Flood mitigation by on-site stormwater management (SUDS) - Preplanning of SUDS in Sandnes City

A CASE STUDY ASSOCIATED WITH TRUST

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1. INTRODUCTION

The city of Sandnes is located south of Stavanger, Norway. It is the fastest growing city in Norway. The total number of inhabitants of the city is about 70.000.

According to members of the municipality of Sandnes the city faces flooding problems. Flooding is a hazard for people and infrastructure and occurs regularly. The sewer system of Sandnes fails in case of heavy rain events.

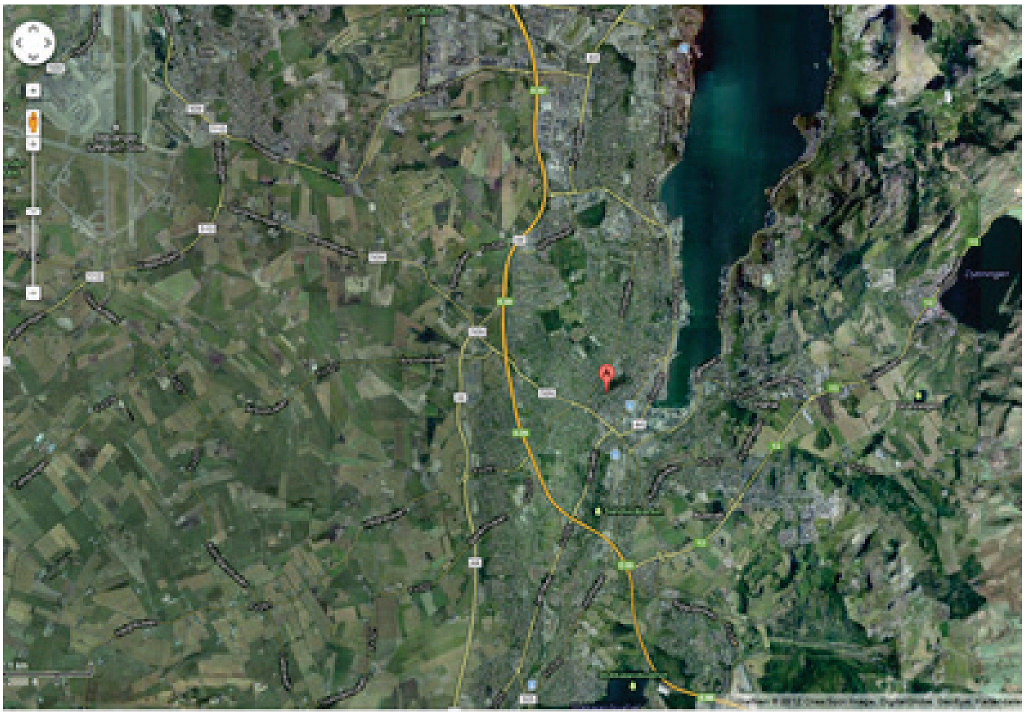


Figure 1. Overview of Sandnes, Norway (source: Google maps)

One solution to obtain flood mitigation might be the realization of on-site measures (**Sustainable urban drainage systems - SUDS**). The technical requirements for those source control measures and the amount of applicable measures have to be investigated. Therefore a feasibility study for Sandnes is planned.

The project in Sandnes takes place in association with the research project TRUST (Transitions to the Urban Water Services of Tomorrow, EC FP7 grant agreement No 265122; linked to Work packages 4.3 Wastewater and stormwater disposal [collection, drainage, treatment, discharge] in urban water systems).

2. DATABASE

The following databases for the project in Sandnes were available.

Table 1. Used database

NO.	DATA
1	Digital Elevation Model (cell size 2m X 2m)
2	Topography (shapes for roads, buildings, water)
3	Ortho photos (cell size 2m X 2m)
4	Supply lines (telephone, power cable, gas pipes)
5	Pipe network potable water, sewer system
6	Geological Map (Berggrunnskart), loose material deposits map
7	Climatic data: Rain data; Stavanger Våland mm 2004-2012; Temperature Bergen (station 76926)
8	Results of Infiltration measurement (N.T.N.U Trondheim)

The data 1, 2, 3, 4, 5 and 7 were delivered by Sandnes municipality. Geological information were derived from Norges geologiske undersøkelse (NGU), website. Results of infiltration measurement were provided from N.T.N.U Trondheim.

3. STUDY AREA

The area to be investigated is located upstream of Julie Eges gate. Figure 2 shows (bold line). The size of the area is about 5.37 ha. This area is of special interest due to a hydraulic bottleneck in downtown Sandnes. The retention of rainwater upstream of Julie Eges gate is an important step to a feasible stormwater management, when it comes to the planned rising of parts of the fjord area.

The investigation area was divided into smaller units. As seen in the Figure 3 below, it consists of 10 different blocks or sub-catchments. The report and the annexes refer generally to these sub-catchments. For a better understanding the roofs are already divided into pitch and flat roofs. The few green area is also shown.

The study area has some particularities regarding the areas. Less than 4% of green area is even for a city center a low value. 50% are occupied by buildings, half of which have flat roofs. Other impervious areas like streets and sidewalks forming the rest of the total value.

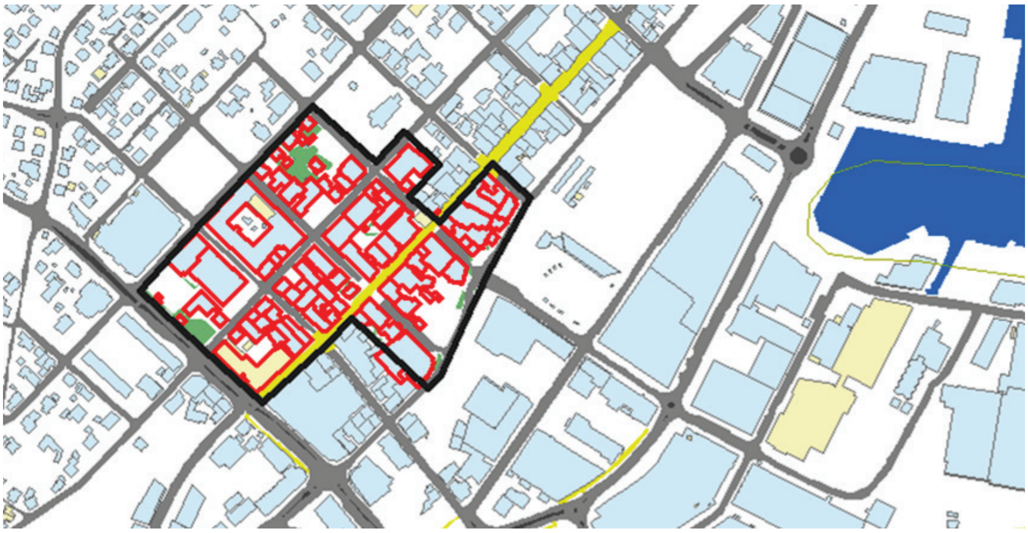


Figure 2. The investigation area southwest of the harbor of Sandnes, size 5.37 ha

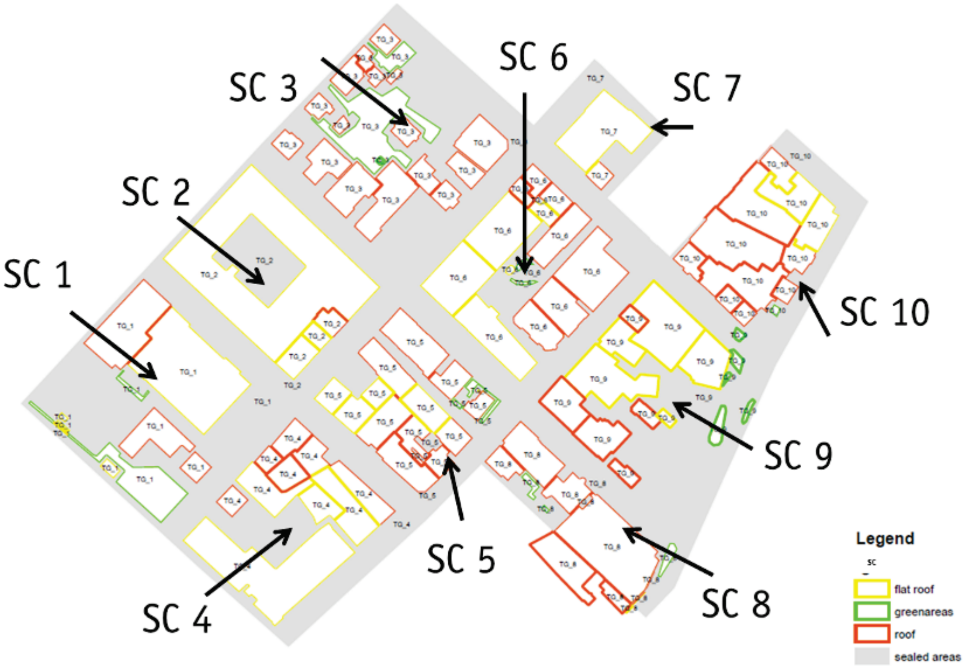


Figure 3. Division of the investigation area into 10 different sub-catchments

Table 2. Distribution of areas in the study area

TYPE OF AREA	SIZE OF AREA (HA)	SHARE OF TOTAL %
Roofs	1.34	25.0
Flat roofs	1.34	25.0
Pitch roofs	1.37	25.5
Streets, sidewalks, courtyard, parking	2.51	46.7
Green spaces	0.2	3.7

4. CONDITION FOR SUDS IN PILOT AREA

There are a large number of different types of SUDS. The selection of SUDS depends on different influencing criteria. Mainly the criteria shown in Figure 4 influence the application of SUDS. They cannot be implemented everywhere. Especially natural factors (geology, soil, and slope) affect the application of the types of SUDS technique. Other criteria, which are related to build-environment, influence the selection of possible location for SUDS (disconnection potential).

In the study area the main constraint is high sealing and supply line (and pipes) in the underground.

Sustainable urban drainage systems treat stormwater decentralized. If possible, the stormwater can be disconnected from the sewer system. Therefore replacement systems (SUDS) were implemented. These SUDS reduce discharge of runoff from impervious area totally or partly by storage and infiltration facilities.

For the implementation of the SUDS mainly two different aspects must be considered:

4.1 Natural conditions

Sandnes is located south of Gandsfjorden – the town center is just west of the harbor. Topographic constitutes the municipality a distinct division between landscapes of Low-Jæren the west and the hilly heath landscapes against Høgsfjorden and High-Jæren the east. Bynuten (671 m) is the highest point in Sandnes.

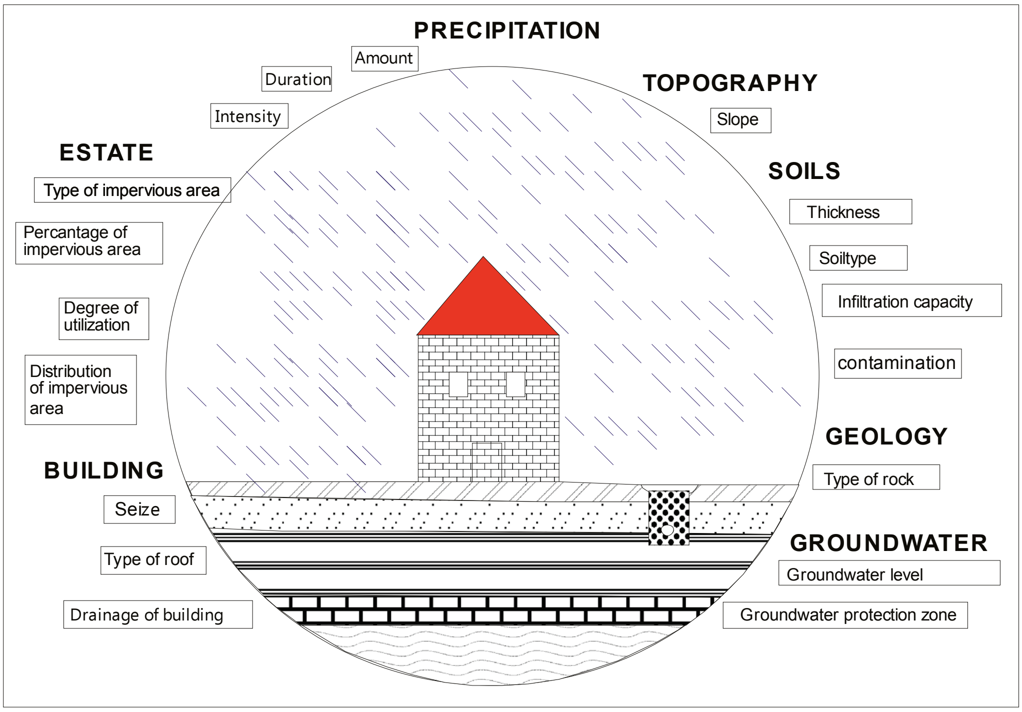


Figure 4. Influencing criteria on planning SUDS

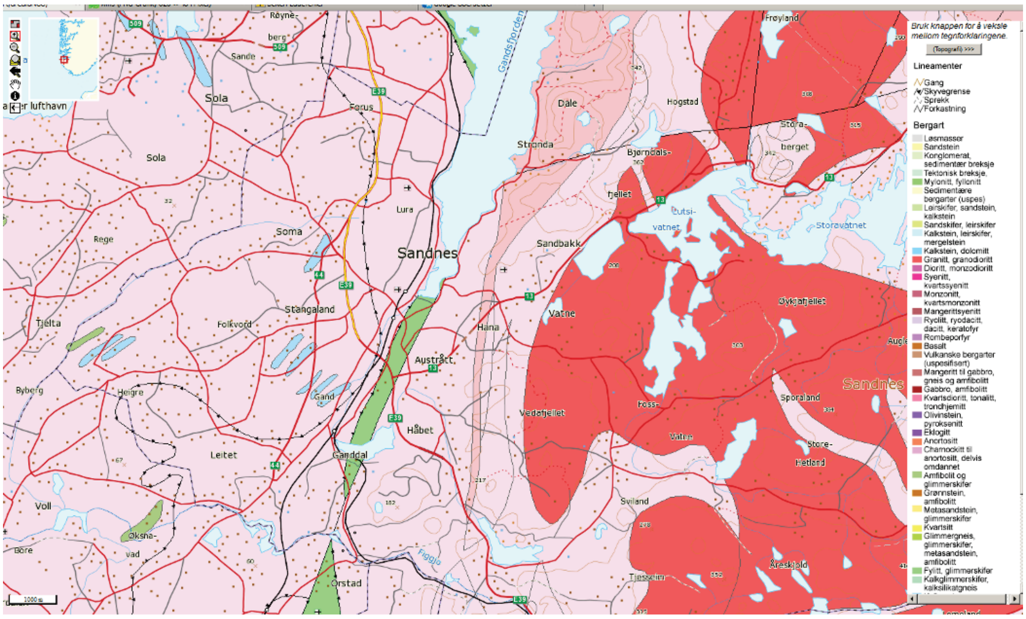


Figure 5. Geological map of Sandnes and surrounding countryside

4.1.1 Bedrock Geology

The municipality belongs at the east to the svekonorvegiske bedrock shield, and consists of two main geological formations of Proterozoic rocks. The old formations, 1 600-1 450 million years old slate, consist of: quartzite, marble and amphibolite. In the upper younger formation dominates granite.

In the west part of the municipality dominates nappes of the Caledonian orogen, which extends to the north. Lower cover consists of mica schist and phyllite, while the middle, situated on the west coast, consists of granite and gneiss from the middle and later Proterozoic.

4.1.2 Loose material: Deposits of Quaternary

In the region of Sandnes mainly three different types of sediments are found:

- Fluvial deposition: River and stream deposition

Fluvial deposition is material that is transported and deposited by rivers and streams. The most typical forms are alluvial plains, terraces and fans. Sand and gravel dominates, and the material is sorted and rounded.

- Fluvio-glacial deposition and Moraine material:

Sediments consist of sorted, often oblique layers of different grain size from fine sand to rocks and boulders. Eskers are often clear surface forms terraces, ridges and fans.

- Moraine material: continuous cover, in places with large thickness

Material picked up, transported and deposited by glaciers, usually hard packed, poorly sorted and can contain anything from clay to stone and block. There are few or no mountain outcrops in the area.

The study area is located in the non-classified zone. A glance at the map suggests, however, that under the anthropogenic influenced sediment one of the three mentioned layer will be found. Therefore on-site investigations were necessary.

4.1.3 Soils and groundwater

Soil is the upper part of earth's crust, which is normally biological active zone. In the study area soils are of surficial deposits and are heavily influenced by human activity (Figure 6). Soil type developments are influenced by the texture of the soil, climate and time.

During the on-site inspections, infiltration measures were taken and soils control showed sandy depositions (Figure 7). Furthermore some construction sites in the study area show under the impervious area and some fill material (30 to 60 cm deep) the similar soil as well. Members of the municipality confirm that sandy soils are known within this region.

Nevertheless it’ not proofed for all investigated sub catchments within the study area. The next soil layer could not be determined.

Groundwater was not detected. At end of March the highest groundwater tables in the course of the year are likely. Thus no groundwater was found, SUDS implementation are not constrained by groundwater.

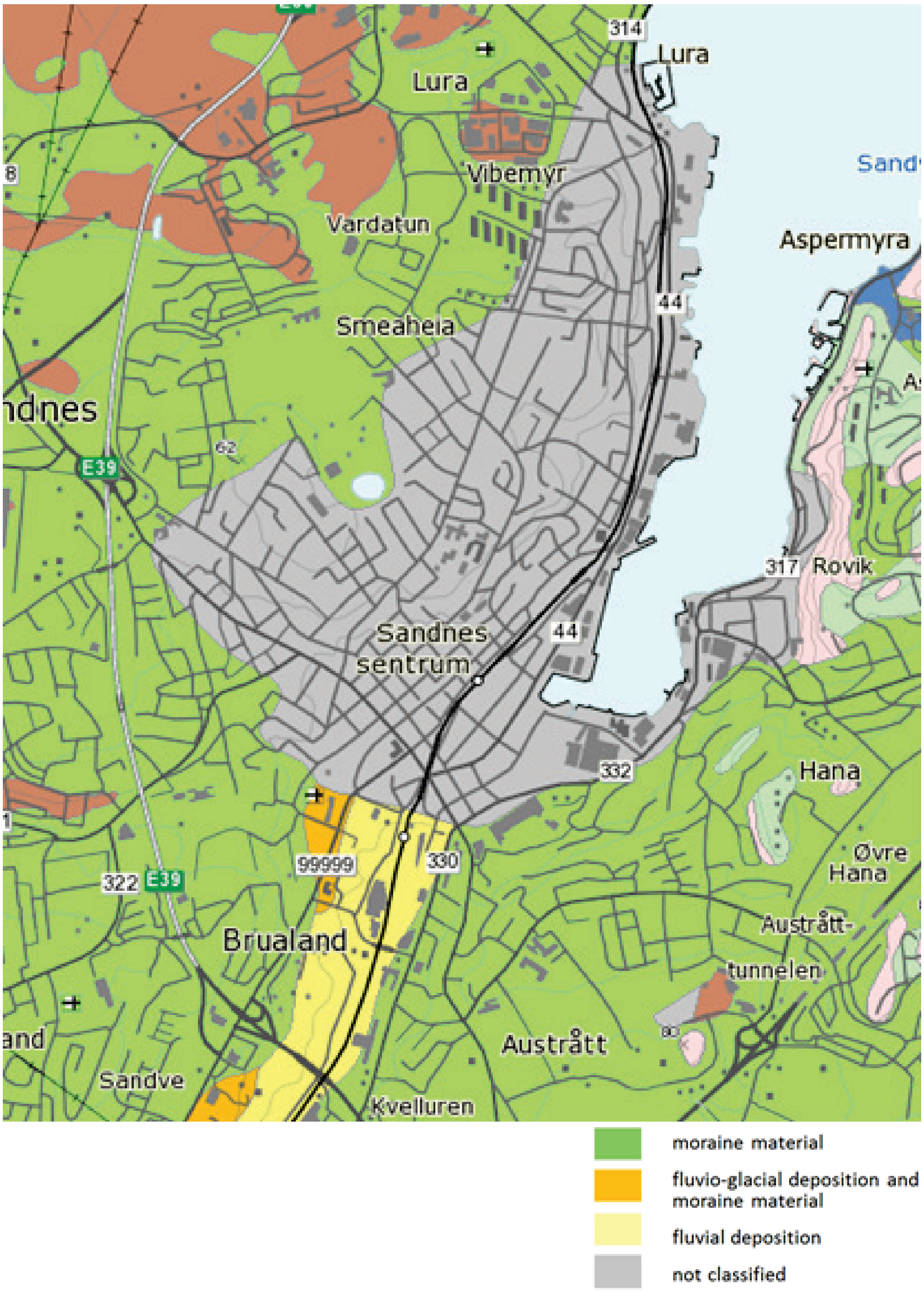


Figure 6. Soil map of Sandnes

4.1.4 Infiltration measurements

For infiltration measures the thickness of loose sediment and the texture of it play a major role for planning and designing SUDS. The more important were the on-site infiltration measurement done by the University of Trondheim (N.T.N.U).

In a highly urban area like the city of Sandnes the natural soil disappeared. In general an artificial layer above natural soil was visible (ongoing construction sites during stay in Sandnes).

The results of the infiltration measurements are shown in Table 3. Six measurements on three places were performed. Because of limited green area in the study area, the places for on-site measurements were very limited. The only suitable place could be realized in sub-catchment 1 (green area). Other green area is private property and is not accessible.

The measurements were performed on the surface and in a depth of 70 cm. Unfortunately the upper 10 cm were still frozen which made a measurement of the hydraulic soil conductivity difficult. Nevertheless an infiltration rate of average value could be determined.

When SUDS are implemented, the bottom of the infiltration layer is usually located in a depth of 60 to 150 cm. Therefore at this depth infiltration measurements should take place. In a depth of 70 cm the soil hydraulic conductivity shows values of 1 to 16 cm/d. These results suggest that the planned SUDS can infiltrate the stormwater completely. However, this assumption needs to be confirmed by modeling (chapter 7) with STORM (IPS software).

If planning becomes concrete, the space allocated for SUDS must be tested again. Especially in strongly urban influenced soils, the compaction of soils even in sandy layer is often high and the value can differ from measurements.

Table 3. Results of infiltration measurements in Sandnes by N.T.N.U

	K_{SAT} [cm/h]	TENSION C [cm]	AVERAGE: K_{SAT} [cm/h]	AVERAGE: C [cm]
Overflaten (0 cm) A	3.7011	-0.55857	1.405	-717.2
Overflaten (0 cm) B	0.47554	-563.52		
Overflaten (0 cm) G	0.03805	-1588.2		
70 cm	11.738	-24.823	9.775	-12.9
70 cm	0.91625	-22.773		
70 cm	16.67	-9.5975		

Figure 7. Construction site in study area and infiltration measurements

4.1.5 Contamination of soils

Any information about contaminated soil was not available. In a city center like Sandnes contaminations are especially likely on properties with an industrial background. When realization of SUDS becomes real, it is necessary to ensure that no contamination present on the property.

Figure 8. Aerial photo.

4.2 Build-environment influence

As to be seen in Figure 4, many criteria have to be considered to get a disconnection potential. In general two different types of disconnection potential can be distinguished:

- Short term potential

Implementation of SUDS is technically easy to perform. The realization can take place within the next one to five years. The costs are moderate because space for SUDS is already available.

- Long term potential

Implementation of SUDS is technically not easy to perform. In general some changes in infrastructure or structural measures at buildings are necessary, like unsealing of areas or reconstruct drainage of buildings.

The long-term disconnection potential turns into short-term potential, when the renewal of infrastructure (new sealing for streets, new design of areas etc.) is planned within the next years. In Sandnes many projects are ongoing because of new design of areas. For example the shopping street Langata gets a new design. This is a very good opportunity to involve stormwater management into the architectural planning.

To estimate the disconnection potential, the orthophotos (aerial photo with Geographical coordinates) were examined at first. Advantage of using the orthophotos is the option to search for more adequate places for SUDS: Information on roof types (pitch or flat roofs), green area, differentiation into different sealed areas and so on. However, occurrence of trees decreases short-term disconnection potentials.

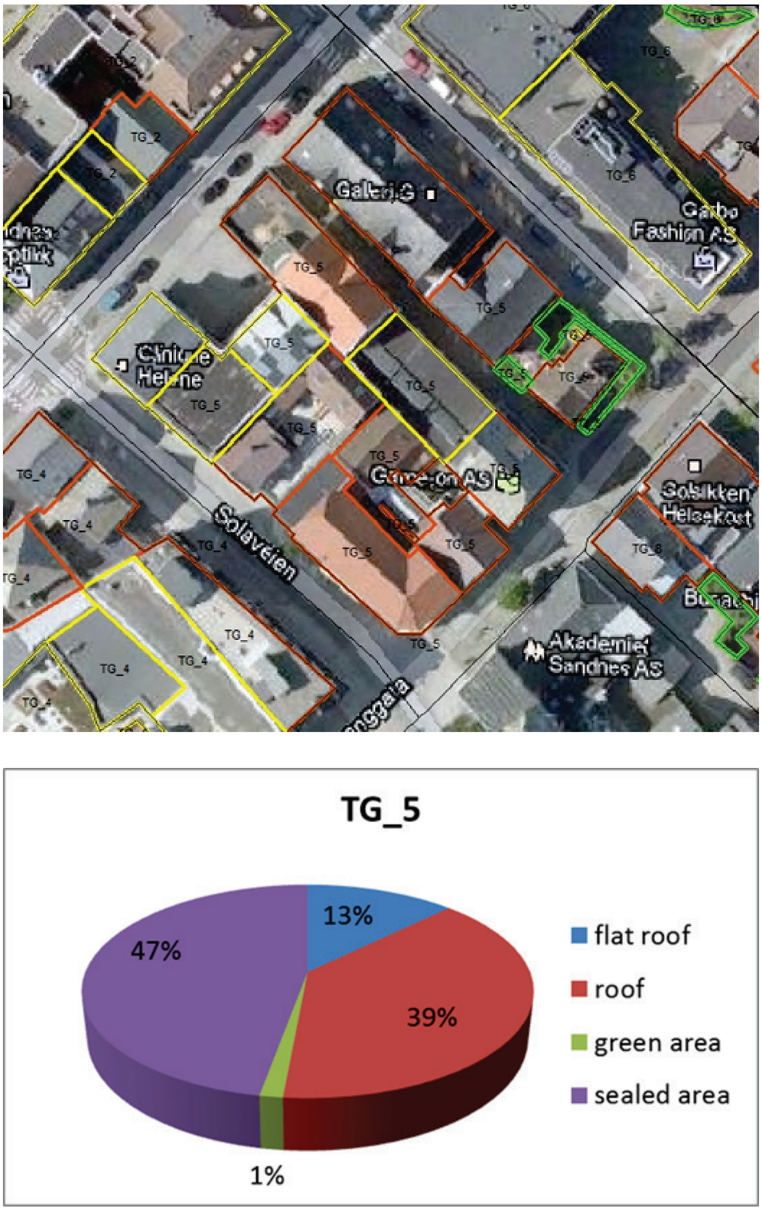


Figure 9. Distribution of area in sub-catchment 5

First results of the GIS assessment show the high degree of impermeability in the study area.

The realization of SUDS implementation depends on the on-site elevation relations. Normally, SUDS have to be implemented at the lowest point of the treated run-off areas. The assessment of the slope direction and slope value supports the identification of possible SUDS locations.

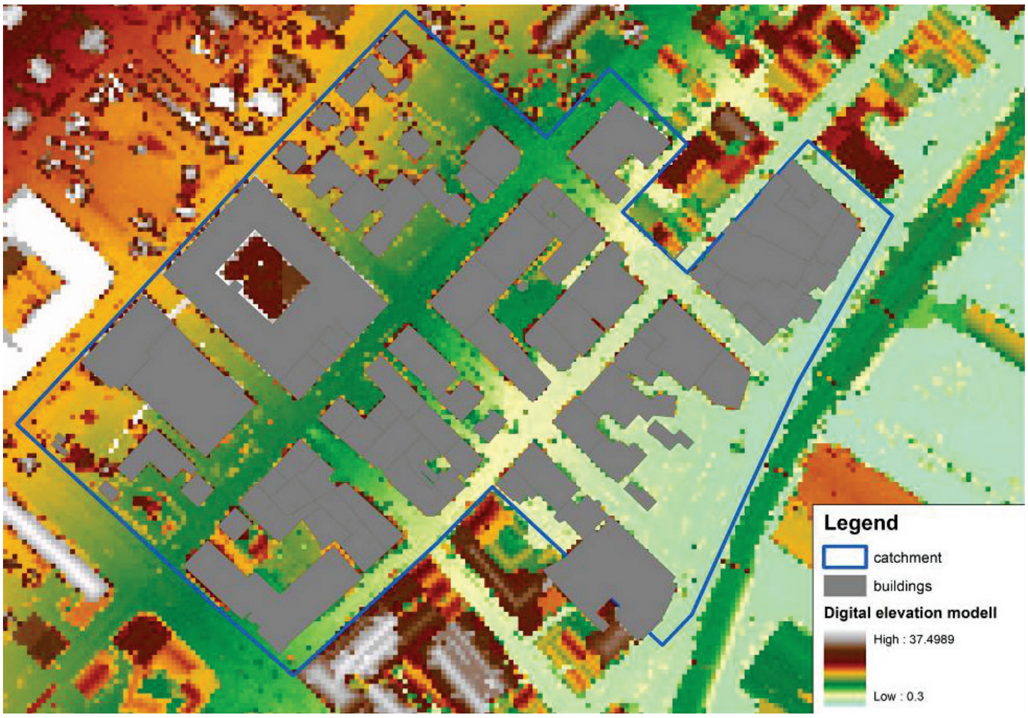


Figure 10. Digital elevation model in the study area

In Sandnes City many cables and pipes occupy underground area. This area is not available for storm water management. All SUDS with underground storages have to be planned at a safe distance. This criterion is considered for all SUDS, but less important for green roofs.

5. MAPPING

The mapping helps to get more information about the drainage situation on-site. It specifies the GIS data bases and gives more information about the drainage situation. Inlets, gullies, down pipes can be identified and are drawn into the sketches. Problems in the implementation of measures can be better identified.

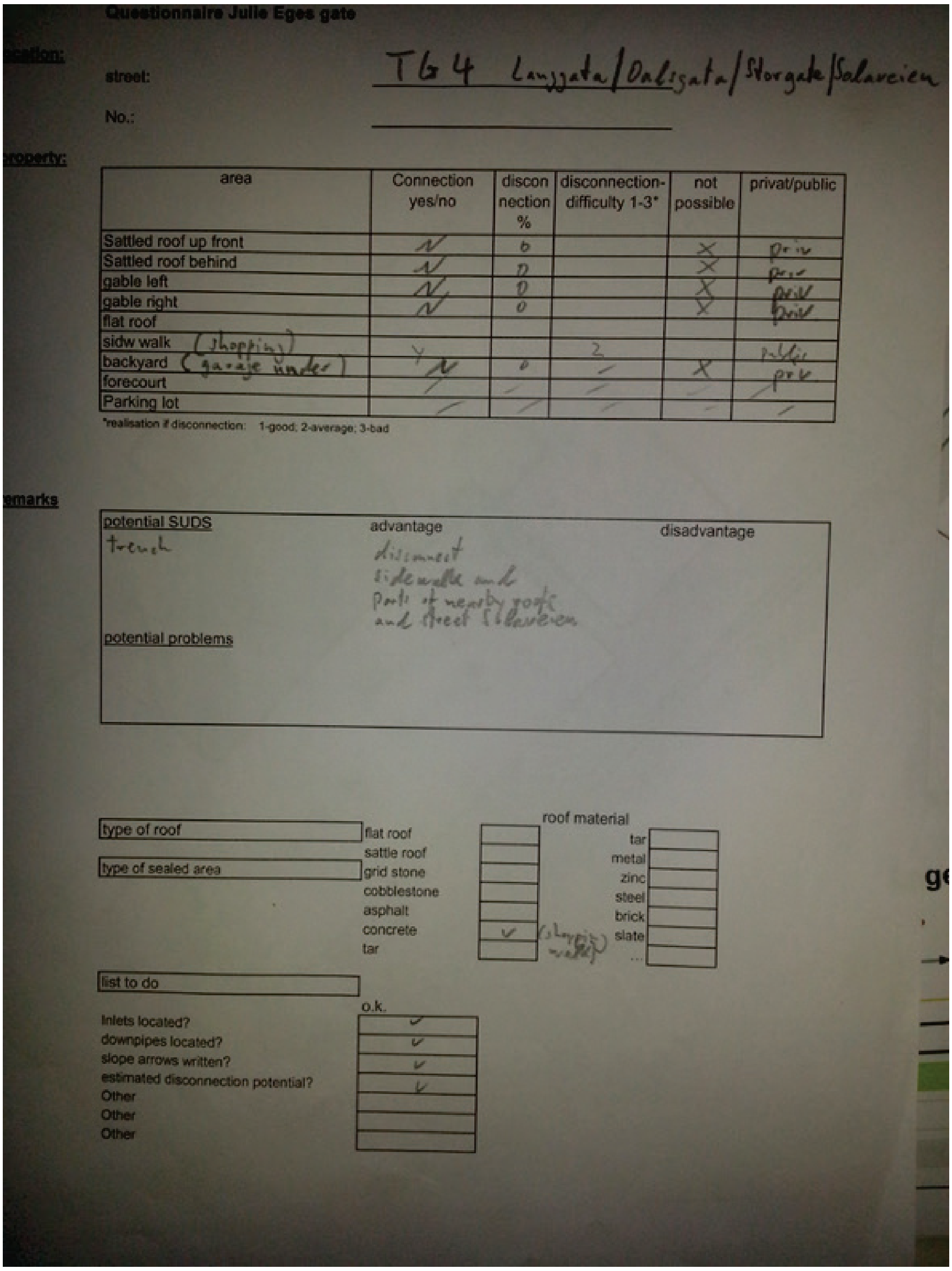
The mapping supports identifying possible on-sites for SUDS and impervious area, which can be disconnected (separated) from the sewer system. Inlets, gullies, down pipes can be identified and are listed on the paper sheets. Problems that might occur during the subsequent implementation are better avoided. The following figures show the documents used for mapping (Figure 11 and Figure 12). For each sub-catchment one questionnaire and a drawing sheet were needed. All mapping documents are stored in annexes 3.

The following data are obtained during the mapping and added to the GIS data (Figure 13):

- Downpipes
- gullies
- gutter
- Inlets
- Slope (street, roof pitch)
- Type of roofs

Figure 11. Example of used data sheets for the mapping

If possible, the flat roofs were inspected with the kind support of Sandnes municipality. To some roofs IPS got access but not to all. Other roofs were assessed by GIS and from the top of other buildings. During the mapping first possible SUDS are drawn on paper (Figure 11) and the disconnection areas are marked.



Questionnaire Julie Eges gate

location:

street: TG 4 Langgata/Dalsgata/Storgata/Salaveien

No.:

property:

area	Connection yes/no	disconnection %	disconnection-difficulty 1-3*	not possible	privat/public
Sattled roof up front	N	0		X	priv
Sattled roof behind	N	0		X	priv
gable left	N	0		X	priv
gable right	N	0		X	priv
flat roof					
sidw walk (shopping)	Y		2		public
backyard (garage under)	N	0	–	X	priv
forecourt	–	–	–	–	–
Parking lot	–	–	–	–	–

*realisation if disconnection: 1-good; 2-average; 3-bad

remarks

potential SUDS	advantage	disadvantage
trench	disconnect sidewalk and parts of nearby roofs and street Salaveien	
potential problems		

type of roof: flat roof, sattle roof

type of sealed area: grid stone, cobblestone, asphalt, concrete ✓ (shopping walk), tar

roof material: tar, metal, zinc, steel, brick, slate, ...

list to do

	o.k.
Inlets located?	✓
downpipes located?	✓
slope arrows written?	✓
estimated disconnection potential?	✓
Other	
Other	
Other	

Figure 12. Questionnaire used for all sub-catchments

Figure 13. Some results of the mapping implemented into GIS framework

6. SELECTION OF OPTIMAL STORMWATER MANAGEMENT

After GIS analysis and mapping the selection of the optimal stormwater management was made. Different types of SUDS were considered (like Figure 14).

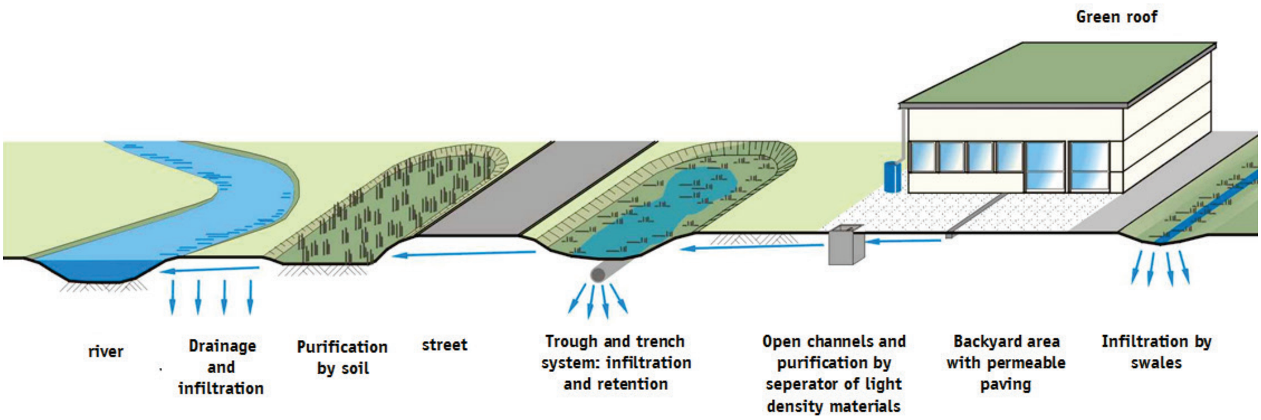


Figure 14. Examples for different types of SUDS

All proposed SUDS in the study area are described in detail in appendix 1 (sketches) and 2 (description).

6.1.1 Green roof

As mentioned in chapter 3, 50% of the area is occupied by roofs. Therefore the investigation of roofs using as on-site measure is obvious. In general green roofs or blue roofs (impound of roofs with rain water without vegetation layers) were considered.

Figure 15. Examples for extensive green roofs

Figure 16. Examples for intensive green roof

Depending on the flat roof construction different kind of green roofs can be implemented. The following aspects in the feasibility study were considered:

- Type of roof
- Roof material
- Static of roof (in general)
- Drainage of building
- Maintenance accessibility

Sometimes the roof is used for other purposes as well. Constraints are e.g. given by many ventilation systems etc).

Statics of roofs

Generally, in Sandnes the limit of the roof snow load is calculated for 1,5 kN/m↗. This is about 150 mm of rain. The weight of an average green roof is approximately 75 kg/m↗ (dry wather). The impound of the roof during a storm event of 35 mm increases the weight to 110 kg/m↗.

In Sandnes the roofs are not designed for additional load, e.g. green roofs, to the snow load. Thus it's problematic to install them at all. But many roofs are not in a good condition any more. If the renewal is pending, the statics should be tested for a Green Roof. Especially when one considers the cost, it makes sense to wait until the renovation of the roof.

Green roofs can be implemented in sub-catchment 1, 2, 4, 6 and 10 (see also details in appendix). The structure of the potential Green roofs can be found in Appendices 1 and 2. Effects on the runoff from green areas are shown in chapter 9.

6.1.2 Blue roof

Compared to a green roof, the blue roof impounds the stormwater on the roof without any additional vegetation. The discharge is throttled down. The higher the water levels on the roof, the higher the discharge. The advantages of a blue roof compared to a green roof are the costs and the weight. The main work is a change of the runoff. Generally blue roofs can be implemented as substitute solution for green roofs.

Impound of the roof is only for limited time. After the rain fall event the roof needs to be emptied for the next storm event. Therefor a flexible throttled discharge is to be constructed.

Disadvantage: almost no additional evapotranspiration.

6.1.3 Swale or rain garden

Term swale (rain garden) refers to a green area, usually in a form of a depression, designed specifically to treat and reduce stormwater runoff. Stormwater runoff flows into these green areas, where it is stored and treated through vegetation and soil. Finally stormwater infiltrates into the underlying soils and replenishes the groundwater.

Swales are designed to allow temporal surface storage (about 150 m↖/ha), but should not be filled with water for more than 72 hours after rainfall has ceased. The required area of swales is about 10-15% of the sealed surface connected to it. Depth should not exceed 30 cm, because of too long duration of draining. In order for the swales to function properly, they must be maintained at the proper slope and on the soils with a good permeability (Hydraulic conductivity: >10^{-6} m/s).

Swales where selected in the study area under the following conditions:

- Green area available
- Infiltration capacity good enough
- Swale is no competition for other purposes

- Swale located at the lowest point of the connected area (easy surface runoff to device possible)

In the study area there is only limited green area for stormwater management available. Therefor it is only suggested for sub-catchment 1. Further detail see appendix 2 and 3. Swales are one of the cheapest SUDS to realize.

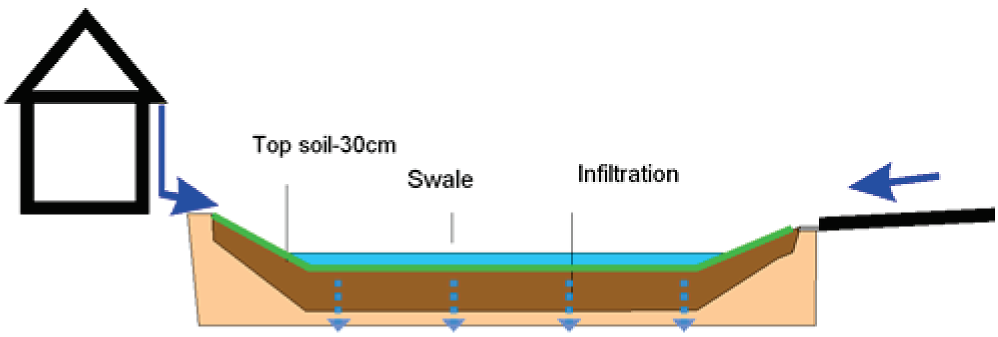


Figure 17. Longitudinal section of a swale

Figure 18. Swale just finished

6.1.4 Rain garden + subsurface storage (trench)

The proposed rain garden consists of two elements: A surface storage and a subsurface storage. Examples for surface storage are described in 6.1.3. The advantage of the system is the combination of the multiple functions:

- More storage volume with surface and subsurface storage
- The needed surface area keeps small
- More green in urban areas
- Purification of stormwater runoff (biological active zone vegetated)
- Throttled discharge to sewer system possible (if necessary)

An infiltration trench is a rock-filled (gravel or other fill material) underground reservoirs, specific designed for receiving stormwater runoff. Stormwater runoff passes through combination of pretreatment measures, such as a rain garden, swale or sediment basin, before entering the trench. Runoff is then stored in the voids of the stones, slowly infiltrates through the bottom and into the soil matrix over a few days. Implementing a trench in addition to a swale enables increase of storage and infiltration of the stormwater (200-400 m↖ /ha).

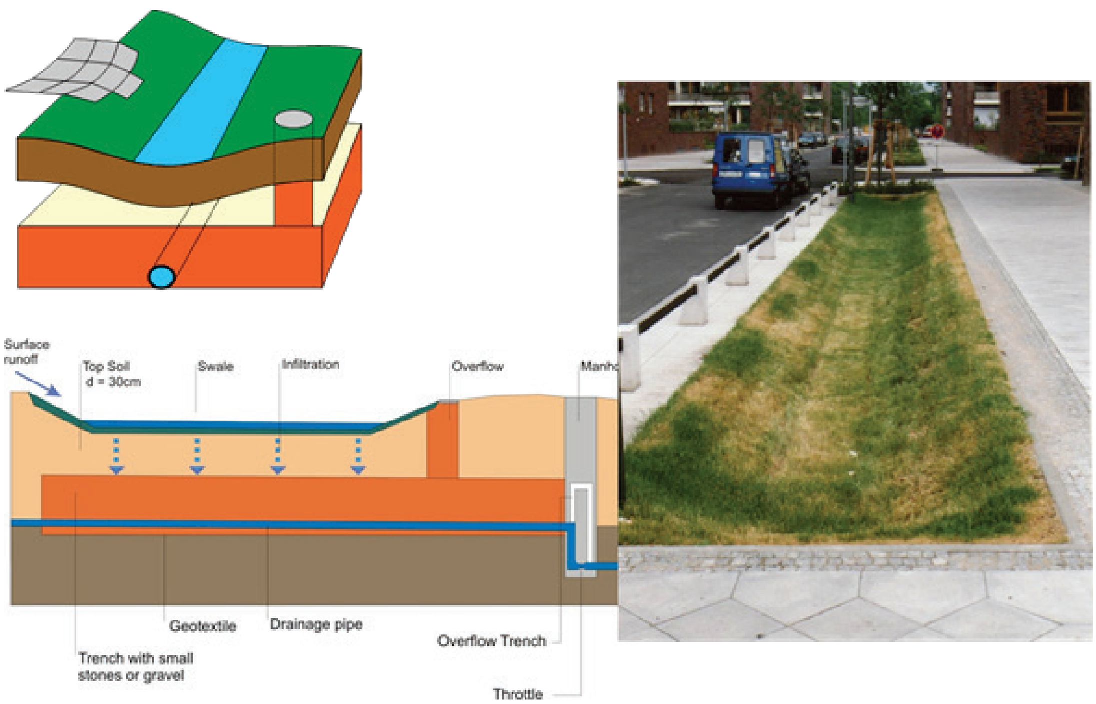


Figure 19. Longitudinal section of a swale-trench-system

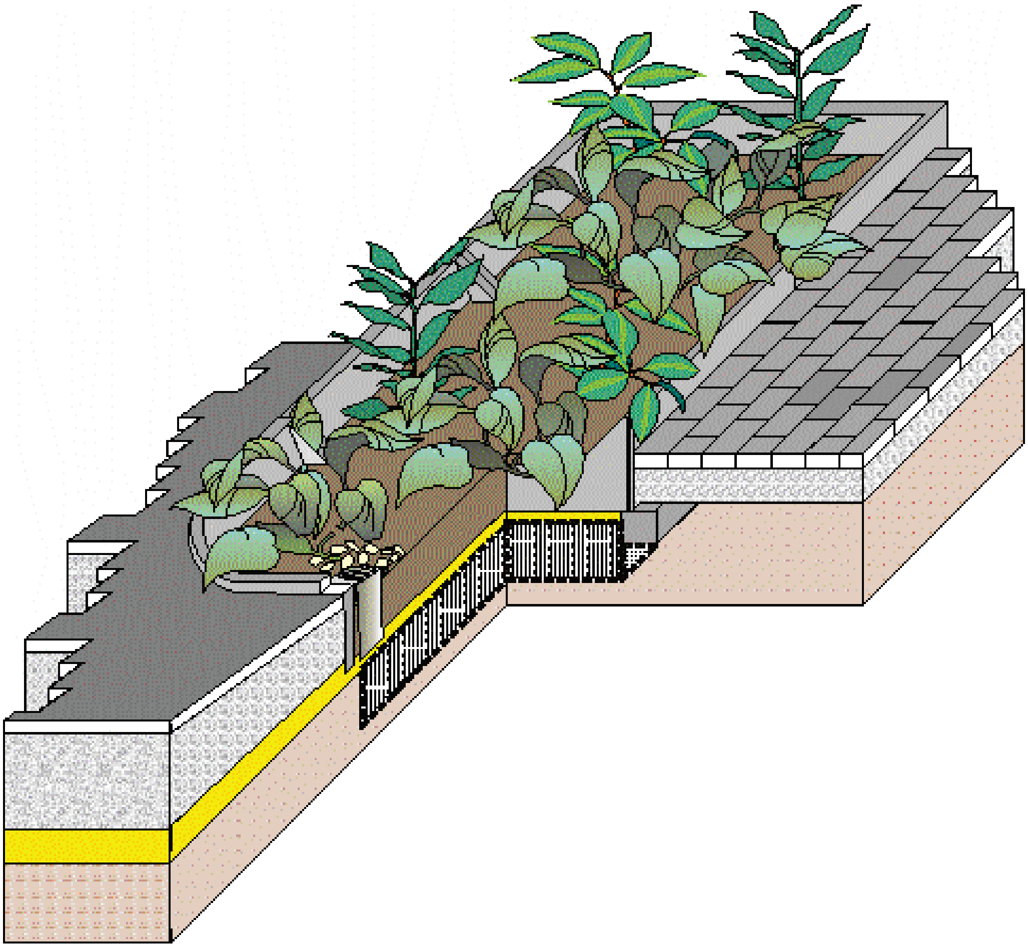


Figure 20. Block picture of a rain garden next to streets (e.g. INNODRAIN®)

Figure 21. Rain garden combined with trees

Rain gardens and subsurface storage where selected when given the following conditions:

- Surfaced storage with green area can be implemented
- Swale or rain garden is no competition for other purposes
- Subsurface storage is necessary due to design requirements (see following chapter)
- Throttled discharge may be necessary (connection to sewer system)

Figure 22. Rain garden INNODRAIN®

The implementation of rain gardens is recommended for the sub-catchments 1, 3, 9 10.

6.1.5 Subsurface infiltration

In many areas of the city center of Sandnes only limited surface area can be used for stormwater management. Therefore SUDS are also planned under the surface. The Figure 23 shows different types of underground storages.

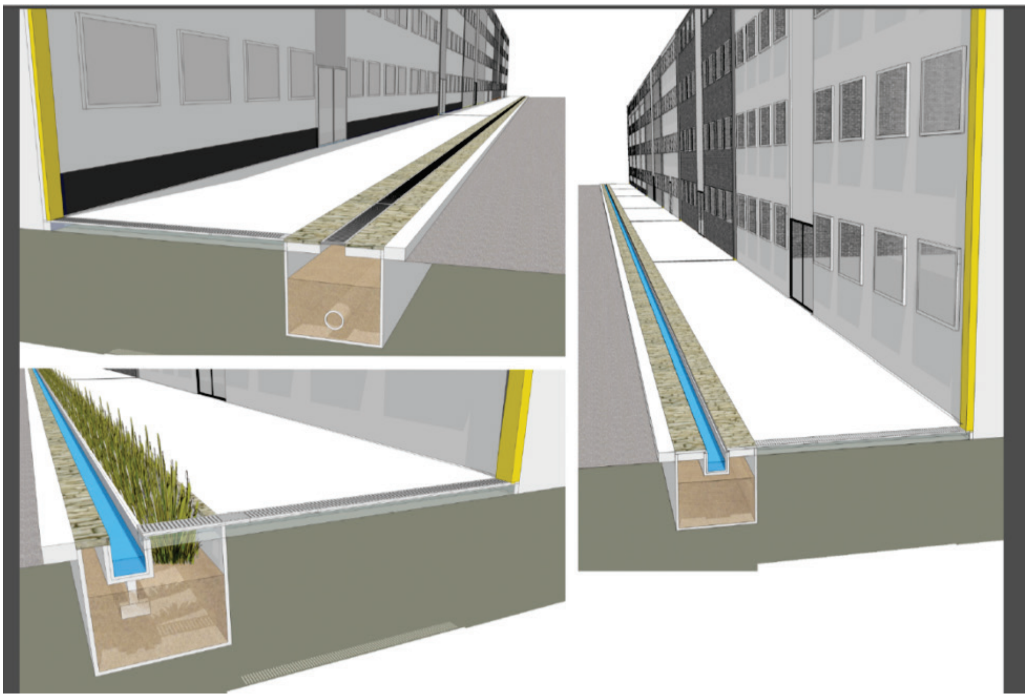


Figure 23. Different types of possible subsurface storages

Subsurface storage (trench) where selected when given the following conditions:

- The pollution of the surface is acceptable (no heavy traffic)
- No surface volume for stormwater treatment available
- No constraints by supply lines or pipes
- Position of SUDS not close to basement

The pedestrian zone in the study area of Sandnes City is rescheduled at the time. This is a great opportunity to reduce runoff downstream. The implementation of underground storage should be combined with the architectural conversation. Probably the green area in the city center shall be increased. This can be combined with surface vegetation (Figure 21and Figure 23) and subsurface stormwater management. It is recommended to combine the underground infiltration storage devices with a throttled discharge to the rain water system. This reduces the risk of flooding, though the design of the SUDS is made for a 10 year event.

Figure 24. Subsurface storage with 95% storage volume

Some recommendations concerning trenches for stormwater storage device

- Use gravel of unique size
- Avoid fine material around gravels
- Wrap with geo-textile
- Porous drain pipe

Inspection manhole with

- Throttle
- Overflow

The implementation of rain gardens is recommended for the sub-catchments 1, 4, 5 and 6 (4,5, and 6 SUDS are part of pedestrian shopping street Langata).

Figure 25. Subsurface storage in Sandnes city with a green surface inlet (without storage volume)

7. DESIGN OF SUDS BY STORM

All chosen on-site measures were implemented into STORM, software for designing SUDS (Ing. Sieker mbH). The design of the SUDS was calculated with local rain data (9 years, Stavanger N4458N13). The average rain amount of the delivered time series is 1313 mm/a (from the beginning of 2004 to the end of 2012). Within the time series the highest rain event took place on the 30th of July 2012. Within 2 hours 37 mm of rain were measured. The highest rain water sum within this event was 15.6 mm in 15 minutes.

Compared to typical storm events in Berlin the intensity of the rainfall events for a ten year period in Stavanger is less than average. The mentioned highest rain is comparable with a five year storm event in Berlin (duration 15 min). The duration of two hours and 37.5 mm corresponded to a one year rain event in Berlin.

A temperature time series for Stavanger was not available. Thus a time series from another region was used (Bergen). The assessment of temperature data showed, that in general only few days per year are below 0°C degrees. In general a long time of frozen periods and lots of snow amount are not likely, but still possible!

The SUDS in STORM are designed for zero overflows within simulation time. Even the high rainfall intensity in 2012 (Figure 27) doesn't lead to a failure of the SUDS. Due to the fact that in the City Center a high potential of damage exists, this SUDS design was chosen (Table 4).

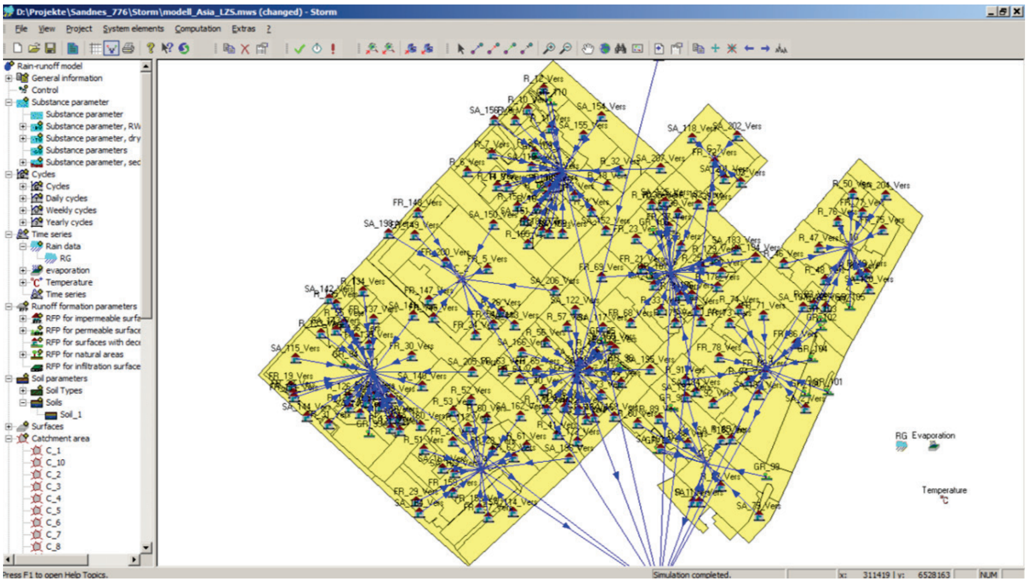


Figure 26. Sandnes City SUDS design with STORM

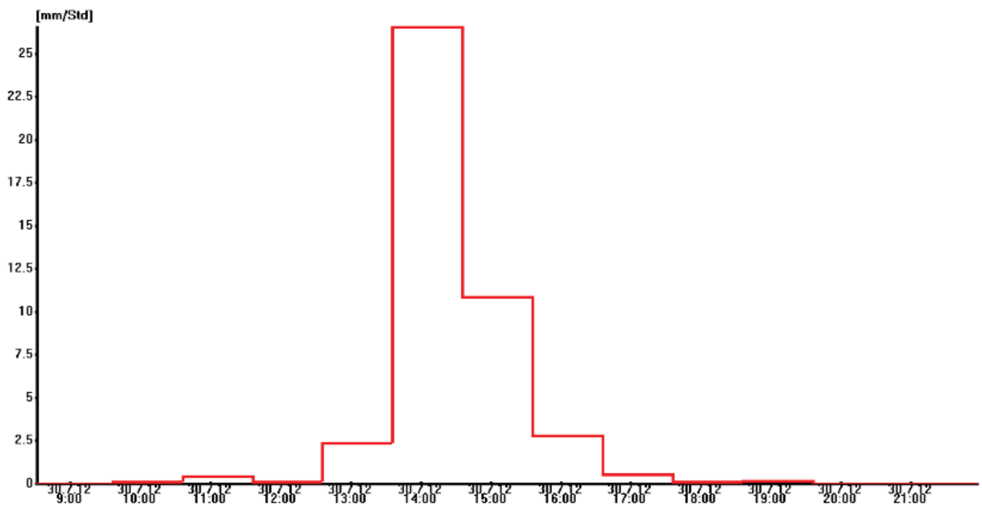


Figure 27. Highest rainfall intensity in Stavanger within 2004 and 2012

In comparison to SUDS designed in Germany, Berlin the sizes of the SUDS in Sandnes are slightly bigger. This is due to greater demands on failure frequency. The intensity of rain events is comparable. The amounts of yearly rain (more than twice as much as in Berlin) play a minor role. In the appendix all SUDS are listed separately with the calculated STORM design.

It is important to mention that green roofs, different than the other SUDS, don't store the complete rain of a heavy storm event. In chapter 9 is described, that green roofs have a positive effect on stormwater peak runoff, but overflows take place between 1 and 10 time a year (depending on type of green roof and chosen throttled discharge). If green roofs shall treat very heavy rain events completely (without discharge to sewer system), an infiltration device or a similar SUDS must be followed.

8. OVERVIEW OF PROPOSED SUDS IN SANDNES CITY

This chapter summarizes the detailed results of the disconnection potential in the study area. The detailed description for single SUDS in the study area is listed in the appendix 1 and 2 (action sheet for all SUDS and sketch for each sub-catchment).

Table 4. Design of SUDS for study area

TG1	SUDS	m²	depth cm	volume m³	infiltration	throttled discharge	Connected area (m²)
park	Swale	90	30	23	yes	No	375
parking	rain garden						1250
	swale	45	30	13.5	yes	No	
	trench	40	120	48	yes	Yes	
flat roof museum	green roof (intensive)	1000	20	200	No	yes	1000
museum forecourt	subsurface storage	30	30	18	yes	No	390
TG2							
flat roof	green roof (extensive)	470	0.06	28	No	yes	470
flat roof	blue roof (impound)	100	12	12	No	yes	450
backyard	subsurface storage	300	20	60	No	yes	300
TG3							
parking	rain garden						630
	swale	70	30	21	yes	No	
	trench	40	60	24	yes	yes	
parking	rain garden						570
	swale	75	30	15	yes	No	
	trench	56	60	33.6	yes	yes	
TG4							
flat roof	green roof (extensive)	180	0.06	11	No	yes	180
flat roof	green roof (extensive)	442	0.06	26.5	No	yes	442
flat roof	green roof (intensive)	360	0.06	21	No	yes	360
pedestrian zone	rain garden						880
	swale	38	30	8	yes	No	
	trench	70	60	42	yes	yes	
TG5							
pedestrian zone	rain garden						880
	swale	19	30	5.7	yes	No	
	trench	60	60	37	yes	yes	
street	rain garden						687
	swale	19	30	6	yes	No	
	trench	29	60	51	yes	yes	
TG6							
pedestrian zone	rain garden						675
	swale	75	30	15	yes	No	
	trench	40	60	24	yes	yes	
TG7							
TG8							
street/sidewalk/parki	rain garden						140
	swale	19	30	5.8	yes	No	
	trench	13	60	7.5	yes	yes	
street/sidewalk/parki	rain garden						510
	swale	19	30	5.8	yes	No	
	trench	26	120	31	yes	yes	
TG9							
street/sidewalk/parki	rain garden						890
	swale	50	30	10	yes	No	
	trench	72	60	43	yes	yes	
TG10							
flat roof	green roof (extensive)	265	0.06	16	No	yes	265

Figure 28. Contribution of suggested SUDS in the pilot area

The Figure 28 and Table 5 show, that the amount and the size of SUDS differ significantly within the sub-catchments. Though almost all sub-catchment are highly sealed (almost no green areas), each sub-catchment provides very different requirements.

The following influencing factors are mainly responsible for this:

- Relation of different types of areas (roofs, streets, parking) to each other
- Distinction of flat and pitched roofs
- Slope
- Use of streets and side walks

Special cases are the sub-catchments 8 and 9. These blocks are about to be completely rebuilt. Many new buildings with flat roofs are planned. This should be combined with the implementation of green roofs, the static must be adapted. This disconnection of potential green roofs is not shown in Table 5, because the buildings don't exist at the moment.

Table 5. Detailed disconnection potential for each sub-catchment

SUBCATCHMENT	AREA m^2	DISC. POTENCIAL m^2	PERCENTAGE
C1	7.800	3.000	38,5%
C10	4.150	265	6,4%
C2	6.055	1.340	22,1%
C3	7.520	1.200	16,0%
C4	5.950	1.840	30,9%
C5	4.640	1.520	32,8%
C6	6.000	1.350	22,5%
C7	1.715	0	0,0%
C8	4.000	0	0,0%
C9	6.270	1.780	28,4%
SUM	**54.100**	**12.295**	**22,7%**

9. EFFECTS OF DISCONNECTION TO THE SEWER SYSTEM OF THE STUDY AREA

9.1 Volume and Peak flow

The software STORM (IPS) is both a tool for designs SUDS and a runoff model. Thus, the effects of SUDS on the urban drainage system can be modeled. A long term simulation (10 years) produced hydrographs for runoff of the complete study area as well as for each sub-catchment.

If it was found possible to realize and implement all SUDS within the study area, 18% of the runoff peak is reduced. Similarly the volume of runoff water is reduced to 15%.

How do the SUDS influence the runoff? Depending on the measures the effects are different. Green roof e.g. reduce the peak runoff due to the storage volume. There is also a little bit more of evapotranspiration, but the runoff volume doesn't change too much. The effect on the runoff peak is higher. Almost all storm events are moderately evened.

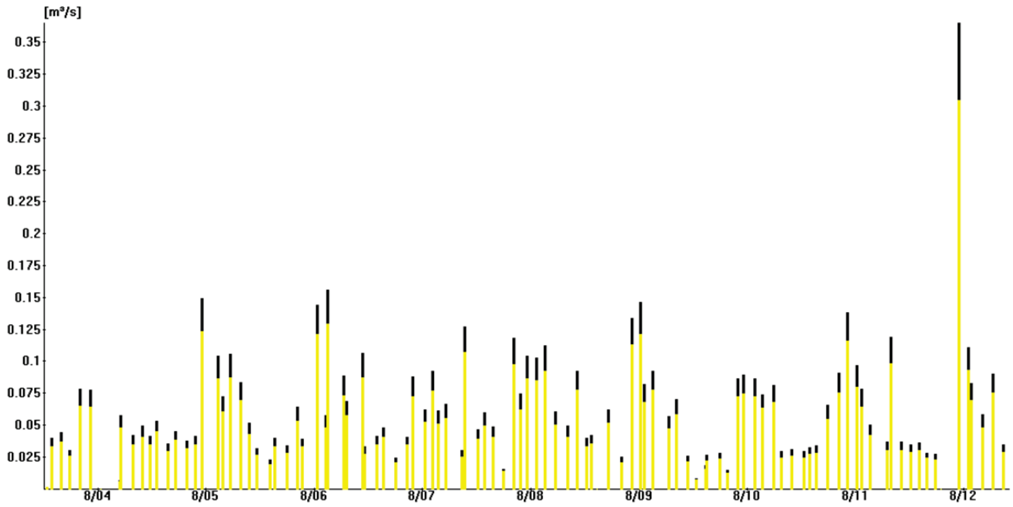


Figure 29. Comparison of runoff in study area: base scenario to SUDS scenario

The Figure 30 and Figure 31 show the details of the changed runoff behavior for each sub-catchment. Sub-catchment 1 and 2 show the different effects of the SUDS on the runoff. In sub-catchment 2 only roof retention is possible due to the size of the buildings. The effect on peak reduction is obvious; the volume of runoff doesn't change too much. Sub-catchment 1 treats stormwater also by infiltration measures. Due to the infiltration rate of the soil the volume of the runoff is reduced as well as the peak flow. The advantages of reduced volume and peak runoff are quiet clear: Hydraulic stress of the sewer system can be diminished. Less storage volume is needed downstream Jule-Eges street.

As the outflow may be effected shows Figure 32. Depending on the throttle discharge on the roof, the runoff from green or blue roofs varies. The red line shows the runoff from flat roofs. The green line depicts the outflow with a throttled discharge of 100 l/s ha, the black line 30 l/s ha and the blue line 10 l/s ha. Within ten years the overflows vary from 0 (green line), to 2 (black line) and 10 (blue line). The stronger the outflow is slowed down, the more often it is about to overflow (emergency overflow).

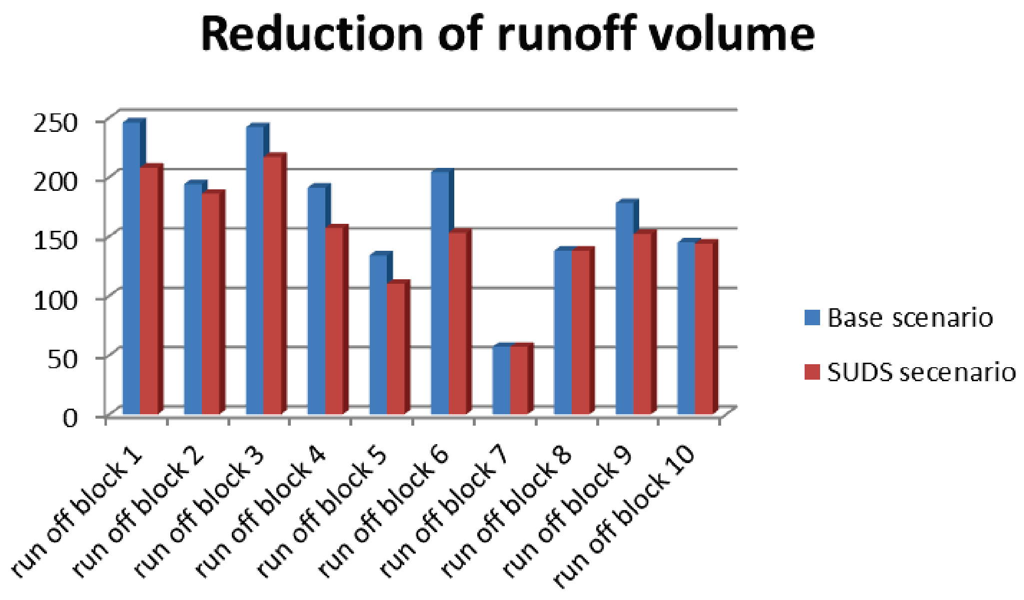


Figure 30. Reduction of volume runoff for each sub-catchment after a realization of proposed SUDS

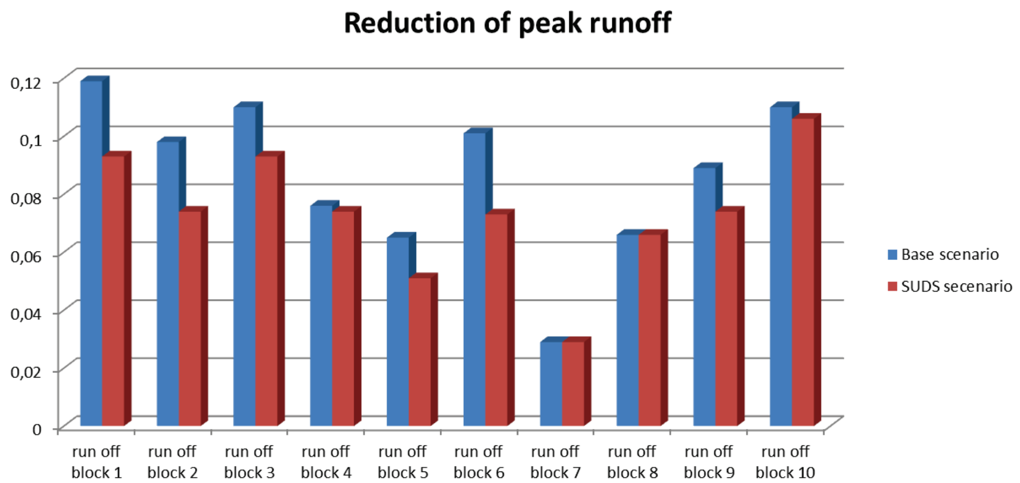


Figure 31. Average reduction of peak runoff (10 year long term simulation) for each sub-catchment after a realization of proposed SUDS

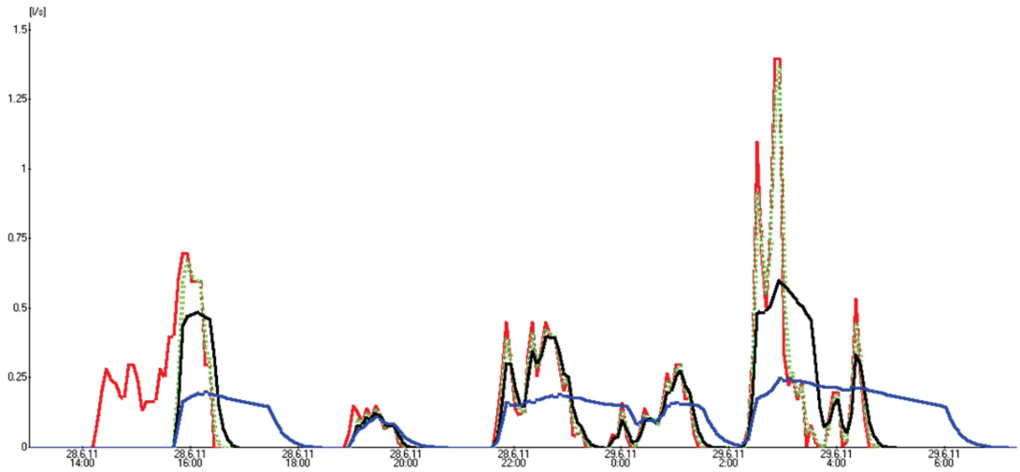


Figure 32. Outflow from green roofs at different throttle performance

9.2 Water balance

SUDS influence the water balance as well. In a highly sealed area like the study area the water balanced deviates greatly from the natural water balance (Figure 33).

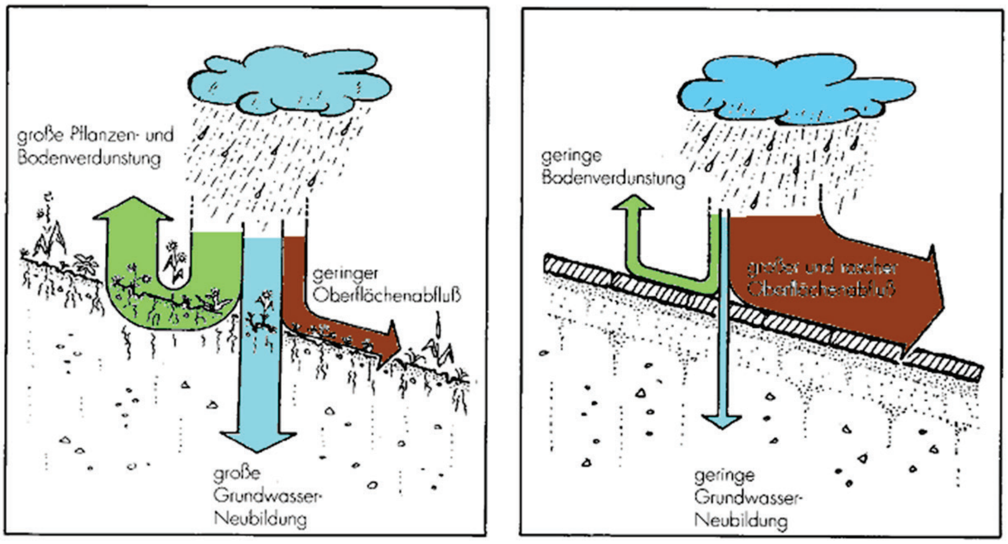


Figure 33. Water balance for natural and urban areas (Geiger, Dreiseitl, 1995)

SUDS improve the water balance in the catchment. The Infiltration rate increases as well as evapotranspiration. The increase of evapotranspiration seems small compared to the amount of planned green roofs. This is due to the fact that the infiltration rate of the vegetation layer of green roofs is calculated very high (to make sure the roof storage is available for the next storm event). This can be changed with a flexible throttled discharge (low discharge for low impound, high discharge for high impound of the roof).

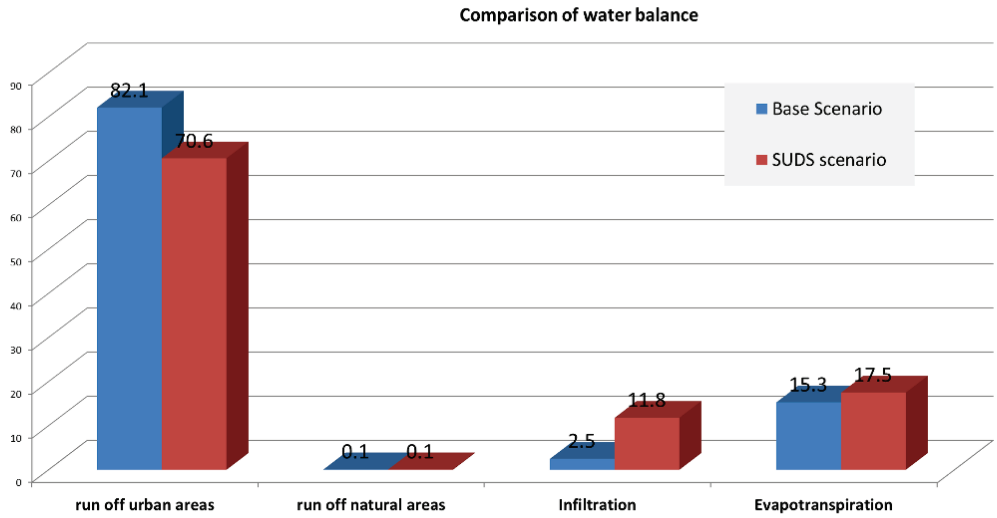


Figure 34. Water balance of study area in comparison (base scenario and SUDS scenario)

10. ESTIMATION OF COSTS FOR SUDS

The costs of the SUDS were calculated roughly. The real prizes of the implementation of SUDS in an existing infrastructure in Norway are not known yet. Generally costs of SUDS can be minimized, when the infrastructure must be renewed anyway. Experiences from Germany show, that the costs can be reduced distinctly - **sometimes up to 50% - when SUDS implementation and renewal of the infrastructure are combined**. For the cost estimation an IPS software was used (Eco.RWB). Depending on knowledge of local prices different databases can be used. The price table is based on experience in western Germany multiplied by the factor 2 due to significantly higher costs of living in Norway.

The cost estimation employed here is based on the following assumptions:

- No renewal of the infrastructure.
- The construction work will be exclusively attributed to the action
- No groundwater management necessary
- No constraints concerning heavy weather conditions (freezing etc.)

SUDS	Type	Subtype	Profile	Mass	Unit price[€/Einh.]	Unit[Unit]	Costs[€]	specific maintanance costs [€/Unit/a]	cost maintainance [€/a]	useful life (year)	year of investigation	cashvalue[€]
Green roof (extensiv)(1)	Evapotranspiration; retention	extensive	Sandnes	1,360	90	m²AE,b	122,400	2	2,176	25	2,013	305,238
Swale infiltration	purification; Evapotranspiration; retention, infiltration	surface	Sandnes	91	32	m²	2,912	2	182	25	2,013	12,451
Rain Garden (INNODRAIN)	purification; Evapotranspiration; retention, infiltration	surface/sub surface	Sandnes	4,170	90	m²AE,b	375,300	2	8,340	30	2,013	1,061,381
Green roof (intensiv)(1)	Evapotranspiration; retention	intensive	Sandnes	1,360	135	m²AE,b	183,600	2	2,720	25	2,013	436,181
Rain Garden II (INNODRAIN II)	purification; Evapotranspiration; retention, infiltration	subsurface	Sandnes	2,450	100	m²AE,b	245,000	2	4,900	30	2,013	709,263
Blue roof	Evapotranspiration; retention	storage	Sandnes	630	25	m²AE,b	15,750	2	1,260	25	2,013	78,325
All €							**944,962**					**2,602,840**
Norwegian krones							**7,087,215**					**19,521,302**

Table 6. Costs for SUDS.

11. SUMMARY

The municipality of Sandnes the city faces flooding problems. Flooding is a hazard for people and infrastructure and occurs regularly. The sewer system of Sandnes fails in case of heavy rain events.

One solution to obtain flood mitigation might be the realization of on-site measures (**Sustainable urban drainage systems - SUDS**). The technical requirements for those source control measures and the amount of applicable measures were investigated. Therefore a feasibility study for parts the city center Sandnes (5,4 ha) was made.

First, a significant potential for separation of rain water (disconnection potential) exists in the study area. Second, the type and amount of SUDS differ significantly within the investigated sub-catchment of the study area (10 sub-catchments). Though almost all sub-catchment are highly sealed (almost no green areas), each sub-catchment provides very different requirements. Especially green roofs and rain gardens can be implemented within the existing infrastructure.

Third, the necessary dimensions of the SUDS were calculated with STORM, software for designing SUDS. Local climate data could be used for a long-term simulation. The SUDS were designed for a 10 year storm event. In some parts a throttled connection to the existing sewer system remains.

Fourth, if the SUDS potential becomes realization, a significant effect on the runoff of the study area could proofed by modeling. The effects on the reduction of peak flow are higher than the reduction of volume. Costs for additional central measures downstream can be reduced. Also the hazard of flooding's in the city is mitigated.

Fifth, in many areas, a modification or redesign is planned. This is a very good opportunity to implement the measures favorable. Especially the reconstruction of the pedestrian zone opens up the possibility for stormwater management.

Last, but not least, SUDS can make a contribution to beautify the environment.

To confirm the effects on the sewer system we recommend the simulation of changed runoff by hydrodynamic modeling (Mouse). May be significant reduction of sewer overflow reduce costs for sewer rehabilitation.

The project in Sandnes takes place in association with the research project TRUST (Transitions to the Urban Water Services of Tomorrow, EC FP7 grant agreement No 265122; linked to Work packages 4.3 Wastewater and stormwater disposal [collection, drainage, treatment, discharge] in urban water systems).

Flood mitigation by on-site stormwater management (SUDS) - Preplanning of SUDS in Sandnes City
A CASE STUDY ASSOCIATED WITH TRUST