Application of the E^{2}STORMED Decision Support Tool in Zagreb

E^{2}STORMED PROJECT
Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities
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1. Pilot city description

1.1. General description

Zagreb is the largest city of the Republic of Croatia and also its capital. It is located in the northwest of the country, along the Sava River, at the southern slopes of the Medvednica mountain. It is an international trade and business center, and an essential transport hub placed at the crossroads of Central Europe, the Mediterranean and the Balkans. Almost all of the largest Croatian companies, media and scientific institutions have their headquarters in the city.

Zagreb is a city with a rich history dating from the Roman times to the present day and the first written mention of the city dates from 1094. Zagreb is covering an area of 640 square kilometers and lies at an elevation of approximately 122 [m above sea level]. It is situated 170 [km] from the Adriatic Sea. In the last official census of 2011 the population of the City of Zagreb was slightly over 790.000.

The wider Zagreb metropolitan area includes the City of Zagreb and the separate Zagreb County bringing the total population up to 1.110.000. It is the only metropolitan area in Croatia with a population of over one million.

Figure 1.1.1. Map of Croatia

1.2. Climate

Zagreb has a continental climate with warm and dry summers and cold winters. The city has the typical spring, summer, autumn, and winter climate variations, with little seasonal deviation. It is very hot during the summer, freezing in the winter and quite pleasant in late spring and early autumn. The wettest time of the year here is in the summer, between late June and October.

During the winter temperatures are about 1 [°C] and during the summer temperatures are about 20 [°C] on average. The average annual temperature in Zagreb is 11,3 [°C]. The warmest month of the year is July with an average temperature of 21,4 [°C]. In January, the average temperature is -0,2 [°C].

It is the lowest average temperature of the whole year. By comparing the values of mean annual temperatures in Zagreb between 1862 and 2013, year 2013 was the twelfth warmest year since the beginning of the measurements with the mean annual air temperature 12,9 [°C].

Average monthly temperatures vary by 21 [°C]. In the winter time records indicate temperatures by day reach 4,2 [°C] on average falling to -0,7 [°C] overnight. In spring time temperatures rise reaching 16,1 [°C] generally in the afternoon with overnight lows of 7,8 [°C]. During summer average high temperatures are 25,1 [°C] and average low temperatures are 15,9 [°C]. Temperatures rise above 30 [°C] on an average 17 days each summer. Autumn and fall temperatures are achieving average of 15,3 [°C] during the day and lows of 8,4 [°C] generally shortly after sunrise.

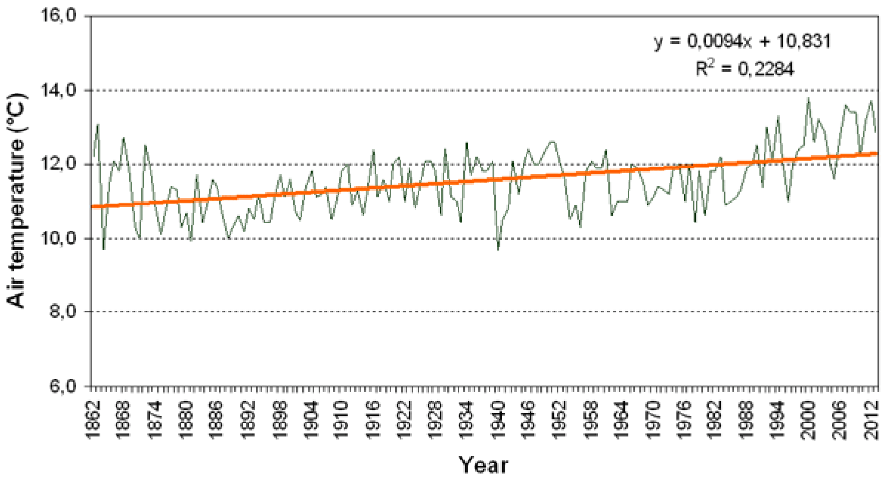

Figure 1.2.1 Average air temperature variations for Zagreb area

The atmospheric conditions are very variable. They are characterized by a diversity of weather situations with frequent and intense exchanges during the year. These are caused by moving systems of low or high air pressure. During the cold part of the year, stationary anticyclonic weather types, with foggy weather or low clouds and a very gentle air flow, are prevalent. In spring, fast-moving cyclonic weather types (cyclone and trough) are characteristic, resulting in frequent and sudden weather changes, from rainy to dry periods, from calm to windy, from colder to warmer.

The climate is modified by the maritime influence of the Mediterranean, which is stronger in the area south of the Sava River than in the north, and which weakens towards the east. The next local climate modifier is the Mount Medvednica which facilitates the intensification of short-term heavy precipitation on the windward side of the orographic obstacle or the appearance of precipitation shadow on the leeward side. This, for example, happens in the eastern part of Zagreb, where the Mount Medvednica acts as an obstacle to the northwestern precipitation outbreaks.

Zagreb fetches an average of 1.060 [mm] of rainfall per year, or 88,3 [mm] per month. The driest month is February with 48 [mm]. Most precipitation falls in June, with an average of 101 [mm]. Snowfall is very common during the winter months. On average there are 96 days per year with more than 0,1 [mm] of rainfall or 8 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in February when an average of 46,6 [mm] of rainfall occurs. The wettest weather is in June when an average of 100,8 [mm] of rainfall occurs.

Over the entire year, the most common forms of precipitation are moderate rain, light rain, and thunderstorms. Thunderstorms are the most severe precipitation observed during 22 [%] of those days with precipitation. They are most likely in June when it is observed during 27 [%] of all days.

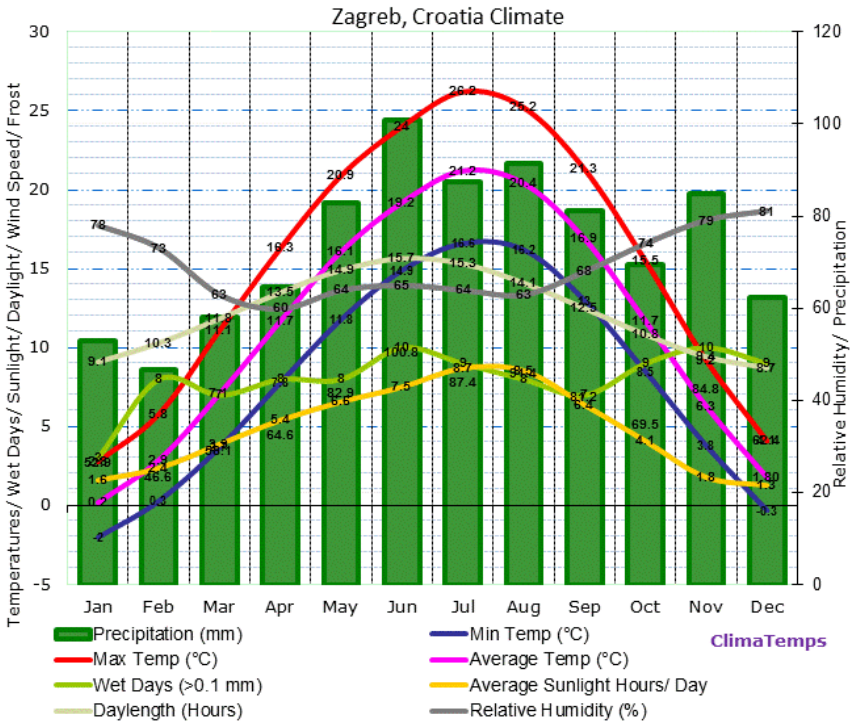

Figure 1.2.2. Monthly precipitation, temperature, humidity and sunlight data for Zagreb

The snow is typically deepest in January, with a median depth of 14,7 [cm]. The depth exceeds 26,6 [cm] only one year out of ten.

There is an average of 1806 hours of sunlight per year. The length of the day varies significantly over the course of the year. The shortest day is December 21 with 8:40 hours of daylight and the longest day is June 20 with 15:42 hours of daylight.

The average annual relative humidity is 69,3 [%] and average monthly relative humidity ranges from 60 [%] in April to 81 [%] in December. The relative humidity typically ranges from 44 [%] to 99 [%] over the course of the year, rarely dropping below 27 [%] and reaching as high as 100 [%]. The air is driest around in March at which time the relative humidity drops below 54 [%] (usually for three days). It is most humid in November when humidity is exceeding 99 [%] (usually for three days).

The wind is most often out of the south west (17 [%] of the time), north east (16 [%] of the time), and west (11 [%] of the time). The wind is least often out of the north west (2 [%] of the time), south east (3 [%] of the time), and south (5 [%] of the time).

Over the course of the year typical wind speeds vary from 0 [m/s] to 6 [m/s], rarely exceeding 10 [m/s]. The highest average wind speed of 3 [m/s] occurring in March, at which time the average daily maximum wind speed is 5 [m/s]. The lowest average wind speed of 2 [m/s] occurring in January, at which time the average daily maximum wind speed is 3 [m/s].

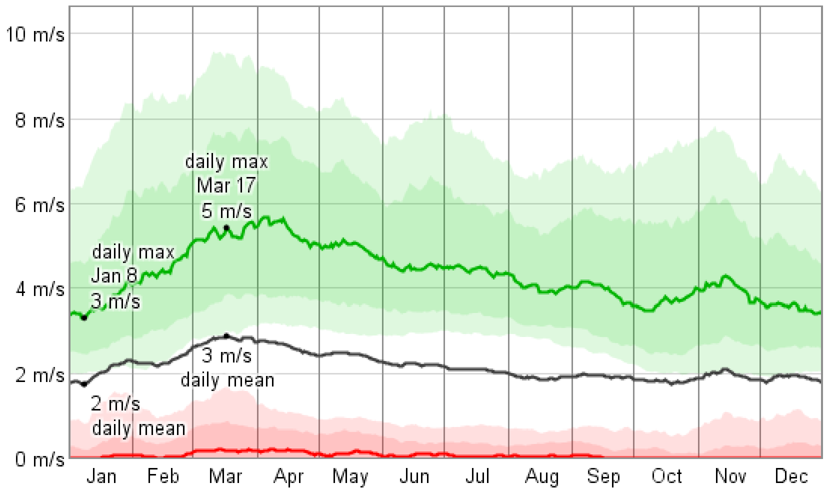

Figure 1.2.4 The average daily minimum (red), maximum (green), and average (black) wind speed with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile)

1.3. Water resources and water management system

The city of Zagreb lies on the alluvium of the Sava River which is the main and largest water source for the city. The Sava River Basin is a major drainage basin of the South Eastern Europe covering the total area of approximately 98.000 [km^2].

Water supply is based on groundwater abstraction. Aquifers of the Zagreb area are found along both the left and the right bank of the Sava River. The thickness of the water-bearing sand and gravel stratum is from several to a hundred meters. Above it, a surface layer (mud, loam, clay), 1 to 8 [m] thick, is found. The aquifer is recharged to a small extent by vertical percolation through the soil, but predominantly by horizontal infiltration from the Sava.

The city development caused the deterioration of the groundwater quality in a several ways. For example: the deep foundations of tall buildings are located in the aquifer, perforating the protective surface layer. Also most of the city's sewer system lies under the covering layer. The system collects storm, domestic and industrial waste water causing wastewater to infiltrate into the aquifer. During the development of the city, sand and gravel from aquifers was used for building. Urbanization processes also affected the hydrological regime of the Sava River. Namely, due to anti-erosion works upriver, the Sava River in the Zagreb area is unsaturated with deposit so it erodes its own bed. In the Zagreb area the bottom of the Sava River has declined by 0,5 to 1 [m] in the last twenty years.

Recent advances in wastewater management in the Sava River basin, in particular completion of the wastewater treatment plant of the city, have contributed to a significant improvement of the water quality of the Sava River.

Water supply in the studied area is carried out through the water supply system of the city of Zagreb which serves the city, but also gravitating parts of Zagreb County with total area of over 800 [km^2]. Water supply system consists of six water intakes with a total of 30 water wells. The total nominal capacity of wells is 5.500 [l/s] of which the City of Zagreb uses about 4.950 [l/s]. Maximum water production of the system is more than 430.000 [m^3] per day. Some wells are located within the construction area of Zagreb, in residential areas or in close proximity to industrial zones and other potential pollutants. In these wells unacceptable levels of pollution have been identified and they are excluded from the regular water supply system.

The length of the public water supply network at the end of 2012 was 2.707 [km] of which 2.358 [km] is accounted for the City of Zagreb with a total of 93.810 connections (of which 81.742 in the City) thus securing the supply for approximately 897,000 residents. The average annual consumption of drinking water is about 70,3 [m^3] per capita. The households water consumption account for 75,58 [%], and other users with 24,42 [%].

Zagreb City sewage system consists of two independent sewage systems, each of which is located on one side of the Sava River. Both were built as a combined sewerage system. The area covered by the public sewage system is 23.500 [ha] and approximately 750.000 inhabitants are connected to sewage system. Wastewater is treated at a central wastewater treatment plant (WWTP) and effluent is discharged into the Sava River. WWTP is located on the left bank of the Sava. At WWTP wastewater is treated with primary and biological treatment processes. The capacity of the WWTP is 1,2 million population equivalent.

The largest part of the city located on the left bank of the Sava River is connected to the WWTP via the main drainage canal. The connection of the city area on the right bank of the Sava River to WWTP was realized in 2011 and until then wastewater of this area was diverted through collectors in the Sava River.

The total length of sewage network is 1.550 [km] of which 10 [km] are open canals. Sewerage network covers approximately 88 [%] area of the City of Zagreb, while about 12 [%] of the area with about 120.000 inhabitants has no connection to the sewage system. Only 20 of the 68 settlements that gravitate towards Zagreb have public sewerage network.

Integral part of wastewater is the rain water from many streams flowing down from the Medvednica mountain. These streams, via open canals, are flowing into the sewage system causing significant amounts of highly diluted wastewater in wet periods, creating additional hydraulic load to the sewage system. Due to heavy precipitation additional quantities of sediment is entering the sewage system.

The capacity of the WWTP is limited and in order to provide undisturbed operation of the plant during severe rainfall events excess of the water overflows to Sava River prior to entering the plant.

1.4. WATER RELATED ISSUES AND CHALLENGES

The water supply system is characterized with high water losses. It is estimated that the difference between the amount of water entering the system and the amount of water that is consumed is between 40 and 50 [%]. This practically means that approximately 135.000 [m^3] of potable water leaks every day in Zagreb. The economic value of these losses is estimated to be 200.000 [€/d]. Such losses in water supply system are due to several reasons, some of which include outdated parts of the water supply system, high pressure and non-economic water price. Another issue is the lack of a complete register of water installations, as well as the rehabilitation of the network in the old parts of the city.

The main sewage system problem is the disposal of the sludge from WWTP. The issue of final disposal of sludge still remains unsolved, which poses a significant problem in the operation and maintenance of this plant. Current solution includes anaerobic sludge stabilization with energetic use of biogas at WWTP and the temporary sludge storage at the treatment plant. The City of Zagreb is in the planning process for a combined solid waste and strained sludge incinerator, as the final solution for the disposal of sludge from the Central Wastewater Treatment Plant of Zagreb.

2. Pilot case 1: Developed area

2.1. General description

The developed case study area is located on the left bank and directly by the Sava River. This part of the city is called Borovje. Borovje is one of the newly built parts of the city and it is located southwest of the city center. Being relatively new this area is still under construction with residential and commercial buildings. The area of the analysis covers a total area of 115.000 [m^2] (11.5 [ha]), which makes most of Borovje. Borovje is one part of a larger administrative unit Savica Sanci with total of 5.710 inhabitants.

Figure 2.1.1 Analyzed location area within the city

Land-use of the analyzed area includes residential buildings, a substantial portion of green areas surrounding residential buildings, parking lots and one primary school. Most of the residential facilities are five-storey buildings. There are about ten residential houses. The number of households in the analyzed area is 526, with total of 1.565 inhabitants. Although most of the households are connected to the sewage network intention is to connect all the households.

Borovje is completely covered by water supply network. Based on the data obtained by the water company the average water consumption for the analyzed area is about 10.350 [m^3] per month. This implies that average per capita water use is 220 liters per person per day.

The terrain topology of the area is predominantly flat with a gentle slope towards the northeast. Lithological composition is mainly gravel covered by the roof of clay-sand mixture. Deeper underneath the gravel is mostly clay.

Figure 2.1.2 Map of the analyzed developed area

The entire area is covered with a combined sewage network without additional stormwater infrastructures or pumping stations. Drainage network has the same orientation as the terrain. Stormwater drains through a large number of street gutters into the sewage network. Total length of sewage network is 2.690 [m] with pipe inside diameter ranging from 400 [mm] to 3.000 [mm]. Wastewaters from the entire area are drained to the main conduit pipe that directs water to central wastewater treatment plant.

During 5-year design storm rain events more than 610 liters per second of stormwater drains from the study area by the sewage network.

Official trusted data considering the occurrence of rain floods were not available for this analysis. By interviewing local residents is it was found out that some local flooding did occur in the last 20 years. For the analyzed area, as well as the city of Zagreb increased risk of flooding exists in the case of heavy precipitation accompanied with high water level of the Sava River. In this case high groundwater table and saturated soil occurs and the excess precipitation that doesn't enter the sewage is retained on the surface. The possibility of the river floods is minimal since river embankment protection is designed for the river discharge with a return period of 1.000 years, Figure 2.1.3. Also the river bottom decreased in the last 40 years due to erosion control works, excessive gravel extraction, construction of various dams and regulation works on the Sava River and its tributaries. However, the risk of embankment failure exists. The most catastrophic flood of Zagreb caused by the Sava River occurred on 26 November 1964. The river embankment was destroyed in several places and water flooded about 60 [km^2] of Zagreb region.

Figure 2.1.3. Embankment protecting Borovje from high water levels of Sava River

Due to urbanization a change in the land use occurs creating additional impervious surfaces. This alters the natural vegetation and natural infiltration and more water is drained into the sewage. These impacts also result in changing the quality of stormwater runoff. Currently there is no control of pollution coming from roadways and parking lots which lead to increased sedimentation in runoff. These excessive levels of sediment often tend to clog gutters increasing the risk of stormwater flooding. Gutters are rarely cleaned which represents one of general problems in stormwater management.

Additional problem related to the study area are significant quantities of groundwater that infiltrate the sewer system through cracks in pipes.

Since Borovje is built according to existing urban planning that favors conventional sewage and drainage solutions there is little possibility for implementing large surface structures for sustainable drainage system. Most of the unconstructed area is intended for residential buildings therefore it is possible to implement only smaller sustainable drainage structures.

By applying structures for sustainable drainage systems the reduction of precipitation that runs off into the sewer can be expected. Thereby reducing the cost of wastewater treatment at the WWTP as well as reducing the required pipe profiles in drainage network can be achieved. Also better stormwater pollution control can be accomplished.

2.2. GENERAL MODEL DATA

Average value of electricity price has been obtained from the electric energy distributer, a company called HEP Group (Hrvatska elektroprivreda). An average value of the said price (including monthly fees, differences between electricity prices during different period of the day etc.) is 0,13 [€/kWh].

The value of electricity carbon emissions has been selected using the default value provided by the software. In this case, it was 0,236 [kg CO_2/kWh]. Unfortunately, we were unable to find any official (trusted) data to confirm if this estimated value is correct.

Period of analysis is 20 years. This value has been chosen in order to determine long scale effects (total costs of different scenarios, environmental impacts etc.) of proposed solutions. Longer periods would result in very unreliable results of the analysis, due to many uncertainties (discount rate, change in weather patterns etc.)

Economic discount rate was chosen at 5.5 [%], a value recommended by the Agency for Public Private Partnership. The afore mentioned agency is the central national body which conducts the procedure for the approval of various infrastructure projects funded both publicly and privately.

Rainfall data was taken from the Statistical Yearbook of Republic of Croatia for the year 2013, made by the Croatian Bureau of Statistics. The mentioned yearbook contains data on average annual precipitation change for the period of 1961 – 2010, which was created by the Croatian Meteorological and Hydrological Service. Data from the measuring station in Zagreb nearest to the analyzed location (Borovje) was selected as input values for the model.

Data on daily temperatures distribution was a bit more difficult to obtain. All publicly available data usually contained only average monthly and daily temperature values. Daily distribution of temperatures was found only for the period of 1941 – 1950 (created by A.Penzar, 1977), so the values were slightly altered to meet current average temperatures.

A flood event has been chosen with a return period of 20 years, as it has been estimated that proposed water management scenarios should prevent flooding of the analyzed area caused by rain events with higher probability of occurrence (lower return periods).

2.3. Scenario 1: Conventional development

2.3.1. General description

Sewer system in the analyzed area is a combined sewer system designed to remove rainfall from the urban area as quickly as possible. It consists of a conventional pipe network with pipe diameters ranging from 400 to 1200 [mm], with two connections to the main combined sewage pipe (D = 3000 [mm]) located north of the area. The main combined sewage pipe transports the combined wastewater to the WWTP solely by gravity; there are no pumping stations located between the analyzed area and the WWTP. Prior to the WWTP a weir is located which allows the wastewater to overflow directly into the Sava river if the hydraulic load is too large for the WWTP.

If an improvement of the existing sewage system is to be made, then it should provide at least one of the following benefits:

- reduction of stormwater runoff peaks entering the existing main drainage pipe, which will reduce the frequency of combined wastewater overflowing events into the Sava river prior to the entrance to the WWTP
- reduction of annual volume of wastewater entering the system, which should result in lower water treatment costs at the WWTP

Taking into consideration the previously determined goals, an improvement of the existing system by adding conventional drainage infrastructure has been designed.

In order to reduce the inflow into the main combined sewage pipe conventional solution is designed with two detention structures whose total volume is 300 [m^3]. These stormwater storage tanks are used to reduce runoff peaks into the existing sewage network. Their purpose is also to retain the stormwater flush for the sediment treatment. Storage tanks are located at the point where sewer network exits the study area and connects to the main sewage pipe. Because the available area for these facilities is rather limited they are designed as in-line storage. This solution allows only temporarily sedimentation thus limiting the potential for water quality control.

The designed solution is presented in Figure 2.3.1.1.

Apart from sewer network all households are comprised of conventional roofs, both flat and stepped. Impervious surfaces are used for all pavements and parking lots. All of these structures collect water and transport it to the drainage network through gutters without the possibility of infiltration into the soil.

Within the conventional solution combined sewer overflows were also considered. Although overflows reduce the amount of water entering wastewater treatment plant thus reducing energy consumption they may produce environmental problems when overflow water is released in natural water bodies. Overflows are not included into conventional solution due to terrain orientation. They would be located the farthest point of the Sava River and would require very long overflow pipe or canal. Also this rather expensive solution is not required since large overflow structure exists prior to wastewater treatment plant.

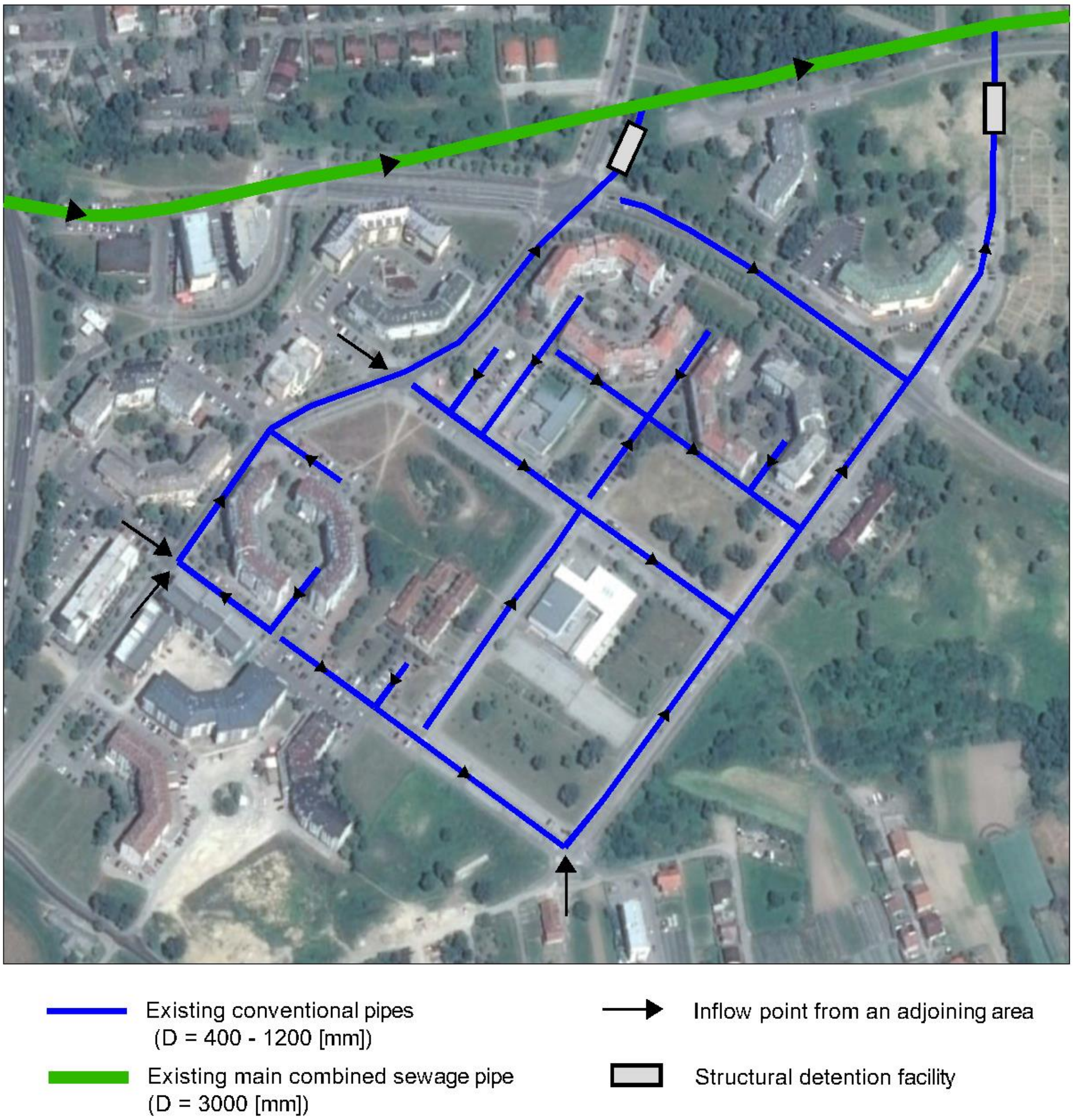

Figure 2.3.1.1 Analyzed conventional drainage system scenario

Some of pretreatment devices such as catch basin inserts could be used. However these structures are not part of standard stormwater management practice in Croatia. Since these structures are not predefined in decision support tool relevant data necessary for their incorporation in conventional drainage system would be very hard to obtain.

2.3.2. Drainage infrastructures included in the scenario

Existing conventional drainage infrastructure in the analyzed area consists of conventional gravity pipe network, conventional roofs and standard pavement. The only infrastructures added by this solution are two stormwater detention facilities.

Underground stormwater detention facilities allow high volume storage of runoff in a relatively small footprint area. The storage objects can be made from a variety of materials, including corrugated metal pipe, aluminum, steel, plastic, fiberglass, pre-cast or poured-in-place concrete.

Concrete detention chamber systems or tanks are much more expensive to construct than stormwater ponds. However in densely developed areas where space for surface stormwater management facilities is scarce or highly valued, underground treatment practices like detention chambers and tanks may be the only feasible option. Detention facilities typically are not designed for containing sediment or other type of water quality control.

In this proposed solution, two concrete underground detention facilities with volumes of 50 [m^3] and 250 [m^3] have been chosen (total volume of 300 m^3); their total construction cost is 81.000 [€].

Construction costs of drainage infrastructure have been changed to values which can be expected from contractors operating in Croatia. It has been difficult to find average unit construction costs for the majority of the infrastructure given by the DST software. Conventional drainage infrastructure unit costs (pipe network, standard pavement, structural detention facility) have been chosen by examining costs of completed stormwater sewage systems in Croatia. A lot of data has been gathered and discussed in the dissertation *Expert decision support system in selection of optimum sewerage system in rural communities* (D.Vouk, Faculty of Civil Engineering University of Zagreb, 2009) which provided us with even more information on conventional infrastructure construction costs.

The ratio of construction costs which can be expected in Croatia and default DST values ranges from 66 to 90 [%]. We believe that a good approximation can be made if the default values are reduced by 30 [%], i.e. 70 [%] of the DST default values roughly approximates the infrastructure construction costs in Croatia.

2.3.3. Water reuse

Proposed conventional solution does not provide rainwater reuse.

2.3.4. Stormwater runoff

The hydrologic and hydraulic analysis is performed using EPA's (Environmental Protection Agency) Storm Water Management Model (SWMM) software since it has the possibility to model the performance of specific types of low impact development controls, such as SuDS. Dynamic wave rainfall-runoff routing simulation was used for a single-event with a 5-year return period and 20-year return period.

After node elevation values were obtained and geometrical characteristics of the drainage system was entered according to the conventional drainage scenario, it was necessary to determine the adequate response of the watershed to a rain event. Initial analysis showed that time of concentration for the surfaces that generate most of the runoff was 35 minutes. The time of concentration represents the time at which all areas of the watershed are contributing to the outlet runoff and storm duration for estimating peak discharges is equal to the time of concentration. For this rainfall duration a constant rainfall value (hyetograph) of 54 [mm/h] was used for 5-year design storm and 72 [mm/h] for 20-year design storm. The values are obtained from the intensity-duration-frequency curves for Zagreb.

Since the flooding was also the object of interest the entire area was considered for the drainage. In this case the watershed time of concentration is extended. However this effect is neglected in order to obtain highest and critical runoff values for which the system is designed. Surface permeability was assessed based on detail digital area images. Horton's infiltration model was selected and soil characteristics are defined according to the experience from similar analysis and data from the literature values.

For some of the parameters a sensitivity analysis was performed in order to obtain relevant values.

Analyzed sewage system consists of the existing drainage network and two stormwater detention facilities designed for a 5-year design storm. It is assumed that this design storm occurs under conditions in which soil is partially saturated and has some minimum infiltration ability. Two detention facilities for two subbasins with a total volume of 300 [m^3] are required, one with 50 [m^3] and other with 250 [m^3]. Pipe diameter size range from 400 [mm] to 1200 [mm].

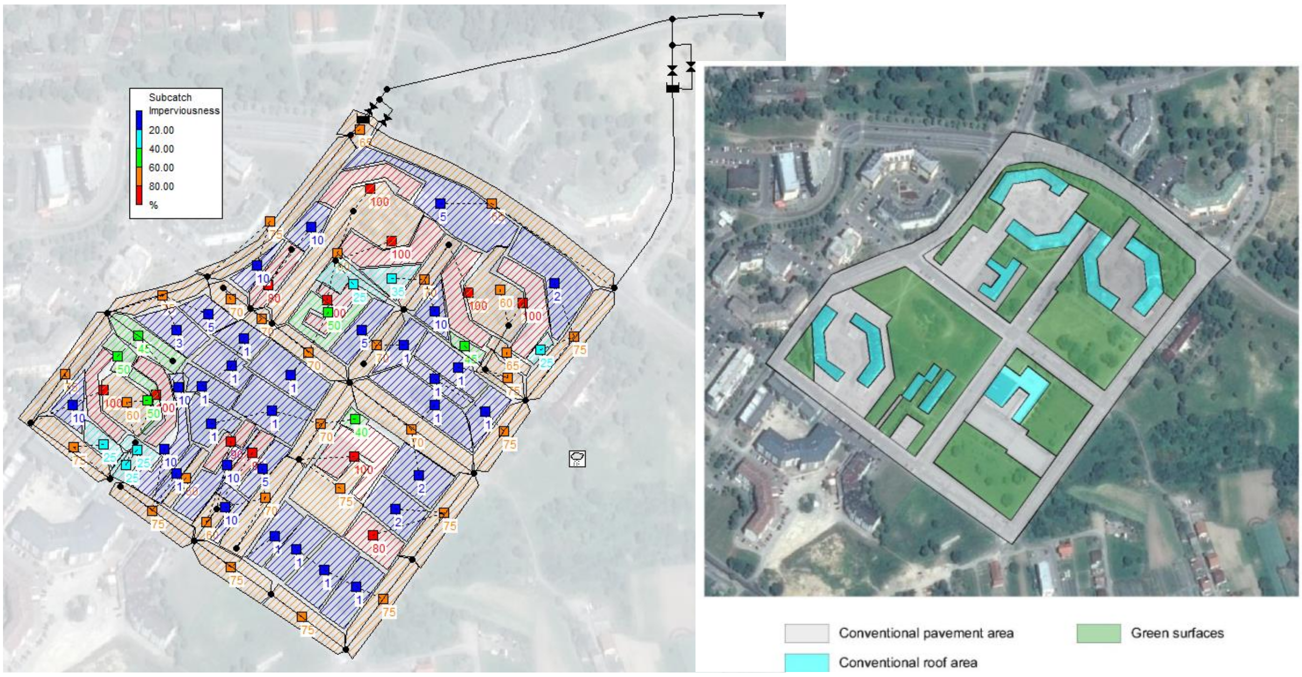

Figure 2.3.4.1 Surface types for the conventional drainage scenario

Maximum runoff value for 5-year design storm is 460 [l/s], Figure 2.3.4.2.

For the existing drainage conditions (without detention structures) maximum runoff occurring for 5-year design storm is 695 l/s. By using stormwater detention structure a peak runoff from a subbasin can be significantly reduced. This has a positive downstream effects which are related to the reduced possibility of flooding and the recipient water quality due to the reduced possibility of wastewater overflow prior to the WWTP. Also, downstream of the detention facilities required pipe diameters could be reduced.

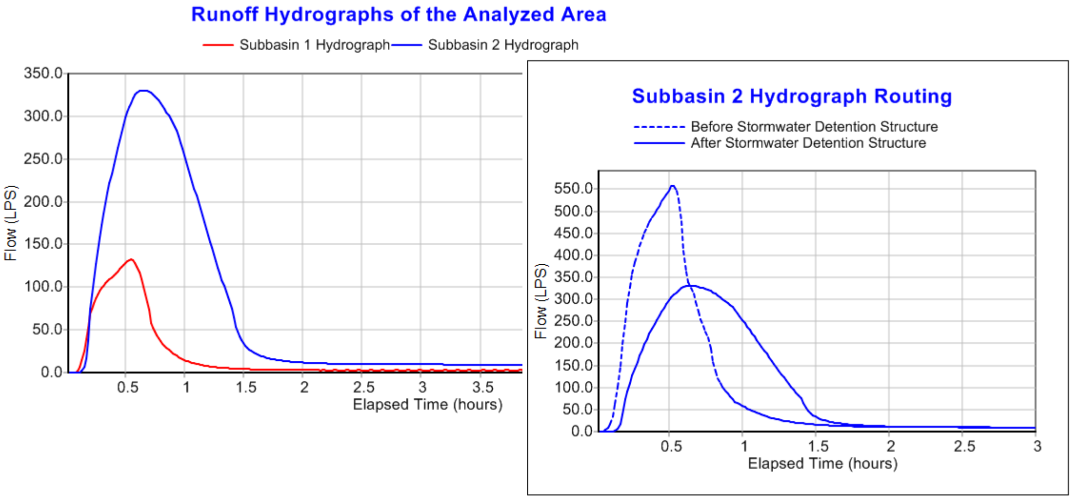

Figure 2.3.4.2 Runoff hydrographs of the analyzed area

For each subcatchment a runoff coefficient is obtained from SWMM model resulting with an average runoff coefficient of the analyzed area in the value of 0.59. Since there is an average of 1.060 mm of rainfall per year, runoff volume from the area of analysis per year is approximately 71 930 [m^3]. This result corresponds well to the runoff volume obtained with DST tool (70.758 [m^3]).

2.3.5. Conveyance and treatment

Since this drainage infrastructure scenario takes into account conventional gravity sewer, water pumping cost and energy consumption were not analyzed. Wastewater from the analyzed area is not pumped until it reaches WWTP.

Data regarding water treatment cost and energy consumption were obtained from the company Zagreb Waste Waters Ltd. that manages the plant. According to the obtained data total annual operation and maintenance costs are 14 million euros respectively or 0.1 [€/m^3] of treated water. Total energy consumption in average is 22.013.300 [kWh] and the total annual wastewate inflow is slightly under 134 million cubic meters per year giving 0,164 [kWh/m^3] as the unit amount of energy consumption.

Energy consumption, emissions and cost of operation of the WWTP could not be divided into wastewater treatment and pumping categories as required by the DST, since this data is not available. Although wastewater is pumped at the entrance of the WWTP, only an aggregated cost and energy consumption value was obtained from the previously mentioned company.

Therefore, in the DST software, pumping costs of the WWTP, as well as its respective emissions and energy consumption are considered as part of stormwater treatment, not stormwater pumping.

The default CO_2 emission value due to electricity consumption for Croatia is 0,236 [kg CO_2/kWh]. This value together with total energy consumption at WWTP gives treatment emission value in the amount of 0,039 [kg CO_2/m^3]. In reality this value is even lower since Zagreb WWTP produces energy from anaerobic digestion that is used for treatment processes at the plant. In some period during the year energy production is such that it covers all the treatment energy needs.

Treatment costs, energy consumption and treatment emissions are also estimated with the decision support tool by entering data for annual volume treated at the treatment plant, treatment plant age and type of treatment process. Values obtained with DST are significantly different than those given by managing company. For example, estimated treatment costs are 0,067 [€/m^3] which is a much lower value and treatment emissions are 0,064 [kg CO_2 /m^3] which is much higher value.

The main problem concerning this part of the analysis is that it is not possible to determine whether some portion or all of the stormwater from this area is released through combined sewer overflow prior to the plant. Thus it is not possible to determine the reliability of these results.

Global results obtained in this tab:

Volume of stormwater conveyed [m^3/year]	0
Volume of stormwater treated [m^3/year]	70.758
Total costs [€/year]	7.075,8
Total energy consumed [kWh/year]	11.604
Total emissions [kg CO_2/year]	2.745,4

2.3.6. Water quality

Runoff from urban areas contains many different types of pollutants whose impact on receiving water bodies must be minimized.

A qualitative estimation of pollutants removal efficiency of each infrastructure in the conventional drainage scenario is consistent with their basic characteristics regarding water quality control. This means that there is a possibility for partial removal of suspended solids while nutrient removal efficiency and heavy metals removal efficiency is very small or missing.

For the conventional drainage infrastructure scenario structural detention facility has medium total suspended solids removal efficiency while pipe network has low removal efficiency. The same structures have low efficiency in heavy metals removal.

Conventional roofs and standard pavement have no impact on removal efficiency for three considered types of pollutants.

Combined sewage water from the analyzed area flows into a main combined sewage pipe which transports wastewater to the wastewater treatment plant. This plant is designed to treat the wastewater of the entire Zagreb area. Since it is a high capacity plant, improvement of wastewater quality produced in the area as small as Borovje will not result in a noticeable change of outflow water quality of the plant designed to treat much higher volumes of water.

A qualitative estimation of treated water quality has been made taking into account the data relating the wastewater treatment plant in Zagreb for which typical values concerning the reduction of organic matter expressed as BOD_5 is 96 percent. Efficiency of organic matter removal expressed as COD is 92 percent, while reducing suspended solids is accounted for 98 percent.

Local water quality improvement will produce some benefits, both ecological and economical (reduction of treatment costs), but this effect will not be visible if the outflow water quality from the analyzed area is considered as the effluent from treatment plant.

Thus Global Outflow Quality cells have been filled in with data on water quality at the point where conventional pipes from Borovje region connect to the main combined sewage pipe. The level of water treatment achieved only by the conventional infrastructure is being observed.

Since the conventional and SuDS scenarios provide different levels of water treatment, we believe it is more efficient to observe the difference in water quality when it flows into the main sewage pipe then its difference after treatment (which, as previously mentioned, would be impossible to detect).

Global water quality for this scenario has been estimated with the following parameters:

Suspended solids removal efficiency:	low
Nutrient removal efficiency:	none
Heavy metals removal efficiency:	low
Average water quality:	low

2.3.7. Flood protection

The possibility of flooding for the analyzed area occurs in the case of heavy precipitation accompanied with high water level of the Sava River causing high groundwater table and saturated soil. In this case the excess of precipitation is retained on the surface due to less infiltration capacity and sewer inability to absorb the excess water.

Conventional systems are usually designed to convey water as quickly as possible or gradually release it downstream. Sustainable drainage infrastructures typically store surface water aiming to infiltrate it into the ground or to the environment.

The existing drainage condition consists of pipe network designed in a way to eliminate risk from flooding caused by rain events with a return period of 5 years. Rainfall events with higher return periods will not necessarily cause flooding of housing areas as rainwater gutters and shafts provide additional detention storage and flooding will primarily occur in the streets, not houses.

Therefore, rainfall events with a return period of 20 years have been chosen for this analysis since the preliminary analysis showed that events with lower return periods will not cause the occurrence of water on the terrain surface thus flooding of the residential areas. For 20-year design storm simulation a fully saturated soil is assumed.

With the existing drainage condition some local flooding occurs in parts where the drainage network has a minimum diameters and is close to the terrain surface, Figure 2.3.7.1.

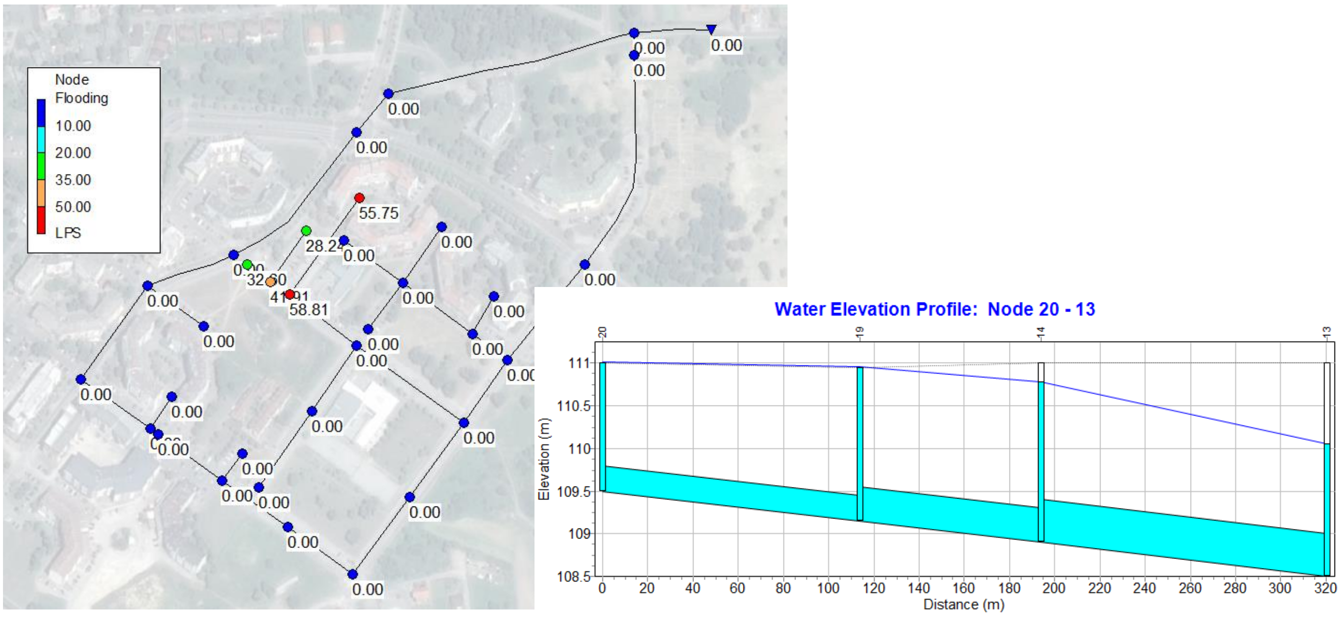

Figure 2.3.7.1 Local flooding occurs after fully meeting the sewer system capacity

Flooding occurs since there is no possibility of quick soil infiltration and the sewer network capacity does not meet the need for the excess of rainfall volume that occurs. Potential areas affected by flooding were estimated with a SWMM hydraulic model. Analyzed area which does not include roof surfaces is associated with model junctions in order to allow ponding. Maximum runoff occurring from the analyzed area is 1 225 l/s. In total, 12 180 m^2 are affected by surface flooding with an average height of 17 mm. It was determined that about 15 households would be affected by a flood. This refers primarily to basement areas.

Also, through the interaction with the local residents, that could remember the last flood event, it was determined that average occurred water depth due to storm flooding was not more than 10 cm. Also around 10 households were affected and the flooding water affected only basement areas. It was also determined that the average economic damage per household estimated by affected local residents is around 9 500 euros. Thereby the data regarding economic damage obtained from the analyzed area corresponds well to the data available for flood protection benefits analysis in the DST tool where average damage per household is related to the flooding water depth.

In the case with a conventional development with two stormwater detention structures a maximum runoff of 1 150 l/s is realized. This lower value realizes due to a partial attenuation of the runoff at the bottom of the stormwater detention structure. When the water in the detention structure reaches the weir height the rest of the runoff overflows through weir. In this way overflow increases the downstream flow and the drainage system acts as a system without detention structures, thus as in the existing drainage conditions.

This conventional development with a detention structures has a very small effect on the flooding if the return period of rainfall is much greater than the detention structure design period. For rainfall periods slightly higher that the design period detention structures can still cause the reduction of the peak runoff, thus protecting the downstream area from flooding.

For a 20-year design storm it was determined that no major changes compared to the existing conditions occurs. About 15 households would be affected on the same flooding area with an average of 17 mm of rain water height, Figure 2.3.7.2.

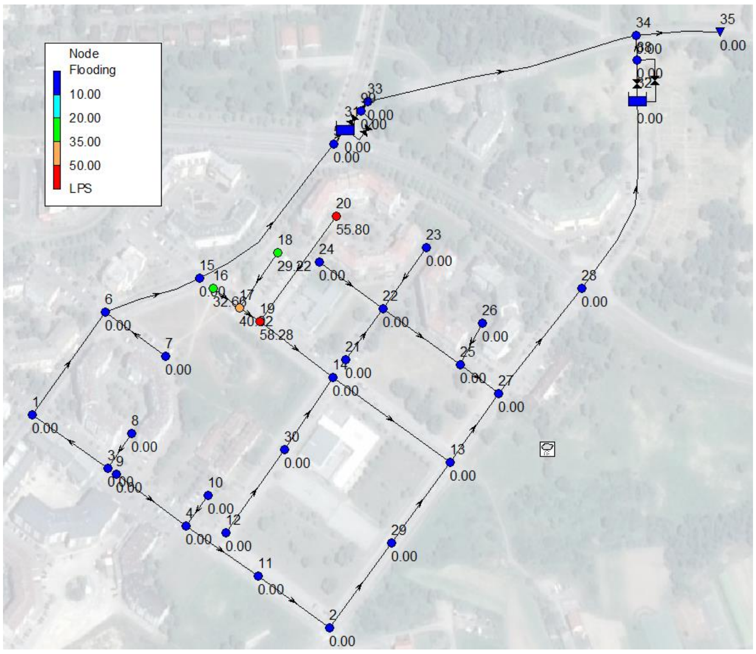

Figure 2.3.7.2 Flooding in the case with a conventional development

The economic consequences of the flooding events for the analyzed area were estimated using affected households method. Benefits of a drainage scenario are computed comparing the situations with and without additional two stormwater detention structures. In the conventional development scenario with additional detention structures significant flood protection benefits are not achieved.

2.3.8. Building insulation

Conventional drainage infrastructures are not related with building insulation benefits since they do not provide thermal cover from solar radiation or have a positive effect in terms of cooling buildings during the warmer summer months.

2.3.9. Ecosystem services

There are no benefits in carbon reduction as the conventional solution does not account for any additional trees planting or increase of existing green surfaces.

Conventional drainage infrastructures in general do not provide additional ecosystem benefits other than wastewater drainage and low level of wastewater treatment thus reducing the negative effects on human health, freshwater bodies and receiving water body characteristics. However they can provide additional dry surfaces during the rain events, but sewer can also be a concern due to odor, noise and potential for fire or explosion due to sewer gasses occurrence. Thus global ecosystem services evaluation in the decision support tool is set to be very low.

2.3.10. Summary

	Conventional solution		
	Financial cost [€]	Energy consumption [kWh]	Emissions [kg CO_2]
Construction of infrastructures	81.000,00	254,787,00	80.706,00
	Financial cost [€/year]	Energy consumption [kWh/year]	Emissions [kg CO_2/year]
Maintenance of infrastructures	300,00	72,00	18,00
Infrastructure landtake	0,00	-	-
Potable water consumed and saved	0,00	0,00	0,00
Wastewater conveyance and treatment	7.075,80	11.604,31	2.745,41
Flood protection	0,00	-	-
Building insulation	0,00	0,00	0,00
Carbon dioxide reduction	-	-	0,00
Other costs and benefits	0,00	0,00	0,00

Table 2.3.10-I Data summary from the DsT software for the conventional scenario

	Conventional solution	
	Energy consumption [kWh/m^3]	Emissions [kg CO_2/m^3]
Water supply acquisition, conveyance and distribution	0,4	0,4
Wastewater conveyance	0,00	0,00
Wastewater treatment	0,164	0,0388

Table 2.3.10-II Energy consumed in the urban water cycle for the conventional scenario

2.4. Scenario 2: Development with SuDS

2.4.1. General description

Existing sewage system needs to be improved in a way to achieve at least one of the goals previously defined in section 2.3.1:

- reduction of stormwater runoff peaks entering the existing main drainage pipe, which will reduce the frequency of combined wastewater overflowing events into the Sava river prior to the entrance to the WWTP
- reduction of annual volume of wastewater entering the system, which should result in lower water treatment costs at the WWTP

Current sewage system improvement using SuDS infrastructure has been designed in a way to reduce stormwater runoff from the area, increase energy efficiency and increase the areas value by constructing green infrastructure.

Since a high portion of the analyzed area is covered with standard pavement, construction of bioretention areas is proposed as a solution which will allow higher infiltration of the rainwater into the ground. Bioretention areas should be placed on parking areas and pedestrian pathways, and apart from reducing the annual runoff from the area should provide additional benefits to the local ecosystem.

Total of 65 rain barrels (water butts) will be placed next to existing buildings in order to collect rainwater. Some of the existing green areas are being used as urban gardens and the local population uses them to grow vegetables. Water butts should be useful in providing part of the water needed for irrigation of this gardens.

Rainwater draining form the existing roofs will be collected in the previously mentioned water butts, and the excess water will overflow into soakways, allowing the rainwater to infiltrate into the ground more effectively.

Portion of the rainwater which will not be able to infiltrate into the ground will be transported to the main combined sewage pipe by existing conventional combined sewage pipe network. After it reaches the main combined sewage pipe it will be transported the water to the city sewage treatment plant and released it into the river Sava after treatment.

Green roofs will be placed on a portion of a local pharmacy's existing roof, covering an area of 200 [m^2]. This infrastructure provides very little energy savings and very small reduction of runoff, but has a significant social impact. Although it does not serve to achieve any of the two goals mentioned at the beginning of this section, it has been chosen as it has a positive effect on the local ecosystem and can influence local population and raise awareness of the importance of energy conservation and environmental protection.

Detention basins or a similar infrastructure which could provide significant runoff peak reduction could not be used as the existing sewage system is a combined one and sanitary wastewater should not be allowed to infiltrate into the ground or retain at the surface without intensive previous treatment.

The designed solution is presented in Figure 2.4.1.1.

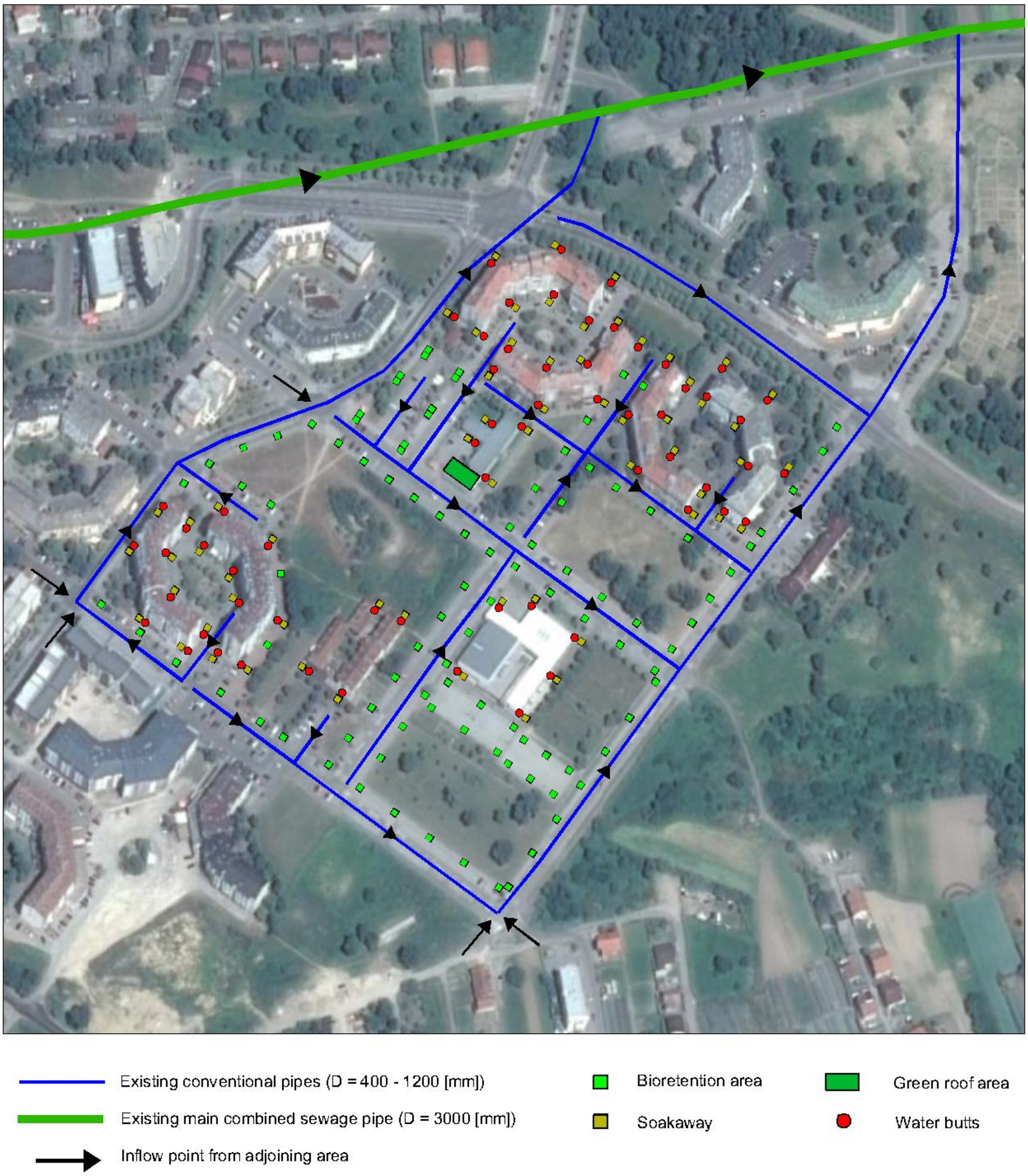

Figure 2.4.1.1 Analyzed scenario with SuDS infrastructure

2.4.2. Drainage infrastructures included in the scenario

Existing conventional drainage infrastructure in the analyzed area consists of conventional gravity pipe network, conventional roofs and standard pavement. The additional SuDS infrastructures in the proposed solution are:

1. Bioretention areas

Bioretention areas will be constructed on low traffic load areas, such as parking lots and paved pedestrian pathways. Total proposed area of this surface is 220 [m^2], with the total construction cost of 16.500 [€].

2. Water butts

Water butts will be placed next to the existing buildings. 65 water butts with a capacity of 1 [m^3] each (total of 65 [m^3]) have been chosen. It is estimated that a total volume of 1300 [m^3] of rainwater could be gathered and used for irrigation each year. This estimate has been given by the local residents who tend to urban gardens. Construction cost of this infrastructure is 11.375 [€].

3. Soakaways

Sokaways will be placed next to the proposed water butts so the excess water can overflow into them and infiltrate into the ground. Total volume of the proposed infrastructure is 220 [m^3] (3.38 [m^3] per soakway), with the total construction cost of 26.400 [€]. Figure 2.4.2.1. shows the placement of the water butts next to the soakaways and their interaction.

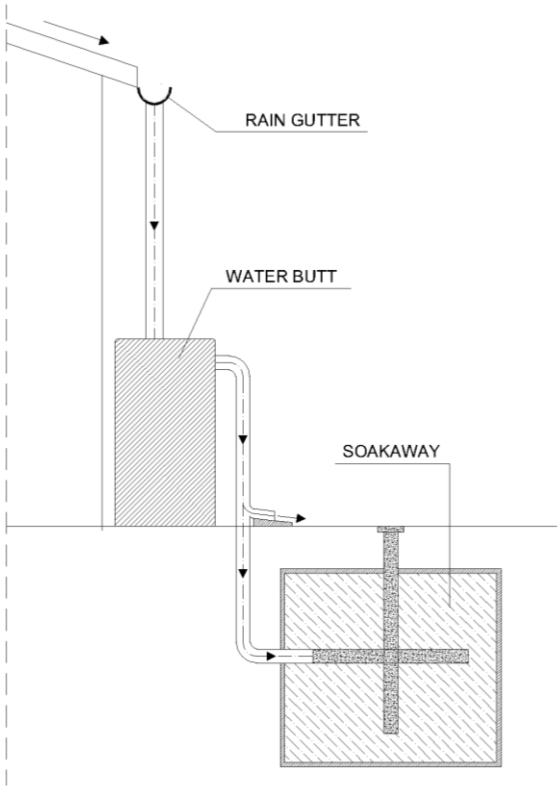

Figure 2.4.2.1 Placement of soakaways next to water butts

4. Green roof

Green roof should be fitted on the portion of the existing roof of the local pharmacy. Total area of this infrastructure is 200 [m^2], with the total construction cost of 26.000 [€].

Unit construction costs of conventional drainage infrastructure have been adapted to meet the local conditions, as it has been explained in section 2.3.2.

Most of the SUDS infrastructure has been rarely or never constructed in Croatia, which made the process of estimating the costs very difficult. Still, an estimation has been made by calculating total costs of work and material required for the desired infrastructure.

Calculations have shown that the average unit construction costs are roughly 30[%] cheaper than the DST default values, so the default values have been altered by multiplying them with a factor of 0.7 in order to gain locally accurate results.

For all the drainage infrastructure included in both scenarios, energy consumptions and emissions during construction and maintenance are estimated according to the default DST software values.

2.4.3. Water reuse

Water supply costs have been obtained from the Zagreb Holding company Vodoopskrba i odvodnja, d.o.o. (VIO), located in Zagreb, which deals with water supply and wastewater management of Zagreb region. The total cost of water consists of fixed monthly fee and a variable amount which is based on water consumption. Those values have been aggregated into a single cost of 2.1 [€/m^3].

Data on the energy consumption in water acquisition, conveyance and distribution was obtained from the previously mentioned company. Gathered data on the energy consumption was not divided into the three categories given in the software; only an average energy consumption for the entire process (from acquisition to distribution) for the city region where Borovje is located was given. This value is 0.4 [kWh/m^3].

A comparison of gathered and estimated data on energy consumption was not possible, as the data on the height difference of the water source and pipe length from the acquisition site to the analyzed location was unavailable. Without this data an estimation given by the software could not be conducted, nor a comparison of these two types of data.

Detailed data regarding water acquisition, conveyance and distribution emissions are not known and could not be obtained since water supplier does not manage these data. However data regarding overall energy consumption have been obtained from 17 Croatian water supplying companies. From these data total average emission in all water related activities is given at 0.4 kg [CO_2/m^3].

Energy consumption and CO_2 emissions values have been entered in the *Energy consumption in water distribution* cell, but they refer to the entire process of supplying water to the consumers.

Water losses in the Zagreb water supply network are very high, around 45 [%], a value also given by VIO.

Amount of reused rainwater is 1300 [m^3], an amount which is estimated to be used for urban garden irrigation by local population. This amount will be gathered using water butts assuming that full capacity of each water butt will be used twenty times during the course of one year.

Global results obtained in this tab:

Total benefits [€/year]	2.730
Total energy saved [kWh/year]	945,45
Total emissions avoided [kg CO_2/year]	945,45

2.4.4. Stormwater runoff

Stormwater runoff analysis was performed with SMWW model in which SuDS are included on a per-unit catchment area. For each catchment an adequate low impact development was defined according to used SuDS infrastructure. In this way low impact development is an intrinsic property of a catchment area. In this scenario water butts and soakaways were provided for impermeable roof surfaces and bioretention areas are used for parking lots and sidewalks. Also a small green roof is used as a one part of the roof on a one low building.

Subcatchments which are affected by SuDS are shown in Figure 2.4.4.1.

Figure 2.4.4.1 Area of the subcatchment occupied with SuDS infrastructure

For some catchments multiple LID's (Low Impact developments) were used. Each of the model parameter compartments were obtained through literature values for local conditions and thorough sensitivity analysis.

The internal catchment routing of runoff between pervious and impervious areas is set directly to the outlet thus runoff from both areas flows directly into the model junction. For green areas which do not drain directly to the sewage flow paths are defined according to the terrain slope.

Water quality and the production of pollutant loads associated with stormwater runoff were not analyzed due to insufficient data.

5-year design storm results with a maximum runoff peak of 570 [l/s] which represents a decrease of 18 [%] respectively, regarding the existing sewer network. However, this runoff value is 24 [%] higher than the runoff peak achieved with the conventional drainage scenario since only the rainfall from roof surface areas is excluded from drainage network.

The incorporation of SuDS into the stormwater management can be effective at reducing the peak runoff rates. This maximum runoff reduction is achieved on account of increased infiltration due to usage of soakaways and bioretentions. It can also benefits the need for smaller diameter pipes. Thus an average runoff coefficient for the SuDS scenario model is 0.50 and it is smaller than the one for the conventional scenario. Since there is an average of 1060 [mm] of rainfall per year estimated runoff volume per year is 61.250 [m^3].

Runoff volume is also obtained with the estimation panel in the decision support tool. Size of upstream drainage area of each drainage infrastructure is obtained from digital aerial map. Corresponding runoff coefficients were taken as recommended values in Table 2.12 from E²STORMED decision support tool guidelines. A yearly runoff value obtained by the DST software differs by 10 [%] than the one calculated (57.653 [m^3]), but the results are still matching.

2.4.5. Conveyance and treatment

Wastewater is transported to the treatment plant solely by gravity, so there are no pumping costs or respective carbon emission.

Water treatment costs, energy consumption, and emissions have been given in point 2.3.5.

Global results obtained in this tab:

Volume of stormwater conveyed [m^3/year]	0
Volume of stormwater treated [m^3/year]	57.657
Total costs [€/year]	5765,7
Total energy consumed [kWh/year]	9.455,7
Total emissions [kg CO_2/year]	2.237,1

2.4.6. Water quality

Remarks regarding this section of analysis have been given in section 3.6.

Most of the SuDS infrastructure was chosen to increase infiltration of rainwater into the ground; it was not chosen to provide stormwater treatment prior its entrance into the existing sewage system as such solution would be too costly to implement. Therefore, SuDS infrastructure provides almost no stormwater treatment.

By using data on water treatment by each infrastructure chosen for the SuDS scenario, following average values of global outflow water quality (sewage water leaving the Borovje region) have been chosen:

Suspended solids removal efficiency: low

Nutrient removal efficiency: low

Heavy metals removal efficiency: low

Average water quality: low

Water quality of treated water as well as the receiving body (Sava River) water sensitivity data has been entered into software, but is not used in the analysis.

2.4.7. Flood protection

The possibility of flooding for the analyzed area occurs in the case of heavy precipitation accompanied with high water level of the Sava River causing high groundwater table and saturated soil accompanied by pipe network inability to absorb the excess water. In this case the excess of precipitation is retained on the surface due to small retention capacity of the water butts and zero infiltration capability of the soakaways and bioretention areas.

As explained in section 2.3.7., rainfall event which causes flooding has been selected with a return period of 20 years under the same conditions when soil is fully saturated.

Flooding areas have been estimated using a SWMM hydraulic model. It was determined that the same surface area is covered by flood as in the case with conventional drainage scenario since the SuDS scenario is primarily focused on improving the downstream effects than the reduction of the flooding impact in the analyzed area. Approximately the same 15 households together with some parking areas would be flooded by 17 [mm] of water, Figure 2.4.7.1.

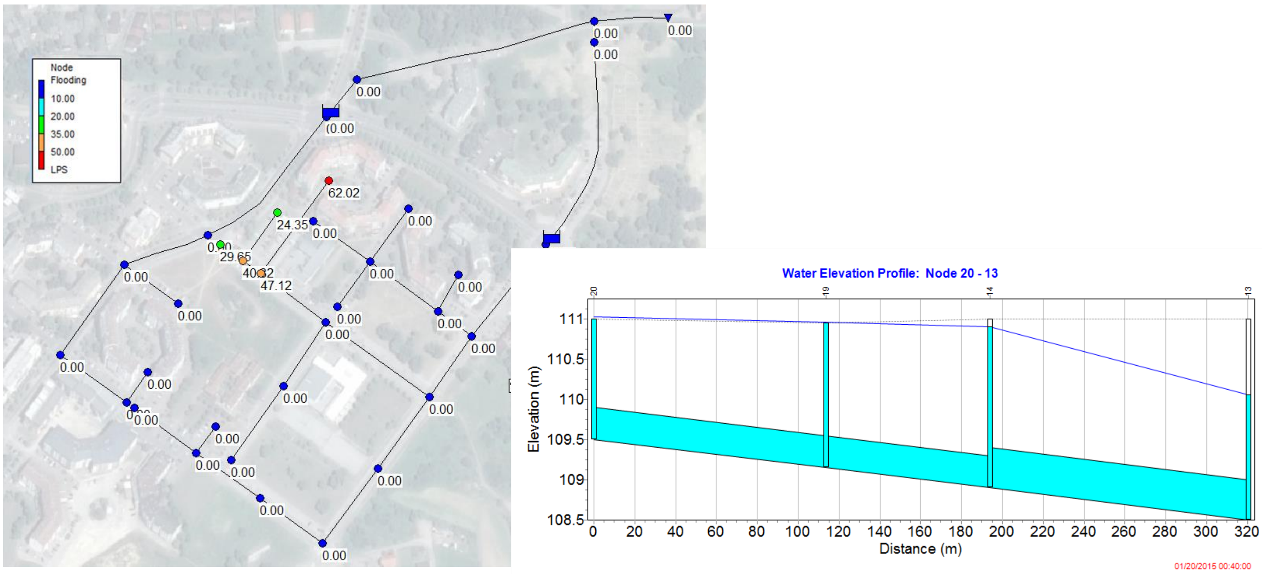

Figure 2.4.7.1 Flooded area in the scenario with SuDS infrastructure

The same water height, regarding to the conventional solution, is the result of the high rainfall return period. In this case, since the infrastructure is designed for lesser rainfall return period, the drainage system with SuDS infrastructures behaves in the same way as the conventional drainage system. With SuDS infrastructure there is only some different distribution of the surface flooding water due to the small retention capability of waterbutts. This retention capability is taken into account through two storage units in SWMM model. After the storage of the system is fully utilized the excess of the water accumulates on the terrain surface while the rest of the water is leaving the area due to the unchanged (as in the conventional scenario) pipe network diameters.

It should be noted that analyzed flooding conditions represent the worst case scenario in which there is no possibility of water infiltration due to fully saturated soil caused by high water level of the Sava River. In scenario that is more likely to occur (rainfall return period less than 20 years), the soil would not be fully saturated thus allowing a certain level of infiltration. In this case it is estimated that with the SuDS infrastructure the smaller area would be affected with flood (comparing with the same flood case and conventional infrastructure). Depending on the conditions it is even possible that the flooding, due to volume reduction through infiltration, does not occur with the SuDS scenario.

For the analyzed flooding case there is no significant difference regarding the flood protection regardless of which infrastructure is used. The same amount of water occurring in the existing conditions is realized with both infrastructure scenarios thus neither solution provides flood protection benefits.

By using the households affected method in the estimation panel it is calculated that for the analyzed scenario with an average water depth of 17 [mm] an average damage is 5.313 [€/household]. Since this is the depth at which the flooding of the basements usually occurs, this value represents a fairly accurate estimate of the damages.

2.4.8. Building insulation

Some building insulation benefits could be expected from the implementation of the green roof, however these benefits will be very small due to the small area chosen for this infrastructure. It was chosen mainly for its ecological and social benefits.

Financial and energy savings achieved by the insulation properties of the green roof have been calculated using the appropriate DST panel, and the results are:

Building insulation benefits:	9,38	[€/year]
Energy consumption avoided:	172,38	[kWh/year]
Emissions avoided:	34,89	[kg CO_2e/year]

Financial, energy and carbon reduction benefits are too small to justify the implementation of the green roof, whose construction cost is 26.000 [€] and requires additional 2000 [€/year] for maintenance. This infrastructure was chosen for its effect on the local population, its ability to change the mindset of the inhabitants. Unlike most of other SuDS infrastructure, green roofs can be easily noticed by the local population as a method of environmental restoration and might inspire them to participate more in projects regarding their neighborhood’s energy saving and environmental protection policies.

2.4.9. Ecosystem services

Two types of SuDS infrastructures chosen for this scenario can have a noticeable effect on the ecosystem: bioretention areas and the green roof.

Total area of 220 [m^2] of bioretention areas were chosen for this scenario, and around 100 trees should be planted on this area as an integral part of this infrastructure, providing carbon dioxide reduction and other environmental benefits.

Green roofs provide multiple ecological, social and aesthetical benefits such as air quality improvement, habitat provision for various species, reduction of greenhouse emissions, noise reduction etc.

Using the appropriate DST panel, carbon dioxide reduction gained from the planting of additional trees and green roof implementation was calculated:

Carbon dioxide reduced by vegetation: 3.683,60 [kg CO_2e/year]

For the analyzed scenario, carbon dioxide reduction value is very high and should result in a significant positive effect on the local ecosystem.

Global ecosystem services have been evaluated as high, since this solution assumes implementation of a lot of vegetation, which should have significant positive effects on the local ecosystem.

2.4.10. Summary

	SuDS solution		
	Financial cost [€]	Energy consumption [kWh]	Emissions [kg CO_2]
Construction of infrastructures	80.275,00	76.014,00	23.657,80
	Financial cost [€/year]	Energy consumption [kWh/year]	Emissions [kg CO_2/year]
Maintenance of infrastructures	4.905,50	1.382,20	364,40
Infrastructure landtake	0,00	-	-
Potable water consumed and saved	-2.730,00	-945,45	-945,45
Wastewater conveyance and treatment	5.765,70	9.455,75	2.237,09
Flood protection	0,00	0,00	0,00
Building insulation	-9,38	-172,38	-34,89
Carbon dioxide reduction	0,00	0,00	-3683,6
Other costs and benefits	0,00	0,00	0,00

Table 2.4.10-I Data summary from the DsT software for the scenario with SuDS infrastructure

	SuDS solution	
	Energy consumption [kWh/m^3]	Emissions [kg CO_2/m^3]
Water supply acquisition, conveyance and distribution	0,4	0,4
Wastewater conveyance	0,00	0,00
Wastewater treatment	0,164	0,0388

Table 2.4.10-II Energy consumed in the urban water cycle for the scenario with SuDS infrastructure

2.5. Results

2.5.1. Time graphs

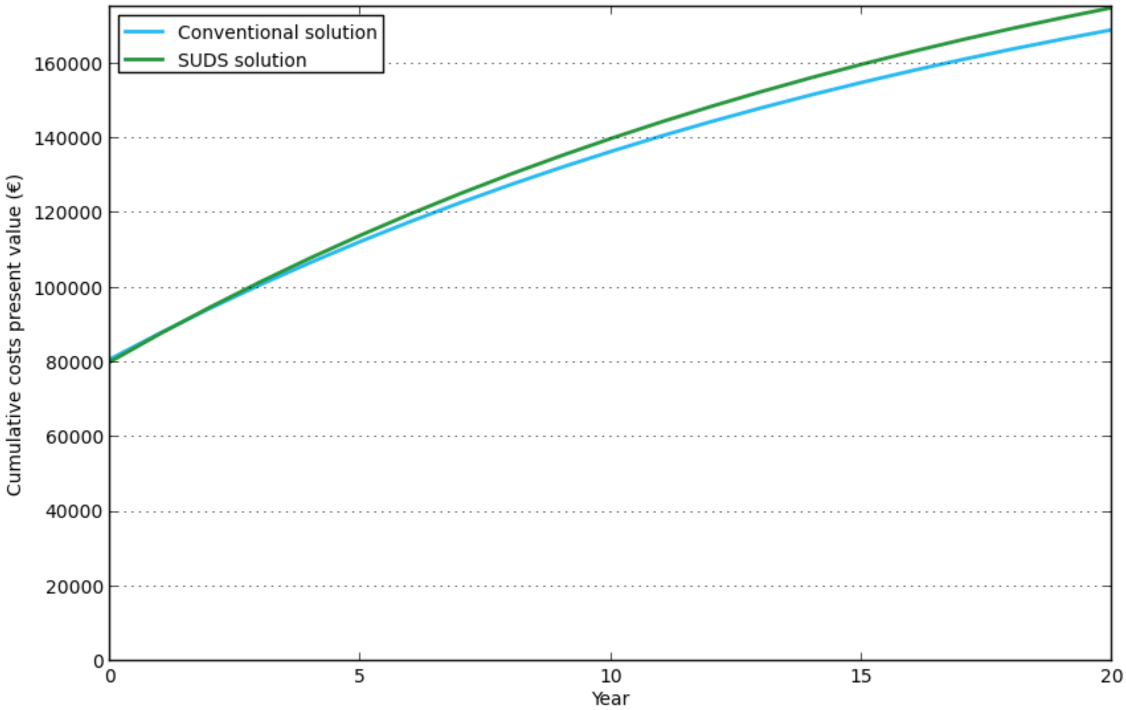

Figure 2.5.1.1.1 Total net costs of stormwater management for both scenarios

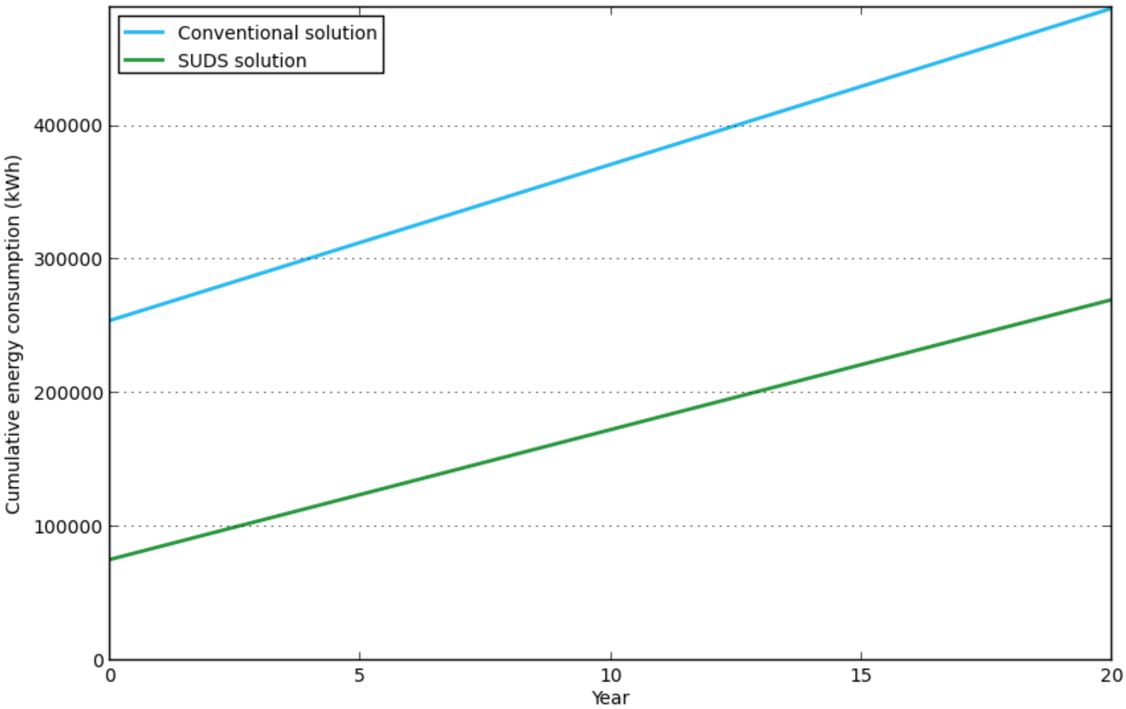

Figure 2.5.1.1.2 Total net energy consumption for both scenarios

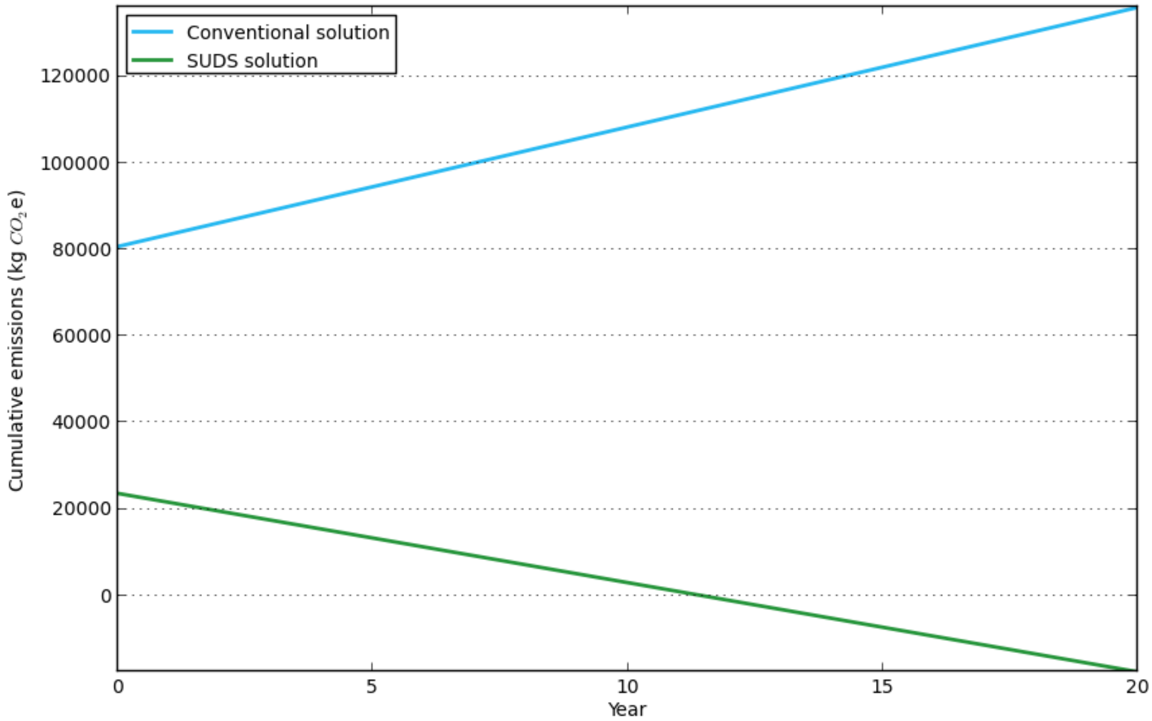

Figure 2.5.1.1.3 Total CO_2 emissions for both scenarios

In order to make a fair comparison, both scenarios have been chosen with the same initial construction costs. Initial investment is the same (or almost the same) for both cases, but each scenario yields different benefits during the period of analysis. Figures 2.5.1.1.1 to 2.5.1.1.3 show the total net costs of stormwater management, energy consumption and CO_2 emissions during the analyzed period of 20 years. This data has also been presented in Table 2.5.1.1-I.

Total net costs of stormwater management during the analysis period are very similar for both scenarios, although at the end of the period of analysis they are slightly higher for the SuDS scenario due to higher costs of maintenance of SuDS infrastructure.

Cumulative energy consumption is much higher in the conventional scenario; at the end of the period of analysis it is almost twice the value achieved in the SuDS scenario. Over half of the energy consumed in the conventional scenario is attributed to the construction of detention facilities. It accounts for 52 [%] of the net energy consumed by stormwater management during the period of analysis, and is the main cause for such a high difference in energy consumption of analyzed scenarios.

Net CO_2e emission values of both scenarios follow different patterns. Conventional scenario has higher initial values of CO_2e emissions, caused by the construction of detention facilities, and has an upward trend during the period of analysis, caused by the emissions generated by infrastructure maintenance and water treatment. SuDS scenario has lower initial emissions caused by construction of the infrastructure, and has a downward trend during the period of analysis, resulting in negative values of emissions at the end of the period. Negative values of CO_2e emissions are interpreted as consumption of CO_2 by the vegetation. This positive ecological effect is caused by the vegetation which is an integral part of some of the chosen SuDS infrastructure (bioretention areas and green roof).

As it has been previously mentioned in section 2.2., analysis period should not be chosen with a value higher than 20 years due to local uncertainties regarding economic, social and environmental factors.

	Net cost of stormwater management (€)		Net energy consumption (kWh)		Net CO_2 emmisions (kg CO_2)	
Year	Conventional solution	SUDS solution	Conventional solution	SUDS solution	Conventional solution	SUDS solution
0	81.000,00	80.275,00	254.787,00	76.014,00	80.706,00	23.657,80
1	87.991,28	87.793,31	266.463,31	85.734,12	83.469,41	21.595,33
2	94.618,08	94.919,67	278.139,62	95.454,23	86.232,82	19.532,86
3	100.899,42	101.674,52	289.815,94	105.174,35	88.996,23	17.470,39
4	106.853,29	108.077,22	301.492,25	114.894,46	91.759,64	15.407,92
5	112.496,76	114.146,12	313.168,56	124.614,58	94.523,05	13.345,45
6	117.846,03	119.898,64	324.844,87	134.334,69	97.286,46	11.282,97
7	122.916,43	125.351,27	336.521,18	144.054,81	100.049,87	9.220,50
8	127.722,49	130.519,63	348.197,50	153.774,92	102.813,28	7.158,03
9	132.278,00	135.418,56	359.873,81	163.495,04	105.576,69	5.095,56
10	136.596,02	140.062,09	371.550,12	173.215,15	108.340,10	3.033,09
11	140.688,93	144.463,54	383.226,43	182.935,27	111.103,51	970,62
12	144.568,46	148.635,53	394.902,74	192.655,39	113.866,92	-1.091,85
13	148.245,75	152.590,02	406.579,06	202.375,50	116.630,34	-3.154,32
14	151.731,32	156.338,35	418.255,37	212.095,62	119.393,75	-5.216,79
15	155.035,19	159.891,28	429.931,68	221.815,73	122.157,16	-7.279,26
16	158.166,81	163.258,98	441.607,99	231.535,85	124.920,57	-9.341,74
17	161.135,18	166.451,11	453.284,30	241.255,96	127.683,98	-11.404,21
18	163.948,80	169.476,83	464.960,62	250.976,08	130.447,39	-13.466,68
19	166.615,73	172.344,81	476.636,93	260.696,19	133.210,80	-15.529,15
20	169.143,63	175.063,27	488.313,24	270.416,31	135.974,21	-17.591,62

Table 2.5.1.1-I Net cost of stormwater management, net energy consumption and net CO_2 emissions for both scenarios during the period of analysis

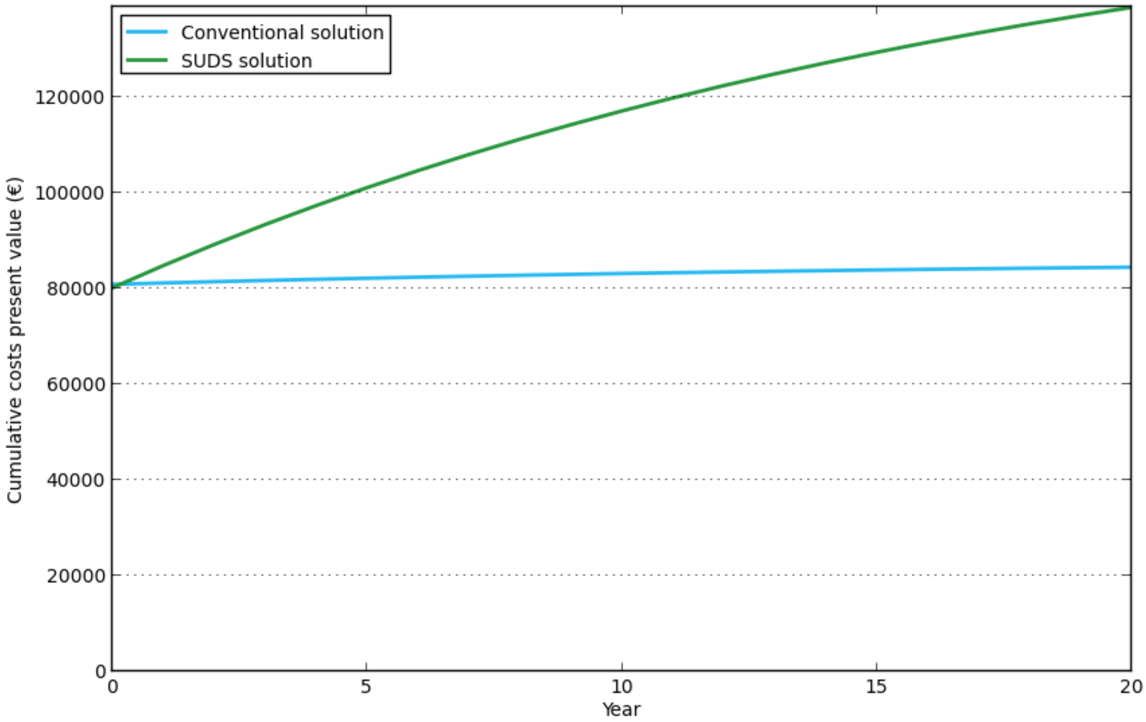

Figure 2.5.1.2.1 Construction and maintenance costs for both scenarios

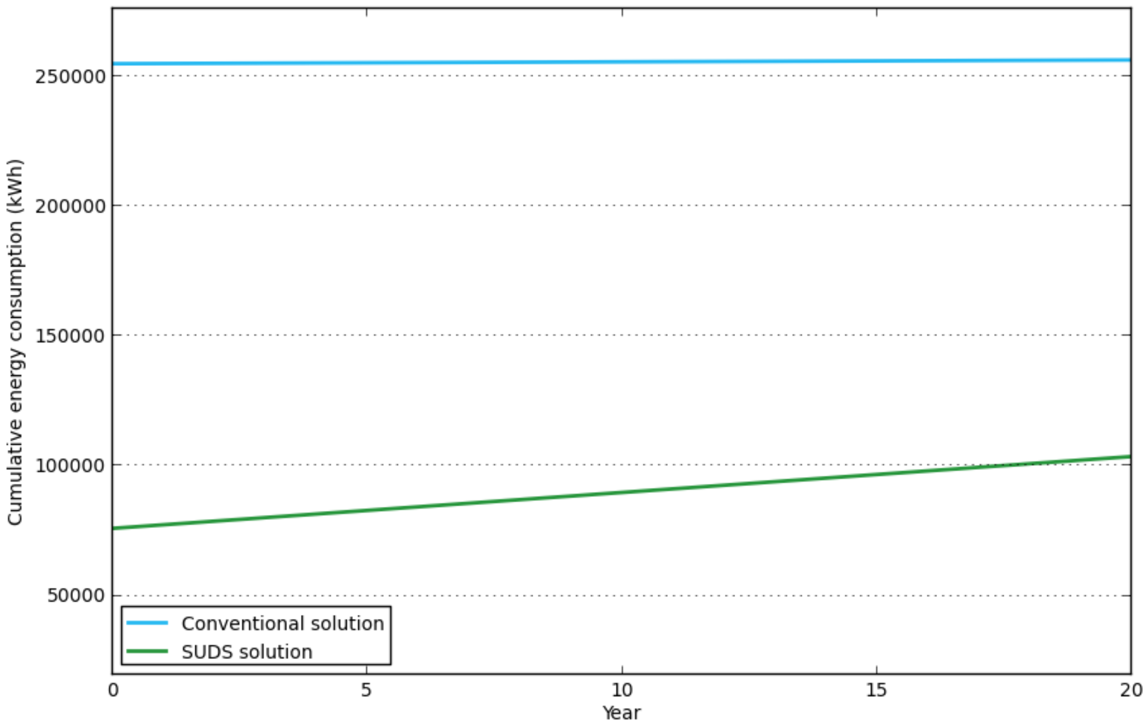

Figure 2.5.1.2.2 Construction and maintenance energy consumption for both scenarios

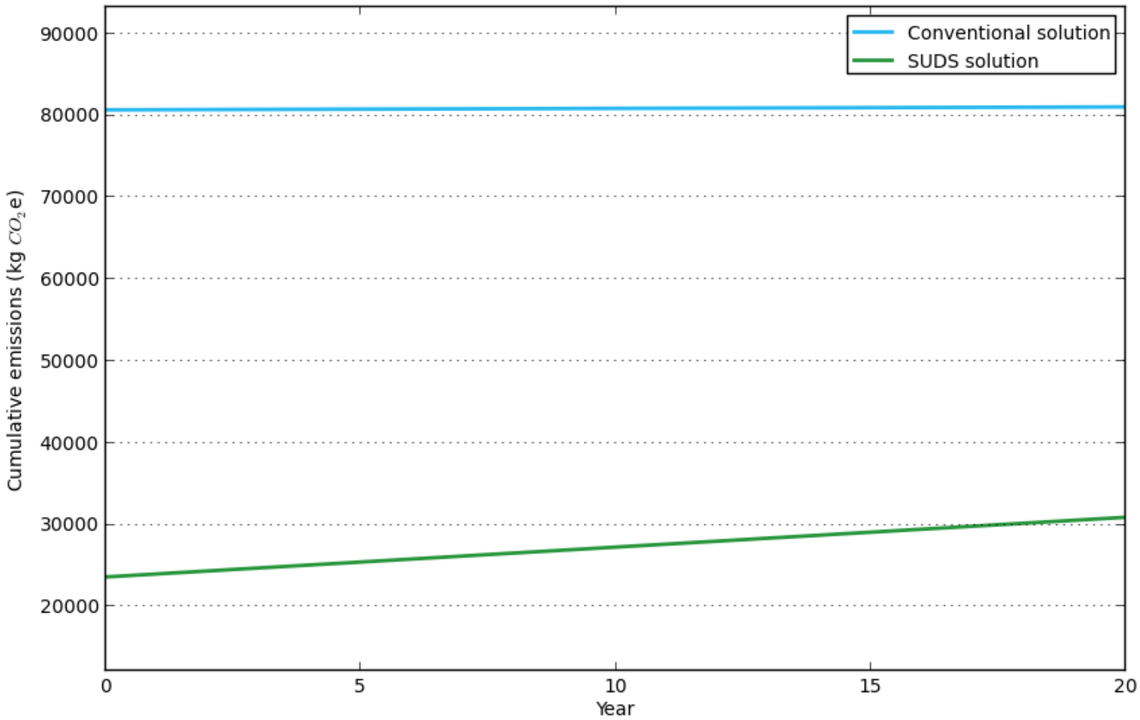

Figure 2.5.1.2.3 Construction and maintenance CO_2 emissions for both scenarios

Figures 2.5.1.2.1. to 2.5.1.1.3. show only maintenance and construction costs, their energy consumption and CO_2 emissions during the analyzed period of 20 years.

Construction costs for both scenarios have purposely been set at the same value, but the maintenance costs of SuDS infrastructure are significantly higher than those needed in the conventional scenario, as seen in figure 2.5.1.2.1. Maintenance costs of conventional infrastructure are only 300 [€/year], which is only 6 [%] of the amount which is needed to maintain chosen SuDS infrastructure (4900 [€/year]).

Energy consumption and CO_2e emissions are lower in the SuDS scenario, making it an energy and environmentally more beneficial solution. High energy consumption and CO_2e emissions in the conventional scenario are caused by the construction of the structural detention facilities.

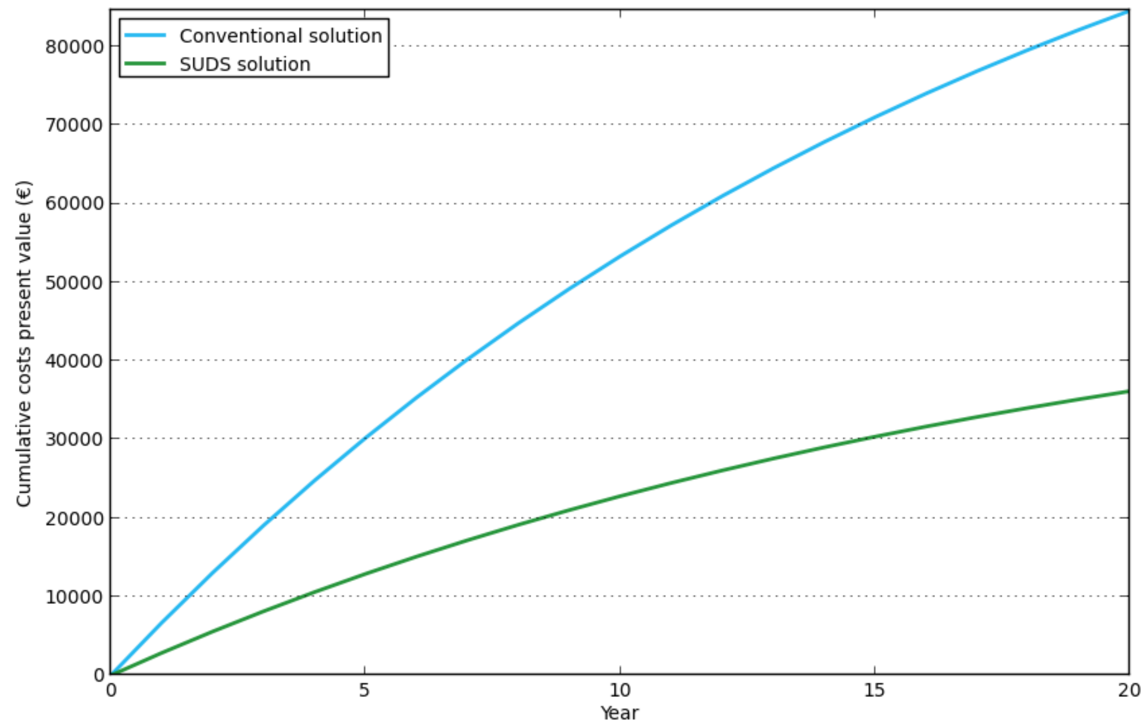

Figure 2.5.1.3.1 Net cost of stormwater management (case without maintenance and infrastructure costs)

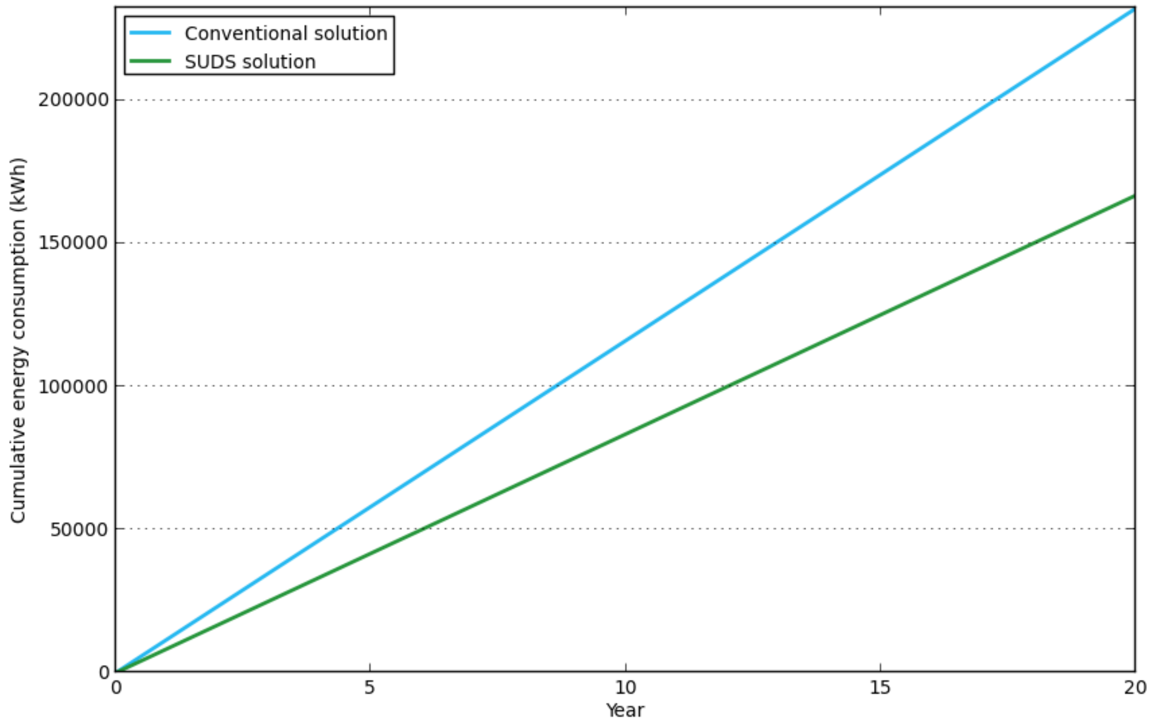

Figure 2.5.1.3.2 Net energy consumption of stormwater management (case without maintenance and infrastructure costs)

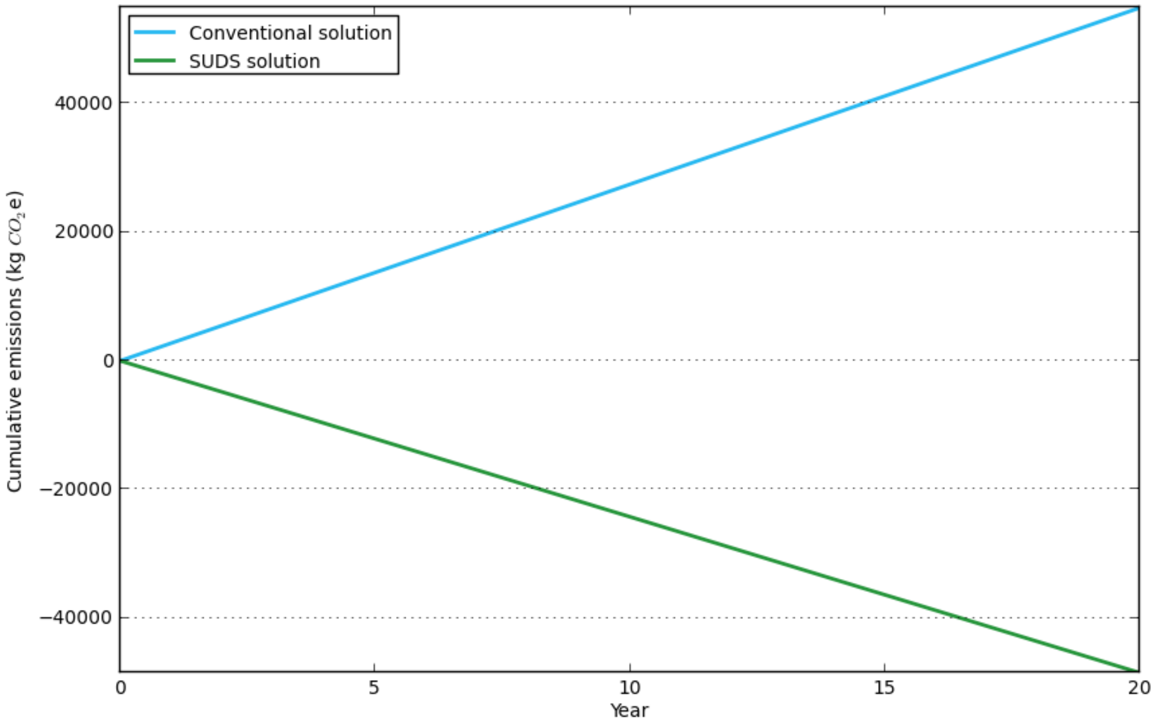

Figure 2.5.1.3.3 Net CO_2 emissions of stormwater management (case without maintenance and infrastructure costs)

Figures 2.5.1.3.1. to 2.5.1.3.3. show the net cost of stormwater management with all costs and benefits included except for maintenance and construction costs, and the respective energy consumption and CO_2e emissions for this case during the period of 20 years.

Therefore, in the previous figures the following parameters are being considered: cost of wastewater treatment and benefits achieved from water reuse, building insulation and reduction of CO_2e emissions. In this case (without construction and maintenance costs) net cost of stormwater management in the conventional scenario at the end of the period of analysis is more than twice the amount calculated for the SuDS scenario.

SuDS scenario produces a lower annual stormwater runoff and provides water reuse. These factors are responsible for the observed difference in the net costs of stormwater management analyzed in this case (when maintenance and construction costs are not considered).

Also, energy consumption is lower in the SuDS case due to previously mentioned reasons; lower need for energy during water treatment and energy benefits gained from water reuse. Energy benefits gained from building insulation caused by the implementation of green roof are negligible.

CO_2e emissions in this analyzed case take into consideration CO_2e emissions caused by wastewater treatment and those avoided by water reuse and increase of vegetation. In the conventional case, only the emissions caused by wastewater treatment are present, and they reach a value of 55.000 [kg CO_2e] at the end of the period of the analysis. In the SuDS case, a different trend can be noticed; CO_2e emissions follow a decreasing trend and during the period of analysis the values are always negative.

This trend is mainly caused by the increase of vegetation which is part of the chosen SuDS infrastructure.

2.5.2. Decision criteria

Quantifying the scenarios has been conducted by adding following weights for the following criteria:

Criteria	Weight
Net cost of stormwater management	35 %
Peak outflow rate	20 %
Net energy consumed by stormwater management	20 %
Net emissions of stormwater management	5 %
Evaluation of ecosystem services	10 %
Social acceptance	10 %

Net cost of stormwater management is considered to be the most important criterion for the stakeholders and was given the highest weight. Maximum and minimum values have been chosen in a way to give the better scenario a score of 100 [%] and the worse scenario a score which is a ratio of better and worse criteria values. For example, if a better scenario has total net costs of 50, and a worse scenario corresponding value of 70, better scenario would be given a score of 100 [%], and the worse a score of 50/70 = 0,714 = 71,4 [%].

Peak outflow rate was chosen as a criterion with a relatively high weight as it directly corresponds to the number of overflow events (overflowing of wastewater into the Sava river) which occur on a weir prior to the entrance to the WWTP. Since the sewage network of the City of Zagreb is designed as a combined one, overflowing events cause significant pollution of the Sava river when they occur and it is quite important to minimize these events.

Net energy consumed by stormwater management is a criterion which can also yield economic benefits and as such is given a high weight.

Net emissions of stormwater management is an ecological criteria, one which is not usually very important to managers and decision making bodies but has recently gained some attention in decision making processes in Croatia. Its value was chosen at 5 [%].

The process of choosing maximum and minimum values for peak outflow rate, net energy consumed and net emissions criteria is identical to the one explained in the case of net cost of stormwater management.

Evaluation of ecosystems services is a criteria which also has a small weight as it is an ecological criteria which does have a rising (but still not high) importance in decision making process in Croatia.

Social acceptance has been added as an additional criterion with a low weight. Social acceptance presents a criteria which should show how eager residents are in accepting the implementation of stormwater management structures. Since the SuDS scenario would increase the aesthetical value of the area and allow water reuse for tending of the urban gardens , it has been given a score of high acceptance, and the conventional one a score of very low acceptance since it does not provide such benefits.

Evaluation of ecosystem services and social acceptance have been defined as qualitative decision criteria whose values range from very low to very high.

This set of criteria have been chosen by the experts and the results of the first DST analysis have been shown to various stakeholders during the second RWGEE. During the discussion that followed, members have come to a decision that the set of criteria used had been chosen well and did not see the need to change it.

2.5.3. Multi-criteria analysis results

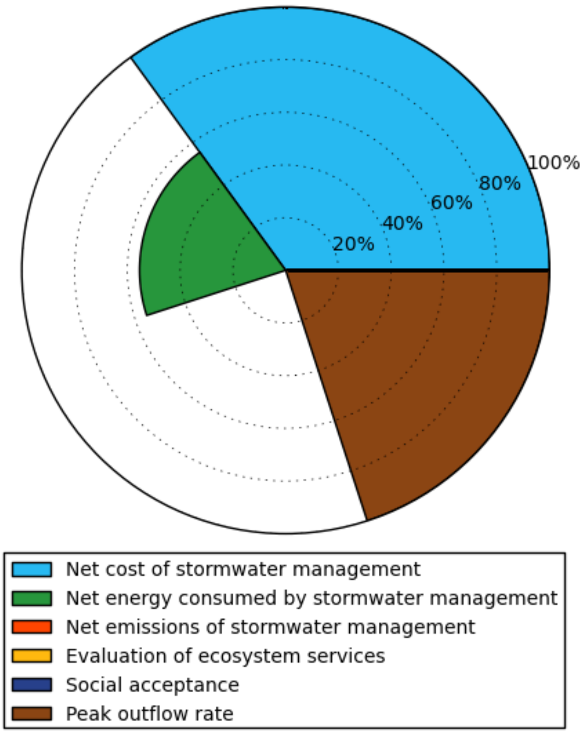

Figure 2.5.3.1 Circular results for conventional scenario

Criterion	Weight (%)	Utility (%)
Net cost of stormwater management	35	100,00
Net energy consumed by stormwater management	20	55,38
Net emissions of stormwater management	5	0,00
Evaluation of ecosystem services	10	0,00
Social acceptance	10	0,00
Peak outflow rate	20	100,00

Table 2.5.3-I Numerical values of circular results for conventional scenario

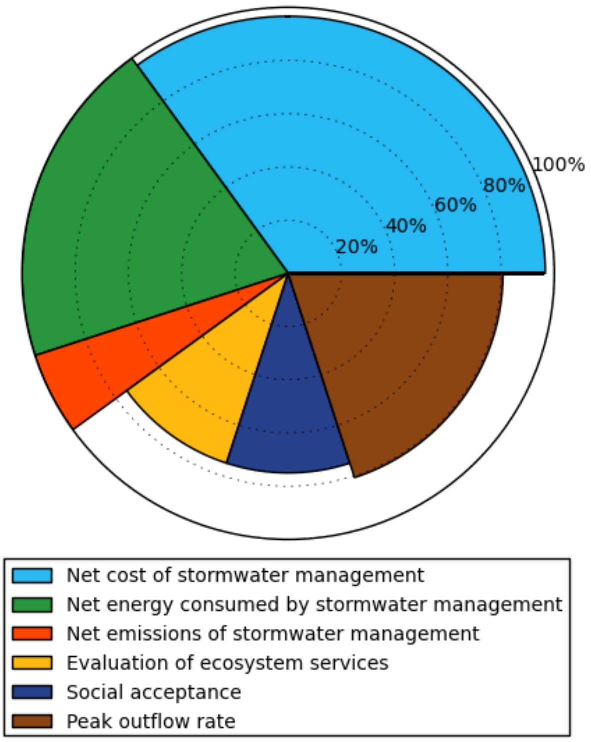

Figure 2.5.3.2 Circular results for SuDS scenario

Criterion	Weight (%)	Utility (%)
Net cost of stormwater management	35	96,62
Net energy consumed by stormwater management	20	100,00
Net emissions of stormwater management	5	100,00
Evaluation of ecosystem services	10	75,00
Social acceptance	10	75,00
Peak outflow rate	20	80,70

Table 2.5.3-II Numerical values of circular results for SuDS scenario

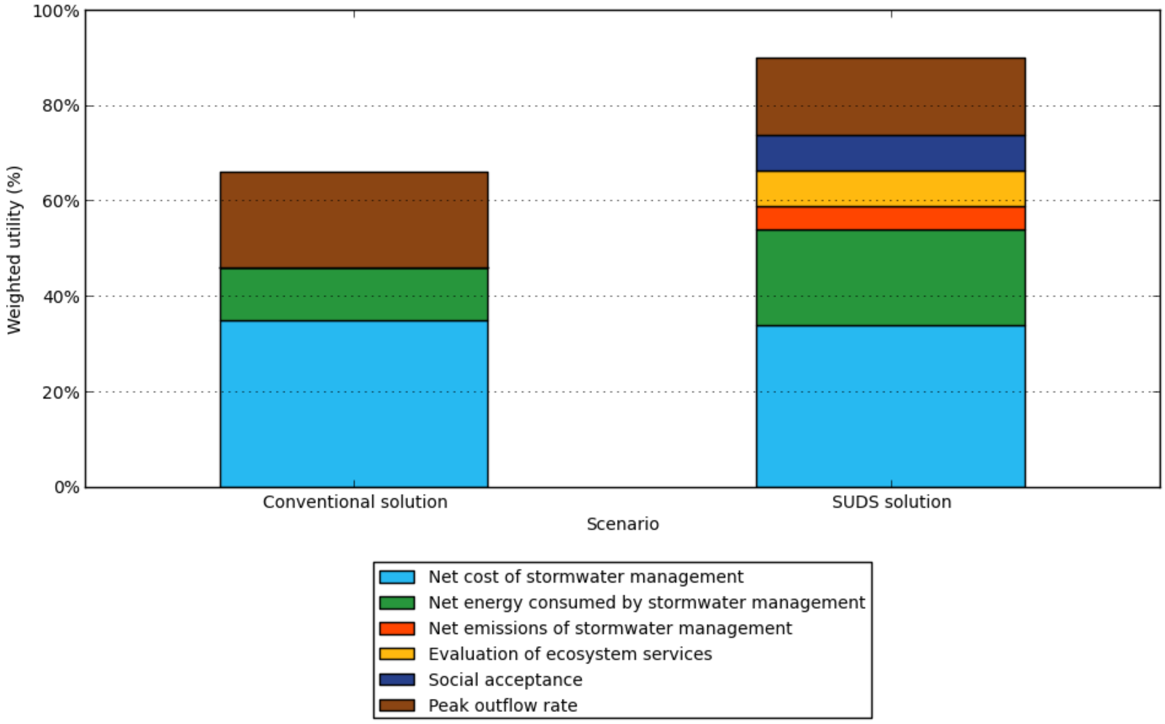

Figure 2.5.3.3 Global results

Criterion	Weighted utility (%): Conventional solution	Weighted utility (%): SUDS solution
Net cost of stormwater management	35,00	33,82
Net energy consumed by stormwater management	11,08	20,00
Net emissions of stormwater management	0,00	5,00
Evaluation of ecosystem services	0,00	7,50
Social acceptance	0,00	7,50
Peak outflow rate	20,00	16,14
Total	66,08	89,96

Table 2.5.3-III Numerical values of global results

As it can be seen on all of the presented figures and tables, by using the proposed criteria and its respective weights, SuDS solution yields a higher score.

Net cost of stormwater management and peak outflow rate are the only criteria where the conventional solution has a higher value. All the other criteria (net energy consumption, net emissions, evaluation of ecosystem services and social acceptance) are in favor of the SuDS scenario, and bring the total score to a value higher than the one with the conventional scenario.

As previously mentioned, criteria which yields economic benefits (i.e. cost of wastewater management and net energy savings) have been given a higher weight. Peak outflow rate was also valued highly as it correlates to wastewater overflowing events which may have significant negative ecological impact on the Sava river and the surrounding ecosystem.

Benefits achieved for the local ecosystem as well as social acceptance (criteria which decision making bodies do not usually see as very important) have been given a small weight in order to slightly impact the final score.

2.6. Conclusions

Stormwater management continues to evolve as a result of increased regulatory requirements and a desire to create sustainable solutions that attempt to bring urban water cycle closer to the natural hydrologic cycle. There is also the intention for increasing the use of stormwater for various purposes and improving energy efficiency in the urban water cycle and in buildings. This attempts are reflected in the efforts addressing both water quality and quantity thus creating processes such as infiltration and bioretention as well as treating urban stormwater runoff apart from centralized wastewater treatment plant.

Such actions often differ from conventional stormwater management that is primarily oriented to be in the service of stormwater runoff quantity thus reducing the possibility of storm floods. In order to choose between these different management approaches it is necessary to be able to compare them.

This decision support tool (DST) software can be used in a way to support the decision making process in choosing a preferable scenario of stormwater management. Since the overall costs of construction and maintenance are usually a sole criterion used in the decision making process, a software which takes into account many other different criteria could provide a useful help to choose maybe a more costly but overall a more beneficial solution.

Such assistance in choosing better stormwater drainage solution was tested on the small developed urban area. This area, called Borovje, is located southwest of the Zagreb city centre on the left bank of River Sava. Two scenarios were analyzed. One, comprising of conventional drainage infrastructure and other that includes a use of sustainable drainage infrastructure and for which the capabilities of this tool are thoroughly tested.

Conventional drainage solution represents an upgrade of the existing drainage situation, namely an upgrade of the combined sewage network with the underground stormwater detention facilities.

Improvement of the existing sewage system using sustainable infrastructure was considered by adding bioretention areas, water butts and soakaways.

In order to make a fair comparison, both scenarios have been designed with the same initial costs. Also, two major goals have been determined for the designed improvement of the current sewage system:

- reduction of stormwater runoff peaks entering the existing main drainage pipe, which will reduce the frequency of combined wastewater overflowing events into the Sava river prior to the entrance to the WWTP
- reduction of annual volume of wastewater entering the system, which should result in lower wastewater treatment costs at the WWTP

Designed improvement using conventional infrastructure was able to provide a fairly significant reduction (35 [%]) in stormwater runoff peaks. This was made possible due to structural detention facilities. Reduction of annual volume of wastewater entering the system was not reduced as there are no types of conventional stormwater drainage infrastructure available capable of reducing the runoff volume (by infiltration or evapotranspiration).

Improvement of the existing sewage system using SuDS infrastructure was able to fulfill both set goals to a certain degree. Just as in the conventional scenario, a reduction of stormwater runoff peaks is achieved, but to a lesser degree than in the SuDS scenario; only 18 [%] reduction is achieved. However, due to the ability of the SuDS infrastructure to increase stormwater soil infiltration as well as to reuse water, a reduction of 18,5 [%] in annual runoff generated from the area is achieved.

Conventional scenario proved to be a cheaper alternative than the SuDS, but only slightly. Its maintenance costs proved to be drastically lower than the ones in the SuDS scenario, but the benefits achieved from reduction in wastewater treatment costs and water reuse managed to balance out the high maintenance costs.

No source wastewater treatment benefits of flood protection benefits have been achieved from either of the analyzed scenarios due to the characteristics of the existing sewage system. In order to achieve such benefits, the entire existing system should be redesigned.

In order to provide a more beneficial solution regarding different criteria, used tool requires a significant amount of input data. In this case some of these data were hard to obtain since the responsible authorities do not possess them or collect them in a way that could be used without significant additional processing. Collecting some of data needed for the analysis was time consuming and in some cases the same data differed from one source to another. Also, for this area and the Zagreb city area some of data differ from default values proposed in DST software.

By using DsT software with case specific data as well as with the default software input values, multiple results were obtained for every scenario regarding different types of infrastructure costs, consumed energy, flood protection, water quality, environmental benefits such as CO_2 emissions etc.

In order to compare these results and to choose most beneficial solution six different criteria are selected. The selection of these criteria is based on sustainability concept which means that obtained solution must meet the economic, environmental and social criteria. For this reason net costs, net energy consumption, net emissions, peak outflow rate as well as social acceptance and evaluation of ecosystem services were chosen. These criteria are considered satisfactory especially criteria containing net values since they contain all achieved benefits at the same time.

For two considered scenarios proposed sustainable drainage solution provides better overall results.

This DST software can provide help in the decision making process. Due to the large amount of the needed data its use can be moderately complicated for a non-expert user. This problem is mitigated by introducing default data that could provide a result for a decision making. However the use of this data should be carried out with caution since these data can be locally very specific.

We also recommend that period of the analysis is not more than 15 to 20 years due to monetary value change, energy and water price change and land use change. Also, the uncertainties and variability surrounding the nature of the rain occurrence and stormwater discharges, as well as the varying treatment capabilities of the same sustainable infrastructures make it much more difficult to set precise numeric limits to some of the SuDS. At the same time some benefits are hard to measure or express as economic or energy value. Therefore we can recommend efforts regarding qualitative analysis but some options must be more clearly defined.

3. Pilot case 2: New development area

3.1. General description

The analyzed undeveloped area is located on the right bank and further away from the Sava River. This undeveloped area is called Podbrezje and it is located in the New Zagreb city district.

Figure 3.1.1 Analyzed location area within the city

The area is mainly a green plain with shrubs and occasional trees, slightly sloping towards the north and covers a total area of 194.000 m^2 (19,4 [ha]). It is physically separated from the surrounding urban area by traffic roads and railroad at the south. The height difference of the area ranges between 114,1 and 111,0 m above sea level.

Figure 3.1.2 View of the analyzed undeveloped area

Figure 3.1.3 Map of the analyzed undeveloped area

Terrain characteristics are typical for alluvial plain of the Sava River lowland area. Lithological composition is mainly gravel covered by the roof of clay-sand mixture. Deeper underneath the gravel is mostly clay.

The area microclimate compared to the climate of the city have some positive deviations resulting from the lack of the development and thus reduced the effects of warming, pollution from traffic, industry and impact of wind flow.

The analyzed area has no existing municipal infrastructure. Closest water supply point is located on the northern edge of the areas while the nearest sewage pipe passes along southern edge. There is no traffic or built road infrastructure.

According to existing planning documentation a significant size of the area is planned to be a green area. Even the central pedestrian/park area (main walking pathways between the buildings and throughout the area) is planned as a combination of green and pedestrian areas. Land use is predominantly for residential purposes with the possibility of commercial facilities that do not interfere with housing. Also construction of two preschools, elementary schools, cultural and information center, swimming pool complex and universal gym is planned. Throughout the area a jogging track is planned.

In total eighteen buildings are planned of which six are two-storey buildings, a skyscraper and eleven multi-storey buildings with north-south orientation.

The total planned capacity is 2.000 households with 5.800 residents. Planned population density is 300 residents per hectare.

Figure 3.1.4 Planned real estate development of the analyzed area

Figure 3.1.5. The future view of the area

Potential water regarding problems to be expected due to urbanization are both quantity and quality related. Urban development causes change to natural watershed conditions by altering the terrain, modifying the vegetation and soil characteristics and introducing pavement and buildings. Problems such as sedimentation, increased temperatures, habitat changes and increased frequency of flooding as well as higher peak flow volumes usually occur. Due to last reasons it is crucial to ensure adequate drainage and mitigate real estate damages as well as not to endanger human lives.

Since the urban plan for this area envisages a large portion of green areas such as grasslands and parks, they may be used to provide more natural friendly and more socially acceptable drainage solution that will not disturb the environment as the conventional infrastructure would. These solutions can provide a positive effect on water quality as well.

Some energy benefits could be expected if green roofs are introduced or if the construction of sustainable drainage structures will require less energy.

3.2. General model data

Since the analysis is performed in the Zagreb area, relatively near to the Borovje area (used for developed area analysis), all the general model data is equivalent to the one presented in section 2.2.

3.3. Scenario 1: Conventional development

3.3.1. General description

For this analysis separate sewer system was considered. The proposed solution is comprised of stormwater drainage network and associated structures primarily for retention. The adopted principle for tracing network is related to the size of the drained area and natural terrain slope. The whole area is divided in two smaller watersheds in which each pipe is draining the same amount of water, respectively. In this way the minimum required pipe diameter is achieved. Since natural terrain slope provides the possibility of gravity drainage, pump stations are not required. Sewer pipes are placed on each side of the building in order to ensure the possibility of connection for all residential and commercial objects, Figure 3.3.1.1.

In order to reduce peak runoff discharge and the use of large diameter pipes downstream, two in-line underground storage tanks were used. They are placed at the exit of the each watershed. Their purpose is also to retain some sediment thus achieving some low water quality control before conveying wastewater to the existing combined sewage pipe.

All buildings are comprised of conventional flat roof that is drained into the sewer network through rain gutters. Impervious surfaces are used for all pavements and parking lots. All rain water from these surfaces is diverted into the drainage network through street gutters without the possibility of infiltration into the soil.

Combined sewer overflows were not considered since the adequate recipient in the vicinity of analyzed area cannot be found. Other pretreatment devices that are not predefined in decision support tool were not analyzed since they are not part of standard stormwater management practice in Croatia, thus relevant data necessary for consideration would be very hard to obtain.

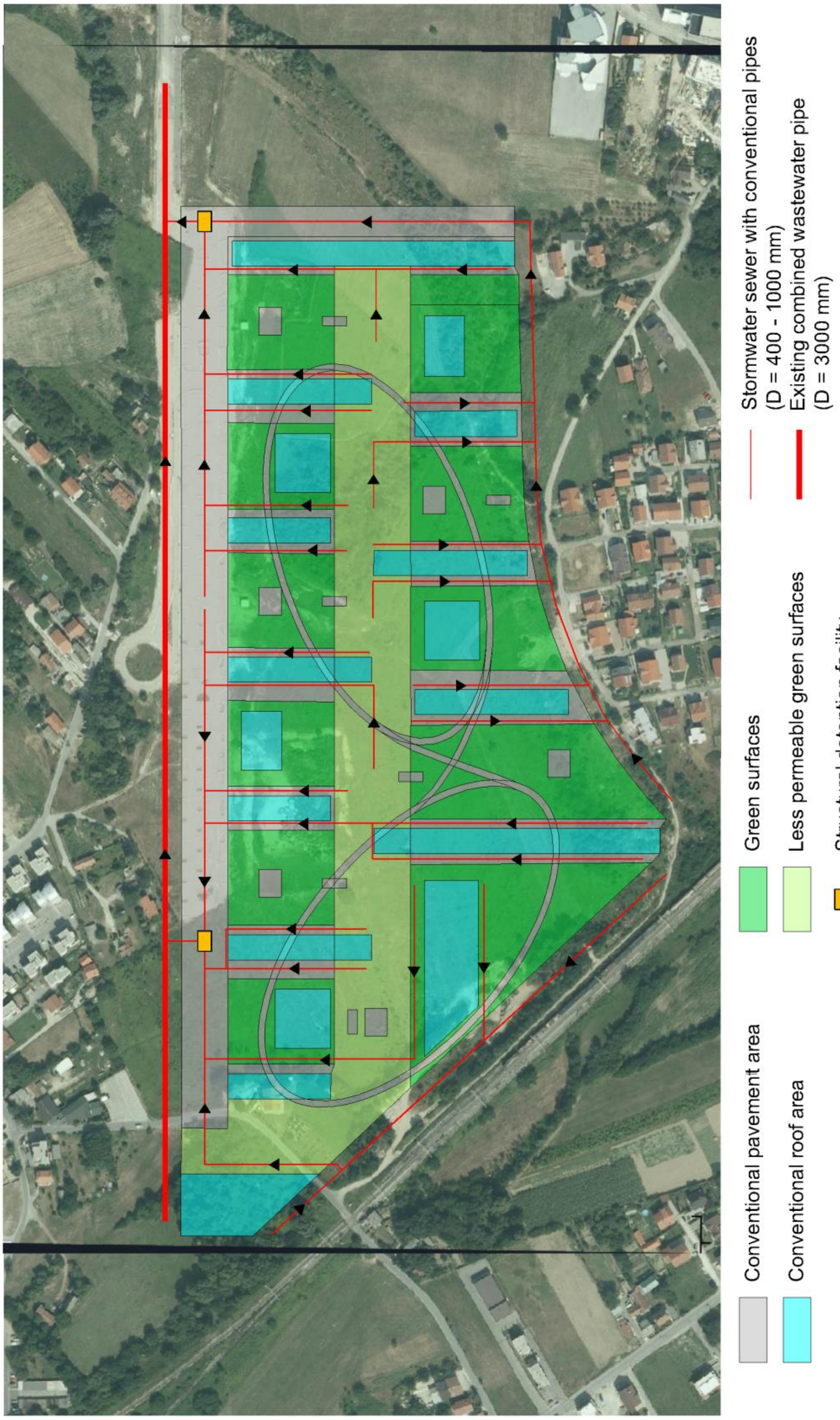

Figure 3.3.1.1 Analyzed conventional drainage systems scenario

3.3.2. Drainage infrastructures included in the scenario

Conventional drainage infrastructure included in the scenario consists of conventional gravity pipe network, conventional roofs, standard pavement and two stormwater detention facilities.

1. Conventional gravity pipe network

The separate sewer systems convey wastewater and stormwater in two separate pipe systems. Stormwater drainage network is an underground pipe system designed to carry rainfall runoff from parking lots, streets, roofs, and other impervious surfaces. Because the stormwater system collects rainfall from urban surfaces, it also carries away hazardous substances such as petrol, rubber and oil, dust, lead and other metals, all of which are left behind on urban surfaces.

The network of underground pipes must be designed in order to secure drainage of large amounts of stormwater whereupon large pipe diameters are required.

Usually they are difficult to construct in high-density areas since the greater excavations are needed in order to secure trenches for large diameter pipes and to avoid damages caused by traffic loads.

Total length of this pipe network is 5.100 m, with pipe diameters ranging from 400 mm to 1000 mm (average diameter is 450 mm), respectively. Construction cost of sewer network is 816.000 €.

2. Conventional roofs

Different roof systems provide waterproofing through a combination of multiple layers of different material. Roof provides protection from weather, notably rain, but also heat, sunlight and wind. Conventional roofs are usually very impervious, so they convey stormwater very quickly. Roofs can be flat or stepped, according to its shape. Stepped roofs usually produce higher runoff rates.

Total conventional roof area is 39.800 m^2, with the total construction cost of 1.671.600 €.

3. Standard pavement

Pavement is the durable surface laid down on urban areas such as a road or walkway. In general, standard pavements are quite impervious and they do not allow water to infiltrate into the subsoil. Water is collected and introduced into the drainage network through curbs and gutters. Standard pavements are usually designed to convey urban stormwater away as quickly as possible into the drainage network.

Total area of this surface is 56.100 m^2, with the total construction cost of 2.019.600 €.

4. Stormwater detention facility

Underground stormwater detention facilities allow high volume storage of runoff in a relatively small footprint area. The storage objects can be made from a variety of materials, including corrugated metal pipe, aluminum, steel, plastic, fiberglass, pre-cast or poured-in-place concrete.

Concrete detention chamber systems or tanks are much more expensive to construct than stormwater ponds. However in densely developed areas where space for surface stormwater management facilities is scarce or highly valued, underground treatment practices like detention chambers and tanks may be the only feasible option. Detention facilities typically are not designed for water quality control although partial water quality control is possible through capturing sediment.

In this proposed solution, two detention facilities with a volume of 450 m^3 each have been chosen (total volume of 900 m^3); its total construction cost is 243.000 €.

Unit costs of construction and maintenance have been adapted to meet local conditions, as explained in section 2.3.2.

3.3.3. Water reuse

Proposed conventional solution does not provide rainwater reuse.

3.3.4. Stormwater runoff

Stormwater runoff analysis was performed using SMWW model, Figure 3.3.4.1. Surface types for the analyzed scenario can be seen in Figure 3.3.1.1. For impermeable surfaces that generate most to the runoff it was determined that the time of concentration is 30 minutes.

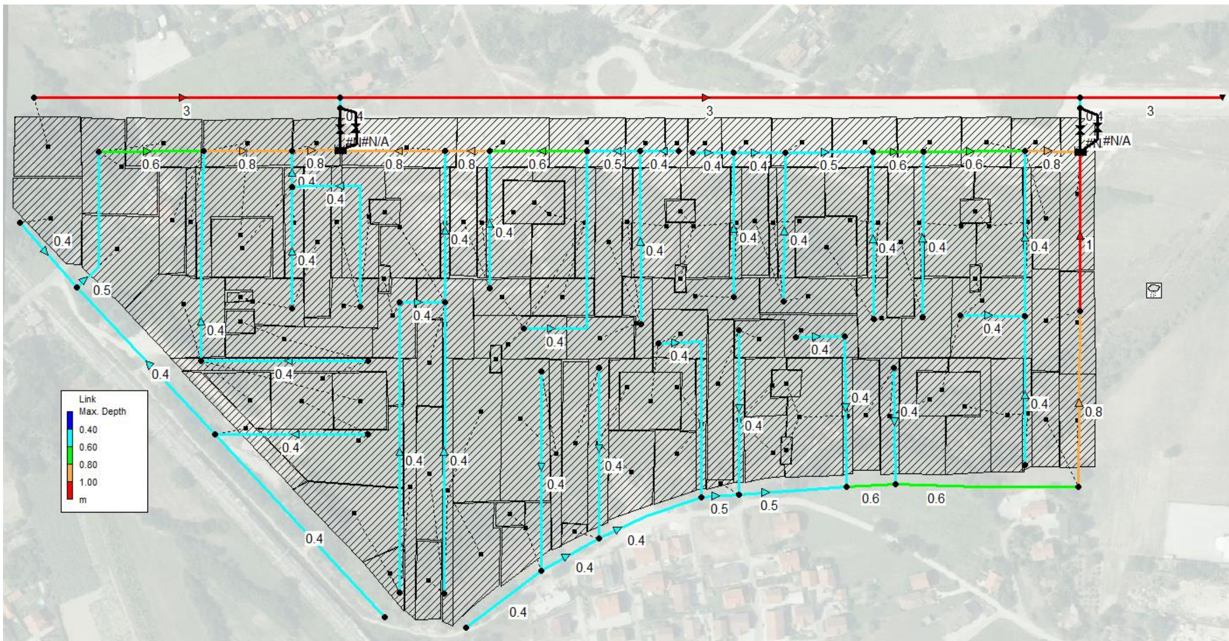

Figure 3.3.4.1 SWMM model of the analyzed conventional drainage systems scenario

For the existing undeveloped conditions characterized with grasslands, shrubs and trees maximum surface runoff is estimated according to the mean runoff coefficient of 0.2.

Q = c * i * A = 0.2 * 150 * 19.4 = 580 l/s … 5-year design storm runoff from the analyzed area before development

After the development with the existing urban planning documentation peak runoff for the 5-year design storm is 1.720 liters per second for which the sizing of the system has been done. The required pipe diameters range from 400 mm to 1.000 mm and the total necessary volume for the storage detention facilities is 900 m^3 (two storage units with 450 m^3).

For the average of 1060 mm of rainfall per year from the area of analysis runoff volume per year is 109.400 m^3.

Percentage of volume reduction was not included in conventional drainage infrastructure scenario since these infrastructure do not provide a significantly reduction of runoff volumes. However, some significant peak runoff reduction is achieved through storage detention facilities. Approximately 35 % reduction is achieved on each storage facility, Figure 3.3.4.2., allowing smaller downstream pipe diameters.

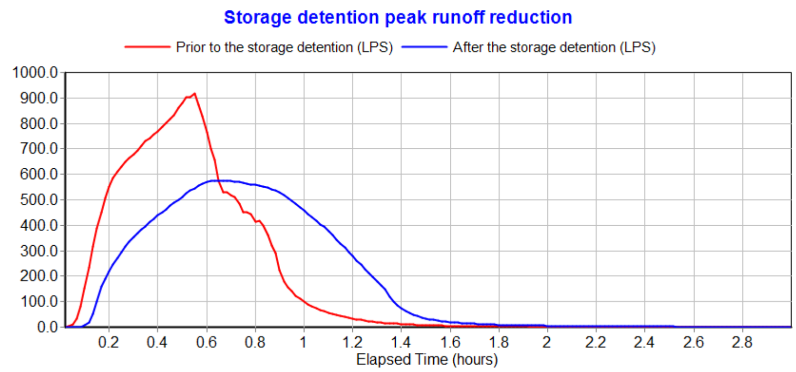

Figure 3.3.4.2 Peak runoff reduction through a storage detention facility

3.3.5. Conveyance and treatment

Since the gravity drainage network is possible due to terrain slope, pumping costs and energy consumption was not analyzed. Wastewater from the analyzed area is not pumped until it reaches WWTP. Pumping cost and energy on the very WWTP were analyzed as wastewater treatment costs and wastewater energy consumption and emissions in the following section of the decision support tool.

Data regarding water treatment cost and energy consumption were obtained from the company managing the plant and they are the same as given in Scenario 1, section *2.3.5. Conveyance and treatment*.

Volume of the treated stormwater is little more than 109.400 m^3/year. Total consumed energy related wastewater treatment is around 18.000 kWh/year resulting with 4.256 kg CO_2/year. Values obtained with DST differs than those obtained by managing company as explained in section *2.3.5. Conveyance and treatment*.

3.3.6. Water quality

Surfaces considered to produce the worst runoff quality from analyzed area are parking surfaces. Since the receiving water body sensitivity is set to be a high value minimum number of infrastructures needed for effective pollutants removal is three.

The conventional drainage infrastructure, except WWTP in general has a low possibility for wastewater quality control. Removal of suspended solids is limited while nutrient removal efficiency and heavy metals removal efficiency is very small or missing. Conventional pipe network has low removal efficiency for total suspended solids and low efficiency in heavy metals removal. Structural detention facility has medium total suspended solids removal efficiency and low efficiency in heavy metals removal while conventional roofs and standard pavement have no impact on removal efficiency for three considered types of pollutants.

The level of water treatment achieved only by the conventional infrastructure in this scenario is given as an average value of removal efficiency for every included infrastructure. This results with low suspended solids and low heavy metals removal efficiency with no efficiency in nutrient removal. Thus the overall water quality leaving the area is set to be low.

Global water quality for this scenario has been estimated with the following parameters:

Suspended solids removal efficiency:	low
Nutrient removal efficiency:	none
Heavy metals removal efficiency:	low
Average water quality:	low

3.3.7. Flood protection

Since Podbrezje is still undeveloped and uninhabited area, data regarding the occurrence of storm flooding for the existing conditions were not available. Thus flooding areas have been estimated by using a hydraulic model that was made based on larger scale terrain map. In general, it is known that the observable flooding did not occur in the last fifteen to twenty years, nor was observed the flooding of the nearby roads. The reason for this is a low runoff coefficient due to vegetation and terrain orientation towards scarcely populated area with a lot of green surfaces.

In order to estimate damage caused by flooding, data needed for DST software was obtained by using a ponding option in SWMM model. Cases with and without drainage infrastructure were considered for both infrastructure scenarios. For this analysis the return period of the flood event with fully saturated soil is chosen to be 20 years, as explained in section 2.3.7., and estimated average time of concentration is 30 minutes. Corresponding rainfall intensity for 20 years return period is 200 l/s per hectare or 72 mm/h.

If the area is developed without any drainage infrastructure excess rainwater volume distributed on the effective surface, which does not take into account the area occupied by buildings, would be 60 mm high on average throughout the entire area. Thus the potential flooding height would result with the average damage per household in the amount of 8 200 €. Since the households affected method was used it was estimated that 20 households in average would be affected per building by this flood, resulting in total of 280 affected households.

Since conventional sewer network sizing was carried out for the return period of 5 years, the excess amount of surface water would occur as the difference between the volumes accumulated for two different design storms. The lesser capacity of sewer network in this case would result with the excess water height of 10 mm. Thus resulting with the average damage per household in the amount of 3 125 €. It was determined that 40 households would be affected in total, Figure 3.3.7.1.

Total flood protection benefits achieved with conventional drainage infrastructure are around 108 600 €/year.

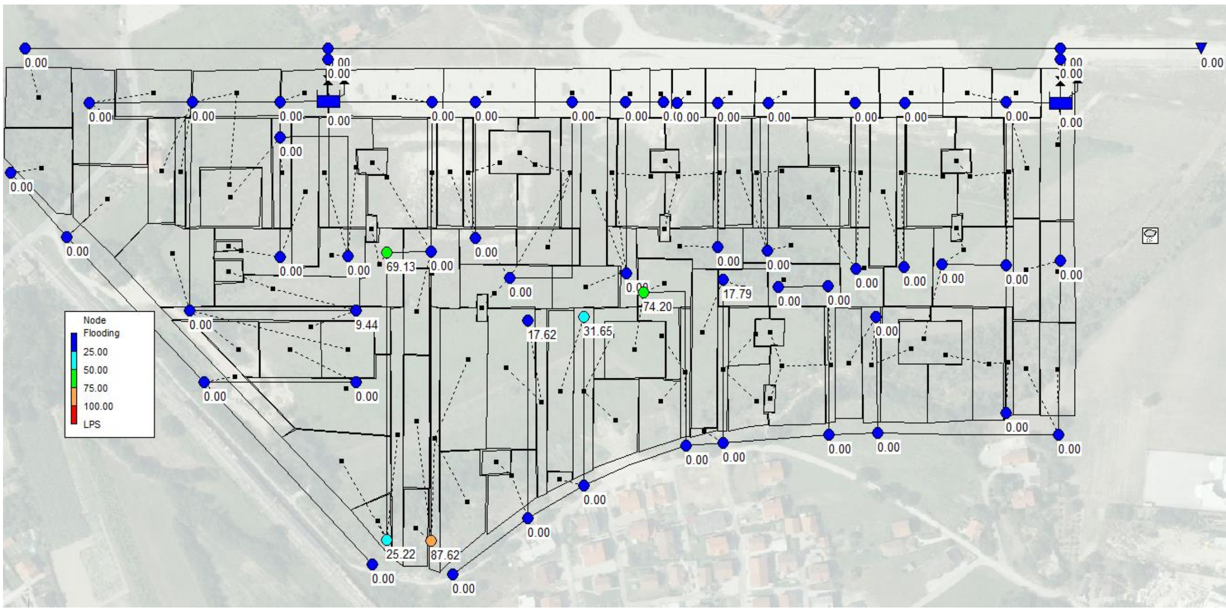

Figure 3.3.7.1. Conventional drainage system flooding nodes for the 20-year design storm

3.3.8. Building insulation and ecosystem services evaluation

Conventional drainage infrastructures are not related with building insulation benefits in this scenario. Conventional drainage infrastructures in general do not provide additional ecosystem benefits other than wastewater drainage and wastewater treatment. However they can provide additional dry surfaces during the rain events, but sewer can also be a concern due to odor, noise and potential for fire or explosion due to sewer gasses occurrence.

There are no benefits in carbon reduction as the conventional solution does not account for any additional trees planting or increase of existing green surfaces.

Global ecosystem services for the conventional infrastructure scenario of the analyzed area have been evaluated as very low as there are small benefits given by low level of water treatment.

3.3.9. Summary

	Conventional solution		
	Financial cost [€]	Energy consumption [kWh]	Emissions [kg CO_2]
Construction of infrastructures	4.750.200,00	15.065.927,00	4.698.387,00
	Financial cost [€/year]	Energy consumption [kWh/year]	Emissions [kg CO_2/year]
Maintenance of infrastructures	34.076,00	53.189,00	14.195,00
Infrastructure landtake	0,00	-	-
Potable water consumed and saved	0,00	0,00	0,00
Wastewater conveyance and treatment	10.969,00	17.989,16	4.255,97
Flood protection	-108.600,00	-	-
Building insulation	0,00	0,00	0,00
Carbon dioxide reduction	-	-	0,00
Other costs and benefits	0,00	0,00	0,00

Table 3.3.9-I Data summary from the DsT software for the conventional scenario

	Conventional solution	
	Energy consumption [kWh/m^3]	Emissions [kg CO_2/m^3]
Water supply acquisition, conveyance and distribution	0,4	0,4
Wastewater conveyance	0,00	0,00
Wastewater treatment	0,164	0,0388

Table 3.3.9-II Energy consumed in the urban water cycle for the conventional scenario

3.4. Scenario 2: Development with SuDS

3.4.1. General description

The general idea of the development with the sustainable drainage infrastructure is the maximum utilization of planned landscape design in terms of the drainage, as well as the compliance with the planned landscape design, Figure 3.4.1.1.

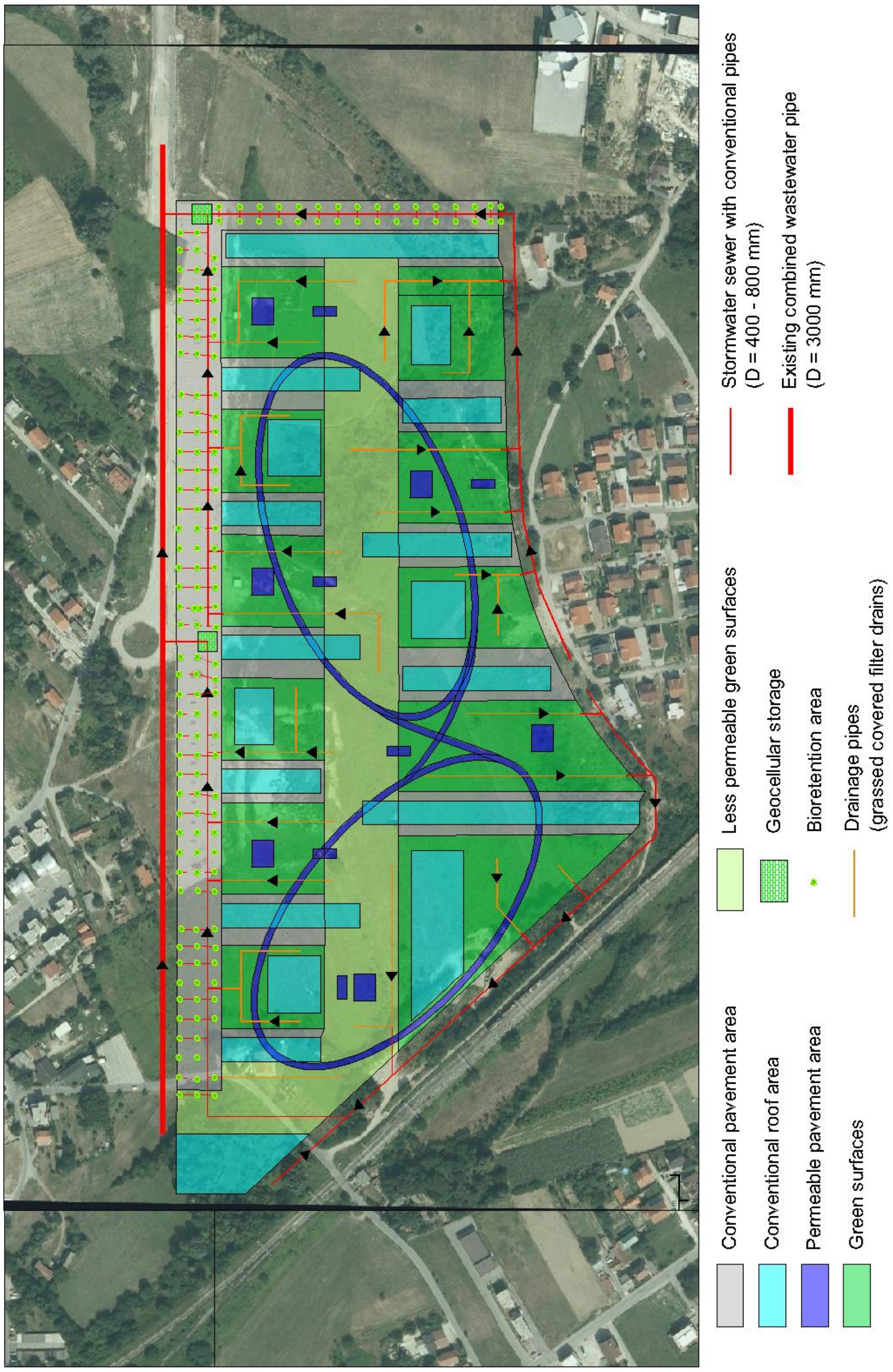

Figure 3.4.1.1 Analyzed scenario with SuDS infrastructure

This idea is paired with the effort to control storm wastewater at its source. This means that the drainage as well as the water treatment will be shifted to predominantly an above ground system rather than an underground one. The purpose of source control is to manage rainfall close to where it hits the ground instead of allowing it to become a problem elsewhere.

For this purpose the planned park areas will be used as filter strips that will drain storm water from impervious building roofs and pedestrian pathways until it reaches drain canal. This drain canals are located within the park area, preferably somewhere at the middle, between two buildings if possible, or on each side of the building but at least 6 to 7 meters away from impervious surfaces. The main purpose of the filter strip is to remove any silt in the storm water so that it does not clog up the filter drain. Adding screens, or a geotextile layer in a trench drain is also possible. The grass or other vegetation slows water down and also traps some of it by allowing it to soak into the ground. In addition, the plants help evaporate some water and filter out pollution from the storm water.

Drain canals (filter drains) are built in a similar way as infiltration trenches. Drain canals, as well as infiltration trenches collect runoff during a storm event, store it in the void spaces within the trench filling and release it into the soil by infiltration. The main difference is that perforated pipe is placed at the bottom of the trench. This drainage pipe is necessary in order to provide drainage in the case of high underground water table and soil saturation since that under these conditions flooding is most likely to occur.

The trench surface is planned be covered with grass so that the drain canals are indistinguishable from rest of the park surface. Drain canal are planned on park areas as well as on less permeable green areas, Figure 3.4.1.2.

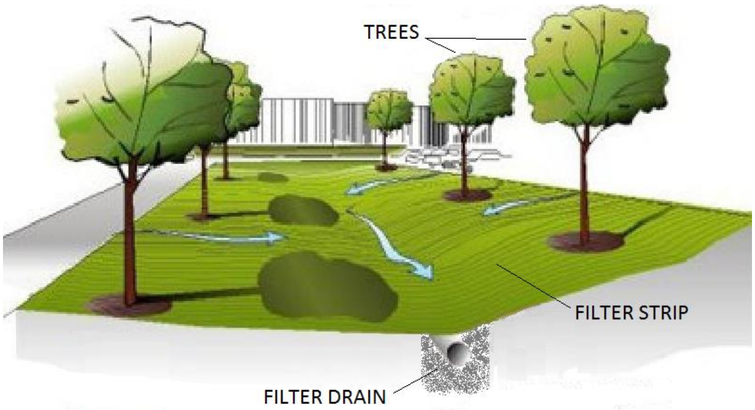

Figure 3.4.1.2 Filter drain sketch

Using the natural filtering properties of the soil, infiltration through park area and infiltration trenches can remove a wide variety of pollutants from stormwater through sorption, precipitation, filtering, and bacterial and chemical degradation.

In order to incorporate the proposed sustainable drainage solution planned green areas would have to be differently designed than as the planned flat plains. This additional landscaping will design park areas as gently sloping areas or areas formed as very shallow depressions so that the center of gravity could be achieved. With this design surface storm water is concentrated to the drain canal.

Since walking pathways are not precisely defined the main walking area between the buildings and throughout the area is considered as less permeable green surface. If the route of any walking pathway is precisely defined, it is recommended that they are built as permeable pavement. Permeable pavement is also intended for playgrounds and jogging track.

Roofs of all buildings are planned as conventional roofs. Since the roof surface area of all buildings is 4 hectares, green roofs are not intended due to high costs of construction and maintenance. The other considered solution included green roofs only for two-storey buildings (six buildings). In this case the overall costs also had a poor effect on the final result, especially financial.

Planned parking areas occupy an area of 2.85 hectares. For these surfaces permeable pavement was considered at the first. However, due to high construction costs this case was dropped. The adopted SuDS solution was an upgrade of the planned conventional solution that considers every fifth impervious parking space as green area with tree. The purpose of these green tree areas is converted to bioretention areas by using a parking curb cut or curb opening if green area is placed lower than parking surface. In this way green parking areas capture, infiltrate, transpire and remove pollutants from runoff thus improving stormwater quality. They also reduce stormwater volume and attenuate peak flow. In order to prevent possible flooding of parking areas, underdrain that routes the treated runoff to the sewer system is provided, Figure 3.4.1.2.

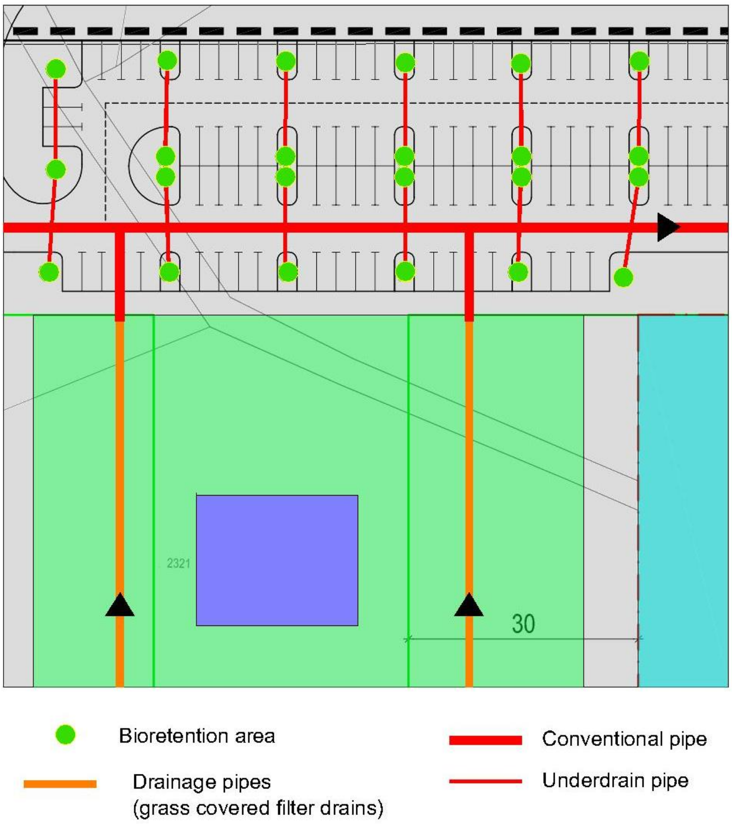

Figure 3.4.1.3 Bioretention areas with adjoining SuDS infrastructure

All storm water drained from parking areas as well as from all residential and park areas is eventually conveyed by conventional sewer pipes surrounding the analyzed area. At the exit from the area, storm water from conventional sewer is temporarily retained by two in-line geocellular systems. These geocellular systems are planned as impermeable structures that provide additional peak attenuation ensuring the use of smaller diameter pipes downstream the sewer network.

Since there is a possibility of high underground water table that would reduce the retention capacity of these structures, the underground infiltration with geocellular systems is not considered. In the case of high underground water level and saturated soil that would reduce the infiltration from green surfaces and bioretentions, it is also possible to use conventional street gutters on parking areas as well as on the park areas, Figure 3.4.1.3. The exact placement of these gutters should be established upon a detailed hydrologic hydraulic modeling.

Figure 3.4.1.4 Park drain gutter

3.4.2. Drainage infrastructures included in the scenario

Sustainable drainage infrastructure included in this development scenario consists of conventional gravity pipe network, conventional roofs, standard pavement, permeable pavement, filter drain, bioretention area and two geocellular system facilities.

1. Conventional gravity pipe network

Pipe network has previously described characteristics. Total length of this pipe network in this scenario is 2 200 m, with pipe diameters ranging from 400 mm to 800 mm. Construction cost of sewer network is 396 000 €.

This infrastructure also includes bioretention pipe network which total length is 1 200 m, with pipe diameters ranging from 100 mm to 200 mm, respectively. Construction cost of bioretention pipe network is estimated to be 126 000 €, resulting with the overall gravity pipe network costs in the amount of 522 000 €.

2. Conventional roofs

Conventional roofs have previously described characteristics. They occupy a significant portion of the area. Flat conventional roofs are intended for all buildings.

Total conventional roof area is 39 800 m^2, with the total construction cost of 1 671 600 €.

3. Standard pavement

Standard pavement is intended for pedestrian pathways alongside the buildings and parking areas. Total area of this surface is 45 800 m^2, with the total construction cost of 1 648 800 €.

4. Permeable pavement

Permeable pavement is intended for all playground areas and jogging track. Total area of this surface is 10 300 m^2, with the total construction cost of 412 000 €.

5. Filter drains

Filter drains are gravel filled trenches that collect and convey water. They also treat pollution thus providing water quality control. The trench is filled with draining gravel and has a perforated pipe in the bottom to collect the water. They are widely used to drain roads and are often seen along the edge of main roads. In this case the planned park areas will be used as filter strips, but a geotextile layer just below the surface is also recommended in order to stop the gravel clogging deeper in the trench.

Figure 3.4.2.1 Grass area as drain trench filter strip

Surface water runs off the edge of a hard surface such as a road and into the filter drain. The water flows down through the gravel which removes some of the pollution. The gaps between the pieces of gravel also provide space to temporarily store water during rainfall.

The trench surface will be grass covered. Some adjustments to the shape and form of the park areas would also be required ir order to secure surface water flow. Grass covered filter drains basically provide an underdrain to avoid a mud creation at the lower levels of formed basins, shallow depressions or swales.

Maintenance of filter strips is relatively straight forward and typically there is only a small amount of extra work required over and above that is required for any grass cover. More intensive maintenance work, such as silt and vegetation removal, is only required intermittently. The formed basins or swales and filter strips should be designed so that special machinery is not required to undertake maintenance. Regular cutting back of grass is required to keep the surface clear and visible.

This total pipe network length is 4 200 m, with pipe diameters ranging from 100 mm to 200 mm according to the drainage area, respectively. For average drain trench width and depth (0.5 x 1.0 m) a total of 2100 m^3 of filter drain volume is needed.

The sole filter strips are not included in sustainable drainage infrastructure since planned park areas are considered to be constructed anyway. Total construction cost of filter drains is 252 000 €.

6. Bioretention area

Bioretention areas, very similar to rain gardens, are designed primarily for stormwater quality. Bioretention systems can be applied to a wide range of development, in many climatic and geologic situations. They work well on small sites and on large sites divided into multiple small drainages. In residential developments bioretention areas can enhance site aesthetics.

Different types of bioretention cells are possible with depth usually from 1 to 1.3 m, depending on local conditions. Generally, cells should be sized to capture and treat the first stormwater flust.

For this case 200 filtration only bioretentions are considered. It is estimated that they can provide adequate runoff quantity control, particularly in conjunction with underdrain bioretention pipe network.

The main reasons for the application of bioretention cells are the construction costs of considered permeable pavement and the compliance with the planned landscape design solution. Since every fifth parking space is planned as green surface it seemed straightforward to use this green area for the purpose of parking drainage. Comparing to the conventional development, sustainable drainage solution has 30 additionally allocated bioretention cells thus providing some carbon dioxide reduction.

Average surface area of one bioretention cell is set to be 4 m^2 resulting the overall of 800 m^2. Total construction cost of bioretention area is 44 000 €.

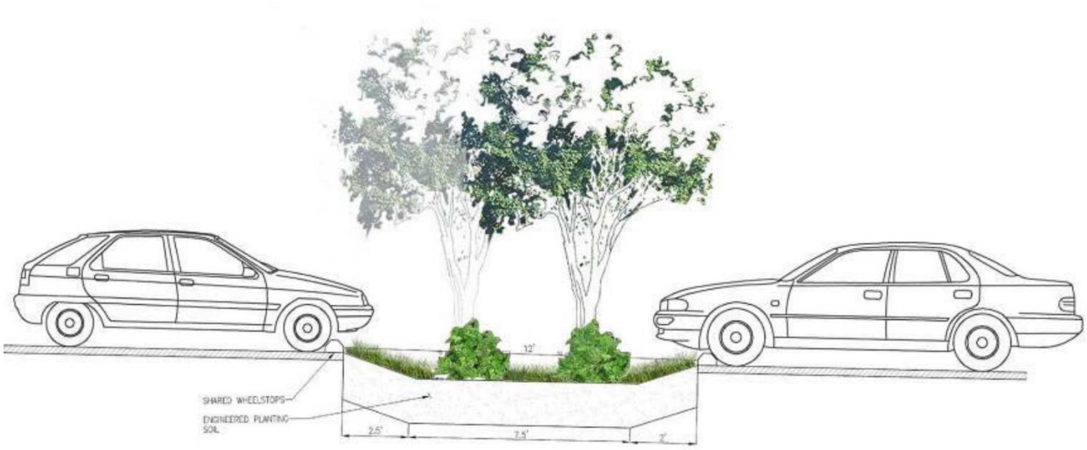

Figure 3.4.2.2. Bioretention areas

7. Geocellular system

Two geocellular systems are designed to store stormwater temporarily in a plastic structures chamber below ground and release it at a pre-determined rate via an orifice plate. This limits the peak flow of water thereby reducing the likelihood of overloading downstream sewer network. The sizing of the attenuation chamber is carried out regarding outflow needed for minimum downstream pipe diameter and 5 year return period runoff. Total required volume is 825 m^3; one system with a volume of 450 m^3

and another with a volume of 375 m^3. The chambers must be encapsulated within an impermeable membrane and geotextile in order to ensure waterproofing.

Proper implementation of a retention system depends on a number of features, including the physical conditions within the project area, properties of the soil, surface areas and design assumptions such as rainfall duration, intensity, frequency and hydrograph shape. For this reason given required volume per geocellular system is based on a simplified calculation and should be determined upon a detailed hydrologic hydraulic modeling.

Total construction cost is 206 250 €.

Figure 3.4.2.3. Geocellular systems

For all drainage infrastructure included in both scenarios, energy consumptions and emissions during construction and maintenance are estimated according to the default DST software values.

3.4.3. Water reuse

This development scenario solution with the sustainable drainage system is not planned to provide rainwater reuse. However it is possible to implement water reuse solution by diverting the excess of stormwater thus creating a storage within geocellular system. In this case, geocellular system works like a detention structure. Stored water can be used for bioretention area gardening or other green area watering. In this case additional use of energy is required.

3.4.4. Stormwater runoff

By introducing SuDS scenario the peak runoff occurring for a 5-year design storm is 1.490 liters per second. Since filter drains provide less storage capacity it was necessary to extended the length of the network (compared to the length of conventional drainage network) in order to ensure adequate drainage. The required total geocellular system volume is 825 m^3 (450 m^3 + 375 m^3).

Since DST software provided a reliable runoff volume results for developed area analysis, the estimation panel in the decision support tool was used for runoff volume calculation. For the average of 1060 mm of rainfall per year from the area of analysis runoff volume per year is 87 100 m^3.

Percentage of volume reduction is included in sustainable drainage infrastructure scenario since infrastructures reduce the volume of runoff through infiltration, interception and/or evapotranspiration. Used values are according to the DST guidelines. 50 % reduction was used for permeable pavements and bioretention areas, while 30 % reduction was used for conventional pavement. This reduction is due to drainage pathway since storm runoff flows from impervious surfaces over filter strip to the filter drains. It is also assumed, as the worst case scenario that only 35 % of precipitation that reaches parking lots would drain to the bioretention areas. This is the reason why the SuDS scenario runoff is only 15 % smaller with regard to the conventional drainage scenario.

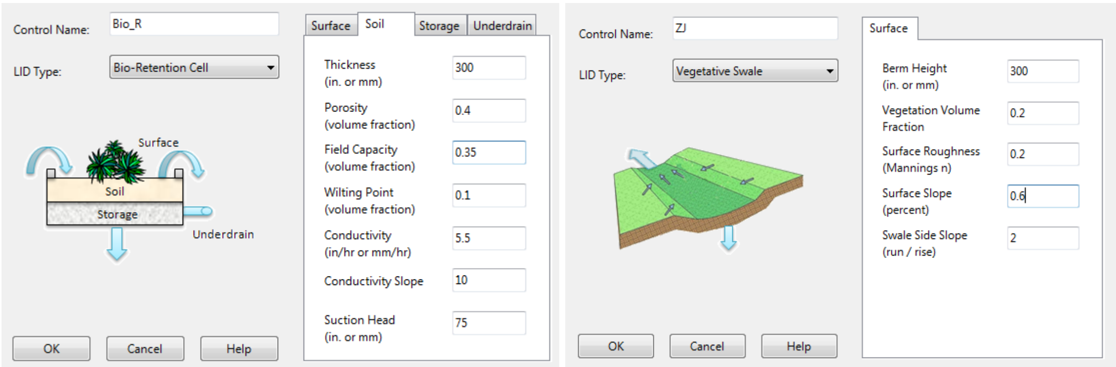

Figure 3.4.4.1. Some of the SuDS used in SWMM model

3.4.5. Conveyance and treatment

Since the gravity drainage network is possible due to terrain slope, pumping costs and energy consumption was not analyzed. Data regarding water treatment cost and energy consumption were obtained from the company managing the plant and they are the same as given in Scenario 1, section *2.3.5. Conveyance and treatment*.

Volume of the treated stormwater is 87 100 m^3/year. Total consumed energy related wastewater treatment is around 13 400 kWh/year resulting with 3 167 kg CO_2/year. Values obtained with DST differs than those obtained by managing company as explained in section *2.3.5. Conveyance and treatment*.

3.4.6. Water quality

Surfaces considered to produce the worst runoff quality from analyzed area are parking surfaces. Since the receiving water body sensitivity is set to be a high value, minimum number of infrastructures needed for effective pollutants removal is three.

The sustainable drainage infrastructure in general has a good possibility for wastewater quality control if they are designed and constructed well. Removal of suspended solids is usually high, except for geocellular systems. Permeable pavement is the only infrastructure providing high nutrient removal. Bioretention area and filter drain have low nutrient removal efficiency but high suspended solids removal efficiency and high heavy metals removal efficiency.

In general used conventional infrastructure in this scenario has very low or missing efficiency.

The level of water treatment achieved only by the sustainable infrastructure in this scenario is given as an average value of removal efficiency for every included infrastructure. This results with high suspended solids and heavy metals removal efficiency but low efficiency in nutrient removal. Thus the overall water quality leaving the area is set to be high.

Global water quality for this scenario has been estimated with the following parameters:

Suspended solids removal efficiency:	high
Nutrient removal efficiency:	low
Heavy metals removal efficiency:	high
Average water quality:	high

3.4.7. Flood protection

For 20-year design storm maximum runoff from the analyzed area is 2.440 l/s. Development with sustainable drainage infrastructure results with slightly lower storage capacity thus the saturated soil conditions results with the excess of rainwater with the average height of 10 mm on larger area. In total 70 households are affected by the flooding.

Sustainable drainage infrastructure results in slightly higher risk of flood, thus total flood protection benefits achieved are lower than with the conventional drainage infrastructure. This is the case for the worst case scenario for which there is a likely possibility of flooding when the high water level of the Sava River is present. In the circumstances that occur most of the time sustainable drainage infrastructure results in lower risk of flood due to the infiltration ability. In such a situation it is possible that the flooding does not occur at all, regardless of the chosen drainage infrastructure (due to infiltration), and therefore such case could not be considered to estimate flood protection benefits.

Total flood protection benefits achieved with conventional drainage infrastructure are around 103 910 €/year.

3.4.8. Building insulation and ecosystem services evaluation

In this scenario drainage infrastructures is not related to building insulation benefits since green roofs are not planned due to high construction and maintenance costs.

Comparing to conventional development, in sustainable drainage solution 30 more bioretention cells are planned, thus providing some additional carbon dioxide reduction by vegetation. This additional carbon reduction is 300 kg CO_2/year.

Global ecosystem services for the sustainable infrastructure scenario of the analyzed area have been evaluated as medium as there are some benefits given by high level of water quality control, urban ecosystem improvement, as well as aesthetical benefits.

3.4.9. Summary

	SuDS solution		
	Financial cost [€]	Energy consumption [kWh]	Emissions [kg CO_2]
Construction of infrastructures	4.756.650,00	14.657.106,25	4.575.856,75
	Financial cost [€/year]	Energy consumption [kWh/year]	Emissions [kg CO_2/year]
Maintenance of infrastructures	42.753,75	55.427,00	14.803,50
Infrastructure landtake	0,00	-	-
Potable water consumed and saved	0,00	0,00	0,00
Wastewater conveyance and treatment	8.164,00	13.388,96	3.167,63
Flood protection	-103.910,00	0,00	0,00
Building insulation	0,00	0,00	0,00
Carbon dioxide reduction	0,00	0,00	-300,00
Other costs and benefits	0,00	0,00	0,00

Table 3.4.10-I Data summary from the DsT software for the scenario with SuDS infrastructure

	SuDS solution	
	Energy consumption [kWh/m^3]	Emissions [kg CO_2/m^3]
Water supply acquisition, conveyance and distribution	0,4	0,4
Wastewater conveyance	0,00	0,00
Wastewater treatment	0,164	0,0388

Table 3.4.10-II Energy consumed in the urban water cycle for the scenario with SuDS infrastructure

3.5. Results

3.5.1. Time graphs

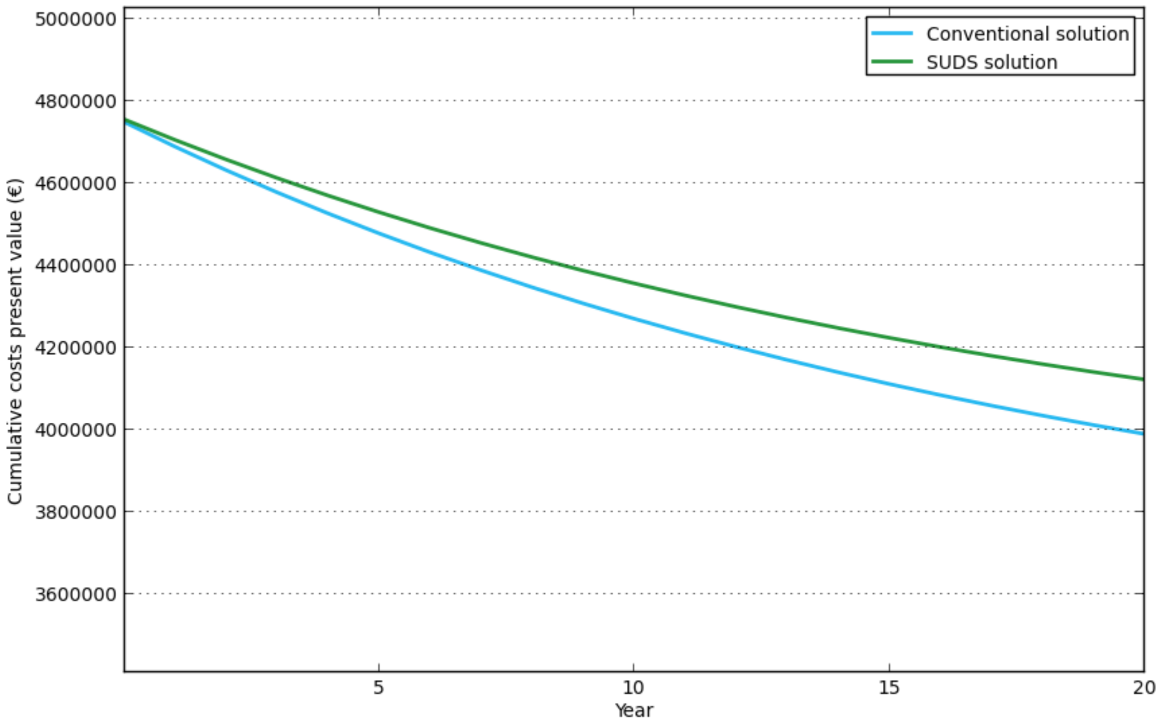

Figure 3.5.1.1.1 Total net costs of stormwater management for both scenarios

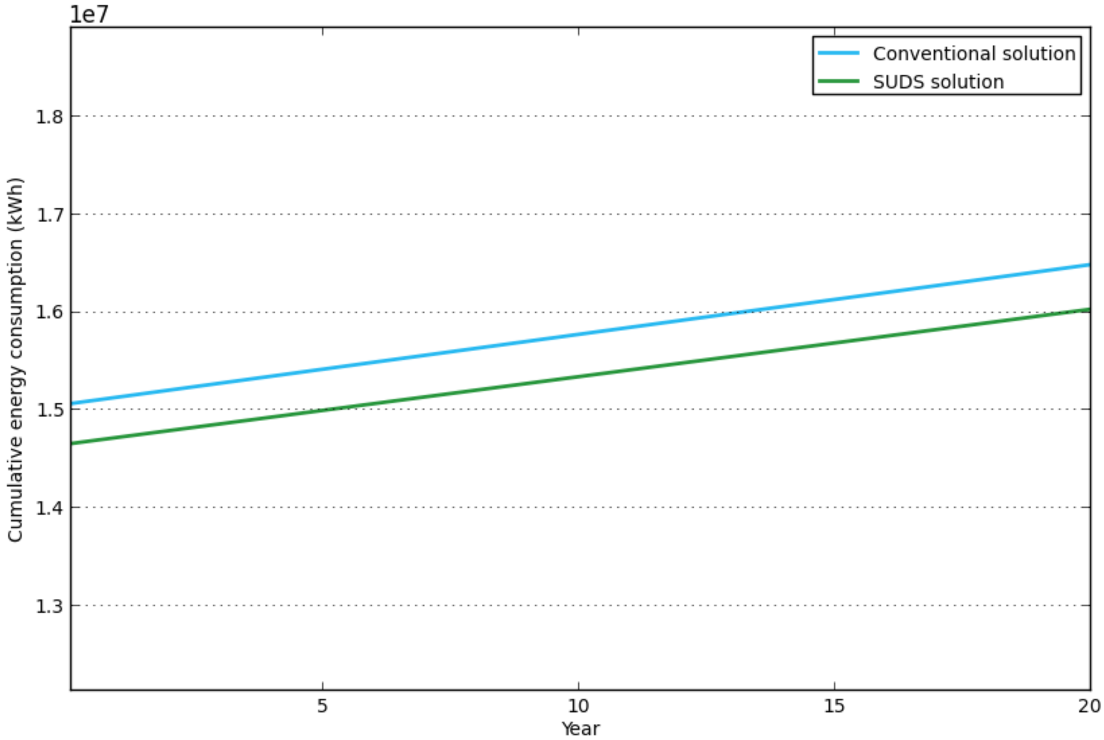

Figure 3.5.1.1.2 Total stormwater management energy consumption for both scenarios

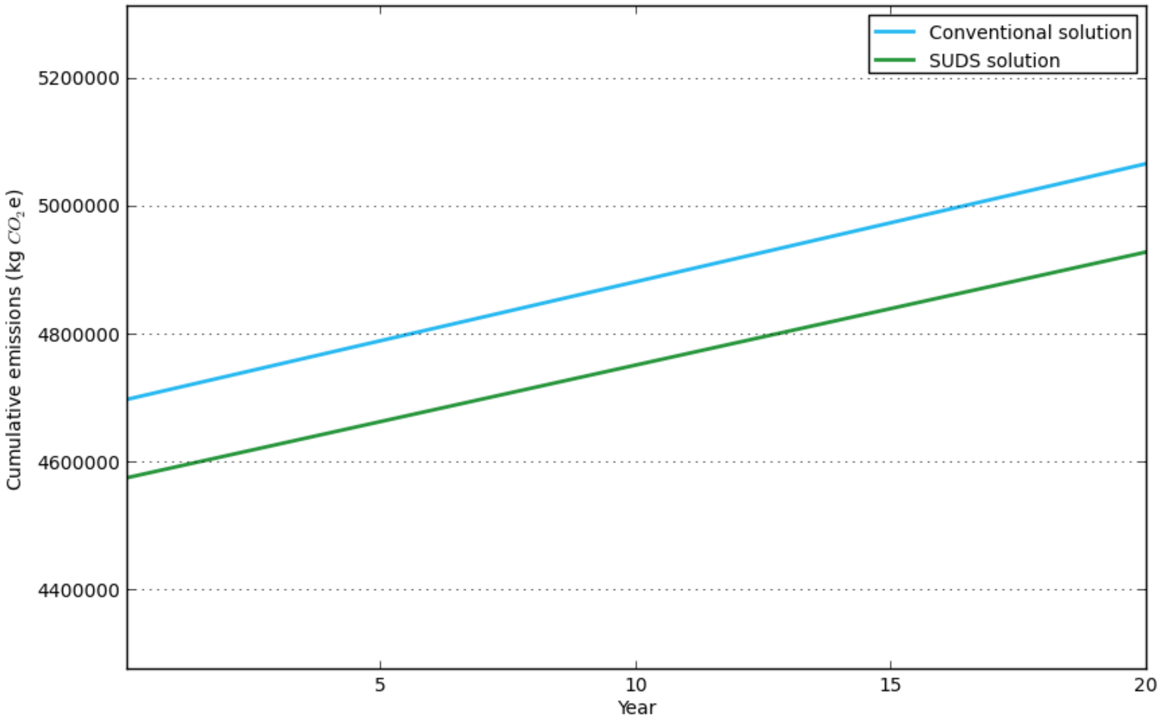

Figure 3.5.1.1.3 Total net CO_2 emissions caused by stormwater management for both scenarios

Figures 3.5.1.1.1 to 3.5.1.1.3 show the net costs of stormwater management, energy consumption and CO_2 emissions during the analyzed period of 20 years. This data has also been presented in Table 3.5.1.1-I.

Just as in the developed area case, both scenarios have been chosen with the same initial construction costs in order to make a fair comparison.

Total net cost of stormwater management is decreasing during the analyzed time period for both scenarios. Reasons for this type of graph behaviour are very high value of flood protection benefits and a fairly high economic discount rate. These factors significantly outweigh the maintenance costs.

Both energy consumption and CO_2 emissions are lower in the SuDS development scenario, as SuDS infrastructure offers solutions with lower environmental carbon impact and provides energy savings.

Year	Net cost of stormwater management (€)		Net energy consumption (kWh)		Net CO_2 emmisions (kg CO_2)	
	Conventional solution	SUDS solution	Conventional solution	SUDS solution	Conventional solution	SUDS solution
0	4.750.200,00	4.756.650,00	15.065.927,00	14.657.106,25	4.698.387,00	4.575.856,75
1	4.689.958,29	4.706.420,38	15.137.105,16	14.725.922,21	4.716.837,97	4.593.527,88
2	4.632.857,15	4.658.809,36	15.208.283,32	14.794.738,17	4.735.288,94	4.611.199,01
3	4.578.732,84	4.613.680,44	15.279.461,48	14.863.554,13	4.753.739,92	4.628.870,15
4	4.527.430,18	4.570.904,21	15.350.639,64	14.932.370,09	4.772.190,89	4.646.541,28
5	4.478.802,07	4.530.358,02	15.421.817,80	15.001.186,05	4.790.641,86	4.664.212,41
6	4.432.709,07	4.491.925,61	15.492.995,96	15.070.002,01	4.809.092,83	4.681.883,54
7	4.389.019,02	4.455.496,79	15.564.174,12	15.138.817,97	4.827.543,80	4.699.554,67
8	4.347.606,66	4.420.967,10	15.635.352,28	15.207.633,93	4.845.994,78	4.717.225,81
9	4.308.353,23	4.388.237,53	15.706.530,44	15.276.449,89	4.864.445,75	4.734.896,94
10	4.271.146,19	4.357.214,25	15.777.708,60	15.345.265,85	4.882.896,72	4.752.568,07
11	4.235.878,85	4.327.808,29	15.848.886,76	15.414.081,81	4.901.347,69	4.770.239,20
12	4.202.450,10	4.299.935,35	15.920.064,92	15.482.897,77	4.919.798,66	4.787.910,33
13	4.170.764,07	4.273.515,50	15.991.243,08	15.551.713,73	4.938.249,64	4.805.581,47
14	4.140.729,93	4.248.472,98	16.062.421,24	15.620.529,69	4.956.700,61	4.823.252,60
15	4.112.261,54	4.224.736,00	16.133.599,40	15.689.345,65	4.975.151,58	4.840.923,73
16	4.085.277,29	4.202.236,49	16.204.777,56	15.758.161,61	4.993.602,55	4.858.594,86
17	4.059.699,80	4.180.909,95	16.275.955,72	15.826.977,57	5.012.053,52	4.876.265,99
18	4.035.455,74	4.160.695,21	16.347.133,88	15.895.793,53	5.030.504,50	4.893.937,13
19	4.012.475,58	4.141.534,32	16.418.312,04	15.964.609,49	5.048.955,47	4.911.608,26
20	3.990.693,44	4.123.372,34	16.489.490,20	16.033.425,45	5.067.406,44	4.929.279,39

Table 3.5.1.1-I Net cost of stormwater management, net energy consumption and net CO_2 emissions for both scenarios during the period of analysis

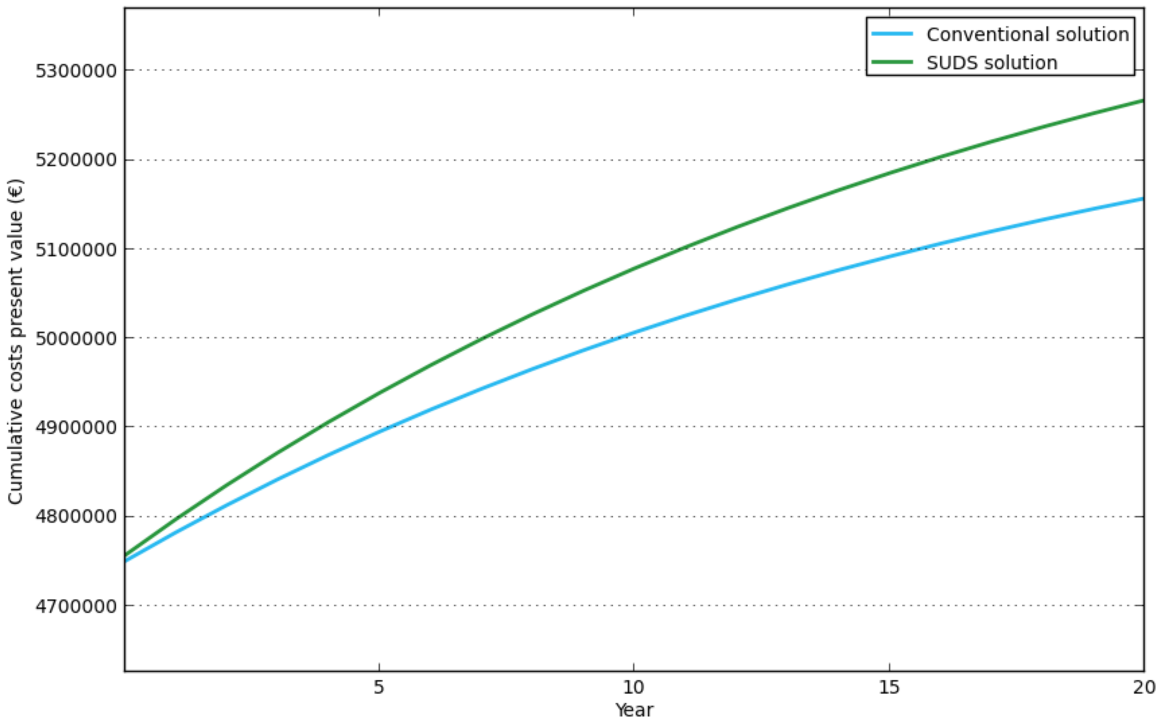

Figure 3.5.1.2.1 Construction and maintenance costs for both scenarios

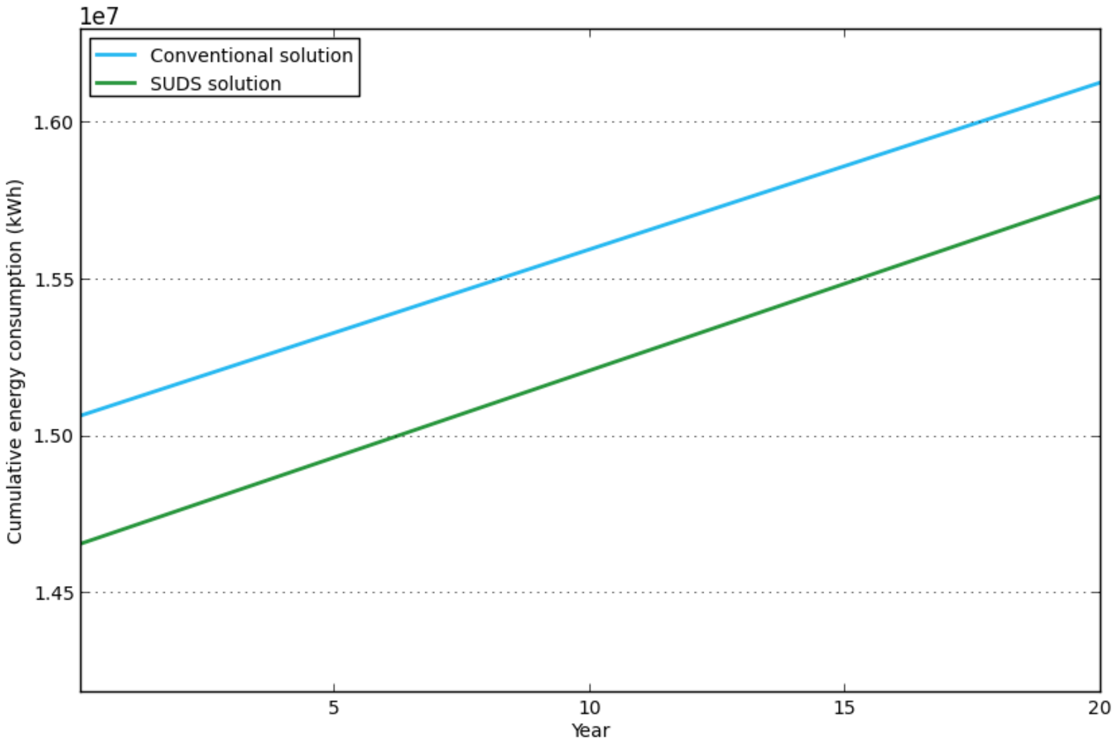

Figure 3.5.1.2.2 Construction and maintenance energy consumption for both scenarios

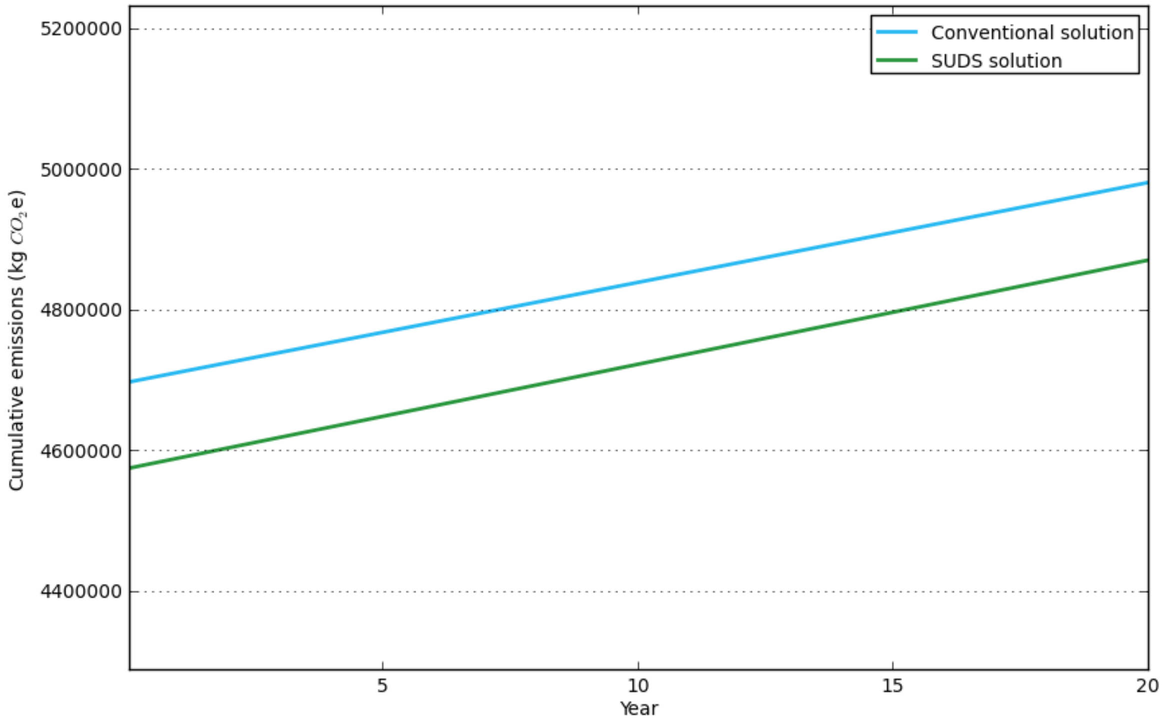

Figure 3.5.1.2.3 Construction and maintenance CO_2 emissions costs for both scenarios

Figures 3.5.1.2.1. to 3.5.1.1.3. show only maintenace and construction costs, their energy consumption and CO_2 emissions during the analyzed period of 20 years.

Construction costs for both scenarios have purposely been set at the same value, but the maintenance costs of SuDS infrastructure are slightly higher, as seen in figure 3.5.1.2.1. Energy consumption and CO_2 emissions are lower in the SuDS scenario, as it is an energy and environmentally more beneficial solution.

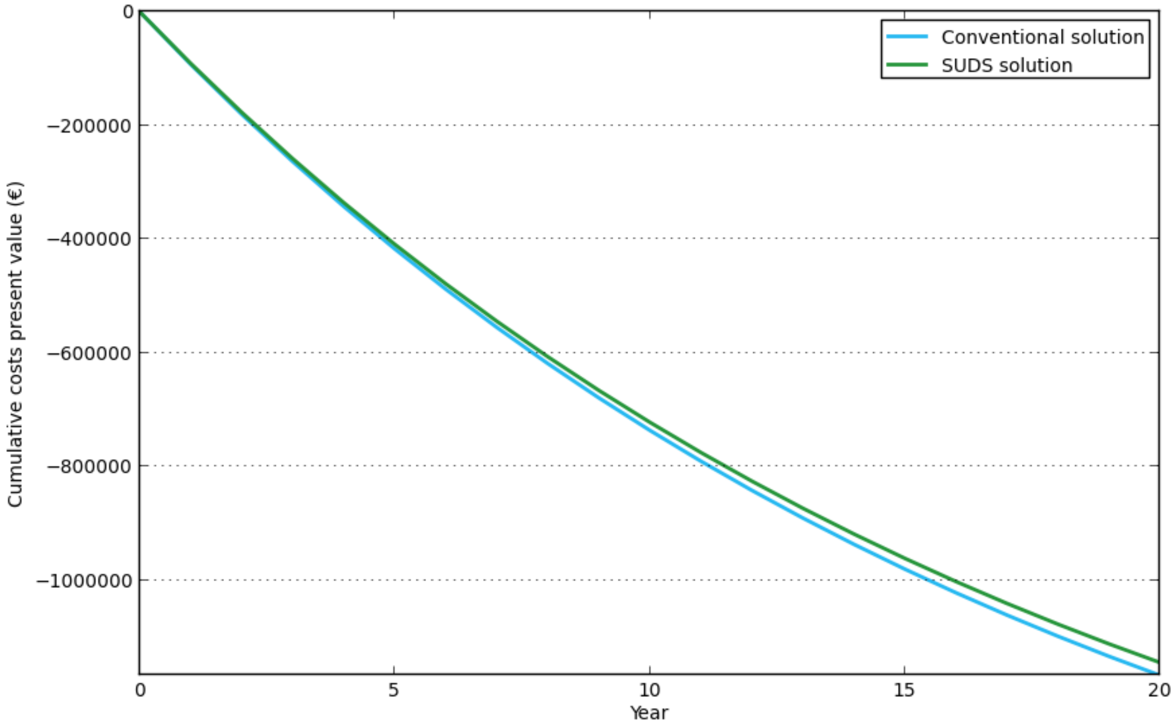

Figure 3.5.1.3.1 Net cost of stormwater management (case without maintenance and infrastructure costs)

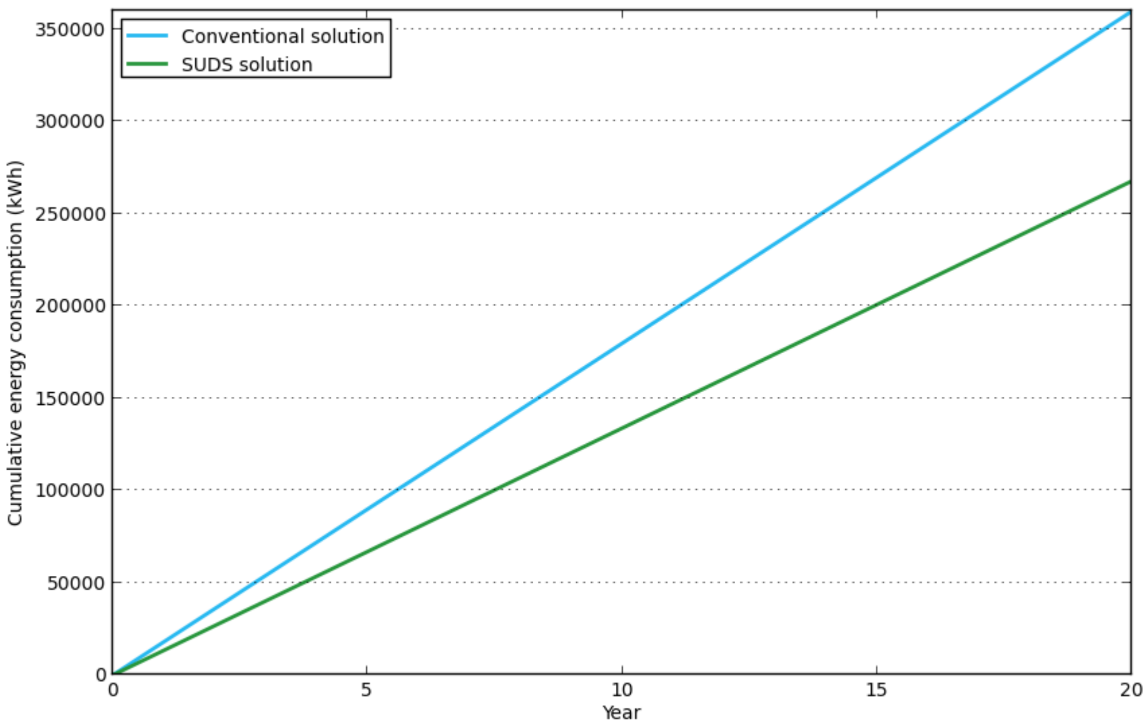

Figure 3.5.1.3.2 Net energy consumption of stormwater management (case without maintenance and infrastructure costs)

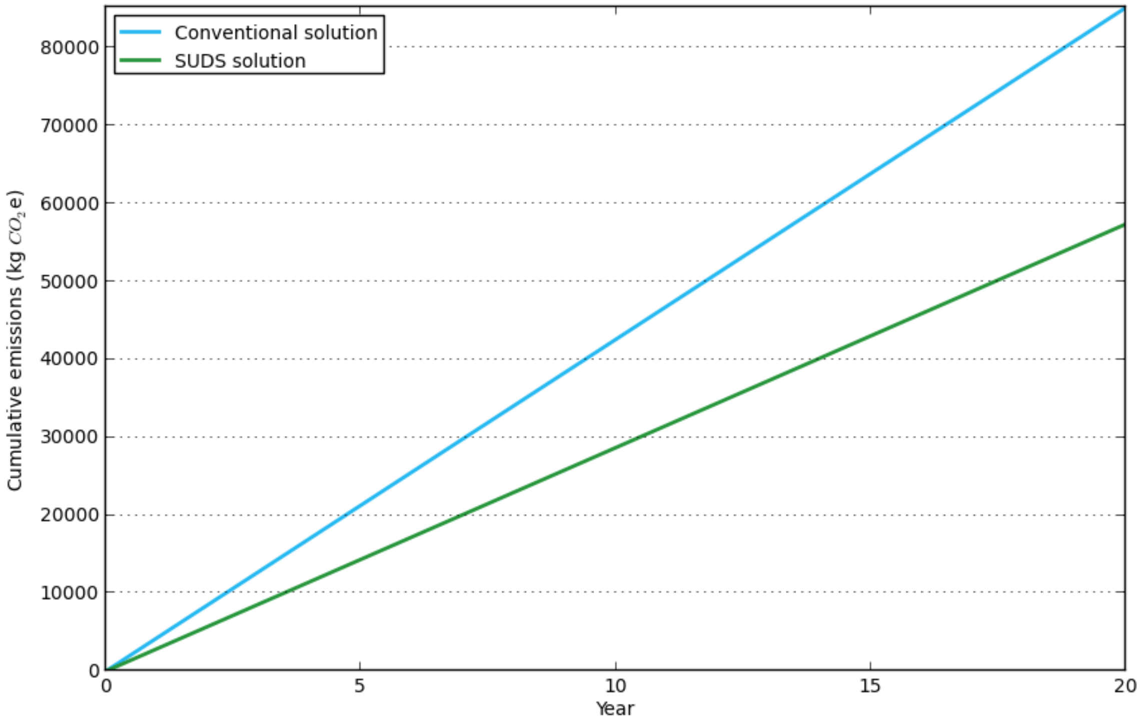

Figure 3.5.1.3.3 Net CO_2 emissions of stormwater management (case without maintenance and infrastructure costs)

Figures 3.5.1.3.1. to 3.5.1.3.3. show all the benefits and costs analysed except for maintenance and construction costs, and also their respective energy consumption and CO_2 emissions during the analysed period of 20 years. By excluding construction and maintenance costs from the analysis only flood protection benefits and wastewater treatment costs are considered in the analysis.

Figure 3.5.1.3.1 shows the economic benefits achieved from flood protection and reduction in costs of stormwater treatment. Flood protection benefits are very large and have similar values for both scenarios, even though the SuDS scenario provides a slightly lower lever of flood protection. SuDS scenario generates a greater reduction of stormwater and thus provides more economic benefits in this aspect. Still, the sum of these two benefits yields a slightly greater score for the conventional solution at the end of the period of analysis.

Energy consumption and CO_2 emissions show a linear growth during the analysed period for the both cases, but the values are higher in the conventional scenario. Only wastewater treatment energy consumption and emissions values are shown here. It is the only parameter in the analysis which generates energy consumption and CO_2 emissions (if construction and maintenance are not considered). Energy consumption and CO_2 emissions are higher in the conventional case because there is a higher volume of water that requires treatment.

3.5.2. Decision criteria

Quantifying the scenarios has been conducted by adding following weights for the following criteria:

Criteria	Weight
Net cost of stormwater management	35 %
Net energy consumed by stormwater management	20 %
Net emissions of stormwater management	15 %
Global outflow water quality	10 %
Evaluation of ecosystem services	10 %
Social acceptance	10 %

Net cost of stormwater management is considered to be the most important criterion for the stakeholders and was given a high weight.

Net energy consumed by stormwater management is a criterion which can also yield economic benefits and as such is given a high weight.

Net emissions of stormwater management is an ecological criteria, one which is not usually very important to managers and decision making bodies but has recently gained some attention in decision making processes in Croatia. For this reason it was given a value of 15 %.

The process of choosing maximum and minimum values for net costs of stormwater management, net energy consumed and net emissions criteria is identical to the one explained in section 2.5.2.

Global outflow water quality has been given a small weight since storm water is not directly released in the environment but continues to flow to the WWTP. If water treatment is considered only from the analysed area, than this criteria would have higher value.

Evaluation of ecosystems services is a criteria which also has a small weight as it is an ecological criteria which does have a rising (but still not high) importance in decision making process in Croatia.

Social acceptance has been added as an additional criterion with a low weight. Social acceptance presents a criteria which should show how eager residents are in accepting the implementation of stormwater management structures. Since there are urban gardens which could benefit from SuDS infrastructure, that scenario has been given a score of medium acceptance, and the conventional one a score of very low acceptance since it does not provide such benefits.

Global outflow water quality, evaluation of ecosystem services and social acceptance have been defined as qualitative decision criteria whose values range from very low to very high.

This set of criteria have been chosen by the experts and the results of the first DST analysis have been shown to various stakeholders during the second RWGEE. During the discussion that followed, members have come to a decision that the set of criteria used had been chosen well and did not see the need to change it.

3.5.3. Multi-criteria analysis results

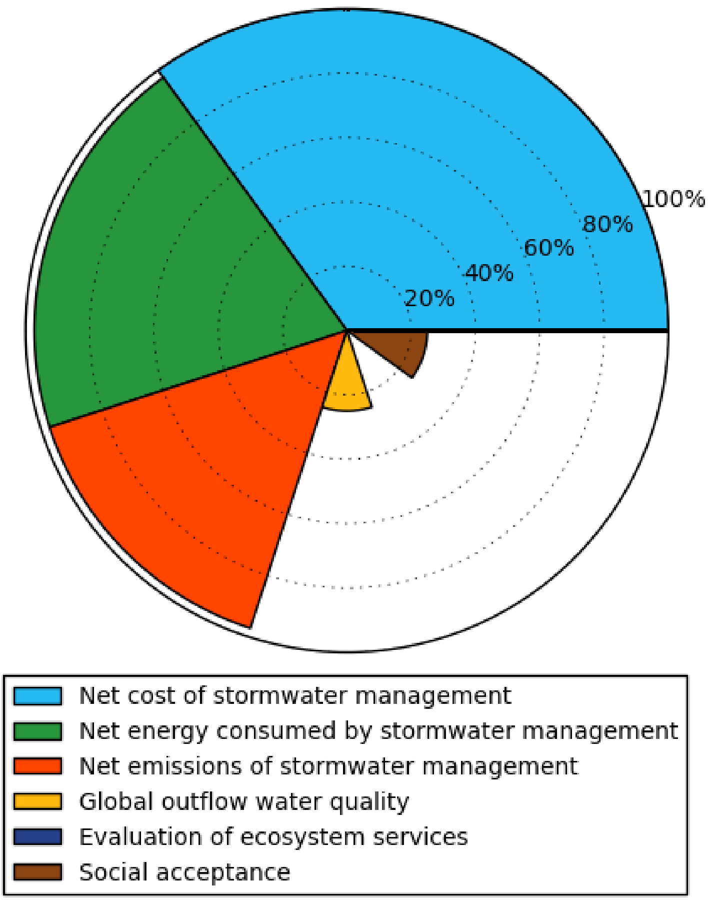

Figure 3.5.3.1 Circular results for conventional scenario

Criterion	Weight (%)	Utility (%)
Net cost of stormwater management	35	100,00
Net energy consumed by stormwater management	20	97,23
Net emissions of stormwater management	15	97,28
Global outflow water quality	10	25,00
Evaluation of ecosystem services	10	0,00
Social acceptance	10	25,00

Table 3.5.3-I Numerical values of circular results for conventional scenario

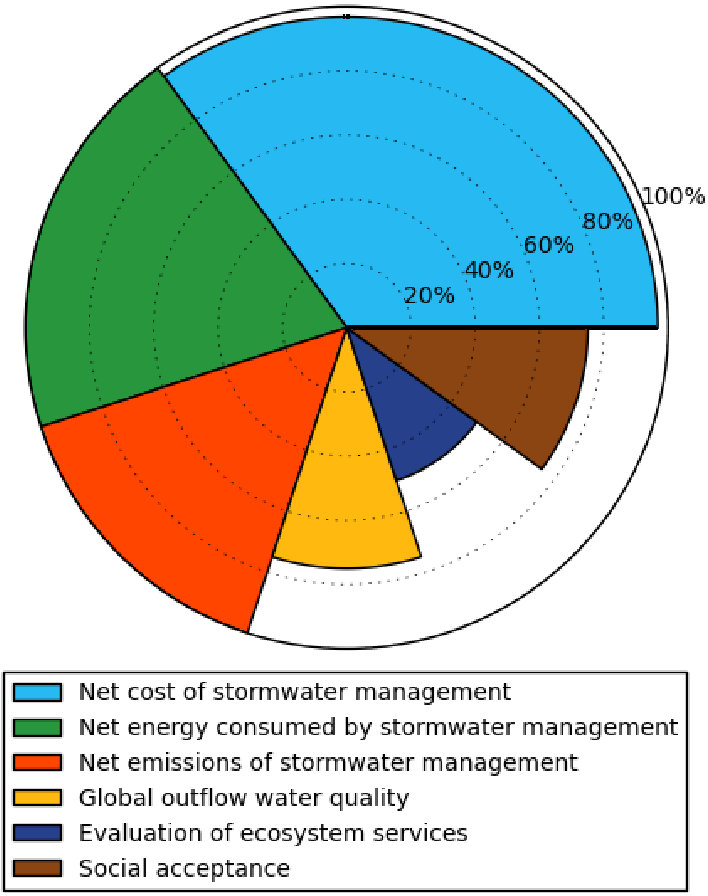

Figure 3.5.3.2 Circular results for SuDS scenario

Criterion	Weight (%)	Utility (%)
Net cost of stormwater management	35	96,78
Net energy consumed by stormwater management	20	100
Net emissions of stormwater management	15	100
Global outflow water quality	10	75
Evaluation of ecosystem services	10	50
Social acceptance	10	75

Table 3.5.3-II Numerical values of circular results for SuDS scenario

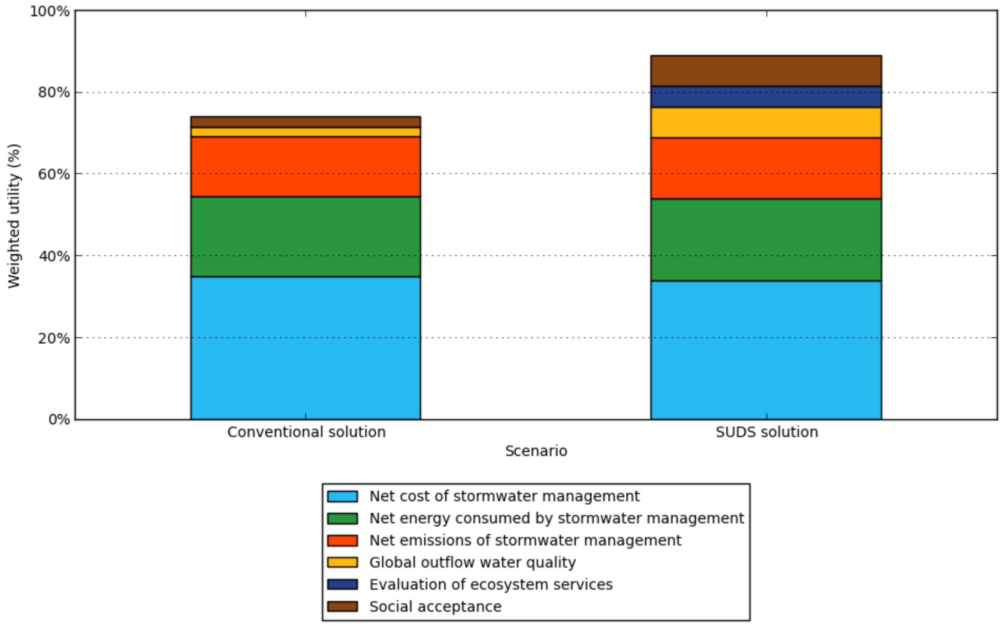

Figure 3.5.3.3 Global results

Criterion	Weighted utility (%): Conventional solution	Weighted utility (%): SUDS solution
Net cost of stormwater management	35,00	33,87
Net energy consumed by stormwater management	19,45	20,00
Net emissions of stormwater management	14,59	15,00
Global outflow water quality	2,50	7,50
Evaluation of ecosystem services	0,00	5,00
Social acceptance	2,50	7,50
Total	74,04	88,87

Table 3.5.3-III Numerical values of global results

As it is seen on all of the presented figures and tables in this section (Figures 3.5.3.1 to 3.5.3.2 and Tables 3.5.3-I to 3.5.3-III), by using the proposed criteria and its respective weights, SuDS solution yields a higher score.

Both scenarios have been chosen with same initial construction costs. During the period of analysis, conventional solution had lower maintenance costs and slightly higher flood protection benefits which resulted in a higher score of the economic criterion, net cost of stormwater management.

Net energy consumption and CO_2 emissions criteria are only slightly higher in the SuDS scenario. Although these criteria also should have a substantial effect on the overall score, they will not give a significantly higher score to any scenario.

All the other criteria (social and ecological criteria) are in favor of the SuDS scenario, and bring the total score to a value higher than the one of the conventional scenario. As previously mentioned, criteria which yield economic benefits (i.e. net energy savings) have been given a higher weight but ecological benefits as well as social acceptance (criteria which decision making bodies do not usually see as very important) have been given a small weight in order to slightly adjust the final score.

In this case, social and ecological criteria are the ones that aid in the decision making process. Since energy consumption and net management costs are very similar, ecological and social benefits are the ones that are used to clearly define a better option.

3.6. Conclusions

The multicriteria evaluation of the undeveloped area regarding the conventional and sustainable drainage infrastructure was made with the same general data and under the same assumptions as the analysis of the developed area. The conventional drainage scenario contains the usual drainage design characteristics according to the traditional engineering approach. The scenario with the sustainable drainage infrastructure tries to maximize the utilization of planned landscape design thus implementing new solutions in conventional landscape design and planning.

Whereas traditional drainage solutions involve expanding and adding structures that convey rainwater away from where it falls, sustainable infrastructure manages stormwater onsite. The flat terrain can cause problems for piped drainage because it often results in very deep trenches and large pipe diameters. SUDS can deal with the shallow or even totally flat terrain in the same way that nature does, by using wide shallow features to manage water flows.

Conventional solution is more economical due to higher maintenance costs of sustainable infrastructure. If energy consumption or CO_2 emissions are considered then sustainable infrastructure provides better results. If other environmental criteria such as water quality or social criteria are introduced than sustainable infrastructure is unquestionably the better solution.

Nevertheless, the use of sustainable infrastructure must be rational. For this analyzed area, with a substantial flat roof area, it has been concluded that the use of green roofs would result in much higher construction and maintenance costs than possible achieved benefits. This example shows the advantage of using DST software for decision making. Whereas the use of green roofs seemed to be undoubtedly logical and beneficial, it eventually proved to be a worse solution.

This large flat roof area could be used for harvesting solar energy by introducing solar panels for example. In this way the SUDS solution would probably achieve even better result. Generated energy could be used for pumping water stored in geocellular system thus improving benefits from water reuse. This water could be used for gardening or watering bioretention areas or even for toilet flushing in the nearby buildings. The inclusion of such infrastructure or such options in DST software is proposed.

However it is questionable whether roof construction costs as well as energy and emissions should be incorporated in drainage infrastructure since every roof is a part of building construction and normally is not tied to sewer construction costs. This is something that should be clearly defined in DST software and DST guidelines. Including the roof area in runoff volume calculation is unquestionably necessary. For this analysis roof expenses were considered in both scenarios.

If the drainage of the area is analyzed in the overall context of the existing sewage system then some of the given solutions might be a surplus and would represent an unnecessary expense. For example, if the existing sewer pipe along southern edge of the area could accept given hydraulic load then stormwater detention is unnecessary. Also, if locally treated water is mixed with poor quality wastewater in combined sewer then controlling onsite stormwater quality is unnecessary as well.

For this reason sustainable drainage infrastructure is most appropriate method of providing efficient drainage to a new developments and should be incorporated into the legislation regarding urban planning thus ensuring complete and matching solutions. If locally treated water with these infrastructures is mixed in the same pipe with the substantial amounts of wastewater originating from other parts of the city with different sewer system, than benefits from energy savings on WWTP concerning treatment are insignificant. In order to achieve the full potential sustainable infrastructure must be implemented in the whole existing drainage system and not just as one its parts.

Many problems that have occurred with the SUDS implementation are due to a lack of attention during design and construction, as well as the lack of proper maintenance. For example bioretention areas are often raised slightly above surrounding hard surfaces but for sustainable drainage infrastructure they should be lower than adjacent surfaces. Good site supervision and the assurance of effective maintenance imposes as a key for efficient drainage. Well-designed SUDS are valued by residents and are often used for other purposes.

In general, with the sustainable infrastructure better hydraulic and treatment characteristics of the stormwater sewer system are achieved, but in the circumstances involving possibility of high underground water level flood protection benefits are questionable or absent as explained in section 2.6.

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