasing the water saving efficiency (Slys et al. 2020). Along with balancing the water budget, these measures help maintain and restore the hydrologic and ecological functions of the study area. Modelling is done using *SWMM* – Storm Water Management Model, in this study. The already provided three sensitive parameters such as width, imperviousness and slope are calibrated. After validating the parameters, a new development plan was added to the existing sewer network. Later, based on the characteristics of runoff and catchment behaviours, different LIDs are chosen for deployment in the model. These are further analysed for the impact on the water budget of the region. The permissible overflow is considered using the DWA A-118. On the existing catchment area, the impact upon adding a new development area (NDA) is evaluated as also the effects of LIDs. Both short-term LIDs and long-term LIDs are also separately analysed to understand their individual efficiencies.

1. Study area

The study area is located in Räcknitz district of the city Dresden shown in Figure 1. The area being studied has 19 sub-catchments and a total area of 25 ha. Considering one rainfall measuring device close to the catchment, the precipitation data recorded every 5 minutes is used for the modelling. The new development area which is to be added into the TU Dresden campus within this catchment has an area of 3 ha.

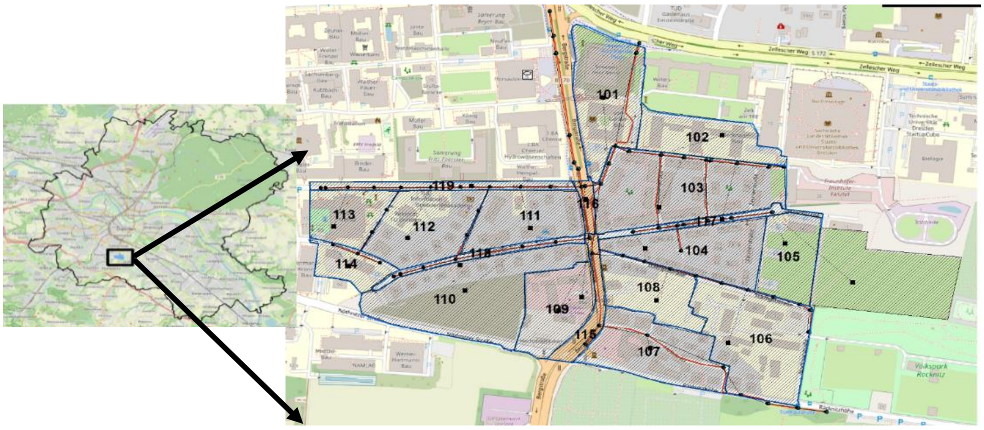

Figure 1 Räcknitz district catchment in Dresden, divided into sub-catchments as seen in SWMM model with a new development area.

2. Objectives

To evaluate the impact of decentralized rainwater management measures on the water budget of the Räcknitz district (Dresden),

1. Assess the current storm water management system's impact on the water budget.

2. Analyse the system's impact after accounting for the new development area.

3. Create and include two Low-Impact Development (LID) concepts, short-term and long-term, and analyse the impact on the water budget.

4. The impact of LIDs on a long-term simulation and its water budget.

3. Material and Methods

4.1 Modelling

The study employs the use of EPA's SWMM tool, which is a publicly available open-source software used globally for water runoff simulation. The tool is versatile and can be used for both short-term and long-term approaches to analyse water runoff quantity and quality in response to rainfall events. SWMM is not only useful in evaluating infrastructure and control strategies, but it can also help to mitigate the effects of water runoff on water bodies by manipulating the values of discharge, infiltration and retention. The study specifically uses the SWMM 5.2 version of the tool to carry out the analysis. The rainfall/runoff process model was used. The infiltration model, which aids in modelling rainfall infiltration into the upper soil zone of the sub-catchment, was set as ‘horton’. Dynamic wave routing was also used for the routing model. Without ponding, the minimum conduit slope was given as 1%. The modelling framework for SWMM is given in.

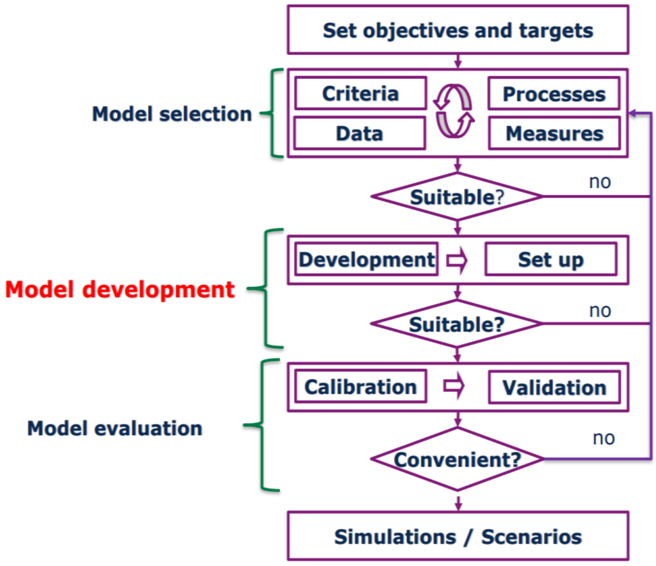

Figure 2 Modelling framework.

Model – Existing Data

Sewer Data

The SWMM model used in the study includes conduit and junction data, as well as the coordinates of the the above in the existing sewer system within the river catchment.
The data is modified in a text file before being added to the SWMM model via a SWMM input file, resulting in a highly accurate schematic representation of the sewer system within the SWMM model. The study can more accurately simulate the behaviour of the sewer system in response to rainfall events by integrating this data, allowing for more precise analysis and evaluation of the system's performance. The conduit and junction data entered can be viewed at ANNNEX III.

Dry Weather Flow

The dry weather flow (DWF) in this study refers to the domestic wastewater generated by the residents of the study area. Assuming no groundwater intrusion and no industrial effluent influencing dry weather flow, ($Qs = Q_{dom}$). Furthermore, the return ratio is assumed to be one, implying that all produced wastewater is returned to the sewer system. The hourly dry weather flow data used in the study is divided into two patterns: weekdays and weekends. The Water consumption data entered into the model can be seen in Annex III-B: Water consumption data and dry weather flow pattern data entered can be seen at Annex III-C: Dry Weather Flow Pattern Data.

Sub-catchment delineation

To define an urban sub-catchment, one approach is to assume that it corresponds to a cadastral unit. Hence the catchment area is subdivided as 19 sub-catchments, each exhibiting distinct shapes and characteristics that influence the discharge. The primary factors that impact the discharge are the width, slope, and imperviousness of the sub-catchments. While this study has neglected certain influencing factors like depression storage and surface roughness co-efficient, it has determined the imperviousness of the area using land-use. The land-uses considered in the study include impervious features such as street areas, flat roofs areas, and sidewalks, as well as permeable features like yard areas, green areas, gable roofs areas, and other miscellaneous areas. Model assumptions for sub-catchment delineation and development are listed in Annex III-A: Sub catchment Delineation Data .

4.2 Calibration & Validation

Calibration

The main goal of calibrating the *SWMM* model, is to increase the credibility of the model in such a way that near real life scenarios can be simulated which can finally aid in suggesting appropriate measures for different rainfall intensity scenarios.

To calibrate the above mentioned SWMM model, 6 different rain events were selected two of low, medium and high return period each respectively. The rainfall return period was calculated using Equation 1 and the Rainfall intensity was calculated using Equation 2.

$$z = \left(\frac{r_{\mathrm{tN}(z)}}{r_{15(1)}} \cdot \frac{t_N + 9(min)}{38(min)} + 0.369 \right)^4$$

Equation 1

$$r_{t_R,z} = r_{15(1)} \frac{38(min)}{t_R + 9(min)} \left(z^{1/4} - 0.369\right)$$

Equation 2

Where z is rainfall return period in years, $r_{\mathrm{tN}(z)}$ is the Rainfall intensity, $r_{15(1)}$ is taken as 102 L/s*Ha for Dresden and t_N is the duration of rainfall in minutes.

After selecting representative events, different sub catchment parameters such as slope, imperviousness and width were varied through a pre-specified range of values shown in Annex II-A: Calibration Sub catchment wise Ranges.

The main goal of varying these parameters was to make the observed flow values for Nodes *06L95-06L98* and *06M5-06M4* to be as close as possible to the flow values simulated through the SWMM model. The parameters chosen to quantify the accuracy of calibration process were Nash-Sutcliffe Efficiency (*NSE*) calculated using Equation 3 and Peak Flow Error (*PFE*) calculated by Equation 4.

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - \text{mean}\ (Y^{obs})\right)^2}$$

Equation 3

$$PFE = \left| \frac{\left(max\left(Y^{sim}\right) - max(Y^{obs}\right)}{max(Y^{obs})} \right|$$

Equation 4

The manipulation of different parameters for different sub-catchments was done using the *SWMM API* (Pichler, 2022) Python Library, which has the capability to modifying the *SWMM* input file, running a simulation of the modified input file and finally reading the output *SWMM* file. Using these capabilities, a semi-automatic calibration was followed, wherein a code was developed (Batheja et al., 2023) to manipulate the Sub catchment parameters from a *CSV* file using a loop and save the best combination of calibrated parameters by passing the data through a function that calculates NSE and PFE based on previously entered data of observed flow values for the nodes *06L95-06L98* and *06M5-06M4*. Finally, at the end of the loop, the combination with best NSE and PFE is stored and written to the input file.

Validation

To validate the average values of slope width and imperviousness of all 6 cases for each of the 19 sub-catchments were taken. Finally, the validated model was run for three dates, each representing a low, medium, and high return period, and the following NSE and PFE was calculated for nodes to test the model's validity in various circumstances, the Python library *SWMM-API* (Pichler, 2022) was used in this whole process to read and average all the Sub catchment values and further on NSE and PFE were also calculated using a script developed (Batheja et al., 2023) where libraries such as NumPy (Numpy, 2021) were used.

Typically, a good representative model is one which has a NSE value close to one & PFE value close to zero. Getting a good NSE and PFE score for all diverse rainfall intensities while validating indicates signs of a well calibrated model.

4.3 New development Area (NDA)

As an extension of the university campus, the open space east of the seminar buildings Zeunerstraße and south of the Volkspark Räcknitz was added to the existing sewer network. This 3-ha large plot consists of 6000 m^2 of the area allotted towards building development and 2500 m^2 of area for roads, sidewalks and parking spaces. The whole area was labelled as 'Sub Catchment 120', properties such as width and imperviousness was calculated and found out to be 128.3m and 28.3% respectively, Slope was assumed to be 9.4%.

Dry weather flows for the given catchment were calculated for a value of 100 population equivalent, which accounts for 90percapita(*Pro-Kopf-Verbrauch von Wasser in Deutschland Nach Bundesland 2016,* n.d.). The outflow from the sub-catchment was given to the nearest junction downstream so that any additional pumping or regulatory valves can be avoided. Later the behaviour of the sewer network due to the addition of the sub-catchment was studied by comparing the loading of the sewer network between the base model and the model with the new development area. A high-intensity event '21.07.1998' is chosen for further analysis. Having the return period is lesser than the return period (10 years, DWA-A-118) of permissible overflow frequency.

Low-impact development (LID) practices

In this study, we design the hydraulic restoration of the area using LID systems and green infrastructures, specifically to control flooding by increasing water infiltration and implementing water detention, retention, and storage. Furthermore, the LIDs implementations have been chosen specifically for the area to achieve optimal interoperability with the surrounding environment. The LID suitability was identified by calculating the ratio of area imperviousness to area infiltration (A_{imp}/A_{inf}). Table 1 shows the following.

A_{imp}/A_{inf}	measures
<= 5	areal infiltration
> 5 & <= 15	trench infiltration, retention cell
> 15	retention cell w. underdrain, infiltration tank, infiltration well, retention tank

Table 1LID Potential

The various LIDs that are proposed in this study are;

Bio-retention Cells are excavations that contain vegetation grown in a designed soil mixture placed above a gravel drainage layer. They offer storage, infiltration, and evaporation of both rainfall and runoff that is captured from the surrounding areas.

Rain Gardens are a variant of bio-retention cells that consist only of the designed soil layer without a gravel layer beneath it.

Green Roofs are another type of bio-retention cell with a soil layer placed on a specialized drainage mat material that carries excess percolated rainfall away from the roof.

Infiltration Trenches are slim ditches filled with gravel that intercept runoff from impermeable areas upslope. They provide space for storage and give extra time for the captured runoff to soak into the natural soil beneath.

Continuous Permeable Pavement systems are excavated areas filled with gravel and surfaced with a porous concrete or asphalt mixture.

Retention tanks are containers that accumulate roof runoff during storms and can discharge or reuse the rainwater during dry periods.

Vegetative Swales are channels or depressions with sloping sides covered with grass and other plants. They slow down the flow of collected runoff and provide more time for it to soak into the natural soil below. Figure 3 shows the typical image of few LID practices. Refer appendix for calculations of each LIDs.

Figure 3 a) Green roof b) Infiltration trench c) Rain garden (Source a) ZinCo. (2022.)., b) SUDs Wales. (2023) c) Earthwatch. (n.d.)

5 Results & Discussions

5.1 Calibration

Table 2 shows average NSE and PFE values obtained for both the nodes *06L95-06L98* and *06M5-06M4* after the calibration process is completed, the values are shown for the corresponding dates.

Date	Return Period (years)	NSE	PFE
18-07-1997	5.807	0.991	0.0292
30-11-2002	4.285	0.92	0.0248
30-05-2014	0.433	0.967	0.0236
22-08-2005	0.478	0.972	0.0201
12-09-2004	1.21	0.99	0.0411
25-07-1997	2.0583	0.9841	0.0087

Table 2 NSE & PFE Values for Calibrated Dates

5.2 Validation

The average values taken for different sub catchment for the validation process are shown in Annex II-B: Validation Model Sub catchment wise Values , Table 3 shows the different dates chosen for validation, their return periods, and the average NSE and PFE value for nodes *06L95-06L98* and *06M5-06M4*.

Date	**15/04/2000**	**10/10/2013**	**16/06/2007**
Return Period (y)	0.915	1.45	2.74
NSE	0.967	0.933	0.992
PFE	0.00764	0.0088	0.0387

Table 3 Model Validation

5.3 Impact of New Development Area

The model showed flooding in nodes even before the new development area, but for few minutes which can be neglected. The count of the flooded nodes and conduits as well as the intensity of flooding has increased after the addition of New Development Area, which can be seen from Figure 4, where more number of yellow and red nodes as well as conduits can be seen that represent higher flow and capacity of water flowing through them. Therefore, showing that the system with NDA has higher loading on the sewer system.

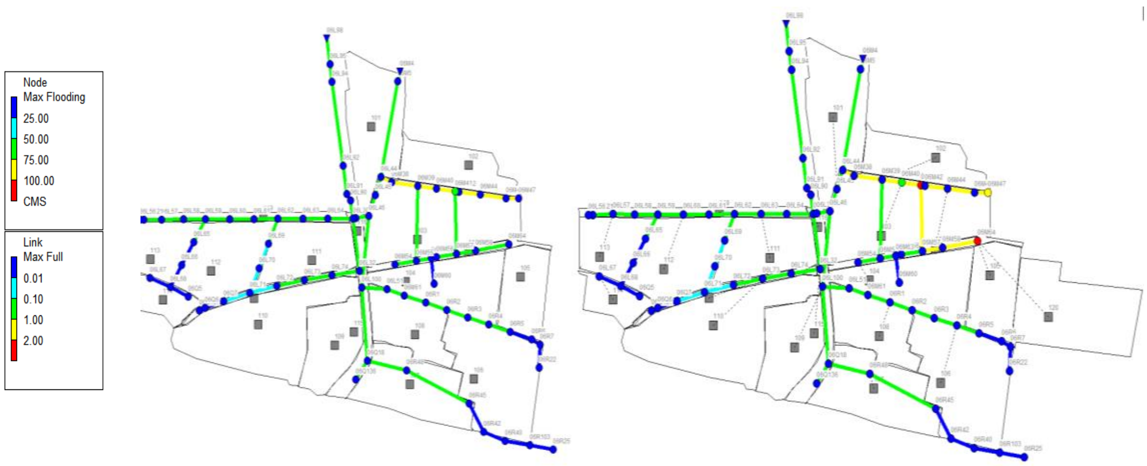

Figure 4 Difference in models before (left) and after (right) adding NDA

Before the addition of the NDA only two nodes *06M41* and *06M47* were flooding after the NDA was introduced observed in seven nodes, Figure 5, compares the flooding in different nodes before and after addition of NDA, 50% increase in flooded volume can be observed in node *06M47*. A 21% increase in outfall is seen in node *06M4* is seen after because of this. The conduits have similar effects to the nodes.

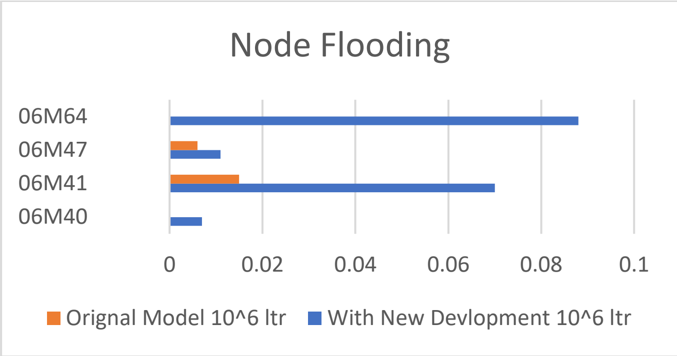

Figure 5 Node flooding comparison with and without NDA

The run-off of the entire system increased after NDA was introduced can be seen by Figure 6, the probable reason for this can be the extra loading on the overall sewer network, which leads to an increased surface runoff.

The need to address the increased capacity of sewer network is crucial as this node would result in the bursting of pipes and eventually the failure of the system. Especially in Sub catchment 102,103,104,105 and 120 since most of the nodes close to these are flooding and appropriate measures need to be implemented in the following to reduce the overflow into the system.

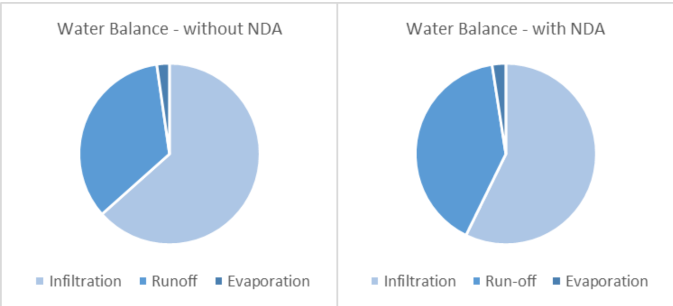

Figure 6 Water Balance of the model

5.4 Implementation of LIDs

Based on the LID potential calculations () and results from () the sub-catchments 102, 103, 104, 105 & 120 are considered for implementing LIDs considering the elevated flooding caused by the addition of the new development area. Table 4 shows LID potential calculated along with recommended LIDs for each sub-catchment.

Sub catchment	LID Potential	Long-Term LIDs	Short-Term LIDs	Mixed LIDs
102	0.54	Green Roof	Rain Garden	Green Roof
103	0.81	Retention Tank, Bio Retention Cell, Pervious Pavement	Rain Garden, Bio Retention Cell w/o underdrain	Retention Tank
104	0.46	Retention Tank, Bio Retention Cell, Pervious Pavement	Vegetative Swale, Bio Retention Cell w/o underdrain	Retention Tank

105	0.25	Pervious Pavement	Vegetative Swale, Infiltration Trench	Pervious Pavement
120	0.39	Pervious Pavement, Green Roof	Rain Garden	Rain Garden

Table 4 LID Potential and Scenario Summary

Long Term LID

The Figure 7 shows the proposed long-term LIDs in the sub catchments.

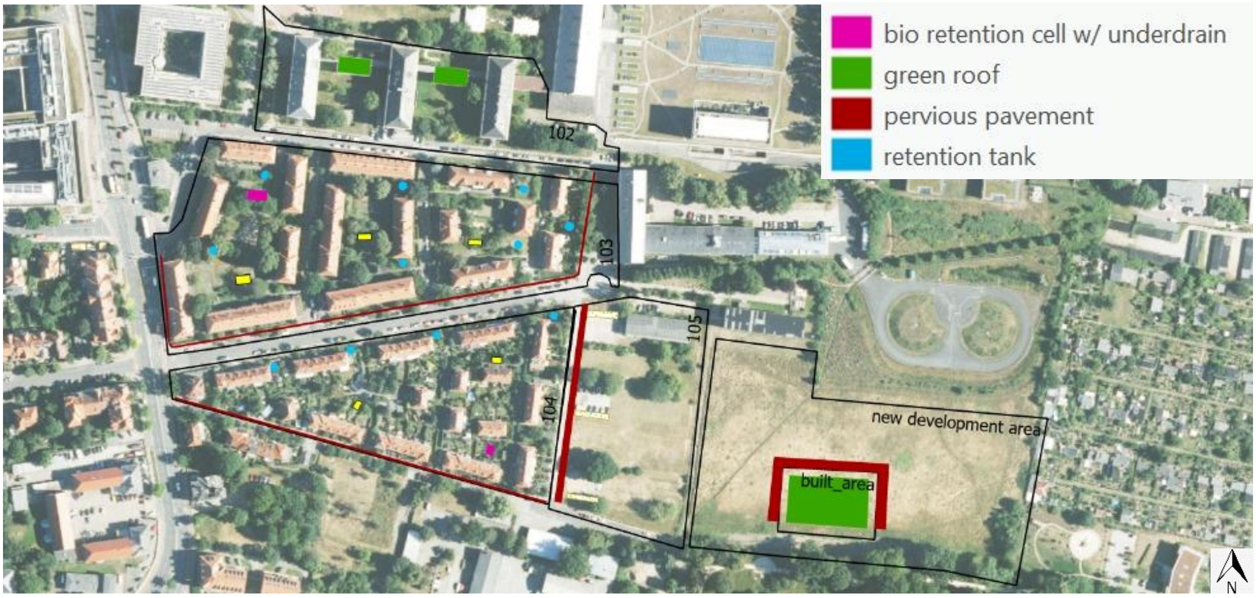

Figure 7 Proposed long-term LIDs.

The **sub-catchment 102** which comes under the TU Dresden consists of yards, parking, and the building Recknagelbau. The 1.22 ha area has 30.76% of impervious area (0.38 ha) consisting of 0.08 ha of a flat roof (6.26% of total area) planned for the green roofs.

The **sub-catchment 103** between the Haeckelstrasse and Zeunerstrasse has a total area of 2.88 ha with an impervious area of 1.26 ha and a pervious area (yard & green areas) of 1.55 ha. This gives ample space to implement retention tanks bio-retention cells and hence suggested reducing the instant runoff of the storm water to the outflows.

The designed 50 m^2 bio-retention cell treats 13% of the impervious area and the drain outflow is connected to node *06M54*.

The retention tanks are placed in the yard areas to optimally collect runoff from the gable rooftops and the adjacent impervious areas. Four retention tanks of 31m2 and a tank of 33m^2 are proposed, treating 33% of the impervious area altogether.

Pervious pavements of 600m^2 area are proposed in the walkways around the sub-catchment.

All the buildings in the sub-catchment have gable roofing. Even though green roofs can be implemented, considering the design difficulties and cost it is not suggested.

The **sub-catchment 104** with a total area of 1.66 ha is located between Zeunerstrasse and Stadtgutstrasse. Gable roofed buildings mostly constitute 0.52 ha of impervious area. The suitable long-term measures that can be implemented in the sub-catchment are retention tanks, bio-retention cells, and pervious pavements, considering the areas has mostly green areas (1.13ha).

Four retention tanks proposed treat 38% of the available impervious areas, including run-offs from the gable roofs. Two units of 31 m^2 bio-retention cells with underdrain are proposed in the open areas, which will treat 13% of the impervious areas. Pervious pavements of 600 m^2 around the sidewalk are proposed which can infiltrate the direct run-offs.

The **sub-catchment 105** located behind the sub-catchment 104 has 3 small parking lots and an office building. The total area of the sub-catchment is 1.13ha out of which 80% constitute the green areas (0.91ha). This area has a large scope for new developments hence the LIDs proposed are minimal. Considering the slope of the sub-catchment, pervious pavement of 1700 m^2 is suggested near the parking area where most of the run-off can be collected.

The **sub-catchment 120** is located to the east of sub-catchment 105, which is the new development area. This area is mostly open spaces hence larger development potential. Thus, minimal LIDs are proposed with maximum efficiency to capture the runoff generated. The sub-catchment area is 3ha, which has 0.85 ha of impervious area (proposed building and traffic area). 600m^2 of green roofs and 300m^2 of pervious pavement are proposed for this area.

Short Term LID

Figure 8 Proposed short-term LIDs

The proposed short-term LIDs for the sub-catchments are shown in

Figure 8. For the **sub-catchment 102** two units of 250 m^2 rain gardens are proposed in the available open area. It will give aesthetics also entrap the runoff from the gabled roof buildings and improve infiltration.

The **sub-catchment 103** has a rain garden and bio-retention cells without underdrains proposed. Rain gardens of 300 m^2 can be implemented in the open spaces around the main buildings. Also, a bio-retention cell of 15 m^2 was proposed in the yard areas. These are without underdrains and can help percolate the captured runoff thereby reducing the overall outflow from the sub-catchment.

Vegetative swale and bio-retention cells are proposed for the **sub-catchment 104,** considering the space availability and efficiency. The sub-catchment has no future development possibility hence the yard areas proposed with 100 m^2 of bio-retention cells and 1200 m^2 of the vegetative swale. These measures will help reduce the flow velocity of the storm water and reduce overall runoff from the sub-catchment.

The **sub-catchment 105** which has parking spaces three units of infiltration trenches with 210 m^2 is proposed. Also, a vegetative swale of 450 m^2 is proposed at the eastern end of the sub-catchment to reduce runoff from the nearby open areas. Sub-catchment 105 has a more open area, which shows the possibility for future development. Hence the LIDs are proposed in such a way that, they do not interfere with any immediate expansions in the area.

The short-term LIDs put forward for the **Sub-catchment 120** are vegetative swales and rain gardens. The area is mostly unoccupied and with huge development possibilities. Hence these measures are preferred which are comparatively cheaper to implement and can be taken off with minimal loss. A vegetative swale of 995m^2 and rain garden of 1200 m^2 are suggested.

Mixed LID

Figure 9 Proposed Mixed LIDs

To benefit from the strength of both approaches a combination of long-term and short-term LIDs was tried in the modelling. This resulted in creating a more effective and efficient model, as well as improved storm water management. Green roofs, retention tanks, pervious pavement, and a rain garden are included in this proposed model, the LIDs implemented in this scenario can be seen in the Figure 9.

LID Scenario Comparison

A detailed overview of the data obtained from the different LID scenarios implemented in the study area is done to see the effectiveness of each of the scenario in the sewer network, comparing it to the original model (Model with NDA and no LIDs implemented).

Figure 10 shows the Average Outfall flow and the Total volume through the Outfalls *06L98* and *06M4,* as it can be seen there is a visible decrease in loading of the *06M4* outfall after the implementation of LIDs, the total flow volume and average flow decrease by 14.8% and 15.2% respectively in *06M4* after the implementation of long-term LIDs, Overall there is an average decrease of 4.3% and 4.9% in the average flow after implementation of short term and mixed LIDs respectively.

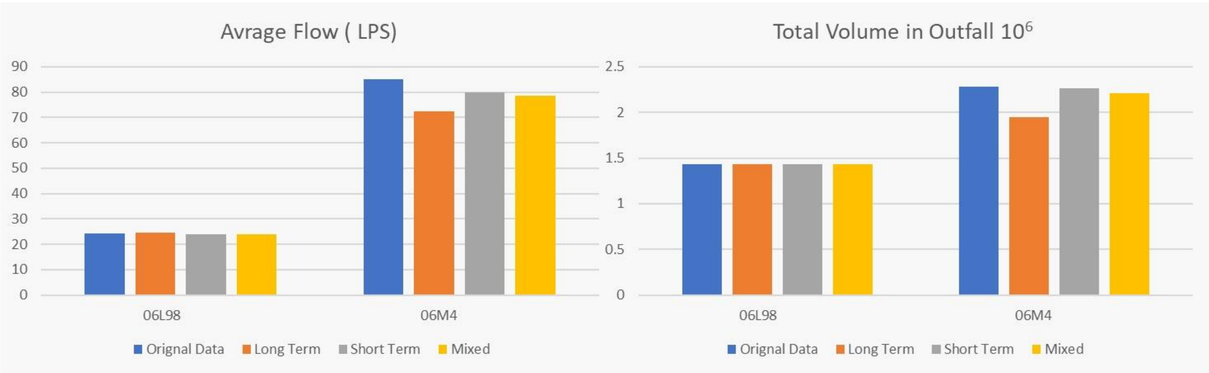

Figure 10 Outfall flow and total volume in different LID scenarios

In the original model flooding was observed at 8 different nodes throughout the sewer network, after implementing LIDs there are no occurrences of flooding in *06M39, 06M40, 06M46* and *06M47*. In case of short-term LID's there has also been a total reduction in flooding in *06M64* as shown by Figure 11 while long term and mixed LID measures reduce the flooding in 06M64 by 97.29%.

From, the overall the Flood duration has been reduced by almost 60.7% on average in case of long-term LIDs, 53.2% and 51.2% in case of short term and mixed LIDs respectively.

In case of maximum flow rate in node *06M42* there an increase in the flow rate has been observed in case of both short term and mixed LIDs while the duration of the flooding and total flooding volume is decreasing this could be due to implementation of LIDs such as infiltration trenches and permeable pavement which create pathways for water to flow more quickly downstream. Overall, the maximum flow rate in the nodes *06M41, 06M42, 06M47* and *06M64* has decreased by 59.26%, 32.67% and 29.82% on average in long term, short term and mixed LID implementation respectively which can be seen from Figure 11.

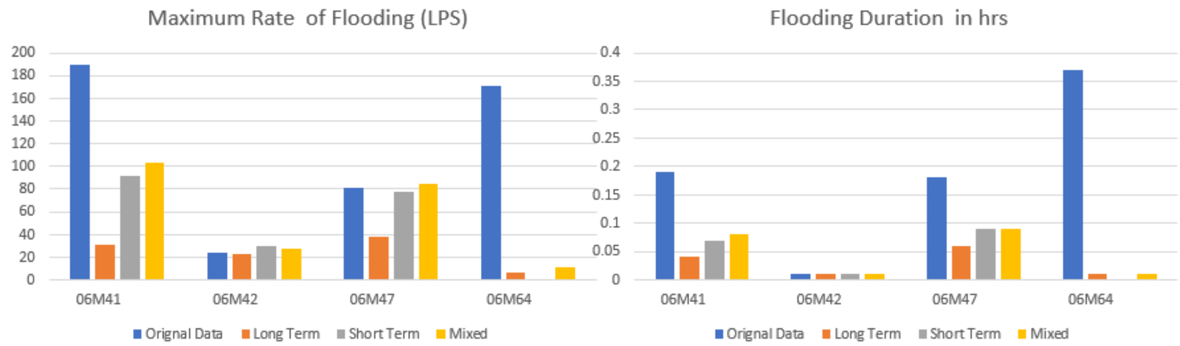

Figure 11Maximum Flooding rate and Flooding duration in different LID scenarios

The total volume flooded in *06M41, 06M42, 06M47* and *06M64* has decreased by 60.72%, 53.28% and 29.82% in long term, short term, and mixed LID implementation respectively.

The node *06M64*, is the outlet for water for two different sub catchments therefore there is an excess loading on it which increases the possibility of it getting flooded and the subsequent downstream nodes getting flooded. Figure 12 shows the water elevation profile between the node *06M64* and *06M47* for the original scenario, as it can be seen the nodes *06M57*and *06M58* are not flooding due to the presence of gradient which pushes the water downstream. Figure 13 shows the node depth of the nodes in the area of focus after the implementation of LIDs.

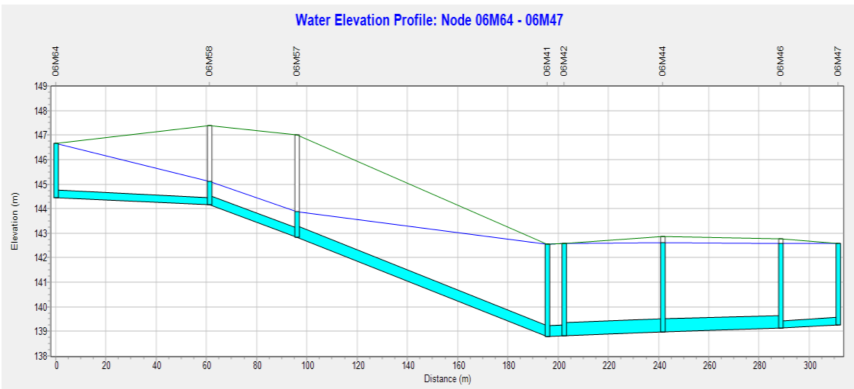

Figure 12 Water Elevation Profile between Node 06M64-06M47

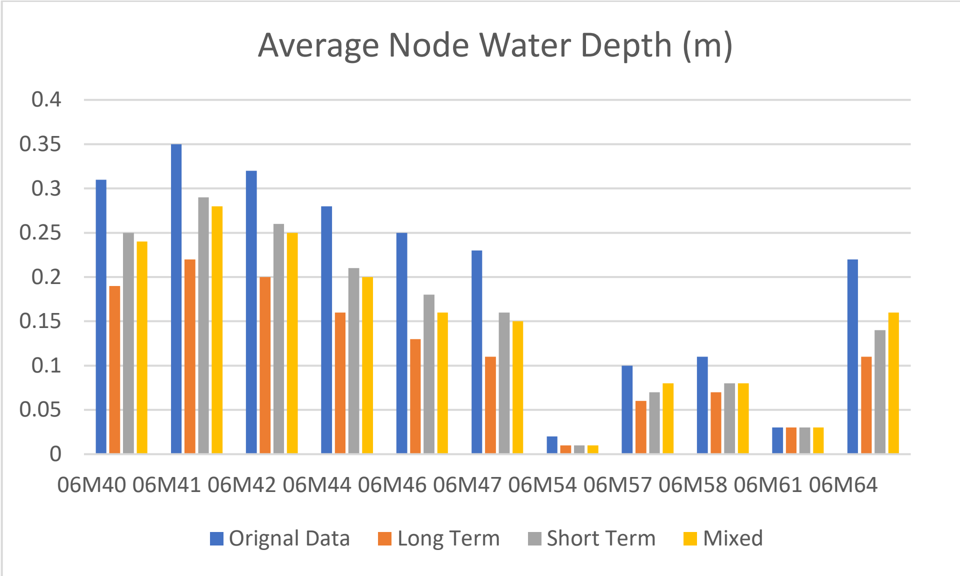

Figure 13 Average Node Water Depth in different LID scenarios

In case of Long-Term LID scenario an average of 40% decrease in Node depth has been as seen, displayed by Figure 13 throughout the catchment, specifically for the node *06M47*, *06M46* a decrease in depth by 52%, 48% respectively has been seen, this can be accounted to the implementation of LIDs such as retention tanks and permeable pavements in the sub catchment 103 and green roofs in sub catchment 102. The nodes *06M64* and *06M54* which are outlet nodes for sub catchments 105,120 and 104 respectively see a decrease in water depth by 50%, therefore the LIDs such as pavements, retention tanks and bio retention cells in these sub catchments help in retaining water and thereby decreasing load on the sewer network.

Typically providing underdrains is not feasible as the whole concept. Involving extreme excavation is always a tedious process. The stored water, especially in tanks could be reused with minimal treatment. Just like green roofs, vertical façades around the building exploits the surface area efficiently increasing the evaporation, as a whole benefitting the water balance. Roofs with increase storage volume and capillary system increases (Cirkel et al. 2018) the evaporation rate even with *Sedum* cover, which holds lesser moisture.

From Figure 13 can be seen that there is an average decrease in node depth by 25.6% in case of application of short-term LID, a reduction of 36% in the depth of the node *06M64* can be seen, this can be mainly attributed to the implementation of rain garden in sub catchment 120 which totally eliminated flooding from *06M64* post implementation. Not only did the addition of rain garden have impact on the flooding and node water depth in the nodes close to sub catchment 120, but there was also an overall less load on the system after implementing the raingarden there was a decrease in total volume of flooding in the system by 78%.

In case of the Mixed scenario there is an average decrease in water depth by 26.2% throughout the sewer network, although this number might seem less but having a look at the minimal number of LIDs selected for this scenario the performance of the LIDs is quite optimal.

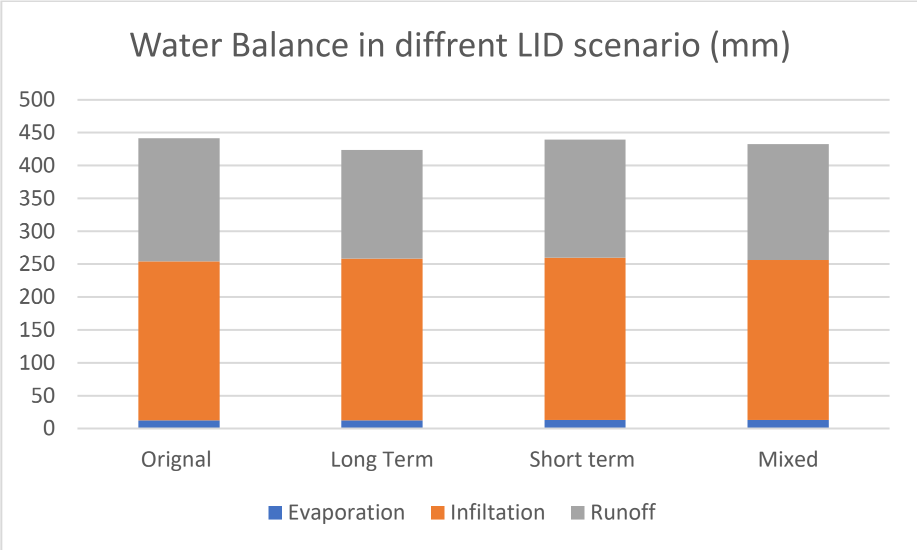

Figure 14 Water Balance of Study area in different LID scenarios

From Figure 14, there is an increase in evaporation and infiltration, in all the scenarios as compared to the original scenario and a decrease in the runoff as compared to the original scenario. This can be accounted to the entrapping of water by the LIDs such as permeable pavement and rain gardens which create pathways for water to enter the ground, while LIDs such as vegetative swale help slow down the movement of water thereby decreasing the movement of water and runoff subsequently, lastly Long term LIDs such as retention tanks and bio retention cells reduce the runoff by collecting the water for reuse, in overall there. In overall the runoff has decreased by 37% on average by implementing long term LIDs and 6.25%, 3.65% on average after implementing short term and mixed LIDs respectively.

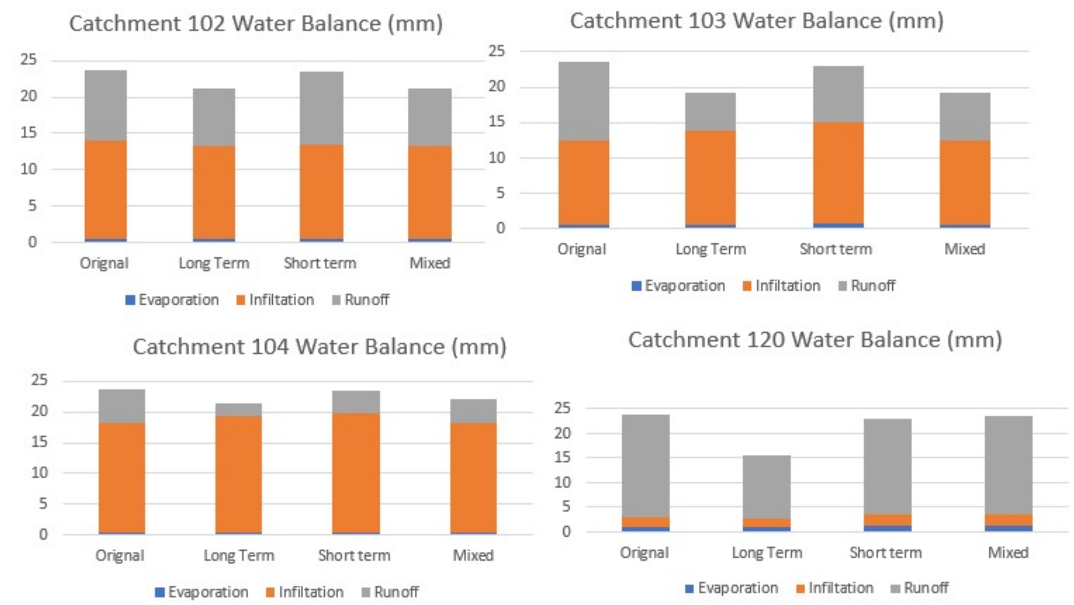

Figure 15 Catchment wise water Balance for diffrent LID scenarios

From Figure 15 in case of catchment 102 there is an increase in evapotranspiration by almost 2% in all the scenarios as compared to the original scenario this can be attributed to the fact that in all the LID scenarios in 102 green solutions were adapted which meant that more number of plants thereby an overall increase in evapotranspiration (Ahn,K et al., 2019), similar pattern is seen in catchment 120 where evapotranspiration has increased by almost 15% in case of both short term and mixed scenario since a large rain garden has been implemented. The precipitation is stored in the green roof which are then available for evapotranspiration after the event. When the height of the substrate layer increases, so does the retention capacity of the green roofs. (Kaiser et al. 2019) With a thick substrate layer comes the relevant capillary system which increases the head to facilitate evaporation rate for a longer duration.

Choosing grasses and herbs, for green LIDs the evaporation rates are longer making precipitation storage stay for long duration in dry periods. Sustainable practices could be overlooked for more advantages, where such green roofs and façade plantings gives adiabatic cooling effect reducing the energy consumption. (Sieker, n.d.)

Overall, it can be observed that evapotranspiration increases by 3% on average throughout the study area in case of short-term LID scenario.

Seeing the infiltration trends there is an significant average increase in infiltration in the study area by 16.25% and 21.3% in case of short term and mixed LID scenarios respectively, while in case of long term LID scenario an increase in 0.86% is seen, this low increase can be accounted to the implementation of LIDs such as green roofs, retention tanks and bio retention cells which retain the water for a certain period of time.

Conclusion

This study evaluates the impact of decentralized rainwater management measures on the water budget of the Räcknitz district in Dresden. The analysis begins by assessing the current stormwater management system's impact on the water budget and then evaluates its impact after accounting for the proposed development area. The results show that the new development area created stress in the sewer system, causing flooding at the outflow node 06M64. This highlights the need for proper planning to ensure that any future development in the sub-catchments does not negatively impact the technical, economic, environmental, and resilience performance of urban water systems (Pro-Kopf-Verbrauch von *Wasser in Deutschland Nach Bundesland 2016,* n.d.)).

The study finds that incorporating decentralized rainwater management measures, such as Low-Impact Developments (LIDs), can have a positive impact on the resilience of the existing network. Short-term LIDs, such as infiltration trenches and rain gardens, can effectively reduce stormwater runoff at the site, thus reducing stress in the sewer network during unforeseen rain events. Additionally, short-term LIDs provide numerous co-benefits, such as improved air quality, increased urban biodiversity, and higher property values, which can help to justify their cost.

However, the implementation of long-term LIDs is challenging due to various stakeholders involved, including regulations and policies, technical expertise, maintenance, and funding. Moreover, climate change can also have an adverse effect on the implementation, requiring adjustments and adaptations over time.

Overall, the measures carried out in this study promote infiltration featuring the living soil zone, aiming to achieve a balance ratio of sealed and unsealed surfaces. Real case scenarios require additional data to provide optimal measures to make LID implementation more feasible. These measures are sustainable and can improve the water budget while mitigating the impacts of urbanization on the environment without altering the existing sewage network

References

Schuetze, T. and Chelleri, L. (2013) "Integrating Decentralized Rainwater Management in Urban Planning and Design: Flood Resilient and Sustainable Water Management Using the Example of Coastal Cities in The Netherlands and Taiwan," Water, 5(2), pp. 593–616. Available at: https://doi.org/10.3390/w5020593.

Sieker. (n.d.). Concept of decentralized stormwater management. Sieker. Retrieved from https://www.sieker.de/en/fachinformationen/dealing-with-rainwater/article/concept-of-decentralized-stormwater-management-276.html

Słyś, D. and Stec, A. (2020) "Centralized or Decentralized Rainwater Harvesting Systems: A Case Study," Resources, 9(1), p. 5. Retrieved from: https://doi.org/10.3390/resources9010005.

Storm Water Management Model (SWMM) | US EPA (2023). Retrieved from: https://www.epa.gov/water-research/storm-water-management-model-swmm.

Urban Runoff: Low Impact Development | US EPA (2022). Retrieved from: https://www.epa.gov/nps/urban-runoff-low-impact-development.

Wu, W., Zhao, Y., Wang, R., Zhao, Y., Fu, G., Zhang, X., & Li, F. (2017). Exploring the Impact of Land Use Change on Runoff with Different Spatial Resolutions Using SWAT: A Case Study of the Wujiang River Basin in Guizhou Province, China. Water, 9(6), 439. doi:10.3390/w9060439

United Nations, Department of Economic and Social Affairs, Population Division. (2018). World Urbanization Prospects: The 2018 Revision, Key Facts. Retrieved March 15, 2023, from https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf

Elmahdi, A., Bakker, M., & Hartmann, T. (2018). Flood Risk Management in an Urban Area: Applying LID Techniques. Environmental Earth Sciences, 77(5), 191. doi:10.1007/s12665-018-7441-2

Lin, B., & Kao, J. J. (2002). Forecasting tourist arrivals using multiple regression and time series models: A case study of Taiwan. Tourism Management, 23(3), 247-256. doi:10.1016/s0261-5177(01)00096-8

(*Pro-Kopf-Verbrauch von Wasser in Deutschland Nach Bundesland 2016*, n.d.)

Juan-García, A., Alves, F., & Franco, J. (2017). The relevance of resilience in sustainable development. Journal of Cleaner Production, 165, 1395-1405. https://doi.org/10.1016/j.jclepro.2017.07.154

Cirkel, D. G., Voortman, B. R., Van Veen, T., & Bartholomeus, R. P. (2018). Evaporation from (Blue-)Green Roofs: Assessing the Benefits of a Storage and Capillary Irrigation System Based on Measurements and Modeling. Water, 10(9), 1253. https://doi.org/10.3390/w10091253

Kaiser, D., Köhler, M., Schmidt, M., & Wolff, F. (2019). Increasing Evapotranspiration on Extensive Green Roofs by Changing Substrate Depths, Construction, and Additional Irrigation. Buildings, 9(7), 173. https://doi.org/10.3390/buildings9070173

NumPy. (2021). NumPy: A fundamental package for scientific computing with Python. Retrieved from https://numpy.org/

Pichler, M. (2022). swmm_api: API for reading, manipulating and running SWMM-Projects with python (0.3). Zenodo. https://doi.org/10.5281/zenodo.7054804

Vibhu Batheja (2023). Urban Water II. Retrieved from https://github.com/vibhubatheja/Urban-Water-II

Zakrisson, A. (2022, November 18). Why Evapotranspiration and Retention Volumes are the Same on Green Roofs. Living Architecture Monitor. https://livingarchitecturemonitor.com/articles/evapotranspiration-retention-volumes-w21

Vibhu Batheja (2023). Urban Water II. Retrieved from https://github.com/vibhubatheja/Urban-Water-II

Appendix

Annex I

Design and Dimensioning of LIDs

Annex I-A: Green Roof – Dimensioning

Referring to,

1. DWA-A-102
2. FLL Dachbegrünung,

these green roofs are designed. The following values are populated into the LID control panels in the SWMM model.

Section	Parameter	*Value*
Surface	Berm Height (mm)	*40*
	Vegetation Volume Fraction	*0.3*
	Surface Roughness (Mannings n)	*0.3*
	Surface Slope (%)	*5*
Storage	Thickness (mm)	*200*
	Porosity (volume fraction)	*0.4*
	Field Capacity (volume fraction)	*0.3*
	Wilting Point (volume fraction)	*0.05*
	Conductivity (mm/hr)	*180*
	Conductivity Slope	*30*
	Suction Head (mm)	*50*
Drainage	Thickness (mm)	*50*
	Void Fraction	*0.7*
	Roughness (Mannings n)	*0.1*

Table 5 Green Roof – Dimensioning

Table 7 Parameters in LID control editor for green roofs

Annex I-B: Pervious Pavement – Dimensioning

Referring to,

Urban water modelling lectures (TU Dresden 2023),

these pavements are designed. The following values are populated into the LID control panels in the SWMM model.

Section	Parameter	*Value*
Surface	Berm Height (mm)	*20*
	Vegetation Volume Fraction	*0.07*
	Surface Roughness (Manning n)	*0.05*
	Slope (%)	*0*
Pavement	Thickness (mm)	*60*
	Void ratio (voids/solids)	*0.2*
	Impervious Surface Fraction	*0.4*
	Hydraulic conductivity (mm/hr)	*100*
	Clogging Factor	*0*

Storage	Thickness (mm)	*200*
	Void ratio (Voids/Solids)	*0.25*
	Seepage Rate (mm/hr)	*80*
	Clogging Factor	*0*
Drainage	No drainage	*/*
	Flow Coefficient	*0*
	Flow Exponent	*0.5*
	Offset (mm)	*6*
	Open Level (mm)	*0*
	Closed Level (mm)	*0*

Table 6 Pervious Pavement – Dimensioning

Annex I-C: Retention Tank – Dimensioning

Referring to,

DWA-A-117,

these tanks are designed. The following values are populated into the LID control panels in the SWMM model.

Having the 21.07.1998 rainfall event into this LID designing, this event has rainfall return period under the limitation of use.

The retention volume for the focus sub-catchments are calculated through the equation,

$$V_{ret} = (V_{in} - V_{out}) \cdot Z \cdot f_A$$

As per DWA-A-117.

Using this volume, the area and depth are separately dimensioned for the number of tanks planned in the study.

Sub-catchment	**Impervious area(m^2)**	**V_{in} (m^3)**	**V_{out} (m^3)**	**Q_{thr} ($Ls^{-1}ha^{-1}$)**	**f_Z**	**f_A**	**V_{ret} (m^3)**	**No. of tank**
103	12600	300	97	8.8	1.15	0.98	229	7
104	5200	124	97	21.4	1.15	0.92	29	4

Table 7 Parameters involved in retention volume calculation.

Annex I-D: Vegetative Swale – Dimensioning

Referring to,

1. DWA-A-138
2. AG Boden,

these swales are designed. The following values are populated into the LID control panels in the SWMM model.

Section	**Parameter**	***Value***
Surface	Berm Height (mm)	*300*
	Vegetation Volume	*0.1*

	Surface Roughness (Mannings n)	*0.2*
	Surface Slope (%)	*0.5*
	Swale Side Slope (run/rise)	*10*

Table 8 Parameters in LID control editor for vegetative swale

Annex I-E: Infiltration Trench – Dimensioning

Referring to,

DWA-A-138,

these trenches are designed. The following values are populated into the LID control panels in the SWMM model.

Section	Parameter	*Value*
Surface (storage volume)	Berm Height (mm)	*3000*
	Vegetation Volume Fraction	*0*
	Surface Roughness (mannings n)	*0.1*
	Surface Slope (%)	*0*
Storage (filter layer)	Thickness (mm)	*500*
	Void Ratio (Voids/Solids)	*0.7*
	Seepage Rate (mm/hr)	*180*
	Clogging Factor	*0*
Drain	No Drain (short term)	*/*
	Flow Coefficient	*0*
	Flow Exponent	*0.5*
	Offset (mm)	*6*
	Open Level (mm)	*0*
	Closed Level (mm)	*0*

Table 9 Parameters in LID control editor for vegetative swale

Annex I-F: Bio-Retention Cell – Dimensioning

Referring to,

1. DWA-A-138
2. AG Boden,

these cells are designed. The following values are populated into the LID control panels in the SWMM model.

Section	Parameter	Value
Surface	Berm Height (mm)	*300*
	Vegetation Volume Fraction	*0.07*
	Surface Roughness (Mannings n)	*0.1*
	Surface Slope (%)	*0.5*
Soil	Thickness (mm)	*500*
	Porosity (volume fraction)	*0.4*
	Field Capacity (volume fraction)	*0.2*
	Wilting Point (volume fraction)	*0.1*
	Conductivity (mm/h)	*100*
	Conductivity Slope	*20*
	Suction Head (mm)	*50*
Storage	Thickness (mm)	*1500*
	Void Ratio (Voids/Solids)	*0.5*
	Seepage Rate (mm/h)	*100*
	Clogging Factor	*0*
Drain	No Drain (short term)	*/*
	Flow Coefficient	*0*
	Flow Exponent	*0.5*
	Offset (mm)	*6*
	Open Level (mm)	*0*
	Closed Level (mm)	*0*

Table 10 Parameters in LID control editor for bio-retention cells

Annex I-G: Rain Garden – Dimensioning

Referring to,

Urban water modelling lectures (TU Dresden 2023),

these gardens are designed. The following values are populated into the LID control panels in the SWMM model.

Section	Parameter	Value
Surface	Berm Height (mm)	*0*
	Vegetation Volume Fraction	*0*
	Surface Roughness (Mannings n)	*0.1*
	Surface Slope (%)	*1.0*
Soil	Thickness (mm)	*900*
	Porosity (volume fraction)	*0.5*
	Field Capacity (volume fraction)	*0.2*
	Wilting Point (volume fraction)	*0.1*
	Conductivity (mm/h)	*0.5*
	Conductivity Slope	*10*
	Suction Head (mm)	*3.5*
Storage	Thickness (mm)	*0*
	Void Ratio (Voids/Solids)	*0.75*
	Seepage Rate (mm/h)	*0.5*

	Clogging Factor	*0*

Table 11Parameters in LID control editor for rain gardens

ANNEX II

Annex II-A: Calibration Sub catchment wise Ranges

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

Table 12 Calibration Sub catchment wise Ranges

Annex II-B: Validation Model Sub catchment wise Values

Sub Catchment	Width(m)	Slope (%)	Imperviousness (%)

101	380.5	3.66	60.2
102	162.4	2.33	43
103	196	7	50
104	223.3	5.4	24.6
105	165.66	9.4	16.6
106	296.75	0.5	30.5
107	104	0.5	43.7
108	209.75	3.66	16.52
109	296.75	2	40
110	176	2	100
111	43	1	7
112	328.5	2	99.98
113	195.25	2	59.6
114	12.09	0	100
115	74.62	0	40.51
116	218.45	0.5	32
117	80.83	3	25
118	32.4	1.33	56.9
119	16.83	2.9	43.7

Table 13 Validation Model Sub catchment wise Values

ANNNEX III

Data Used	
Precipitation (mm/5 min)	*1996 to 2005*
Evaporation (mm/d)	*January to December (monthly)*
Sub-catchment data	*Area (ha)* *Impervious Area (ha)*
Water consumption (m^3/day)	*Every street*
Dry Weather Flow (m^3/hour)	*Weekdays* *Weekend*
Conduit data	*Material* *Shape* *Length (m)* *Diameter (mm)*
Junction Data	*Conduits in connection* *Co-ordinates (latitude, longitude)* *Invert elevation (m.a.s.l)* *Manhole depth (m)*

Table 14 Data used for model setup

Annex III-A: Sub catchment Delineation Data

Parameter	Value
Roughness of impervious surfaces (N-Imperv)	0.013
Roughness of pervious surfaces (N-Perv)	0.15

Depression storage of impervious surfaces (Dstore-Imperv)	1.27 mm
Depression storage of pervious surfaces (Dstore-Perv)	2.54 mm

Table 15 Sub catchment Delineation Data

Annex III-B: Water consumption data

Street	Water Consumption (m3/d)
Haeckelstraße	9.425
Zeunerstraße_east Bergstr.	32.424
Zeunerstraße_west Bergstr.	128.833
Bergstraße	462.328
Mommsenstraße	3.516

Table 16 Water consumption data

Annex III-C: Dry Weather Flow Pattern Data

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

Table 17 Dry Weather Flow Pattern Data

Annex III-D: Conduit Data

ID_link	From_Node	To_Node	Length (m)	Material	Shape_Xsection	Diameter (mm)
06Q187-06Q6	06Q187	06Q6	11.3	CONCRETE	EGG	450
06Q5-06L68	06Q5	06L68	35.55	CONCRETE	EGG	450
06L72-06L73	06L72	06L73	50.71	CONCRETE	EGG	450
06Q6-06Q7	06Q6	06Q7	34.99	CONCRETE	EGG	450
06L71-06L72	06L71	06L72	50.54	CONCRETE	EGG	450
06L68-06L66	06L68	06L66	40.96	CONCRETE	EGG	450
06L67-06L68	06L67	06L68	39.89	BRICK	CIRCULAR	250
06L70-06L71	06L70	06L71	42.93	CONCRETE	EGG	450
06L73-06L74	06L73	06L74	50.23	CONCRETE	EGG	450
06Q7-06L71	06Q7	06L71	49.44	CONCRETE	EGG	450
06L94-06L95	06L94	06L95	28.66	CONCRETE	EGG	600
06L30-06L90	06L30	06L90	28.83	CONCRETE	EGG	600
06L58-06L59	06L58	06L59	40.03	CONCRETE	EGG	450
06L64-06L30	06L64	06L30	45.67	CONCRETE	EGG	600
06L57-06L58	06L57	06L58	39.18	CONCRETE	EGG	450
06L121-06L57	06L121	06L57	32.92	CONCRETE	EGG	450
06L92-06L94	06L92	06L94	134.35	CONCRETE	EGG	600
06L62-06L63	06L62	06L63	45.77	CONCRETE	EGG	600
06L95-06L98	06L95	06L98	40.28	CONCRETE	EGG	600
06L69-06L70	06L69	06L70	42.33	CONCRETE	EGG	450
06L63-06L64	06L63	06L64	44.3	CONCRETE	EGG	600
06L61-06L62	06L61	06L62	43.19	CONCRETE	EGG	525
06L66-06L65	06L66	06L65	42.22	CONCRETE	EGG	450
06L59-06L60	06L59	06L60	43.8	CONCRETE	EGG	525
06L90-06L91	06L90	06L91	12.38	CONCRETE	EGG	600
06L60-06L61	06L60	06L61	44.17	CONCRETE	EGG	525
06L69-06L62	06L69	06L62	42.6	CONCRETE	EGG	450
06L65-06L59	06L65	06L59	42.07	CONCRETE	EGG	450
06L56-06L121	06L56	06L121	7.28	CONCRETE	EGG	450
06L91-06L92	06L91	06L92	45.08	CONCRETE	EGG	600
06L32-06L30	06L32	06L30	84.08	CONCRETE	EGG	450
06M58-06M57	06M58	06M57	34.92	CONCRETE	EGG	375
06R42-06R45	06R42	06R45	69.54	CONCRETE	EGG	450
06L74-06L32	06L74	06L32	50.31	CONCRETE	EGG	450
06L100-06L46	06L100	06L46	119.28	CONCRETE	EGG	1050
06R48-06Q18	06R48	06Q18	73.46	CONCRETE	EGG	450
06R45-06R48	06R45	06R48	127.71	CONCRETE	EGG	450
06R6-06R5	06R6	06R5	40.51	CONCRETE	EGG	600

06M56-06M57	06M56	06M57	36.9	CONCRETE	EGG	450
06Q18-06L100	06Q18	06L100	117.53	CONCRETE	EGG	900
06M61-06L51	06M61	06L51	33.33	CONCRETE	EGG	600
06L51-06L100	06L51	06L100	48.6	CONCRETE	EGG	600
06R40-06R42	06R40	06R42	43.01	CONCRETE	EGG	375
06M54-06M55	06M54	06M55	38.76	CONCRETE	EGG	450
06R5-06R4	06R5	06R4	40.41	CONCRETE	EGG	600
06M55-06M63	06M55	06M63	27.64	CONCRETE	EGG	450
06Q136-06Q18	06Q136	06Q18	36.18	BRICK	CIRCULAR	300
06R2-06R1	06R2	06R1	39.75	CONCRETE	EGG	600
06R1-06M61	06R1	06M61	40.06	CONCRETE	EGG	600
06R4-06R3	06R4	06R3	39.89	CONCRETE	EGG	600
06R3-06R2	06R3	06R2	40.18	CONCRETE	EGG	600
06M60-06M63	06M60	06M63	41.36	BRICK	CIRCULAR	250
06R103-06R40	06R103	06R40	44.73	CONCRETE	EGG	375
06R22-06R7	06R22	06R7	36	CONCRETE	EGG	375
06R25-06R103	06R25	06R103	43.06	CONCRETE	EGG	375
06R7-06R6	06R7	06R6	17.81	CONCRETE	EGG	600
06L46-06L45	06L46	06L45	34.8	CONCRETE	EGG	1050
06M55-06M39	06M55	06M39	119.73	CONCRETE	EGG	450
06M64-06M58	06M64	06M58	61.1	BRICK	CIRCULAR	300
06L31-06L46	06L31	06L46	23.59	CONCRETE	EGG	750
06M57-06M41	06M57	06M41	99.55	CONCRETE	EGG	450
06L44-06M5	06L44	06M5	172.19	CONCRETE	EGG	1050
06M39-06M38	06M39	06M38	48.05	CONCRETE	EGG	525
06M38-06L44	06M38	06L44	21.51	CONCRETE	EGG	525
06M46-06M44	06M46	06M44	47.06	CONCRETE	EGG	525
06L30-06L31	06L30	06L31	5.71	CONCRETE	EGG	750
06M40-06M39	06M40	06M39	34.35	CONCRETE	EGG	450
06M47-06M46	06M47	06M46	22.85	BRICK	CIRCULAR	300
06M42-06M41	06M42	06M41	6.65	CONCRETE	EGG	450

06M41-06M40	06M41	06M40	33.58	CONCRETE	EGG	450
06M5-06M4	06M5	06M4	16.46	CONCRETE	EGG	1050
06M44-06M42	06M44	06M42	39.33	CONCRETE	EGG	525
06L45-06L44	06L45	06L44	30.49	CONCRETE	EGG	1050
06M63-06M56	06M63	06M56	9.24	CONCRETE	EGG	450

Table 18 Conduit Data

Annex III-E: Junction Data

ID	Invert elevation (m.a.s.l.)	Manhole Depth (m)	X-coordinate	Y-coordinate
06L66	149.99	3.92	410751.143	5653515.603
06L58	146.51	3.64	410754.133	5653587.807
06Q5	152.93	3.2	410762.447	5653465.788
06Q187	153.52	3.43	410783.003	5653443.446
06L67	152.08	2.97	410693.202	5653495.299
06L57	146.74	3.53	410714.954	5653587.567
06L59	146.31	3.67	410794.165	5653588.077
06L121	146.9	3.45	410682.031	5653587.373
06L65	148.16	3.68	410772.759	5653551.87
06Q6	153.26	3.21	410793.561	5653447.463
06L56	146.94	3.44	410674.751	5653587.319
06Q136	159.52	3.08	411066.916	5653334.17
06R48	159.77	2.46	411158.821	5653348.642
06R6	154.62	2.27	411385.275	5653398.073
06R45	162.81	2.65	411271.951	5653296.042
06R22	156.48	3.82	411398.593	5653353.354
06R25	167.14	3.68	411424.404	5653223.89
06R103	166.95	3.83	411381.836	5653230.385
06R5	153.97	3.12	411346.506	5653409.832
06R40	166.81	3.51	411337.66	5653237.286
06R4	153.36	3.4	411307.871	5653421.678
06R3	152.77	3.22	411269.541	5653432.714
06R42	166.53	3.15	411298.344	5653251.171
06L63	143.9	3.61	410971.09	5653588.9
06L70	149.05	3.61	410891.7	5653510.705
06L60	145.95	3.62	410837.963	5653588.246
06L62	145.15	3.54	410925.32	5653588.689
06L61	145.54	3.6	410882.134	5653588.452
06L74	147.57	3.61	411023.292	5653499.452
06Q7	152.46	3.25	410826.885	5653458.122
06L64	142.75	3.63	411015.385	5653589.067
06L73	148.8	3.53	410973.662	5653491.771
06L72	150.01	3.44	410923.769	5653482.701

06L69	147.1	3.47	410908.437	5653549.579
06M38	137.84	4.18	411131.442	5653646.469
06L100	147.36	4.69	411077.519	5653480.242
06M60	148.86	2.49	411209.01	5653485.561
06L90	140.27	3.69	411056.852	5653617.754
06L92	137.39	2.84	411043.358	5653672.663
06L91	139.59	3.62	411050.091	5653628.097
06M63	144.79	3.43	411203.43	5653526.283
06L31	141.32	3.96	411066.705	5653590.008
06M54	145.63	3.72	411137.812	5653516.148
06R1	151.53	3.04	411193.029	5653455.845
06M40	138.62	3.93	411213.245	5653636.638
06L51	150.41	2.75	411122.814	5653477.191
06M61	150.92	3.01	411154.711	5653467.514
06M56	144.47	3.91	411212.564	5653527.709
06L94	131.56	3.59	411023.687	5653805.54
06L95	131.21	3.8	411019.856	5653833.935
06M5	132.05	4.04	411142.711	5653806.202
06M46	139.13	3.64	411338.924	5653621.248
06M64	144.45	2.2	411343.917	5653548.019
06M44	138.99	3.87	411292.223	5653627.064
06M58	144.16	3.22	411283.534	5653538.665
06M42	138.82	3.76	411253.174	5653631.765
06M47	139.27	3.31	411361.775	5653620.952
06R2	152.16	2.78	411231.074	5653444.324
06L71	150.94	4.23	410874.512	5653471.393
06L68	151.31	2.45	410730.188	5653480.413
06L30	141.19	3.24	411061.043	5653589.247
06L32	145.18	3.81	411073.163	5653506.063
06Q18	155.83	2.61	411087.399	5653363.988
06M55	143.83	2.79	411176.117	5653522.082
06R7	155.24	2.27	411400.76	5653389.28
06L46	140.49	2.46	411089.99	5653593.646
06M57	142.85	4.15	411249.015	5653533.406
06L44	137.2	4.25	411111.805	5653655.147
06M39	138.29	2.97	411179.153	5653640.806
06M41	138.79	3.77	411246.574	5653632.548
06L45	138.75	3.81	411101.89	5653626.321
06L98 129.72 FREE NO	129.72	0	411014.305	5653873.824
06M4 131.58	131.58	0	411146.928	5653822.107

Table 19 Junction Data