The alternative stormwater system versus the traditional piped stormwater system

Alket Kumaraku[1], Eduart Blloshmi[2], Lavdim Osmanaj[3]

[1] Department of Hydraulic and Hydrotechnics, Polytechnic University of Tirana, Albania,
[2] Department of Geodesy, Polytechnic University of Tirana, Albania
[3] Prishtina University, Kosovo

ABSTRACT

The urbanization process is an issue concerning many branches of urban planners and civil engineering, not only to ensure proper spaces and environment or living places, but moreover to offer a comfortable manner of life, serving to the people by all the types of services needed. Stormwater drainage system is a type of service not directly connected to people daily living activities, such as drinking water, electricity, etc., but directly to their properties and indirectly to their outside activities, such as work, leisure time, etc. Despite of the urbanization process, which is going to be increased in many big cities, the intensity of the rainfall is also going to be increased more and more due to climatic changes. Nowadays, we are facing more rare rainfalls, but with more and more severity and higher intensity (the less frequent intensities forecasted before are happening more frequently). Then, which of this phenomenon is the most likely to impact on highest levels/volumes of surface runoff, in order to take the proper measures?

In this article, to express better the up-mentioned impact, it is developed a hydraulic model of a city wastewater combined system. The model has been developed based on the city urban plan and in the registered rainfall intensities for this city. During the model construction, there are performed preparatory work in to fronts. The first work has been based on the division of the urban area into storm water catchments, to be also in conformity with the pipelines trace and connection, from the upper and farthest point of each part of the system inside the catchment, to the discharge point into the river. Another issue is the exact value of the runoff coefficient in the respective areas. The runoff coefficient is function of the surface type, the impervious vs. pervious surfaces inside a catchment, the slope of the surface where runoff is created, etc. The next goal of the preparatory work for the model is to define the IDF curves, for different rainfall intensities' return periods and durations. Upon hydraulic model development, different scenarios are created. The scenarios have taken into the consideration the change of the urban area and its development, vs the same rainfall intensities and the change of rainfall intensities vs the stable and not dynamic urban process.

Keywords: *SUDS, attenuation measures, stormwater system, hydraulic modelling*

GENERAL

The stormwater system has been changed over times and its elements have been developed during these periods. So, from the simple open channel as gutters, channels, grated channels etc., it has been later developed as piped system, in order to avoid the contact of the human being with these waters, as per aesthetically or hygienic motives.

The elements of the piped or even grated or other types of stormwater systems have been developed during the years, from concrete pipes and manholes, brick-wall manholes, and to the latest ones, plastic pipes and plastic manholes (with also composite material covers).

The purpose of all of these elements and the whole system is to drain and deliver away from the urban area (or the runoff "creation" flows), the whole runoff waters. The waters are delivered and discharged to the natural main watercourses, such as streams, rivers, lakes or even seas. The runoff flow depends as much as from the physical characteristics of the urban areas surfaces, and also from the rainfall intensity parameters (duration, frequency, etc.). The surfaces characteristics are changing over the years, turning from the natural permeable areas to the paved impermeable ones. The rapid urbanization of the cities, accompanied by the increase of the impervious area, is not followed by real-time response in the re-dimensioning of the piped system part affected by the increase of the impervious area. These issues are actually a real challenge in stormwater system concept.

This problem is going to be not only an economical issue (due to high costs of piped system construction) but it is going to be an environmental issue. The economic issue is overcome in many areas (the availability of the money in rich countries and the frequent floods in poor countries), but the environmental issue cannot be solved if not proper measures or change in the stormwater drainage system concept change.

The environmental issue and the negative impacts generated during the storms by the rapid urbanization process are mainly:

- The runoff water management on the ground surface;
- The underground water table preservation;

There are given 2 examples how the urbanization is impacting the increase of the runoff[1]

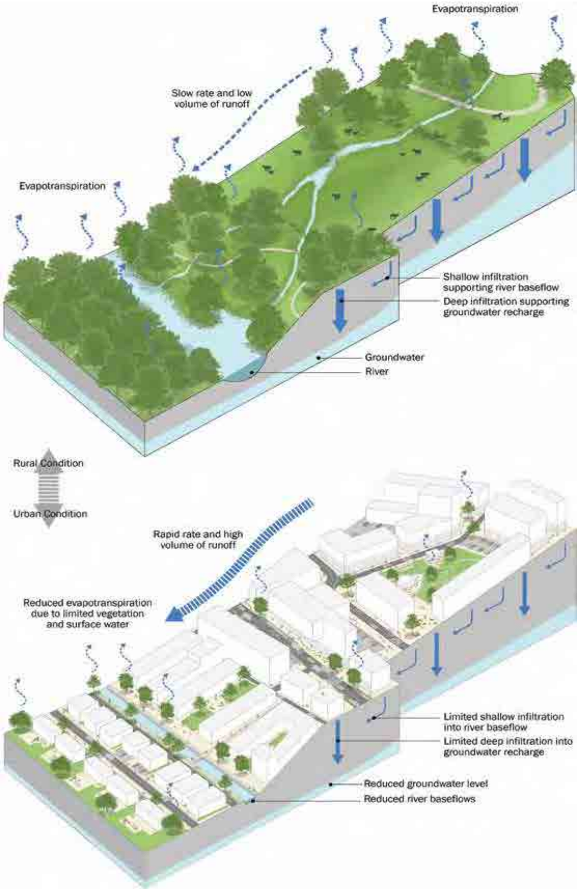

Figure 1. The change of runoff flow due to urbanization process

The alternative solution, which are spreading and finding more and more use in the urban area design, is the use of sustainable drainage systems, or the so-called SUDS.

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[1] The SUDS Manual C753 by CIRIA

THE SUSTAINABLE DRAINAGE SYSTEMS – SUDS

The sustainable drainage system (hereinafter SUDS) concept has derived mostly by the 2 (two) up-mentioned problems (or negative impacts) generated by the stormwaters in the impervious areas.

The main purpose is that the surface water should be managed for maximum benefit, now and in the future. The sustainable drainage systems are designed to maximize the opportunities and benefits we can secure from surface water management. There are four main categories of benefits that can be achieved by SUDS: water quantity, water quality,amenity and biodiversity. These are referred to as the four pillars of SUDS design [1]:

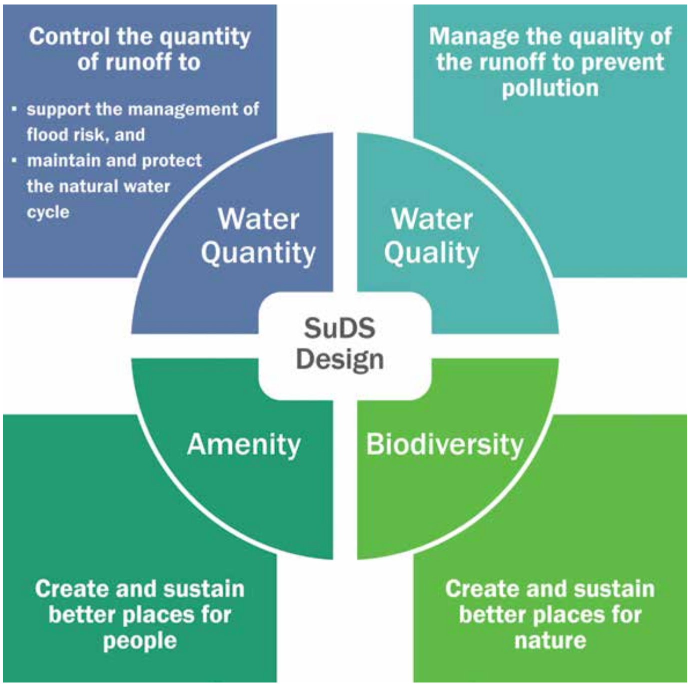


Figure 2. The four pillars of SUDS solution impact

The SUDS can be used to harvest rainwaters from the impervious areas (such as roofs, asphalted or concrete paved roads, paved squares or parking lots, etc.); to reduce the stormwater peak by maintaining the water and discharging it a lower flow rate (such as underground inline or not inline reinforced concrete tanks, soakaways or infiltration systems, bio – retention systems, swales and ponds, etc.

In the urbanized developed areas, the runoff after urbanization of the natural ground area is much higher and it can be discharged quicker than in the pre-urbanized or natural ground area. This is because of the high infiltration rate of the natural area versus the impervious urbanized areas. So, the runoff hydrograph of the impervious area is much higher and shorter than the runoff hydrograph of the natural areas. The difference between them can be diminished, if not totally removed, by using SUDS for water or peak flow attenuation, as it can be seen in the following figure.

As mentioned in the above for pillars, the SUDS can be used to increase the quality of life in the urban areas by reducing the flooding probability, increasing the drainage capacity of the system (even through maintaining it), increasing amenities and to help using better the landscaping area. Most of SUDS should be design in a close collaboration with landscaping specialist, in order to make more useful their use or if possible, to have even double functions ones.

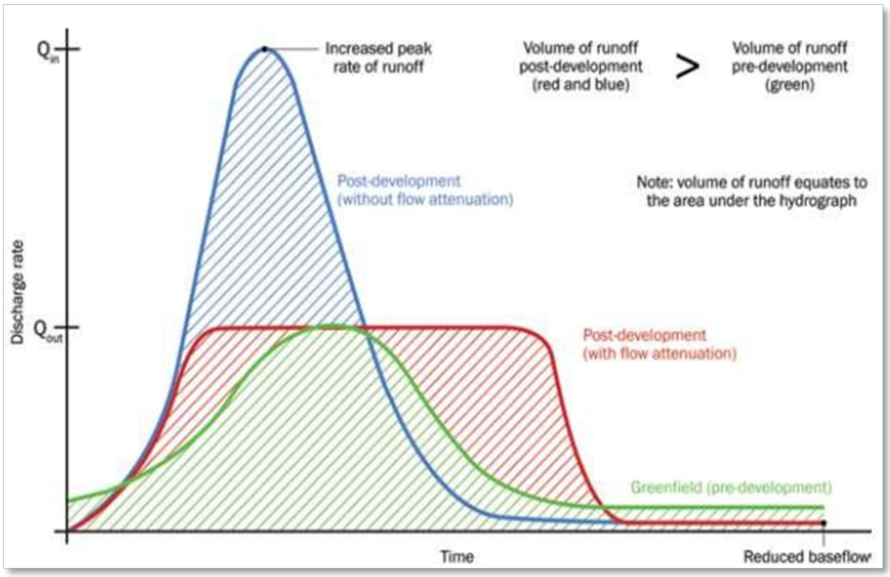


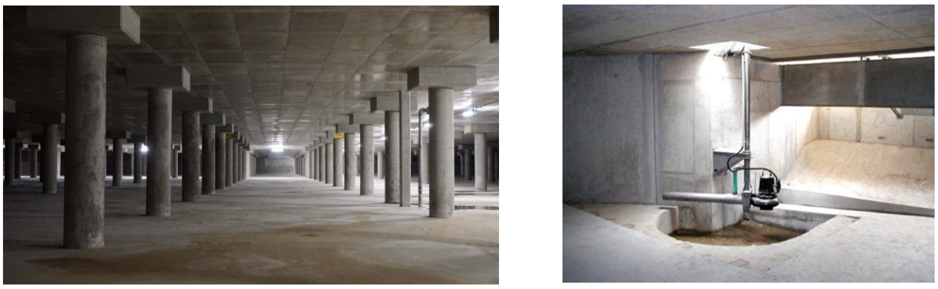
Figure 3. Runoff hydrographs of the different land developments [1]

Such SUDS as mentioned above should be design in parallel with the landscape design process, to find better location, from the hydraulically point of view and the urban design point of view, because these systems could also be used (if possible) even as playgrounds or recreational areas (permanent ponds, etc.). But the main priority is the peak flow maintaining, which is being presented in a hydraulic model at the following paragraphs.

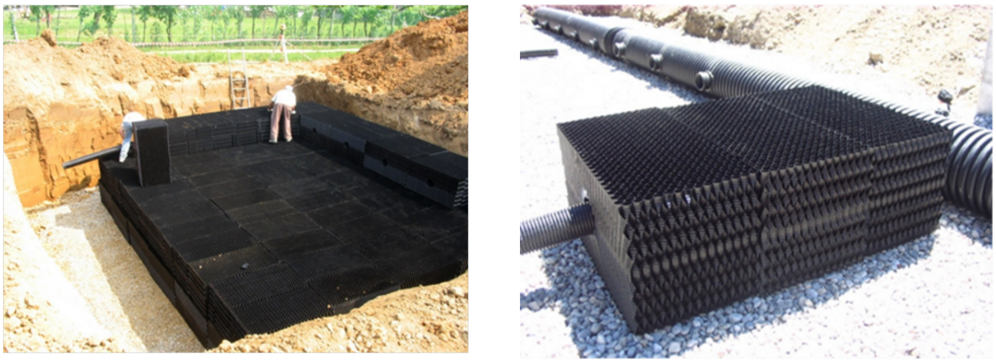

a) Bioretention


b) Swale


c) Temporary detention ponds

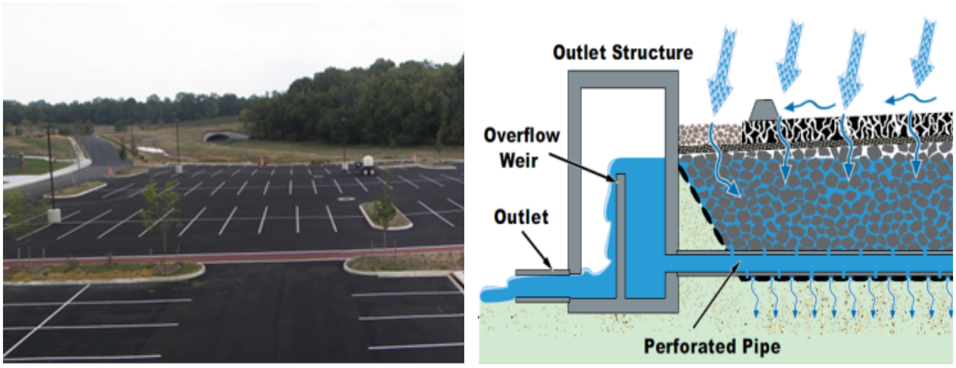


d) Attenuation stormwater tank



e) Rain harvesting and maintaining plastic systems

f) Stormwater maintaining pond (double function, even as a playground)



g) Parking lot with porous asphalted layers and its sketch of the draining

Figure 4. Different types of SUDS solutions

HYDRAULIC MODEL

The hydraulic model needs

The hydraulic model to compare the traditional stormwater drainage piped system and the alternative stormwater drainage system (SUDS) has been built for an urban area.

The urban area has the been developed during the years and the impervious area has been drastically decreased. There are analyzed the urban area data in a time interval of 25 years, which is the nearly the service period of a water system in an urban area, and between them the stormwater drainage system. These systems are designed based on the urban area development plan, so in the end of this plan period, it is needed to increase or to interfere in the existing system, in order to cope with the new development plan, but also to keep in mind both environmental problems due to urbanization.

So, hydraulic models are needed to compare both solutions and to analyze, which of them is better, by the financial point of view, and by the amenities increasing.

The hydraulic model data and built-up

The hydraulic model has been developed for a part of the city area, splitting this area into catchments, each of them discharging in the proper main combined collectors (through many catch pits on the tertiary and secondary pipes, not visualized in this model, since it has been skeletonized). The main collectors are installed with concrete or reinforced concrete pipes, connected and controlled from the reinforced concrete pits, manholes and chambers. The pipes are considered in an average condition, better that they can be in reality, since there are not enough data about their situation, the diameter blockage percentage, etc.

Another assumption is the runoff coefficient, which has been calculated, analyzing the type of the surface, the coefficient for each of them and a composite one has been resulted, using it as one value for all the catchments. That is because some of there are areas, actually are almost more than 95 % paved, but some other areas are not so urbanized, with much less impervious surface. Therefore, the former paved areas have higher runoff coefficient than the latter areas, generating higher runoff flows in their discharging pipes, during the shortest and most intense rainfalls.

The hydraulic model has been created, based on the following data:

- Land development maps of the city in the last 25 years.
- The rainfall intensities of the measured and evaluated hydrological data series of the rainfalls.
- The runoff coefficients are given by literature but also analyzed and evaluated because of the

surfaces with different permeability inside each of the catchment areas.

The maps of this model are given in following figure, presenting the part of the city water system being modelled.

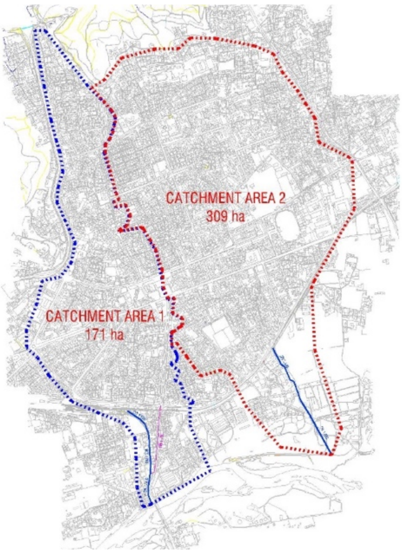


Figure 5. The catchment areas plan

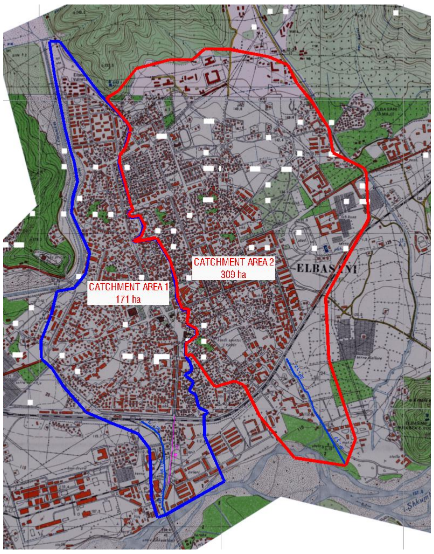


Figure 6. The catchments areas map 1990 [2]

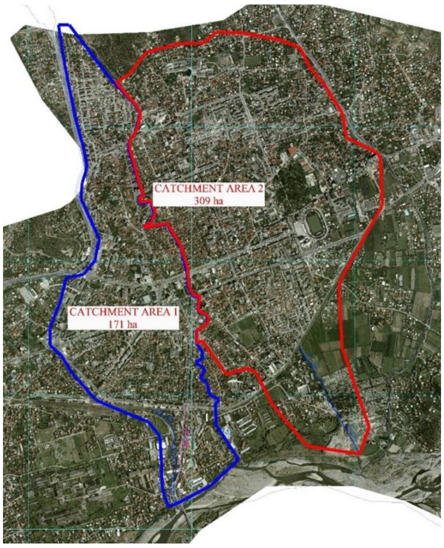


Figure 7. The catchment areas map 2015 [2]

The rainfall data and intensities, used to build up the hydraulic model, are given in the table, as follows:

Table 1. IDF curves data of the rainfalls in the city area [3]

PLACE	Rainfall Duration [hours]	Return Period T (years)			
		100	50	20	10
CITY	24	7.21	6.50	5.58	4.83
	12	10.17	9.25	8.00	7.00
	6	18.67	16.67	14.00	12.00
	2	40.00	35.50	29.50	25.00
	1	62.00	55.00	46.00	39.00
	0.50 (30 min)	110.00	96.00	80.00	68.00
	0.33 (20 min)	111.01	99.01	84.01	72.01
	0.1667 (10 min)	167.97	149.97	125.97	107.98

The catchment areas data for this hydraulic model are given in the table below.

Table 2. The catchment data

Catchment	Surface [ha]									
	Total	Year 1990				Year 2015				
		Apartm.	M-F attac	Suburb.	Unimpr.	Total	Apartm.	M-F. attac.	Suburb.	Unimpr.
1	171	0	69	67	35	171	5	89	62	15
2	309	20	95	108	86	309	35	137	110	27

The runoff coefficient of the different types of ground surfaces are given in the table below (acc. Viessman and Lewis at 2003).

Table 3. The runoff coefficients proposed by Viessman and Lewis [4]

Residential	
Single-family	0.30–0.50
Multi-family detached	0.40–0.60
Multi-family attached	0.60–0.75
Residential suburban	0.25–0.40
Apartments	0.50–0.70
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yards	0.20–0.40
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95

The runoff of the catchment areas is calculated according to the following formula:

$$C = \frac{C_1 \times S_1 + C_2 \times S_2 + C_3 \times S_3 + C_4 \times S_4}{S_1 + S_2 + S_3 + S_4}$$

And these coefficients are given in the following table for each catchment in the respective years, taken into the consideration during this hydraulic modelling study.

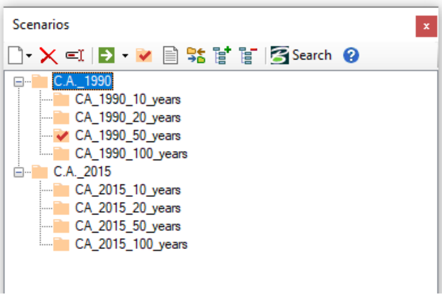
Table 4. The runoff coefficient for the catchments of the city in different years

Catchment	Surface [ha]	C (Runoff coefficient)	
		Year 1990	Year 2015
1	171	0.52	0.58
2	309	0.50	0.60

The time of concentration has been calculated using the Kirpich method for the sheet flow (the shallow concentrated flow is not considered, due to the surface type) and the Manning formula for the channelized flow. The resulted time of concentration is nearly t = 30 - 35 min ≈ 0.5 hours, from the furthest point to the outfall of each catchment areas.

The hydraulic model consists of some scenarios, but we've chosen to analyse 2 scenarios for each type of catchment (one type of catchment without SUDS and the next one with SUDS integrated in the drainage system).

The different scenarios are presented in the figure below:



- C.A_1990
  - CA_1990_10_years
  - CA_1990_20_years
  - CA_1990_50_years
  - CA_1990_100_years
- C.A_2015
  - CA_2015_10_years
  - CA_2015_20_years
  - CA_2015_50_years
  - CA_2015_100_years

Figure 8. The scenarios of the hydraulic model

The scenarios that are analysed and which data are compared are the scenarios CA_1990_20 years and CA_2015_20_years. The catchment models used in both scenarios are given in the figures below.

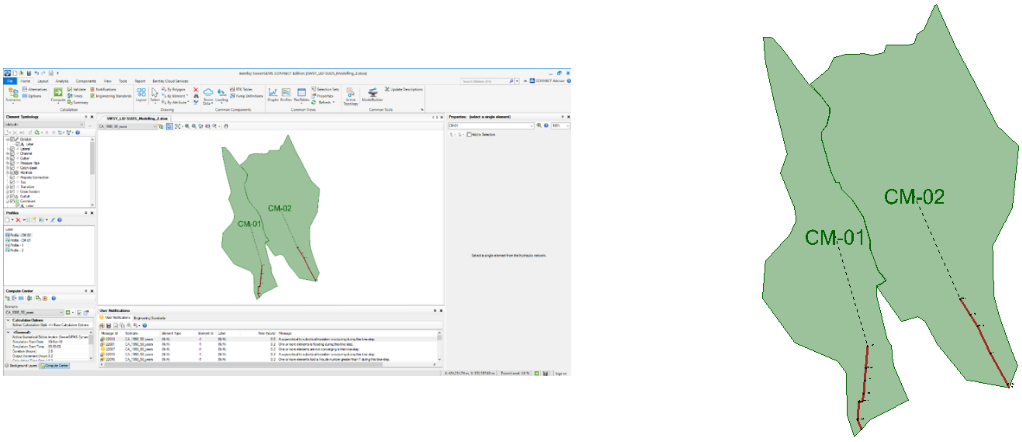


Figure 9. The catchment layout without attenuation system.

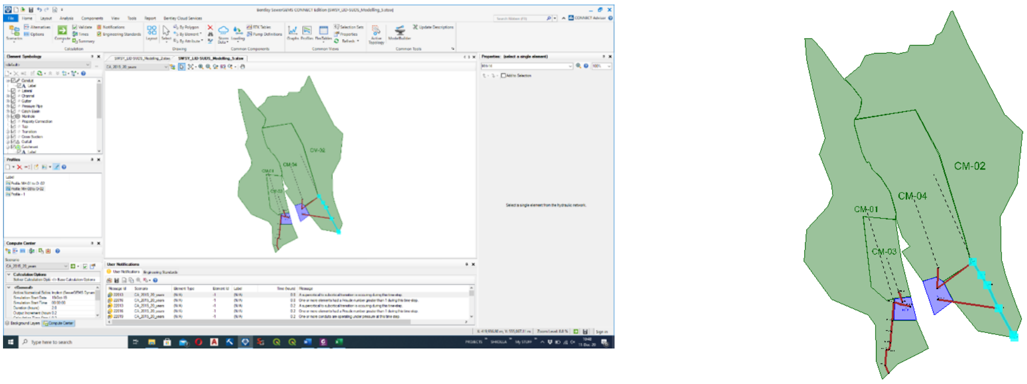


Figure 10. The catchment layout with attenuation system (SUDS – Swale type)

The results of the hydraulic simulation

As it is mentioned above, the storm with a return period T =20 years has been taken into the consideration to analyse the hydraulic model simulation. In the graphs and tables below are given the hydraulic line or water level at the peak flow, for both types of catchments, with or without attenuation system.

After the simulation, it has been clear the distinction between the runoff flows in the pipes in both types. There are higher levels or bigger depths of the water flows inside the pipes in the system without attenuation measures than in the system with attenuation measures.

In the figures and tables below are given the results from these hydraulic model simulations, which shows the important role of SUDS in peak flow attenuation during the storms.

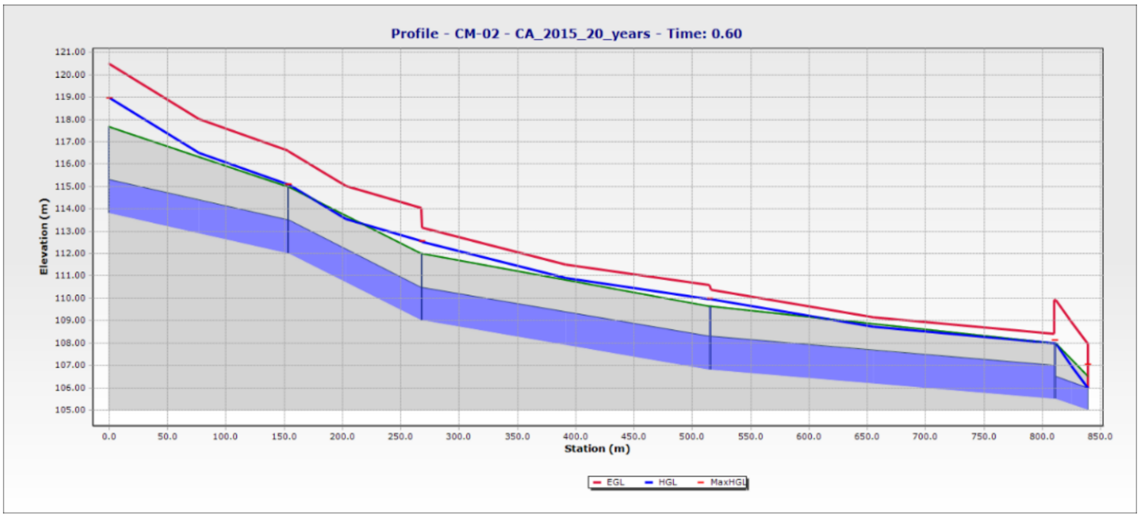


Figure 11. The profile of hydraulic and energy line in the pipeline of the catchment 2(without attenuation) year 2015, return period T = 20 years

Table 5. The hydraulic data of the pipeline of the catchment 2 (without attenuation) year 2015, return period T = 20 years

Label	Elevation (Ground) (m)	Elevation (Invert) (m)	Flow (Total In) (L/s)	Flow (Total Out) (L/s)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Overflowing?
MH-08	117.66	113.8	32,956.83	9,680.73	118.95	118.95	TRUE
MH-09	115	112	9,680.72	9,572.04	115.1	115.09	TRUE
MH-10	112	109	9,571.77	6,202.55	112.55	112.54	TRUE
MH-11	109.64	106.8	6,199.28	5,046.38	109.97	109.96	TRUE
MH-12	108	105.5	4,896.74	4,850.08	108	108	FALSE

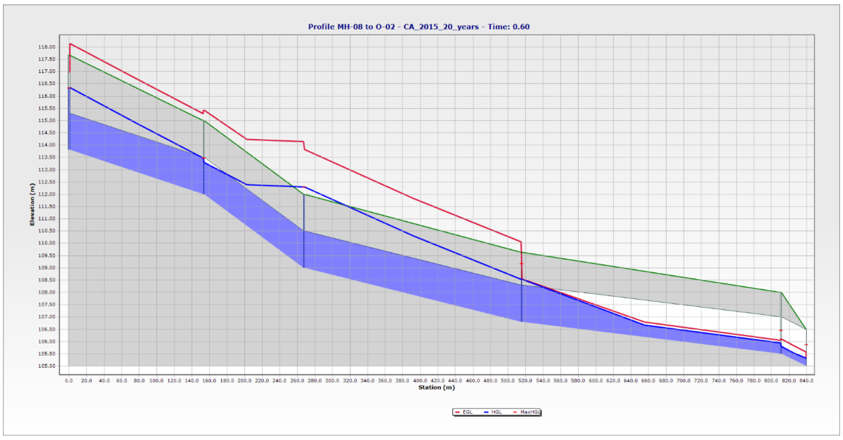


Figure 12. The profile of hydraulic and energy line in the pipeline of the catchment 2 (with attenuation) year 2015, return period T = 20 years

Table 6. The hydraulic data of the pipeline of the catchment 2 (with attenuation) year 2015, return period T = 20 years

Label	Elevation (Ground) (m)	Elevation (Invert) (m)	Flow (Total In) (L/s)	Flow (Total Out) (L/s)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Ever Overflowing?
MH-08	117.66	113.8	16,766.04	16,849.84	116.32	116.32	FALSE
MH-09	115	112	10,511.26	10,514.12	113.47	113.3	FALSE
MH-10	112	109	10,655.24	9,660.11	112.3	112.3	TRUE
MH-11	109.64	106.8	9,366.39	957.11	108.54	108.54	FALSE
MH-12	108	105.5	633.46	616.1	105.93	105.81	FALSE

CONCLUSION

As it can be seen the attenuation measures integrated in the stormwater system affect the whole system and it can avoid the flooding of the system by the peak flows of a storm. The biggest depth in the first case (without attenuation) is approximately H = 1.30 m in the area of manhole no. 08, while in the second scenario presented above, there is no flooding in the area of the manhole no. 08, as it has be seen in the system without attenuation measures.

REFERENCES

[1] The SUDS Manual C753 by CIRIA;

[2] ASIG Website, Albania;

[3] Buletini i shirave maksimale IHM, Tiranë, 1985;

[4] ASCE 1975, Viessman, et al. 1996, and Malcom 1999.