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# Disconnection of stormwater in DemFil Area (Bagsværd)

## Hydraulic Simulation and Water Quality Analysis

*Master of Science Thesis in the Master's Programme Geo and Water Engineering*

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Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013
Master's Thesis 2013:6

Technical University
of
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## Preface

This master thesis was carried out in the environmental engineering department at Technical University of Denmark as part of my master study in Chalmers University. This project is 30 ECTS, and it was made during the summer and autumn 2012.

All the chapters in this report include the hydraulic analysis of sewerage system and quality analysis of roads runoff in the DemFil region (Bagsværd).

The MIKE URBAN model and most of information about the sewerage system in the DemFil area was provided by the Nordvand (water utility) and Rambøll (consulting company).

Appendices can be found in the back of the report. Moreover, MIKE URBAN simulations, calculation files, SCF databases and digital copy of the report are available on the attached DVD.

I would like to thank my supervisors Peter Steen Mikkelsen and Eva Eriksson. They are highly appreciated for their inspiration and guidance in the process of this study. I gratefully acknowledge the support from Sophie Skau Damskier and Andreas Oliver Henriques. Moreover, I would like to express my sincere gratitude to Morten Borup, Luca Vassar, Hans-Christian Holten Lützhøft, and Qianqian Zhou for their help throughout this thesis.

Masoumeh (Mahtab) Moghadas ____________________________ 6-January-2013

## Abstract

Climate change and extension of impervious surface cause increasing amount of stormwater in the urban area. Therefore, the urban planners are trying to improve the sewerage system in order to reduce the risk of flooding. Disconnecting stormwater from the sewerage system is one of the methods that can be considered as improvement to urban drainage.

In 2008, the roads runoff is disconnected from the combined system in the DemFil region (Bagsværd). Because of environmental effects, this water has not been allowed to discharge into a nearby lake. Therefore, the disconnected pipes are joined to the downstream combined system.

This study covered the hydraulic analysis of the sewerage system and roads runoff quality of the DemFil region. The hydraulic condition of the DemFil sewerage system was investigated for prior situation (only combined sewer system), current situation (the roads runoff separated but not discharge to the lake), and future situation (the separated water discharge into the lake). These analyses were mostly done via MIKE URBAN (MU) software. In addition, some ameliorative measures were investigated to minimize the flooding in the DemFil area. Therefore, separating additional roads runoff, separating roofs runoff, making basin in one sub-catchment, and enlarging the pipes were modeled via MU as ameliorative measures.

Moreover, the separated roads runoff quality of DemFil area was calculated based on a Source Classification Framework (SCF).

The results of the hydraulic analysis demonstrated that the flooding nodes were considerably decreased after disconnecting the roads runoff in the area. Discharging separated water into the lake was not effective enough to reduce the flooding nodes in the downstream, however, the overflow from the downstream basin dropped off. Moreover, a simplified Multi Criteria Analysis (MCA) suggested that the disconnection roofs runoff to a separate system is the best means to improve the sewerage system in the DemFil area.

From the SCF, it was found that benzene has the highest concentration in DemFil roads runoff. Furthermore, the concentration of pollutants in the area is not exceeding the standard values. Additionally, roads and supply activity (distributing electricity- gas and water) are the significant sources of pollutants in the area.

Key words: Stormwater, hydraulic of sewerage system, MIKE URBAN, ArcGIS, water quality, Source Classification Framework (SCF), MCA.

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# 1. Introduction

## 1.1. Background

Increased rainfall intensity is one of the climate change outcomes in recent years which affects the return period of flooding. In addition, growing the impervious areas due to urbanization has a significant role in increasing the stormwater volume. This phenomenon is not only important because of the risk of flooding and disturbing the structures but also because of discharging large volumes of polluted water into the lakes and rivers. Therefore, the urban drainage system should cope with changing of climate, growing population and expanding urbanization.

Flooding is one of the important environmental challenges in Denmark and Sweden because of high rainfall intensity caused by climate change. Rain gages in Copenhagen demonstrate that the annual average rainfall is about 660mm [1]. Heavy rain with 150mm rainfall within 2 hours caused flooding in Copenhagen in July 2011, i.e. 23% of the annual precipitation. Many homes and critical infrastructures were damaged, and travel in the city was disrupted because of flooding and runoff in the city [2]. Hence, some research and several practical initiatives in recent years have focused on climate change adaptation in the urban area and on finding appropriate measures and strategies in order to decrease flooding in the urban drainage system.

Disconnecting roads runoff from combined sewerage system can be one of the recommended options. This may be practical as roads are typically publically owned. On the other hand, the roads runoff quality is often poor to be discharged into the surface water. The overall objective of this thesis is thus to investigate the hydraulic conditions of the sewer system as well as environmental effects of disconnected roads runoff in a case study area.

## 1.2. History of Sewerage System in Copenhagen

Sewage systems were established in 1857 in Copenhagen in order to improve the sanitary conditions. The wastewater was discharged into the harbor area which produced odors and sedimentation of sludge [3]. In order to develop the hygienic conditions in the harbor, most of the wastewater was directed into the Sound in 1903 [1]. The wastewater from the western part of Copenhagen has been treated in Damhusån wastewater treatment plant from 1930 [4]. Lynetten treatment plant was built in 1980 for treating the wastewater from the eastern part of Copenhagen. Additionally, from 1997 removing the nutrients was planned and implemented. In order to decrease discharging wastewater into fresh and marine waters during extreme rainfall, some basins were constructed from 1994. Moreover, until 2007, 90% of the sewer system consisted of a combined system and the rest was a separate system [1]. One of the next improvement plans for Copenhagen urban drainage is disconnecting stormwater from combined systems. Therefore, water from new development areas will be divided into three fractions: 1) wastewater from households and industry 2) rainwater from contaminated surfaces such as roads and parking area 3) rainwater from clean surfaces like roofs [1].

## 1.3. Case Study Area

The case study in this project is located in Bagsværd, which is one of the Copenhagen suburbs. It is one of the regions of Gladsaxe municipality. The flooding and surcharging problems in the area persuaded the municipality to start disconnecting roads runoff from the combined sewerage system in 2008. The municipality has not been allowed to discharge this water directly into a nearby lake, due to environmental issues. Therefore, the disconnected pipes are joined to the combined system in downstream manhole.

Recently the municipality decided to examine the efficiency of a disc filter which is hoped to purify the stormwater before discharging into the lake. Discharging water into the lake is expected to have a positive influence on the downstream sewer system. Moreover, it leads to a decrease of the untreated water to the lake by reduction of overflows from the downstream basin.

## 1.4. Thesis Aim

This thesis covers two important concerns with regard to the urban drainage system in the DemFil area (Bagsværd), the hydraulics of the drainage system and the quality of the disconnected water which is supposed to discharge into the lake.

The objective of the first part of this thesis is investigating the hydraulic conditions of the sewer system in the case study area. Moreover, some measures will be examined in order to decrease flooding in the catchment area during extreme rainfall events. The analyses in this part are mostly done using MIKE URBAN and ArcGIS. MIKE URBAN is one of the most powerful programs for the hydraulic analysis of urban drainage systems. It has the flexibility to integrate with ArcGIS program.

The aim of the second part of the thesis is to investigate the environmental effects of discharging roads runoff into the nearby lake in the case study area. The pollutants loads in the disconnected stormwater will be determined via the Source Classification Framework (SCF). The structure of the SCF is based on relational database and it is used for determining pollutants loads as well as defining the sources of pollutants.

# 2. Theory

This chapter contains some explanation about the theories and concepts of topics which are discussed in this report. It is broken down into two main parts of theories; Hydraulic and Quality.

## 2.1. Hydraulic Theories

### 2.1.1. Sewer Systems

Generally sewerage systems are divided into two types in urban drainage: combined and separate. In older cities, all rainfall runoff, domestic sewage, and industrial wastewater are collecting with combined sewer system and final destination of this network is the wastewater treatment plant. As it can be seen in Figure 1, during heavy rainfall, the volume of water may exceed the capacity of sewer system or treatment plant. In this case, combined sewer overflows (CSOs) directly discharges exceeded flow into a nearby water body [5]. As a result, many pollutants within flow release into the receiver water. In extreme rain events, the risk of flooding from manholes and surcharging in basements is high in the combined sewer system.

On the other hand, in modern cities, domestic sewage and industrial wastewaters flow into different pipes from urban runoff and stormwater. Stormwater can be contaminated with organic materials, metals, suspended solids and other harmful substances because of traffic, agriculture and many other urban activities. In many places, nevertheless, stormwater releases to the water body without any treatment. On the other hand, in some cases the stormwater is treated before discharging into the receiver.

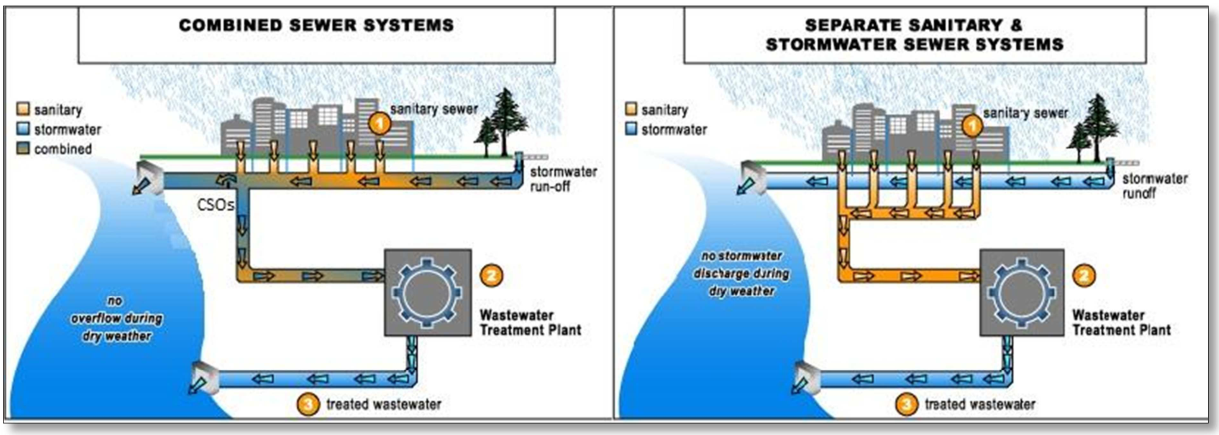


**Figure 1, combined and separate sewer system [6]**

### 2.1.2. Flooding and Surcharging

In recent years, much research has widely focused on flooding. There is growing concern about this phenomenon because of recent flooding which itself is the result of climate change and increasing impervious area in the cities [7].

Flooding is a consequence of extreme rainfall when the runoff is exceeded the urban drainage capacity. This excess water flowed in the urban surface is flood. Moreover, surcharge is the excess wastewater which is more than the capacity of pipes, but still it remains in the manholes and cannot escape to the surface. Surcharging is problematic for any sewage inlet (bath and toilets) which are lower than hydraulic surcharge [8]. The distinction of flooding and surcharging can be observed in Figure 2.

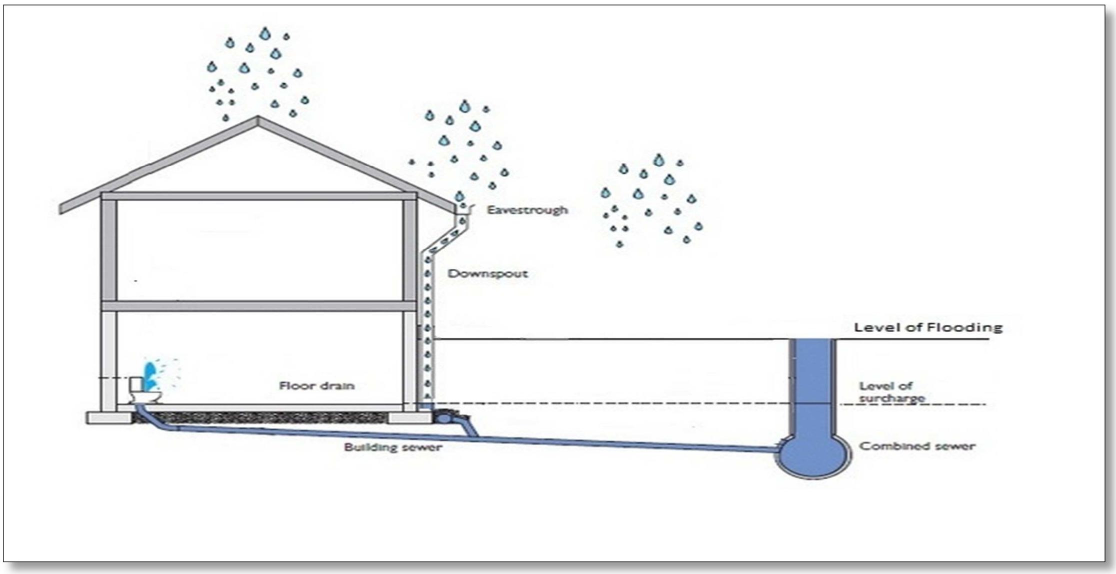


**Figure 2, Level of flooding and basement surcharging [9]**

### 2.1.3. Improvement in Sewerage System

Different methods are investigated over the last few years in order to find optimum adaptation in the sewerage system to prevent flooding and surcharging. There are two major solutions; the first solution which is regarded as a traditional method is to increase the capacity of sewerage system by enlarging the pipes or removing the blockage and sediments from the pipes [7].

The second one is decreasing the inflow into the sewerage system by separating the stormwater into the alternative system, infiltrating the flow, and storing and reusing the flow [7].

Disconnecting roofs and roads runoff (using infiltration trench or construction separate pipes), making basin, and upsizing the pipes are the techniques investigated in this report to decrease the volume of stormwater in the case study area.

### 2.1.4. Modeling

The main purpose of urban drainage modeling is to represent the drainage system and investigate the responsibility of the system in different conditions. The models can be as simple as rational method. It is applied for investigating the effects of different rainfall intensity on the runoff properties and the sewer system capacity. Nowadays, the more complicated models are used for urban drainage design and control. There are several computer programs covering the hydraulic and hydrology as well as water quality in drainage systems. SWMM is the first simulation program for modeling stormwater quantity and quality from primarily urban area. It was introduced during the early 1970s in the USA. Additionally, other programs are used for modeling the sewer system around the world such as HydroWorks and InfoWork, but the most popular program in Europe is MIKE URBAN developed in Denmark [7].

### 2.1.5. MIKE URBAN

MIKE URBAN is one of the most efficient programs for modeling the urban water. It is capable of modeling sewer system (separate and combined), stormwater drainage and water distribution. MIKE URBAN provides MOUSE and SWMM engines for modeling hydrology, hydraulic and water quality phenomena. MOUSE engine is more useful because it provides a comprehensive approach for simulation of each phenomenon [10].

It consists of three main modules. The first module is Model Manager (MM) and the second one is Collection Systems (CS). Collection systems includes modeling the pipe flow, modeling the control features such as gate opening and pump discharges, modeling the transport of pollutant and sediments from surface waters into the drainage system, and simulating the chemical and biological process in the system [11]. The third module is Water Distribution (WD) which is applied for modeling the distribution network. Moreover, WD not only is capable of modeling the fire flow analysis, demand allocation, distribution, and water quality analysis but it also provides other useful tools for automatic calibration of water distribution models, analyzing the capacity of distribution system for fire-flow and advanced control simulation to extend period simulation [12].

Since MIKE URBAN stores data in a standard Geo database format, it has the flexibility to integrate with GIS. Therefore, it is possible to use the Arc GIS tools. MIKE URBAN has some other noticeable advantages such as integrated approach to water cycle problems and open data structure. Furthermore, it is possible to modify and expand the structure of data supported by URBAN ONLINE at the same time. It helps user to make a fast decision, forecast, and automate model updating. Additionally, MIKE VIEW is used to display results quickly and simply. Furthermore, using several simulation engines and equations for physics of motion and biological process provide more realistic results and high execution speed and modeling the complex system [13]. Besides, MIKE URBAN enable to model the ponds, wetlands infiltration and retention basins.

### 2.1.6. Modeling Requirements

In MIKE URBAN CS, adding the background, the spatial reference, and coordinate system are performed like ArcGIS program. Nodes and links are used to make the sewerage network, and then the catchment areas are delineated and connected to network. Moreover, the hydrological data and precipitation time series are allocated to the model. Before running the model, the issue of boundary condition should be addressed. These boundary conditions are defined as the catchments loads, networks loads, and external water levels. After running the model, results can be presented in different formats such as time series, profile plots, animation on the horizontal plan, result comparisons, thematic maps, and statistical analysis [14].

Since hydrology plays a key role in modeling the sewerage system, some of the most important terms of hydrology are defined as follows.

#### *2.1.6.1. Return Period*

Return period is a significant parameter of the sewerage system designing. Normally, a higher return period leads to higher rain intensity and extreme rainfall event.

It is obvious that the network should be designed for no flooding or surcharging in the system for reasonable return period. The combined sewerage system in Denmark should be designed for 10 years return period and water should not be raised to the ground more than one time in 10 years. On the other hand, the return period for separate system is 5 years.

#### *2.1.6.2. Rainfall- Runoff Modeling in MIKE URBAN*

The process of runoff modeling starts with creating catchments. Each catchment should be connected to the sewerage system via manhole to transfer the generated surface runoff into the network. As evident from Figure 3, hydrological model should be defined for catchments. Surface runoff model and continuous hydrological model are two classes of hydrological models for catchments, but the surface runoff model is more common. There are four different surface runoff models in MIKE URBAN; time-area method, kinematic wave, linear reservoir, and unit hydrograph Method. Based on the available data, each of these methods can be used in the simulation. It should be noted that in each simulation, only one of these methods can be applied [15].

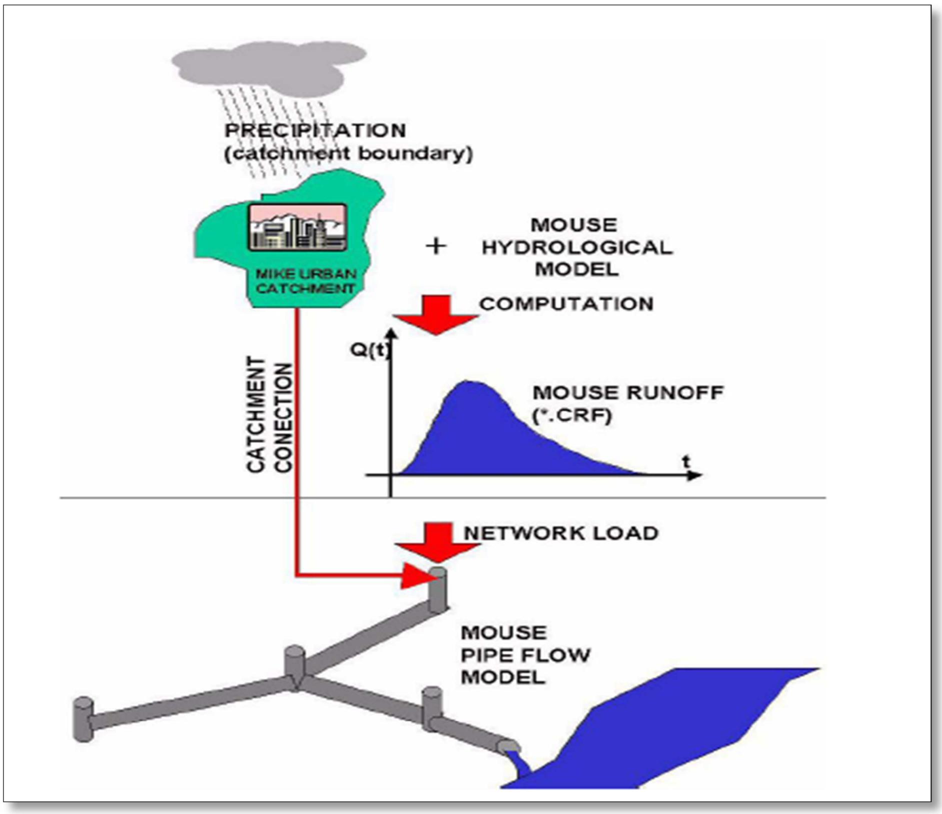


**Figure 3, Conceptual model of runoff modeling in MIKE URBAN [15]**

#### *2.1.6.3. Time-Area Method*

Since time-area method is used in this project, this method is explained here. It should be mentioned, there are several methods for determining the requirement size of storm sewer. Rational method is applied for simple models and time-area method is more useful for complicated models.

As indicated in the Figure 4, the area which contributes to discharge water into outlet increase during time [16].

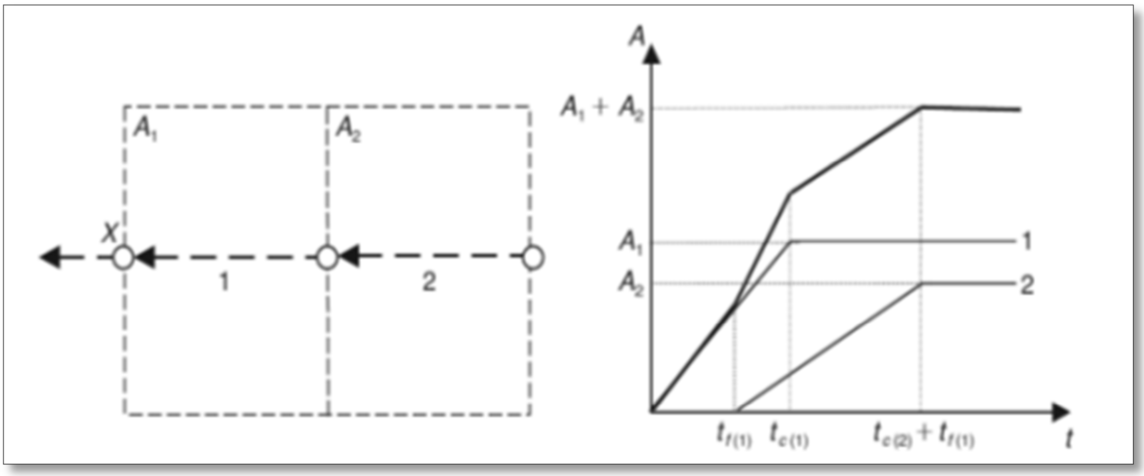


**Figure 4, Time-Area Diagram for outlet X in simple sewer network**

Time-area method can be defined in MU by some input data. The first one is the percentage of impervious area representing the proportion of impermeable area that contributes to generate runoff in the catchment. The second one is initial loss which represents the depth of precipitation needed for starting the surface runoff. The third one is hydrological reduction factor considered due to water losses (evaporation or infiltration) from surfaces where not impervious completely. The last one is time-area curve. MIKE URBAN applies three types of curves for different shape of the catchments. These curves represent the catchment surfaces which contribute to water discharge from catchments as a function of time. Figure 5 displays the curves for rectangular, divergent and convergent catchments, respectively [15].

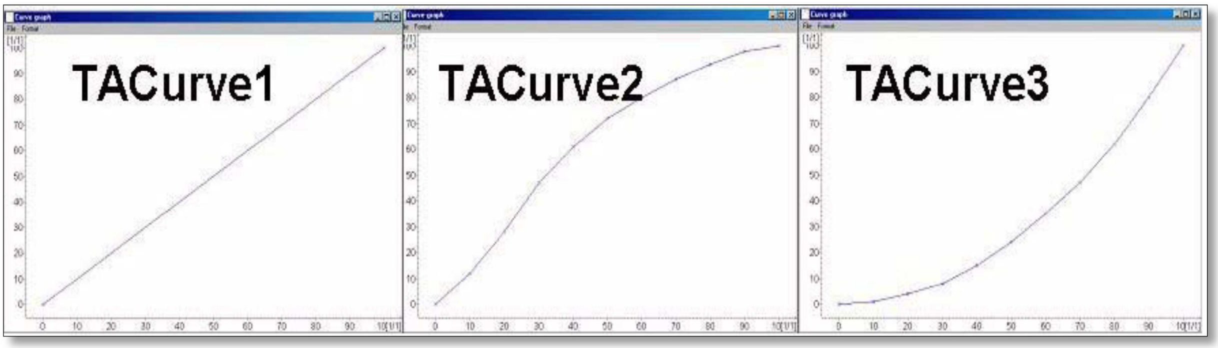


**Figure 5, the applied curves in MU in time-area method for rectangular, divergent, and convergent catchments respectively**

The surface area of each catchment is divided into number of cells in form of the circles around the outlet point as detailed in Figure 6 [17].

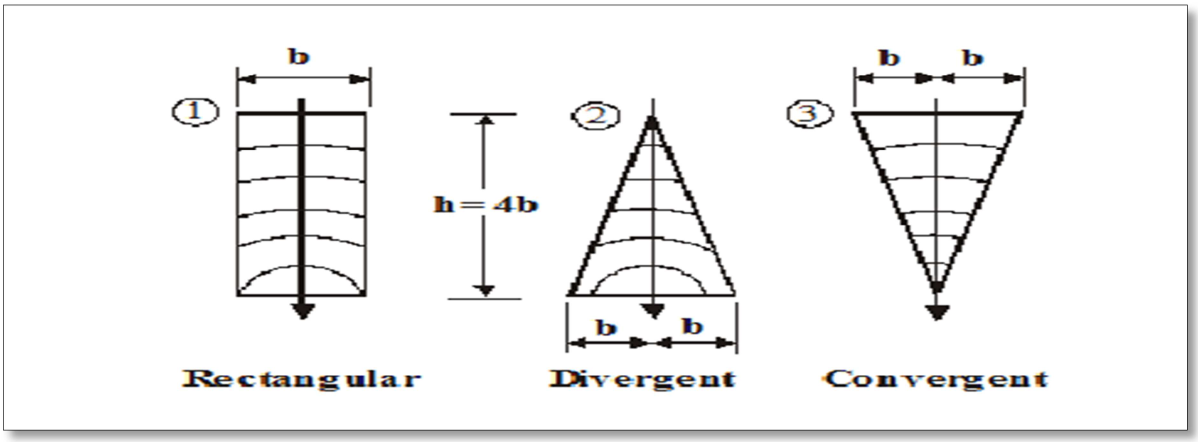


Figure 6, surface dividing in MU in time-area method

The number of cells is determined by equation I, where $t_c$ is the time of concentration and Δt is simulation time step.

$$\boldsymbol{n} = \frac{t_c}{\Delta t} \tag{I}$$

Then the area of each cell is calculated based on the related time-area curve. The total area of all cells gives the impervious area. When the rain depth on the whole catchments becomes lower than initial loss value, the runoff simulation stops. The accumulated volume from each cell is moving to downstream direction in every time step [17]. Therefore, the water volume in certain cell is determined as below formula:

$$\boldsymbol{V_{cell}} = \boldsymbol{V_{inflow}} + \boldsymbol{V}_{\textbf{generated in cell}} - \boldsymbol{V_{outflow}} \tag{II}$$

The hydrograph can be resulted from the most downstream cell outflow. It should be mentioned that, the final runoff is reduced by the hydrological reduction of catchments [17]. Therefore the total flow is determined by equation III.

$$\boldsymbol{Q_{total}} = (\boldsymbol{i} \times \boldsymbol{A_{Catchment}} \times \boldsymbol{Imperviousness}\% \times \boldsymbol{Reduction\ Factor}) + \boldsymbol{Q_{additional}} \tag{III}$$

In this equation $i$ is rain intensity. It is assigned to the model by defining the time series in MIKE URBAN. Furthermore, $Q_{additional}$ can be a constant value for wastewater from household or industry.

#### *2.1.6.4. Time Series*

In order to do surface runoff computation, the precipitation data are input to the MIKE URBAN model as a time series with *Rainfall Intensity* item. Moreover, the precipitation time series can be defined by rainfall depth and rainfall rate. The rainfall time series are linked to the MIKE URBAN surface with defining the *boundary condition* item for all catchments or for individual catchment [18]. Furthermore, it is possible to input time series for evaporation, temperature and catchment discharge in the model as boundary condition of catchments [17] .

#### *2.1.6.5. Rain data*

Selecting appropriate rain data is one of the challenges of designing storm in urban drainage engineering. There are different types of rain data which can be applied for runoff calculation model. One of them is historical rain series which are measured by local or regional rain gauges. Ideally, the urban drainage should be designed based on this historical rain data. But these historical data have not covered the rain data for a long return period; the longest record of rain data was started from 1979 in Copenhagen. Additionally, these types of rain data contains lots of details, consequently a long time is needed for simulating with these rainfall time series [19].

Filtered rain data, is another type of rain data in which the important characteristics are extracted by treating the rain data. Intensity-Duration-Frequency (IDF) curves are one of these types of rain data.

The most common type of rain data is synthetic rain series generated with the same statistical properties and format as the historical rain series [19]. Chicago Design Storm (CDS) is one of the well- known synthetic rain series. It is derived from IDF curves and reflects the maximum mean-intensities for specific duration of time and a chosen return period. It assumes a general synthetic shape of heavy rains. The simulation time is significantly decreased by using CDS as time series in MU, therefor the computational cost is reduced by using CDS [19]. There is an argument regarding the accuracy of using CDS rain data; however, it is common method applied in MU simulation. In this project the CDS was created for different return periods by using a spreadsheet files established by IDA [20]. This spreadsheet can be used for simulating of ungauged location in Denmark based on the regional precipitation patterns and mean annual rainfall. Figure 7, depicts the mean annual rainfall in Denmark for the standard normal period of 1961-1990. It is obtained by doing daily measurements at 300 locations. Also the dashed-line, in Figure 7, separates the west and the east region of Denmark. It should be considered that, the input rain data is one of the uncertainties results from absence of the appropriate actual rain data at a particular location [21].

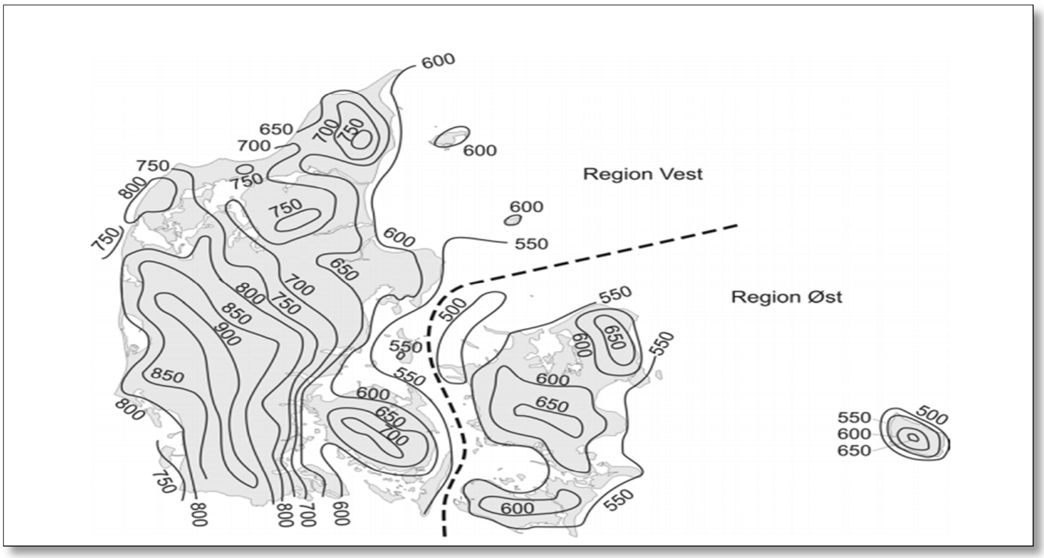


**Figure 7, Mean annual rain data and boundary of west and east region [21]**

## 2.2. Quality theories

### 2.2.1. Pollutants and Sources

The stormwater quality depends on some factors such as the intensity of rain, the number of dry days before rain, degree of urbanization (Traffic intensity, building construction ,and industrial activity), level of vegetation cover, and local practices (sweeping, pet control, etc.) [22].

The main pollutants of stormwater are heavy metals, organic compounds, pesticides, and fertilizers. They have several sources such as transportation, heating, gardening, industrial practices, construction activities, and bird and animal feces. Water pollution has numerous effects on environment, plants, animals, and human. These effects depend on the type and concentration of pollutants. Some of the pollutants resources and their effects are explained as follows.

Heavy metals are known as toxic metals such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), and some other metals which can be harmful and dangerous in high concentration. Transportation is a large contributor to metal concentration of urban runoff. Lead (Pb) affects the nervous system even at low concentration. It can be found in some kind of paints, old car fuel, and old plumbing. Recently, the lead spreading has decreased in the nature due to extreme legislation about its usage. Cadmium (Cd) disturbs the reproduction and growth system of animals and human [23]. Waste incineration, production of some kind of batteries, fossil fuel combustion and some industrial activity such as cement manufacturing are some sources of emission cadmium into environment [24]. Zinc (Zn) can be released into environment by mining, smelting industry, burning waste and coal, and galvanization of other metals. Zinc in low concentration is essential for human body but higher dosage has adverse effect on health such as loosing appetite and weakening the Immune system [25]. Copper is used for making electrical equipment, construction (roofing and plumbing), and some other industrial practices. It is harmful for human at long-term exposure. Moreover, nickel and chromium are released by industrial activities and vehicles. They are toxic and harmful for water-living organisms as well as human [23]. Indeed, metals harmfulness is not only depending on the concentration but also speciation, redox condition, waters pH, dissolved and suspended carbon, since metals have the ability to interact with other compounds.

Another group of contaminants in stormwater is organic substances. They have a long list of possible sources but the major part of them is related to traffic and transportation system. Moreover, persistence organic pollutants (POPs) are kind of organic substances which are very resistant in the environment. Most of them are long lived and the organisms could not degrade them, so they are accumulated in the fatty tissues [26]. Endrin, aldrin, DDT, hexachlorobenzene, and dioxins are known as POPs. They are mostly formed from industrial activity and combustion [27].

Polycyclic Aromatic Hydrocarbons (PAHs) are known as one of the organic pollutions. Some of the PAHs are carcinogenic. When fuel is not burned thoroughly, a group of more than 100 different chemicals are formed which are called polycyclic aromatic hydrocarbons. Also, they can be found in traffic exhaust, tar, asphalts, rubber tires, and petrol stations. Since they are more soluble in oil than water, they could be found in soil and sediments more than water [28]. Figure 8 illustrates some members of PAHs group.

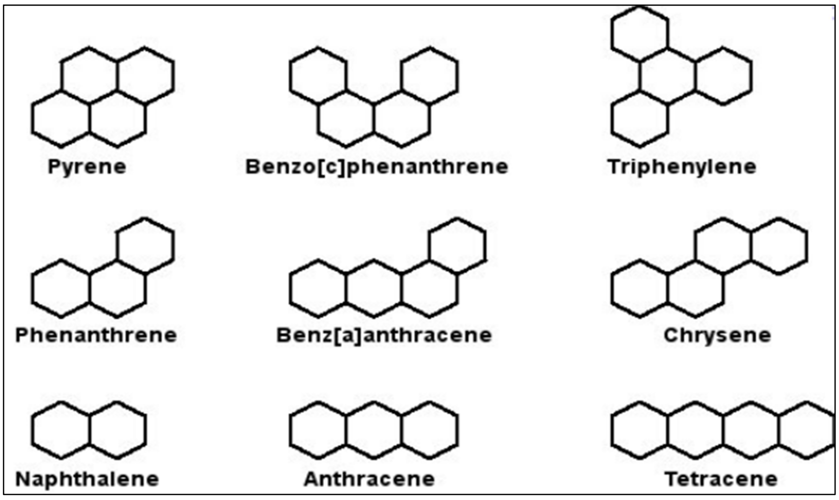


**Figure 8, structures of some simple, benzenoid PAHs [29]**

The other group of organic pollutions is Phthalates. They are used as plastic softeners in PVC and other plastics such as cable foil, woven plastic, wall covering, rubber tires, and automotive components [28]. High levels of exposure to this pollutants leads to cancer and disrupt the endocrine system in human body [30]. BBP, DBP and DEHP are the members of phthalates group which are hazardous to human health. Figure 9 displays the chemical structure of DEHP. Besides, there is not sufficient scientific information about hazardous of DINP, DIDP and DnOP to human reproduction [28].

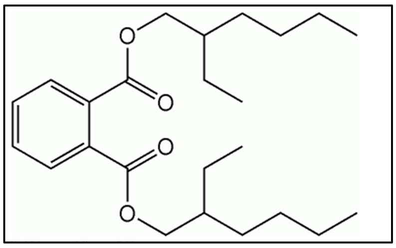


**Figure 9, chemical structure of DEHP [31]**

Nonylphenols (NPs) are applied in concrete, sealants, PVC, plastic covers on roofs, paints, automotive components, rubber tires, additives in car care products, and oils [28]. These kinds of organic pollutant are very persistent in the environment and toxic for aquatic organisms. Besides, they affect hormones and cause endocrine disruption in human body. Figure 10 shows the chemical structure of nonylphenols.

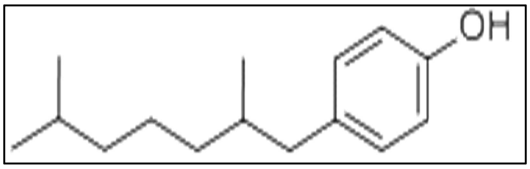


**Figure 10, chemical structure of NPs [32]**

Additionally there might be some other organic pollution in stormwater such as oil, brominated flame retardants, aliphatic compounds, per-fluorinated compounds and chlorinated paraffins [22].

Based on the above discussion, the major sources of stormwater pollution are transportation, industrial activities, construction, agriculture, and using some urban facilities such as plastic and metal guardrails or traffic signs and some electronic equipment.

According to the results of a recent investigation [33], the concentration of some heavy metals (like copper, zinc and chromium), PAHs, and DEHP (belongs to the family of phthalates) are higher than Environmental Quality Standards (EQS) in the stormwater of Copenhagen area.  Therefore some remediation methods should be applied for improving the stormwater quality or preventing stormwater pollution.

### 2.2.2. Disc Filter

Several methods are used for pollution reduction in stormwater such as; sedimentation basin, infiltration in soil, and vegetation filters. Additionally, disc filters are used for the same reason. In DemFil project, the efficiency of disc filter is going to be tested for decreasing the traffic runoff pollutants. Therefore, it is expected to discharge cleaner water into the lake, as a result less amount of water will be treating in wastewater treatment plant.

The system consists of a filter with $20m^3/h$ hydraulic capacity and filter backwash system. The clogged materials are removed from the filter under pressure, when pressure reaches a certain level. By adding chemicals, suspended materials are settled and flocculated before passing through the filter, so, the discharged water become cleaner. The Figure 11 represents one of the typical disc filters.

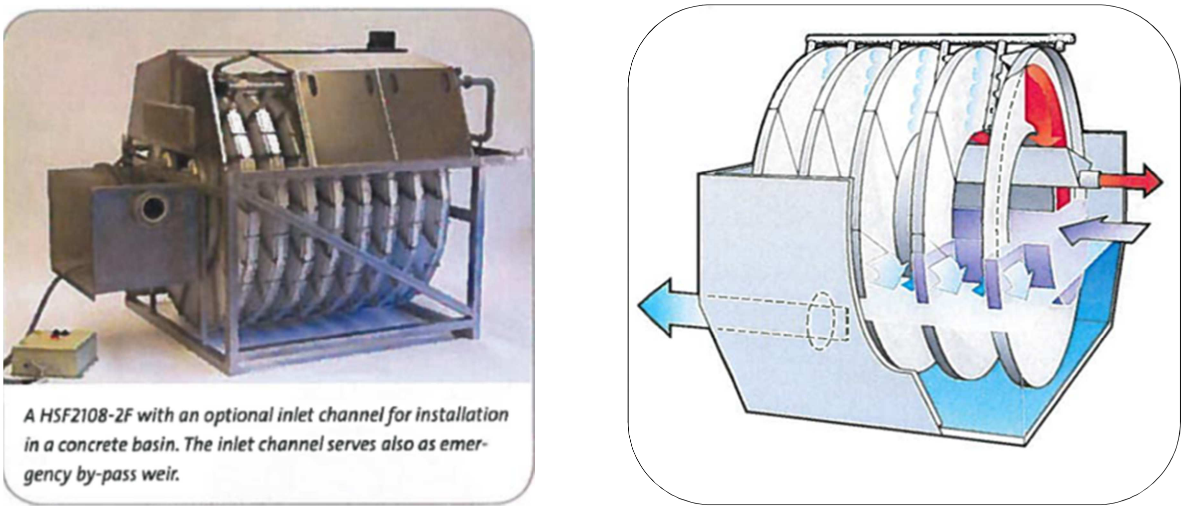


**Figure 11, Disc filter [34]**

The advantage of disc filter is that, this compact technology is neither bulky nor large, so it is proper for urban area. Moreover, it is even suitable for climate change adaptation by working in extreme rainfall events.

### 2.2.3. Source Classification Framework (SCF)

In order to ameliorate environmental management, several new legislative tools have been presented during the past decade by European parliament such as Water Framework Directive (WFD). It was introduced in year 2000 based on improving ecological and chemical status of surface water. In 2008, Environmental Quality Standards Directive (EQSD) was defined. It contains a list of priority substances (PSs) and priority hazardous substances (PHSs) which are important because they are persistence, bio-accumulative, and toxic. This list is closely connected with WFD purposes. In order to implement EU legislation, it is necessary to use a source classification system like Source Classification Framework (SCF). Source Classification Framework is kind of rational database which contains the qualitative and quantitative description of sources of pollutants, receiving compartment, temporal release pattern, and release factor. By applying SCF not only pollution sources are identified exclusively but also pollution loads are estimated. Table 1 describes different attributes which are used in SCF.

**Table 1, Different attributes which are used in SCF [35]**

| Attribute | Description |
|---|---|
| **Chemical** | The name of the chemicals |
| **CAS#** | The Chemical Abstracts Service registry, uniquely identifies the pollutant being released |
| **RSS** | A textual description |
| **NACE** | A numerical code from the Statistical Classification of Economic Activities in the European Community |
| **NOSE-P** | A numerical code from the EU harmonized Nomenclature for Source of Emissions |
| **COMP** | Environmental compartment which receive pollutant |
| **RATIO** | Estimated fraction of the pollutant released to the specified compartment |
| **RPD** | A combination of daily, weekly and yearly release profiles for the specified source |
| **RF** | Release factor including units |
| **References** | All relevant literature references |
| **Comment** | Any comment related to the Release Strings (RSs) that might be relevance but does not fit in the other categories |

According to Table 1, each of the pollutants can be identified by a unique number which is CAS# (Chemical Abstracts Service registry number) e.g. the CAS# for benzene is 71-43-2 and for atrazine is 1912-24-9. Moreover, NACE is a numerical code that identifies the economic activity which leads to releasing the pollutant e.g. “01” (agriculture) and “28” (Manufacture of fabricated metal products) and so on. Also, NOSE-P is numerical code for identifying the process which leads to discharging the pollutants such as “101” (combustion process) and “107” (Processes involving use of solvents and other products). Besides, COMP indicate the compartment in which pollutants are released such as air, surface water (direct), surface water (indirect), urban permeable surface, urban impermeable surface, and ground water. Also, the portion of released pollutants to each compartment is defined by RATIO e.g. 30% of specified pollutant release to air and 70% of its release to water indirectly [35].

As the SCF contains different categories of data about source and process of releasing pollutants, it can be used for supporting pollution management as well as estimating the pollutant concentration in the environmental compartment. Therefore, when large amount of pollutants relating to one category are available, it is easier to allocate a limit fund to monitor the priority pollutants. More information about SCF can be obtained from Holten Lützhøft et al paper [35].

# 3. Case Study (DemFil AREA)

As it can be seen in the Figure 12, Bagsværd is one of the Copenhagen suburbs located 12km northwest of Copenhagen city center. The Gladsaxe municipality has a responsibility to provide the requirements and demands of this area. Nordvand is the water utility company which has collaboration with the municipality to construct infrastructures. Rambøll is one of the consulting companies assisting the Nordvand Co. to design and model the required infrastructure.

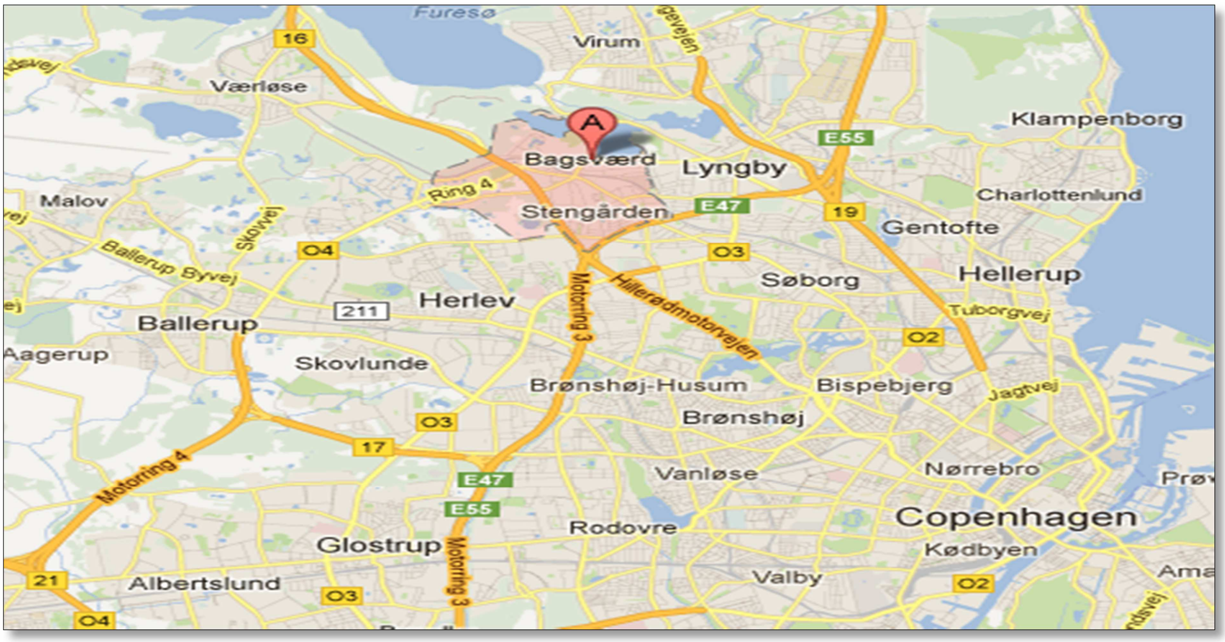


**Figure 12, location of Bagsværd area.**

This report has mainly focused on the area between the Bagsværdvej, S-train railroad, Bindeledet st and Triumfvej. The idea of this project comes from the "Demonstration facilities for filtration of road runoff water for discharge into freshwater area"[1] (DemFil) project. Therefore, this investigated area is called DemFil in this report. DemFil area is mostly covered with residential houses, and there is not any industrial factory. A few shops are located in the Bindeledet st e.g. butchery, cloth shops, and flower shop, etc. Moreover, in northwest of the Bagsværdvej, there is a garden market which is extremely close to the lake. Figure 13 illustrates this area.

[1] Demonstrationsanlæg for Filtrering af vejvand for udledning til ferskvandsområde

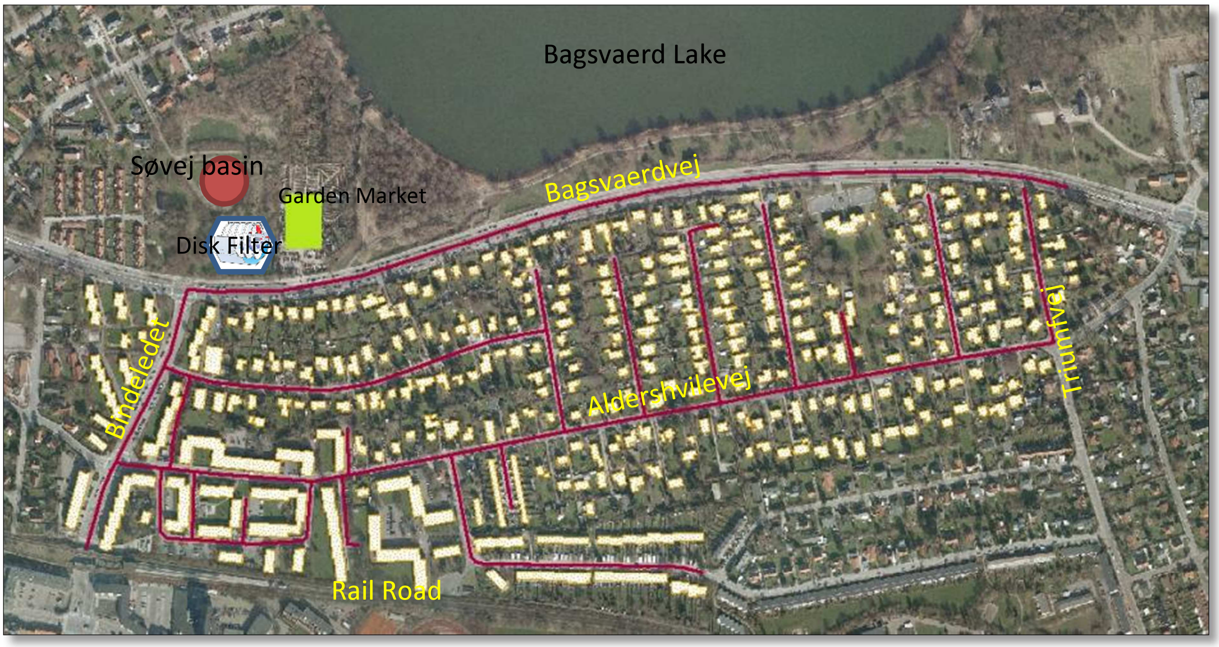


**Figure 13, DemFil area**

## 3.1. Hydraulic Analysis

### 3.1.1. Modeling DemFil Area in MIKE URBAN

An available model for the area was covering a larger area than DemFil. Furthermore, the model had been converted from MOUSE model to MIKE URBAN model. Therefore, there were differences between the shape of catchments in the model and the reality. The available model was calibrated in Søvej basin, in 2008 and 2010, so the model has been used in this project without modification of elements.

#### *3.1.1.1. Input Data*

Since the model for DemFil area was prepared by Rambøll Co. and it was calibrated before, no changes in the details of elements are made for the current situation. In order to examine the performance of the sewerage system in different return periods, the model needs rainfall data. The longest available local rain data is related to the rain station 30252 (Søvej Station), which was established in 2008, so it contains only four-year rain data. Station 30222 is another rain station 5km from the catchment which contains 30 years rain data. This rain data still is not long enough for covering long return period. Additionally, the file of rain data is too bulky, and model needs exceedingly long time of simulation. Therefore, the synthetic rain series was made via spreadsheet file established by IDA [20]. As it can be seen in the Figure 14, the required data for making the CDS in this file are annual mean rain, the region pattern, return period, safety factor, and rain duration.

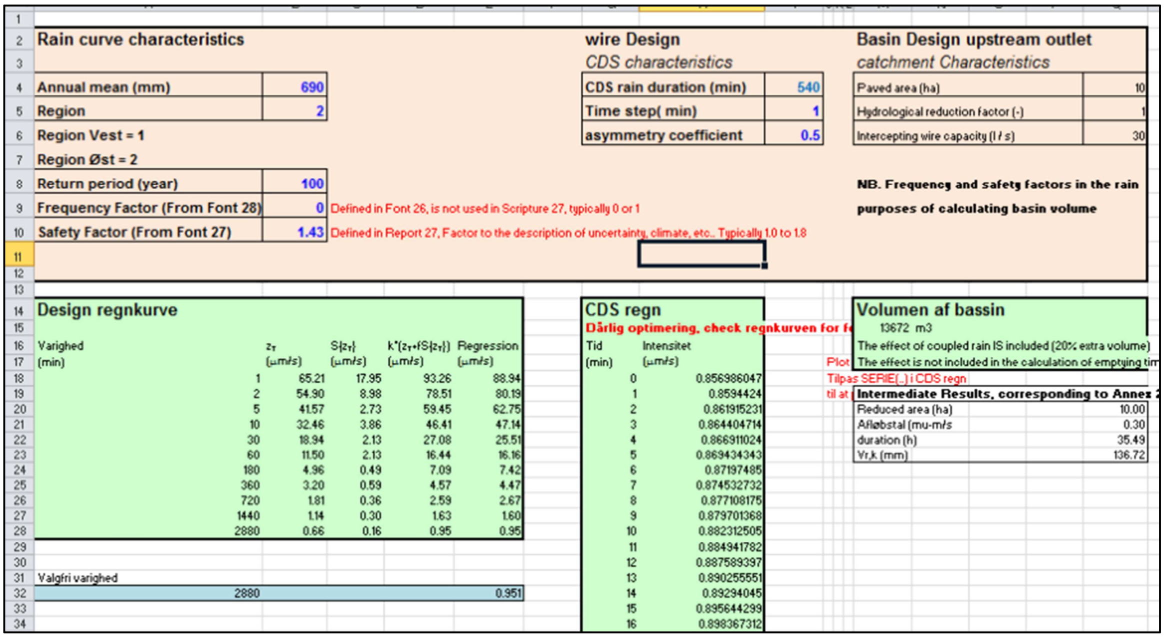


**Figure 14, spreadsheet file for making CDS rainfall distribution graph**

According to the records from station 30222 Søborg [36], the annual mean rainfall is considered 690mm for the last decade (Appendix A). Moreover, the eastern region pattern was used for calculation of CDS in DemFil area. Besides, a safety factor of 1.43 was used. The idea behind this value is to include uncertainty and effects of climate change, so the rainfall should multiply with 1.3 as the climate factor and 1.1 as the model error. The last but not least parameter is rain duration. In order to estimate the enough duration time, the model was run for one-day rain-block with the rain intensity equal to 7µm/s. According to the outlets hydrograph, the time of concentration was around 4 hours for most of the outlets, so the duration of rainfall was defined equal to 9 hours (540min) to be on the safe side. Based on these data, the CDS was made for 5, 10, 20, 50, and 100 years return periods. Then the gained rain intensities are input into the MU as the time series. Figure 15 illustrates one of the time series in MU from CDS spreadsheet.

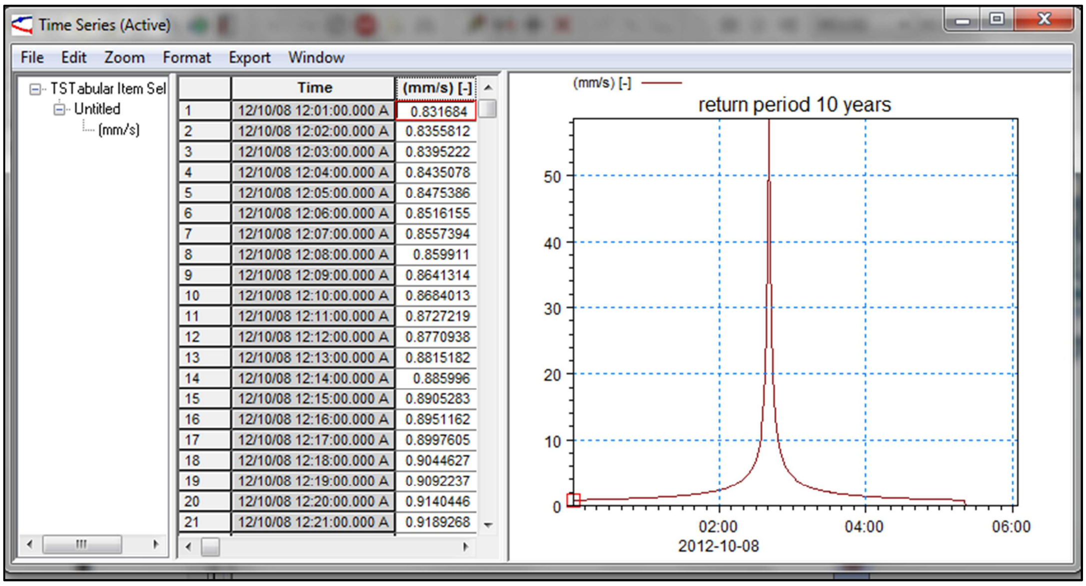


**Figure 15, Time series in MIKE URBAN**

Before starting the simulation process, the boundary conditions should be addressed in the model. In this project the rainfall time series, for different return periods, were defined as boundary conditions in each simulation (see Figure 16).

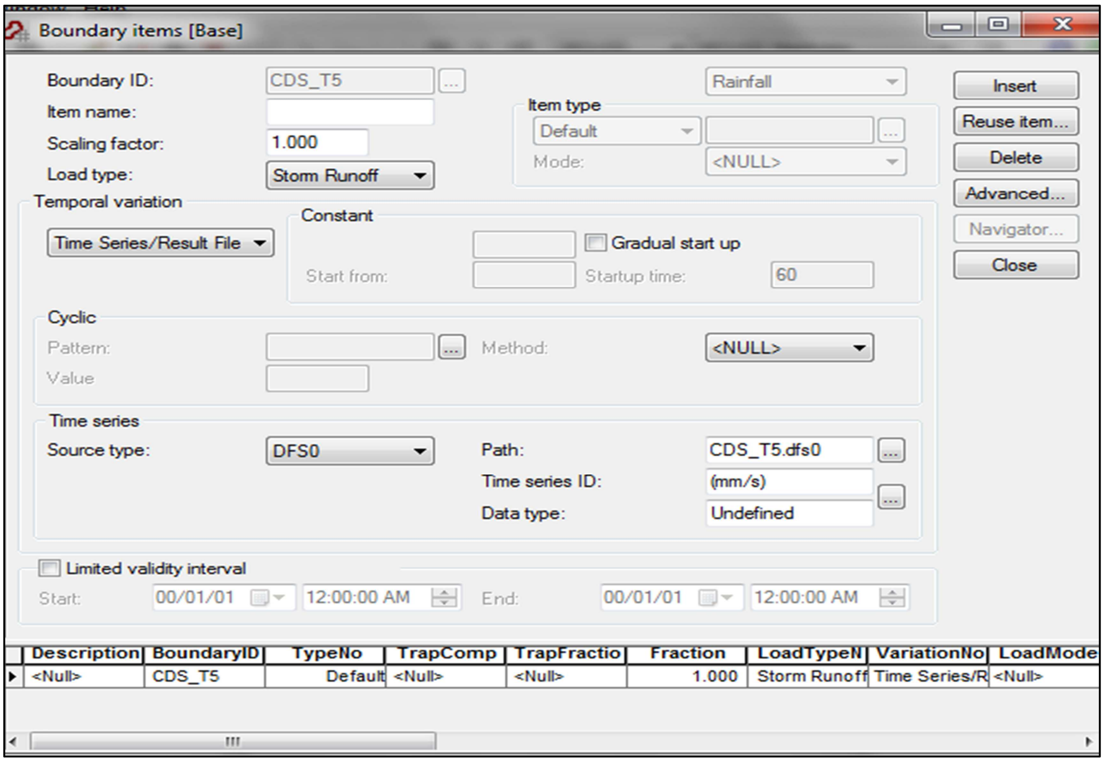


**Figure 16, defining the boundary condition**

Finally the rainfall-runoff and hydrodynamic simulations have been done for different situations. MIKE VIEW program has been applied for representing the simulation results.

### 3.1.2. Modeling DemFil Area in ArcGIS

ArcGIS program has been used to determine the areas of buildings roofs, roads and parking in the main catchment area.

First of all, the catchment area map and vector layers of pipes, manholes, catchments and basins were imported to the ArcGIS program. The coordinate system was not changed since all layers have the same coordinate system. Then, new layers were made as a feature class for main catchment, roofs, roads and parking. Firstly, the reasonable boundary was defined around the catchment area. Figure 17 displays the imported layers from MU into ArcGIS and the main catchment made as a boundary in ArcGIS. Then, the catchment was split into 13 sub-catchments around the main pipes. In further parts of the report, each part of the catchment was referred with catchments IDs; A, B, C, D, E, F, G, H, I, J, K, L, and M.

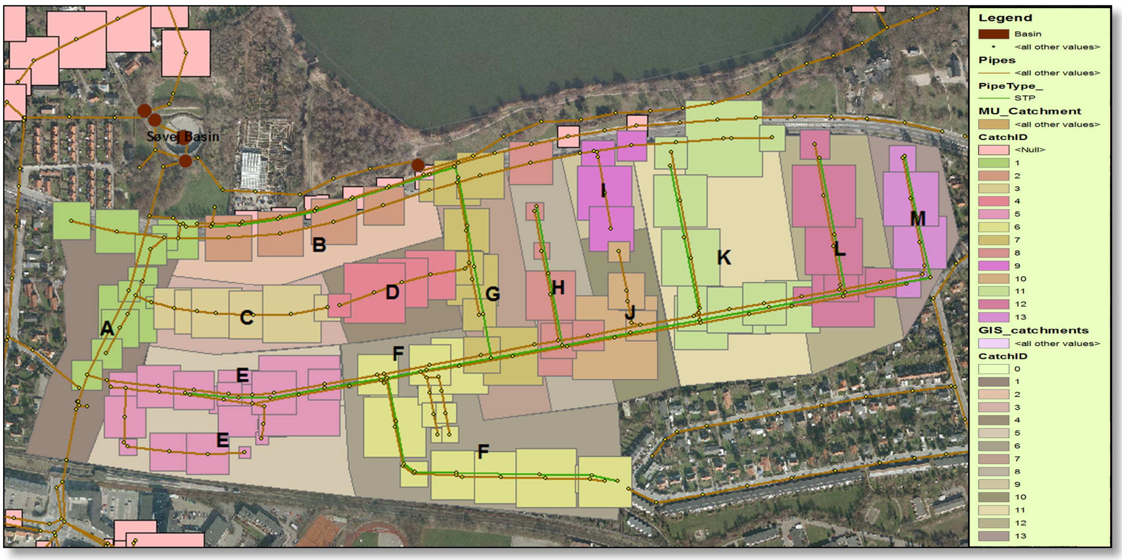


**Figure 17, the imported layer from MU and sub-catchments in GIS**

Since, there is not clear boundary for each sub-catchment in the MU model, there is a difference between the area of the MU model and the ArcGIS model. Additionally, the streets, buildings and parking were drawn in the separate layers according to Figure 18.

It should be noted that there was some uncertainty in drawing the vector files, due to the quality of the background picture e.g. some places could not be recognized as building or impervious area. Some parts of houses are below the tree leaves, or the boundary of houses was not recognized because of shadows.

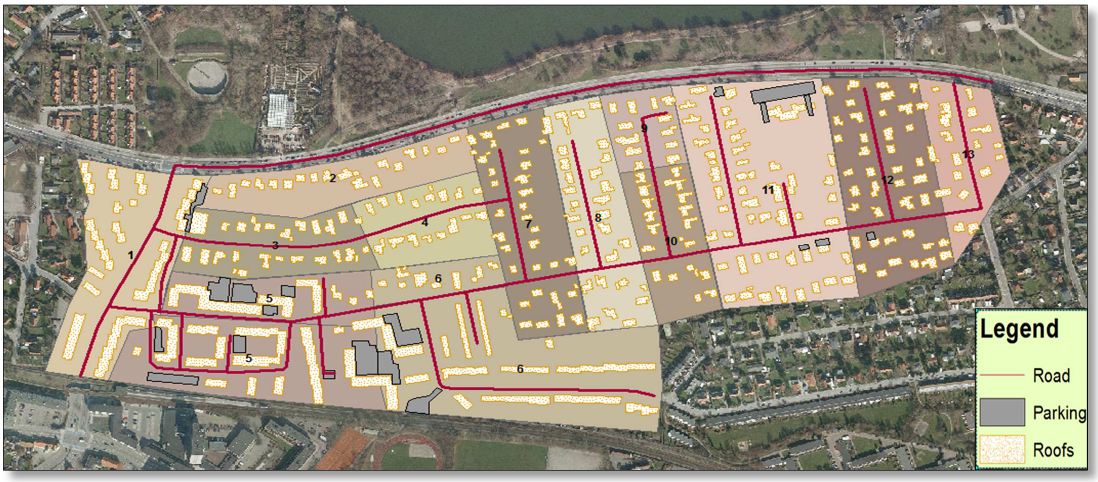


**Figure 18, created layers in GIS**

The imperviousness of each sub-catchment in GIS was calculated based on equation IV.

$$\boldsymbol{Imperviousness} = \frac{A_{streets} + A_{roofs} + A_{parkings}}{A_{total}} \qquad \text{(IV)}$$

Where, $A_{streets}$ is the area of street, $A_{roofs}$ is the area of roofs and $A_{parkings}$ is the area of parking located in the specified catchment area, also, $A_{total}$ is the total area of the specified catchment. The imperviousness is affected by the main catchments boundary. Therefore, there is a difference between the percentage of imperviousness in MU and ArcGIS model. Table 2 represents the areas and imperviousness of each sub-catchment in the ArcGIS and MU model.

**Table 2, sub-catchments impervious area In MU and GIS**

| Catch ID | impervious area (GIS) | | | | Area in GIS (ha) | Area in MU (ha) | Imp GIS (%) | Imp MU (%) | Imp area GIS (ha) | Imp area MU (ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Roofs (ha) | Separated road (ha) | Not separated road (ha) | Parking (ha) | | | | | | |
| **A** | 0.73 | 0.00 | 0.92 | 0.05 | 3.69 | 3.00 | 46% | 37% | **1.70** | **1.10** |
| **B** | 0.27 | 0.00 | 0.00 | | 2.25 | 1.44 | 12% | 15% | **0.27** | **0.22** |
| **C** | 0.43 | 0.00 | 0.24 | | 2.22 | 2.30 | 30% | 23% | **0.67** | **0.53** |
| **D** | 0.24 | 0.00 | 0.16 | | 1.88 | 1.68 | 21% | 19% | **0.40** | **0.31** |
| **E** | 1.31 | 0.24 | 0.55 | 0.51 | 5.55 | 5.00 | 43% | 46% | **2.37** | **2.31** |
| **F** | 0.98 | 0.60 | 0.06 | 0.28 | 6.58 | 5.09 | 20% | 29% | **1.32** | **1.50** |
| **G** | 0.42 | 0.30 | 0.03 | | 3.20 | 3.12 | 14% | 21% | **0.45** | **0.65** |
| **H** | 0.48 | 0.25 | 0.00 | | 2.81 | 1.93 | 17% | 20% | **0.48** | **0.39** |
| **I** | 0.22 | 0.00 | 0.09 | | 1.08 | 1.27 | 29% | 19% | **0.31** | **0.25** |
| **J** | 0.29 | 0.10 | 0.11 | | 1.98 | 1.84 | 20% | 22% | **0.39** | **0.40** |
| **K** | 0.86 | 0.38 | 0.03 | 0.22 | 6.16 | 4.91 | 18% | 16% | **1.12** | **0.80** |
| **L** | 0.64 | 0.30 | 0.00 | 0.01 | 3.83 | 2.59 | 17% | 21% | **0.65** | **0.54** |
| **M** | 0.26 | 0.20 | 0.00 | | 1.93 | 1.33 | 13% | 20% | **0.26** | **0.27** |
| **total** | 7.12 | 2.36 | 2.20 | 1.08 | 43.16 | 35.49 | | 0.24 | 10.40 | 9.27 |

### 3.1.3. Sewer System in the DemFil Area

Before 2008, the entire sewerage system in Bagsværd was combined system, but it has been changed in the recent years in order to decrease the risk of flooding. In this chapter, the changing process of the sewerage system is considered.

#### 3.1.3.1. The Previous Situation

According to the Rambøll report [37], there were some flood records and complaints about basement surcharging in the Bagsværd area, in heavy rain events before 2008. The Figure 19 shows the pipe network in this situation. In prior states the entire sewerage system was combined and all roads, roofs and parking runoff were collected via the same pipe as domestic wastewater.


**Figure 19, Sewerage system in the DEMFIL area**

It should be mentioned that, the dark green pipes below the lake are not a part of Nordvands sewer system. It primary contains traffic runoff from Bagsværdvej, but it is not considered in this project as well because of the shortage of data.

#### 3.1.3.2. The Current Situation

In 2008, the separated system for collecting the roads runoff was constructed in the DemFil area. The separated water flows to Søvej basin and after that, in downstream join into combined sewer system. Then it is driven to the treatment plant. Figure 20 shows the sewerage pipes in this situation (green pipes are separated road runoff). As a result, surcharging and flooding in the neighboring Aldershvilevej area decreased, yet there are some flooded nodes in the catchment. Therefore, the sewerage system still needs some improvement measures.

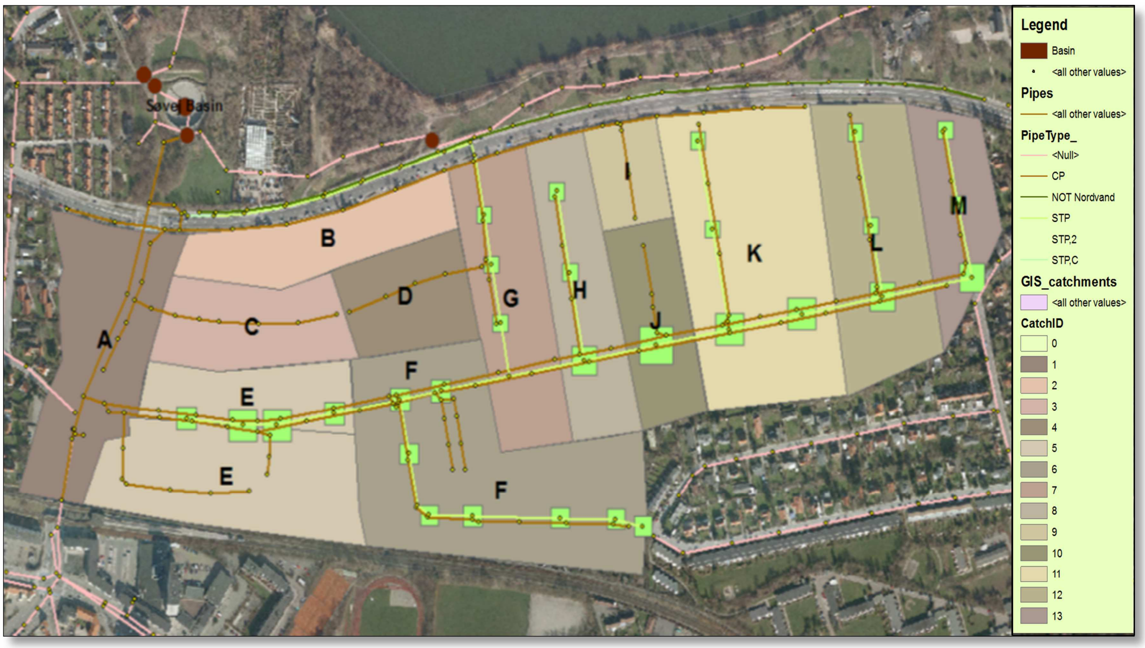


**Figure 20, sewerage system in the current situation, (separated pipes and catchments are green)**

#### *3.1.3.3. The Future Situation*

It is desirable to discharge the separated traffic runoff into the Bagsværd Lake in future, due to improvement of the sewer system. It may be reasonable suppose this action causes reducing the flood in the downstream sewerage system. Furthermore, discharging water into the lake leads to a decrease in overflow from the basin in downstream. Recently, municipality decided to examine the efficiency of disc filter for a short time. The polluted water were hoped to be purify before discharging into the lake. Figure 21 indicates the sewerage system in this situation.


**Figure 21, discharging treated water into the lake**

## 3.2. Quality Analysis

As part of DemFil project, the pollutants should be measured before and after passing through the disc filter. In order to evaluate the efficiency of the filter, these sequence measurements should be done for one year for different runoff events. This thesis was started before installing the disc filter, and the results of experimental test were not available during this thesis. Consequently, the concentrations of pollutants are going to be estimated by source classification framework.

### 3.2.1. Apply SCF for Case Study Area (Catchment Area)

As a result of discharging roads runoff into the lake via separated pipes, many pollutants will be released into the lake. In this project the SCF database was established for the DemFil area based on potential pollutants released to Bagsværd Lake via separated pipes. The release factor of most of pollutants depends on the number of inhabitants and surface area. The pollutants load and concentrations were estimated with respect to data from Gladsaxe municipality. Besides, there were some assumptions made regarding local observation and customary information from different statistical literature, websites, and papers. The lists of assumption are available in Appendix B. These assumption are mostly made based on the unite of the release factors. This model contains 25 priority pollutants (PPs) such as heavy metals, benzene, DEHP, diuron, etc. The initial database can be found in Appendices II (DVD).

The roads area is 2.4 hectare based on ArcGIS in the DemFil area and around 1190 inhabitants are living in the area. The mean annual rainfall is 690mm for recent 12 years.

Consequently, the volume of precipitation will be 24000($m^2$) ×690($l/m^2$/year) = 20,898,736 (l/year).

Each pollutant is divided into different items to represent the activity and process of producing the pollutants. Therefore, the loads of pollutants are calculated based on the size and the release factor of each activity or process (Pollutant load= Size×Release Factor). Then the concentration of each pollutant is determined by dividing the pollutant load by the volume of precipitation. The possible emission into the roads runoff (calculated loads and concentration of pollutants) can be found in Appendix C.

In this project, the substances which released to the compartments of groundwater and combined sewerage system are not taken into account, since these compartments do not have influence on stormwater quality. Moreover, some of the pollutants are removed from the database in this thesis, due to lack of data on release factors.

# 4. Results

This chapter covers the obtained results from simulation of MU for the hydraulic analysis as well as results of pollutants load calculation for quality analyses.

## 4.1. Hydraulic Analysis Results

The hydraulic analyses of the DemFil sewerage system are mostly done in MIKE URBAN program. After running the model for different situations, the results are represented via MIKE VIEW. In this section, the flooded nodes, maximum water levels in the sewerage system, link discharge, and weir discharge are represented as a result of the hydraulic analysis of the sewer system for different situations. Moreover, some other potential measures are modeled for improving the sewer system in the DemFil and the results are reported in this section.

### 4.1.1. Different Hydraulic Situation

#### *4.1.1.1. Previous Situation of the Sewer System*

As it mentioned before, all the runoff in the catchment area was going through the combined sewer system in the previous situation. In this project, no simulation was done for this situation and the result, which is shown in Figure 22, took from a technical report of Rambøll company [37]. Red dots indicate the flooded manholes for 10 years CDS rain data with a safety factor 1.43.

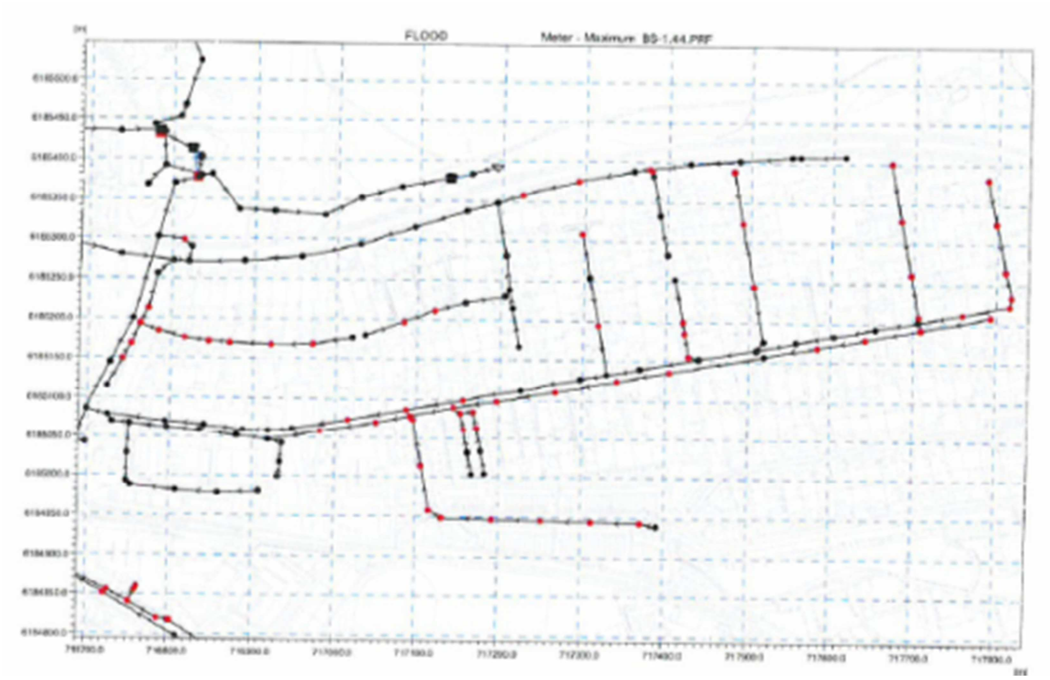


**Figure 22, the flooded nodes in the previous situation,(CDS, T=10, CF=1.43(for checking the catchments ID see Figure 17))**

It is apparent that most of the manholes in catchments A, C, D, F, J, K, L and M had flooding. Therefore, it was necessary to do some methods to reduce the flooded nodes.

#### *4.1.1.2. Current Situation of the Sewer System*

After simulation model for rainfall (CDS) events with different return periods, following results are obtained from MIKE VIEW. Figure 23 shows the flooded nodes for different return periods in small scale.

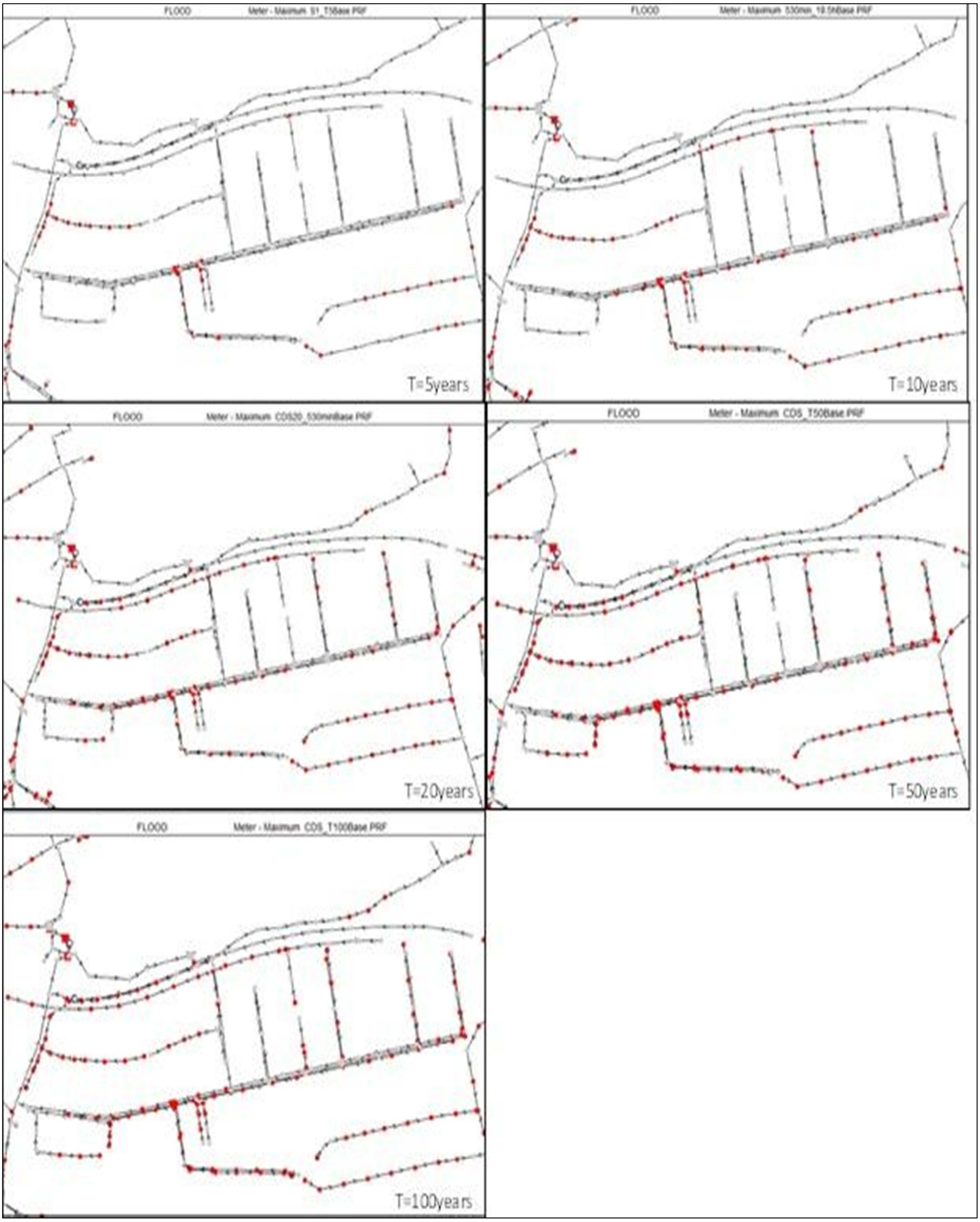


**Figure 23, the flooded nodes for 5,10,20,50 and 100 years return periods in the current situation (for checking the catchments ID see Figure 17)**

After disconnecting the roads runoff the flooded nodes are reasonably reduced, especially in catchments J, K, L, and M.

As expected, numbers of flooded nodes grow up by increasing the return period. The Figure 24 illustrates the relation between the number of flooded nodes and return period in this situation.

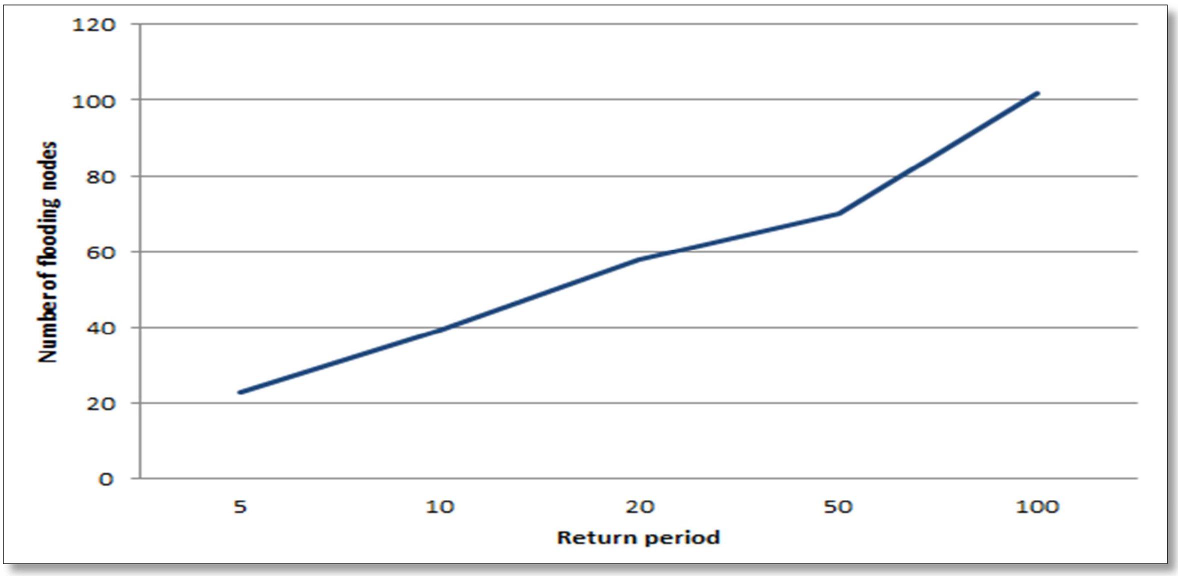


**Figure 24, relation between the numbers of flooded nodes and return period.**

Since the combined system should be designed for 10 years return period, the more investigations are done for this return period time series. Figure 25 shows the maximum water pressure level (red dash-line) in one of the profile plot in the catchment F. The maximum Water level is high even in the manholes which do not have flooding.

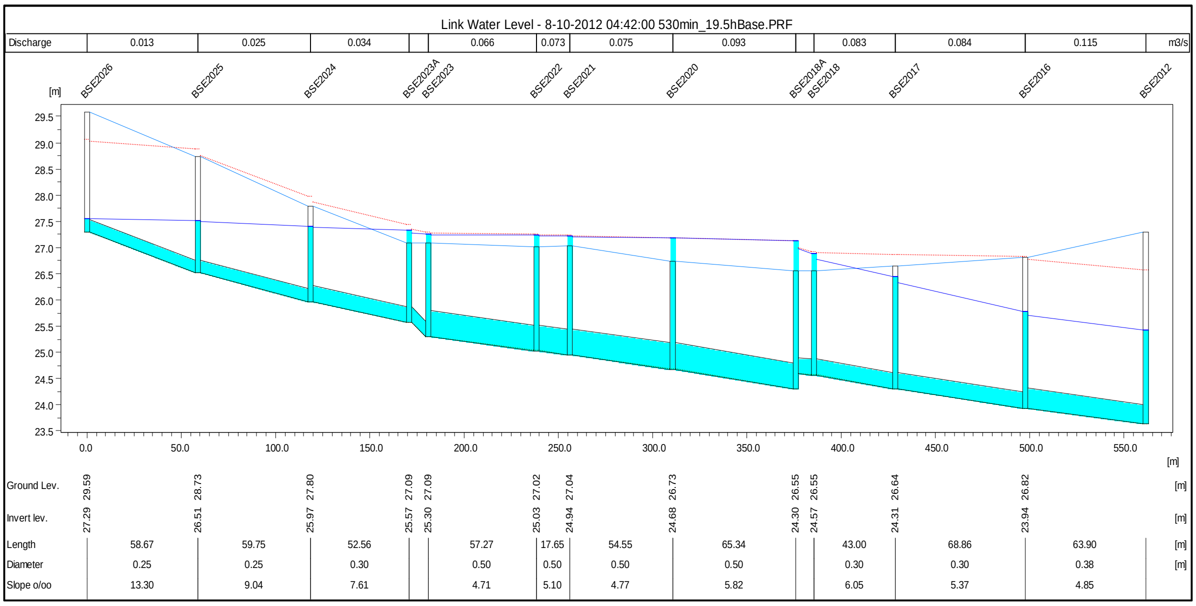


**Figure 25, water level in pipes which are in catchment F, (CDS, T=10, SF=1.43)**

In addition, Figure 26 reveals that the most of manholes are flooded in catchment C.

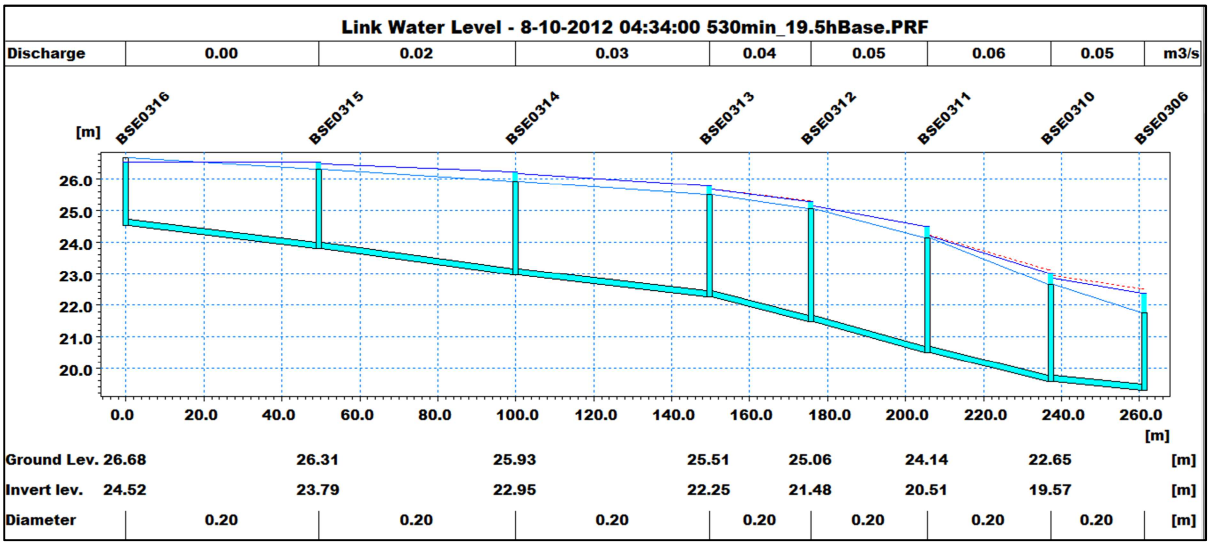


**Figure 26, water level in pipes which are in catchment C, T=10 (CDS, T=10, SF=1.43)**

Figure 27 indicates that the water level is high even in manholes without flooding in catchment A.

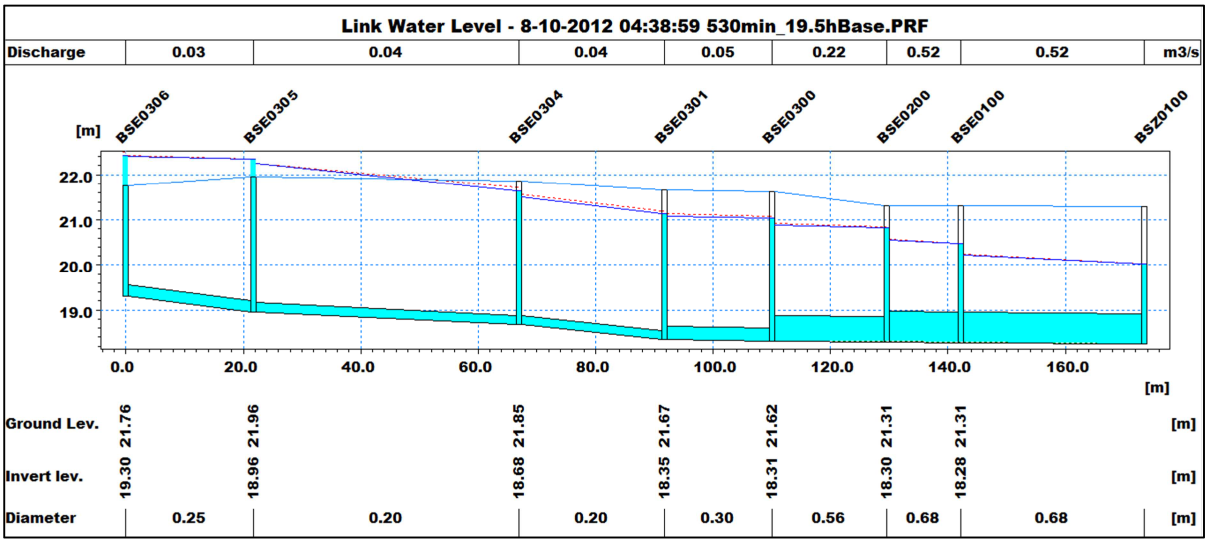


**Figure 27, water level in pipes in catchment A, (CDS, T=10, SF=1.43)**

Overall view of these figures demonstrates that the risk of flooding in the catchments A, C, and F is still high and may needs more improvement measures to reduce flooding and the water level in manholes.

#### *4.1.1.3. Future Situation of the Sewer System*

After doing some changes in the initial model, the disconnected stormwater discharges into the lake via the disc filter as outlet in the DemFil area. Figure 28 indicates the results of simulation for rainfall (CDS) events with different return period. As it can be seen in the following figure, there is no significant difference between the number of flooded nodes in the current situation (see Figure 23) and this situation.

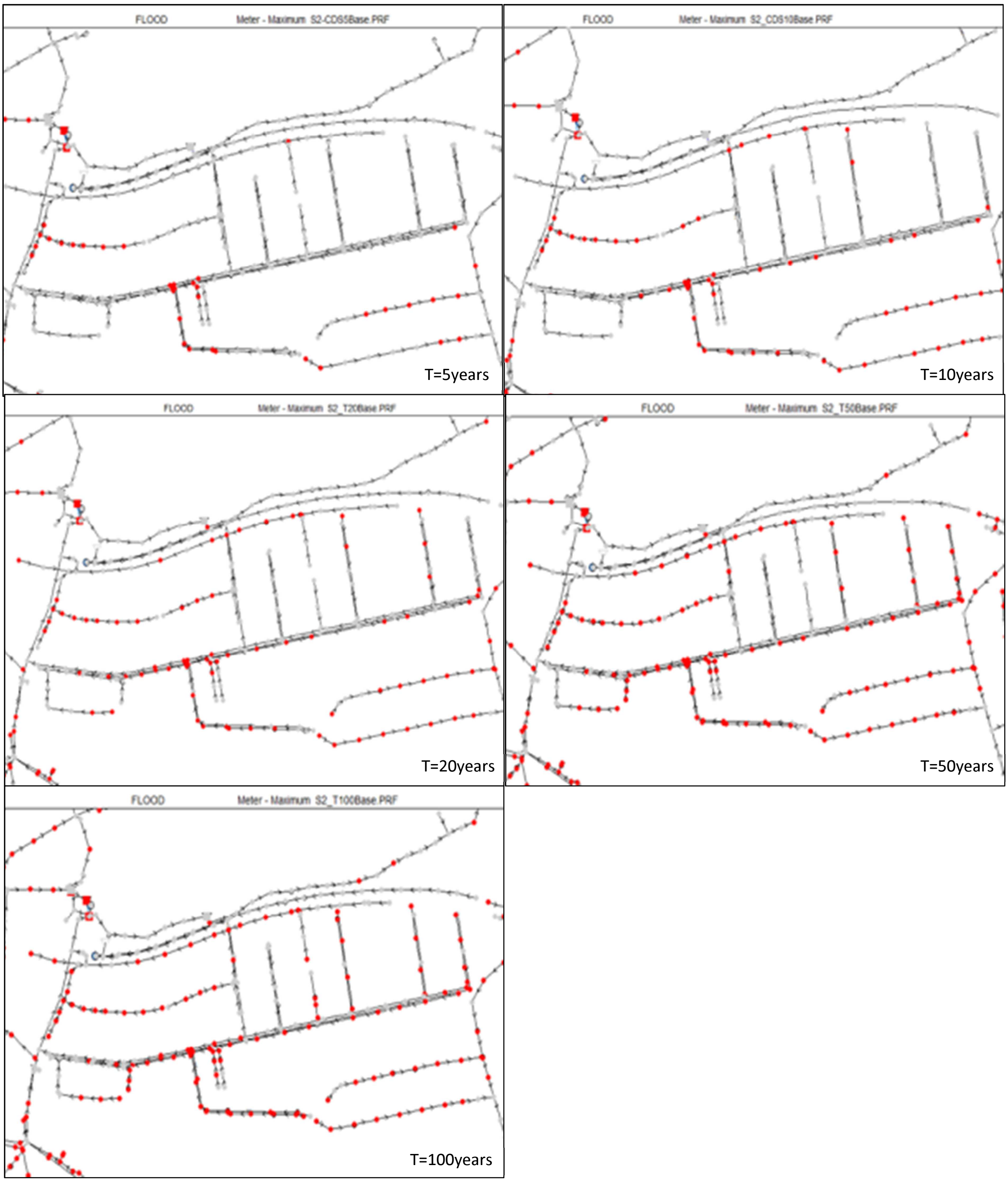


**Figure 28, the flooded nodes for 5,10,20,50 and 100 years return periods in the future situation**

Figure 29 indicates the flow and volume of disconnected roads runoff discharging into the lake. According to this figure, the maximum flow is equal to $0.37 m^3/s$ and accumulated volume is $1030\ m^3$.

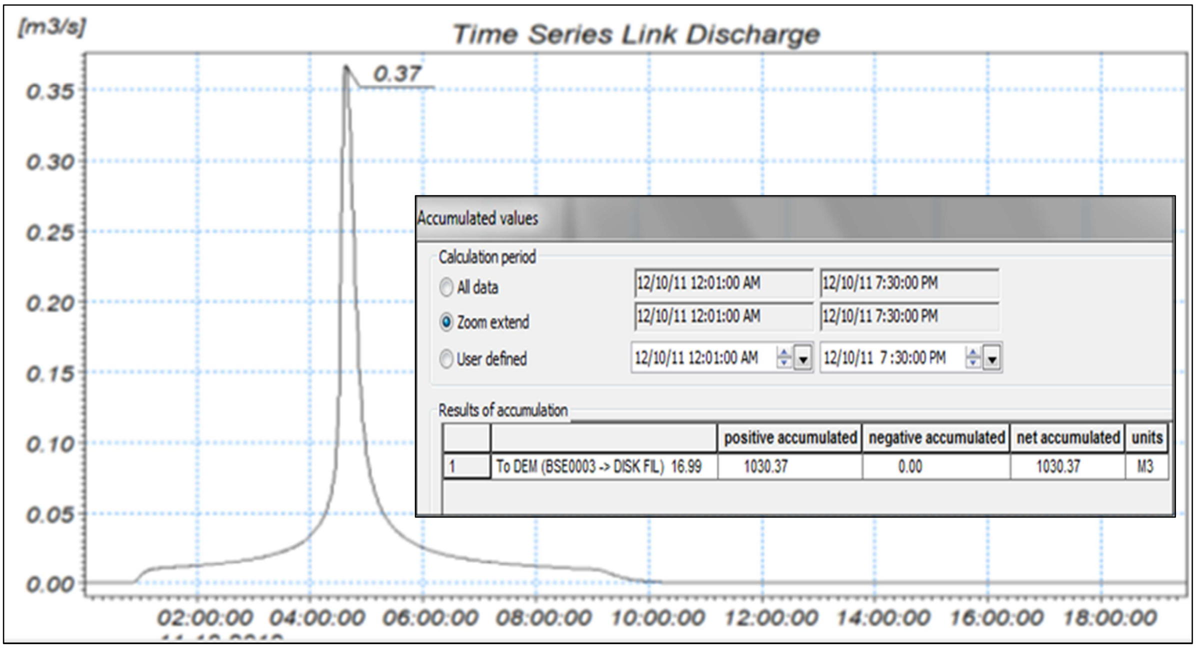


**Figure 29 , Link discharge of the pipe connected to Disc filter, (CDS, T=10, CDS=1.43)**

### 4.1.2. Correlation between Current and Future Situation

There is a possibility that discharging water into the lake caused some changes in the hydraulic conditions of the downstream sewer system. In this section, these changes are considered and they have been compared with the current situation (before discharging water into the lake). These situations are assessed for CDS rainfall with return period 10 years and safety factor.

#### *4.1.2.1. Flooding in the Downstream*

Although it was expected to have less flooded nodes in the downstream, Figure 30 indicates that discharging water into the lake was not efficient enough to decrease the flooded nodes (CDS, T=10, SF=1.43) in downstream as well as upstream. The numbers of flooded nodes in downstream sewerage system are approximately the same as the current situation.

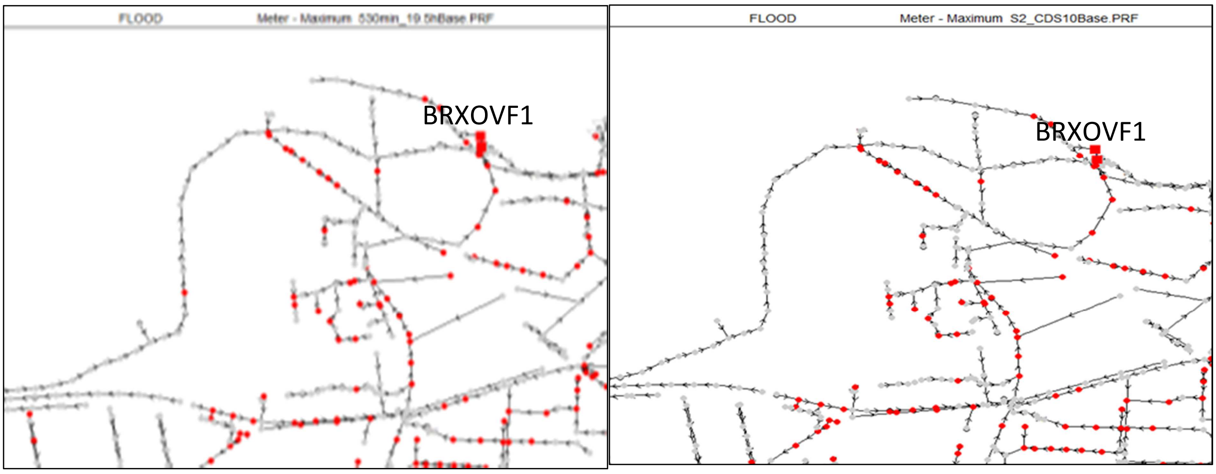


**Figure 30, Downstream flooded nodes before (left pic) and after (right pic) discharging stormwater into the lake, (CDS, T=10, SF=1.43)**

#### *4.1.2.2. Maximum Water Level in Downstream*

It seems that discharging water into the lake has a positive influence on maximum water level in the downstream system. Therefore, some parts of the downstream sewerage system are selected to examine the water level in them. Figure 31 shows the selected profiles for investigating the maximum water level. These pipes are located between the first manhole after separation node and basin.


**Figure 31, the pipes and manholes which are selected for water level control**

Figure 32 illustrates the maximum water level in the selected profile before discharging roads runoff into the lake (current situation). Moreover, Figure 33 indicates the maximum water level in the same profile section after discharging water into the lake.

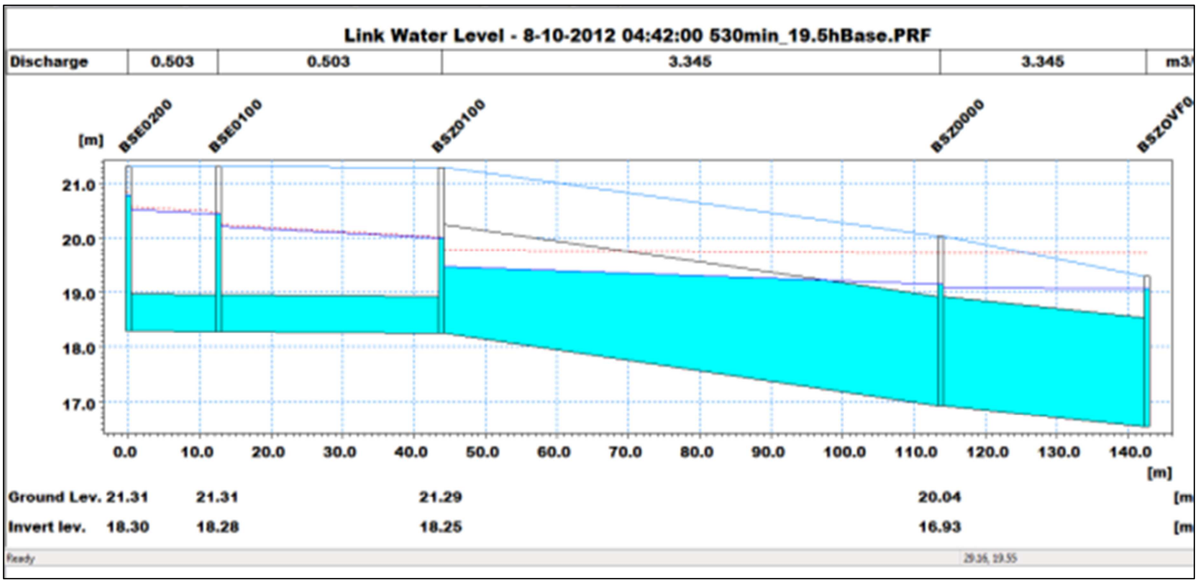


**Figure 32, Water level in selected pipes before discharge stormwater into the lake, (CDS, T=10, SF=1.43)**

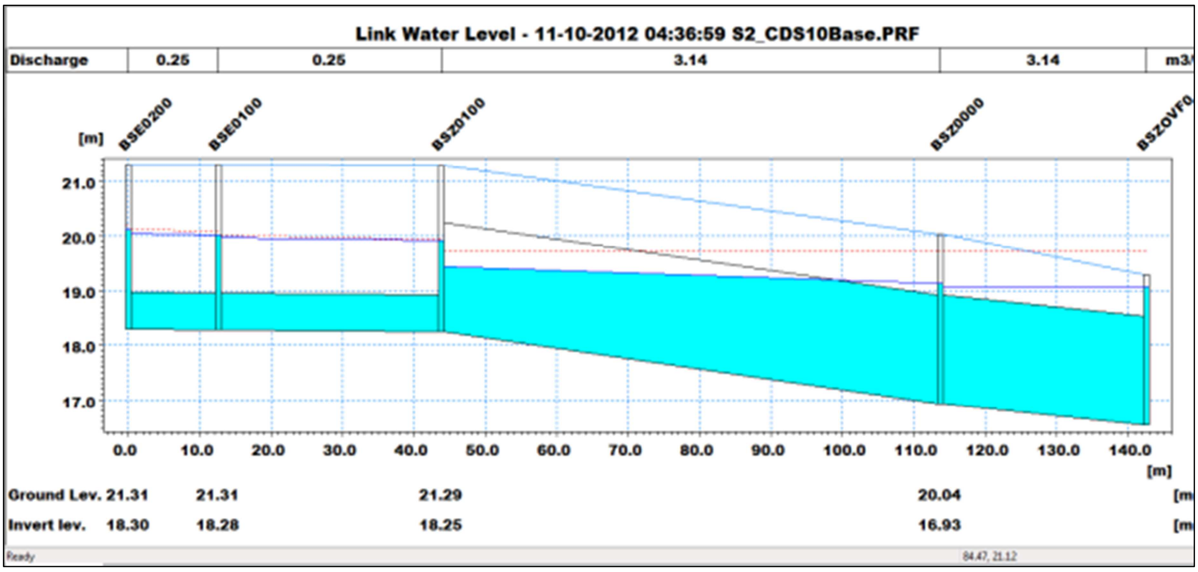


**Figure 33, Water level in selected pipes after discharge stormwater into the lake, (CDS, T=10, SF=1.43)**

As evident from these two figures, after discharging the roads runoff into the lake, the maximum water level dropped from 20.8m to 20.2m in manhole BSE0200 (CDS, T=10, SF=1.43). In the second manhole, (BSE0100) there is a reduction in maximum water level from 20.5m to 20.1m. The water level reduction, in the manholes, decreased by going far from separation node e.g. the maximum water level is 16.57m in the manhole BSY0044 for both situations (see Figure 34).

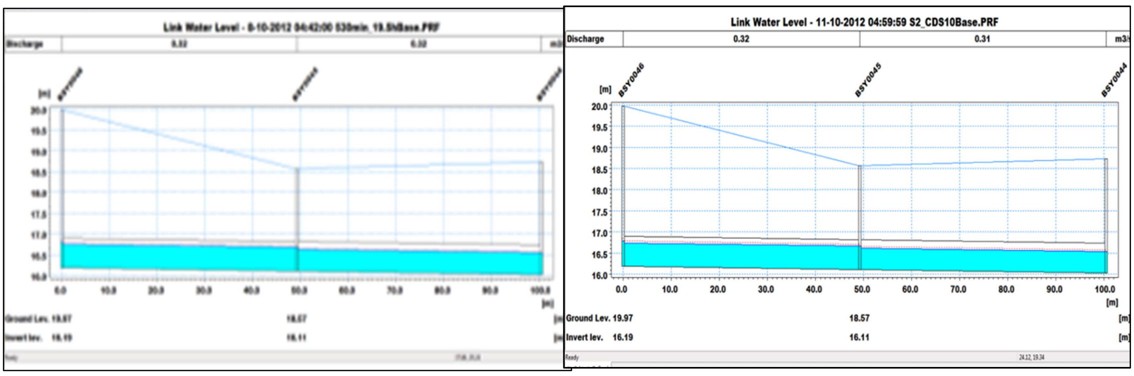


**Figure 34, maximum water level in the further pipes, (CDS, T=10, SF=1.43)**

#### *4.1.2.3. Overflow from Downstream Basin*

It was predicted that, the overflow from the Søvej basin reduced by discharging the DemFil roads runoff into the lake. Reducing the overflow not only help the sewer system in the downstream but also prevent discharging polluted water into the lake (CDS, T=10, SF=1.43). Currently in extreme rain event the overflows from the Søvej basin discharges into the Bagsværd Lake.

It is known from the Nordvand report [38] that discharging the DemFil roads runoff into the lake caused 1300 $M^3$/year less overflow from the Søvej basin into the lake during extreme events.

According to the results from MU (see Figure 35) for CDS rain data with 10 years return period, the maximum overflow from the Søvej basin before and after discharging water into the lake is 3.48$m^3$/s and 3.28$m^3$/s respectively. Moreover, the accumulated volumes of overflow for these situations are 12673 $m^3$ before discharging water and 11680 $m^3$ after discharging water into the lake (see Appendix D).

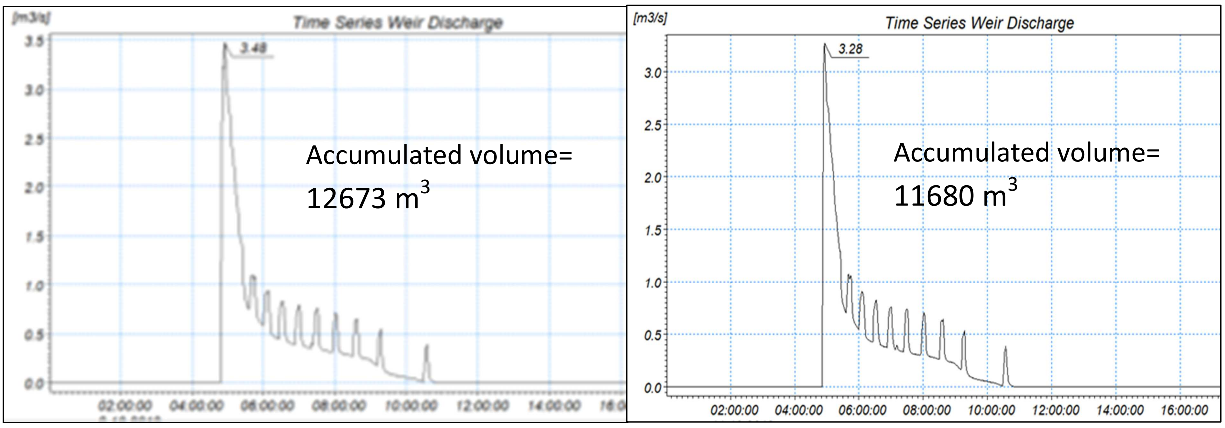


**Figure 35, weir discharge from the basin before (left pic) and after discharging water, (CDS, T=10, SF=1.43)**

In order to determine the annual overflow from the basin, the long term simulation (LTS) seems desirable in further work. In this project due to lack of time, this simulation has not been done.

### 4.1.3. Potential Improvements in the Sewerage System

There are some flooded nodes in the DemFil area even for 5 years return period rainfall. In order to improve the function of the sewer system in the area, some changes are made in the model with the 10 years return period. All these methods are modeled in the future situation (after discharging road runoff into the lake) since this situation is more realistic for future than the current situation. Therefore, the results of these alternatives simulations are compared with the results from future situation with 10 years return period. These alternative measures are considered as follows:

#### *4.1.3.1. Disconnecting the Additional Roads Runoff*

As mentioned before, in some catchments, the roads runoff has not yet been disconnected from the main sewer system in the DemFil area. Therefore, the combined sewerage system in some catchments has the potential to have a less connected impervious area. The runoff from these reduced area, from the combined system, can be connect to additional separate sewer system or infiltration trenches. Therefore, in this alternative the imperviousness of each catchment connected to the combined system is reduced by removing the roads area from the equation (IV).

As mentioned previously, there is a difference between the catchments area in MU model and ArcGIS. This is because of uncertainty about the catchments boundary which was made in ArcGIS. Therefore, the new imperviousness of catchments without roads area, for the MU model is calculated based on the following equation:

$$\mathbf{IMP\ MU}_{\ (\mathbf{without\ road})\%} = \frac{\boldsymbol{Imp\ MU}_{\ \%}}{\boldsymbol{Imp\ GIS}_{\ \%}} \times \boldsymbol{Imp\ GIS}_{\ (\boldsymbol{without\ road})\%} \qquad \text{(V)}$$

In this equation “Imp” means the imperviousness of each catchment. Table 3 listed the new imperviousness of catchments connected to the combined sewer system (without roads area).

**Table 3, new impervious area for disconnecting more roads runoff**

| Catch ID | impervious area (GIS) | | | | Area in GIS (ha) | Area in MU (ha) | Imp GIS (%) | Imp MU (%) | Imp GIS without road | ALT1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Roofs (ha) | Separated road (ha) | Not separated road (ha) | Parking (ha) | | | | | | Imp in MU without road |
| **A** | 0.73 | 0.00 | 0.92 | 0.05 | 3.69 | 3.00 | 46% | 37% | 21% | 17% |
| **B** | 0.27 | 0.00 | 0.00 | | 2.25 | 1.44 | 12% | 15% | 12% | 15% |
| **C** | 0.43 | 0.00 | 0.24 | | 2.22 | 2.30 | 30% | 23% | 19% | 15% |
| **D** | 0.24 | 0.00 | 0.16 | | 1.88 | 1.68 | 21% | 19% | 13% | 11% |
| **E** | 1.31 | 0.24 | 0.55 | 0.51 | 5.55 | 5.00 | 43% | 46% | 33% | 35% |
| **F** | 0.98 | 0.60 | 0.06 | 0.28 | 6.58 | 5.09 | 20% | 29% | 19% | 28% |
| **G** | 0.42 | 0.30 | 0.03 | | 3.20 | 3.12 | 14% | 21% | 13% | 19% |
| **H** | 0.48 | 0.25 | 0.00 | | 2.81 | 1.93 | 17% | 20% | 17% | 20% |
| **I** | 0.22 | 0.00 | 0.09 | | 1.08 | 1.27 | 29% | 19% | 21% | 14% |
| **J** | 0.29 | 0.10 | 0.11 | | 1.98 | 1.84 | 20% | 22% | 15% | 16% |
| **K** | 0.86 | 0.38 | 0.03 | 0.22 | 6.16 | 4.91 | 18% | 16% | 18% | 16% |
| **L** | 0.64 | 0.30 | 0.00 | 0.01 | 3.83 | 2.59 | 17% | 21% | 17% | 21% |
| **M** | 0.26 | 0.20 | 0.00 | | 1.93 | 1.33 | 13% | 20% | 13% | 20% |
| **Total** | 7.12 | 2.36 | 2.20 | 1.08 | 43.16 | 35.49 | | | | |

In some catchments, the roads runoff was collected by separate pipes in current situation, so the new imperviousness is not changed or the difference is negligible such as catchments B, F, G, H, K, L, and M. As a result, the imperviousness of remain catchments (catchments A, C, D, E, I and J) are changed in MU.

Figure 36 illustrates the flooded nodes (CDS, T=10, SF=1.43) before and after disconnecting more roads runoff from the sewerage system. Comparing these two situations represents that, the flooded nodes are decreased in a few catchments area.


**Figure 36, before and after doing measure respectively (CDS, T=10, SF=1.43)**

In addition, the stormwater volume in the DemFil sewerage network can be checked in two selected points. As evident in Figure 37 the northern pipes (green pipes) of the DemFil are joined in the node BSE0100 node, and the southern pipes (blue pipes) are linked to the node BSE2000.

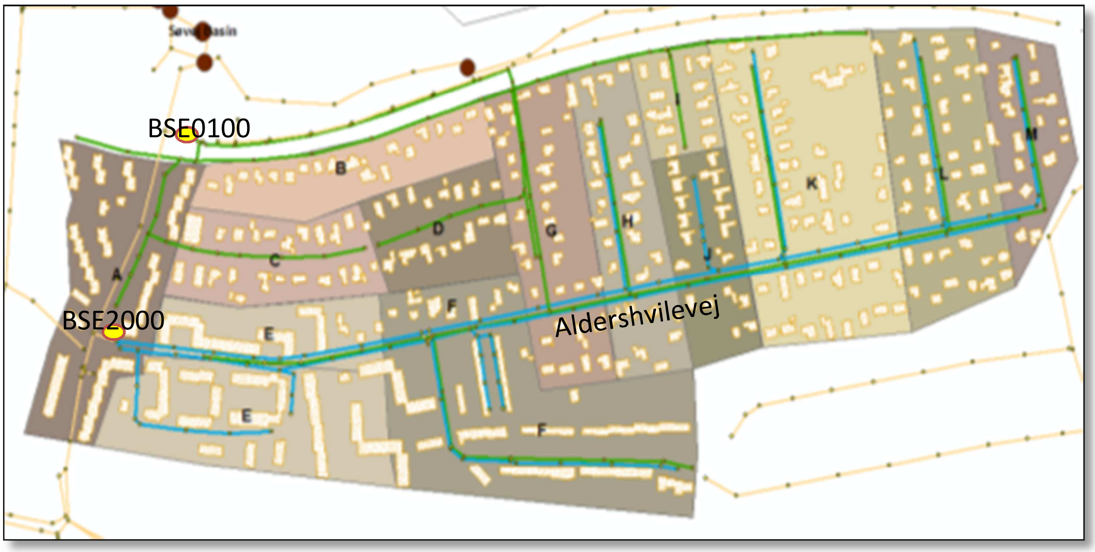


**Figure 37, selected point for checking the stormwater volume in the DemFil area**

Figure 38 displays the hydrograph in BSE0100 before and after doing this measure in the area. As can be seen in this figure, the link discharge graph indicates that the peak flow was dropped off from 0.3m$^3$/s to 0.28m$^3$/S. Furthermore, the accumulated volume of total flow decreases from 1310m$^3$ to 914m$^3$ (see Appendix E). Total flow is combination of stormwater and wastewater, but in this case the wastewater flow does not change, so the change in the total runoff equals the flow of stormwater.

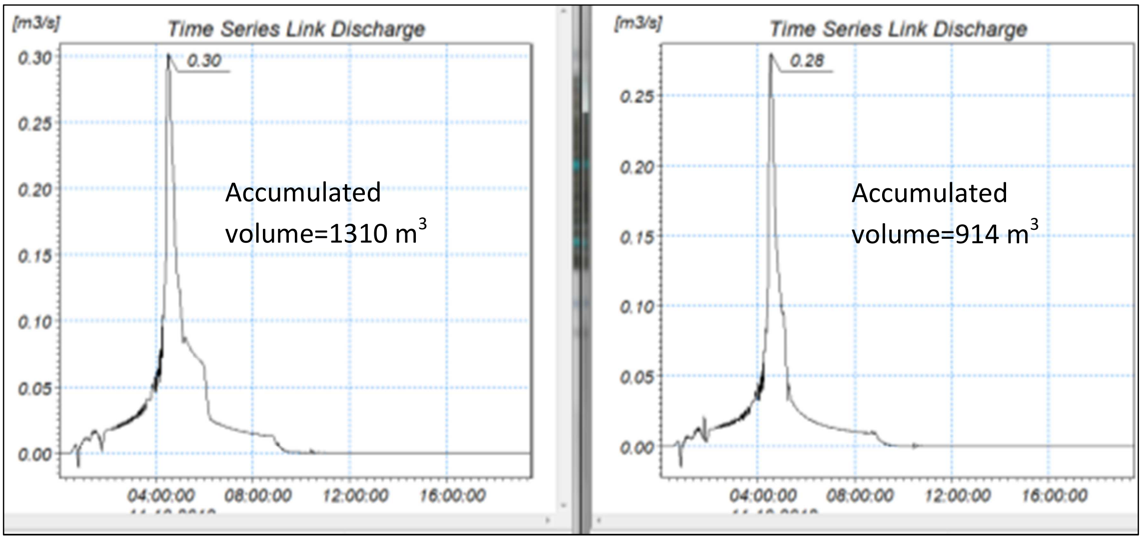


**Figure 38, flow in the node BSE0100 (CDS, T=10, SF=1.43)**

Moreover, Figure 39 illustrates the peak flow in the node BSE2000 reduced from $0.77m^3/s$ to $0.70m^3/s$ after disconnecting additional roads runoff (CDS, T=10, SF=1.43). The accumulated volume is $3201m^3$ before doing measure and $2864\ m^3$ after doing measure.

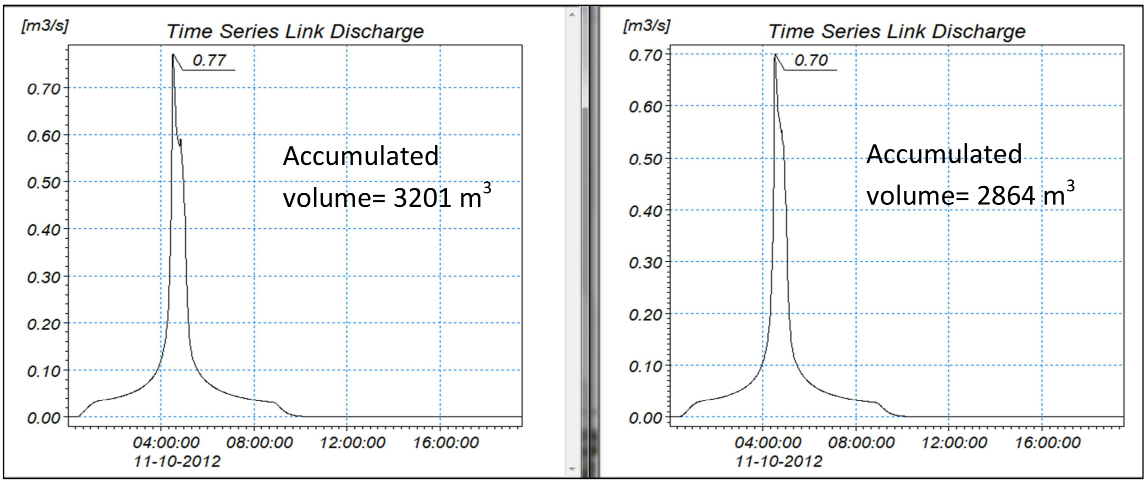


**Figure 39, flow in the node BSE2000 (CDS, T=10, SF=1.43)**

#### *4.1.3.2. Disconnecting the Roofs Runoff*

In this scenario, the roofs contribution in the combined sewer system is eliminated. The imperviousness of the connected catchments to the combined system is decreased, as a result of removing the roofs area. This measure can be implemented by connecting the roofs runoff into the separate sewer system or using the infiltration methods. In some countries, the roofs runoffs are collected by house owners for consuming in the gardens or flash tanks.

Table 4 listed the new imperviousness of connected catchments to the combined system (without roofs area). In this scenario, just the areas of parking and not separated roads are contributing to generate the sewer system load.

**Table 4, new impervious area for disconnecting roofs runoff**

| Catch ID | impervious area (GIS) | | | | Area in GIS (ha) | Area in MU (ha) | Imp GIS (%) | Imp MU (%) | Imp GIS without roof | ALT2 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Roofs (ha) | Separated road (ha) | Not separated road (ha) | Parking (ha) | | | | | | Imp in MU without roofs |
| **A** | 0.73 | 0.00 | 0.92 | 0.05 | 3.69 | 3.00 | 46% | 37% | 26% | 21% |
| **B** | 0.27 | 0.00 | 0.00 | | 2.25 | 1.44 | 12% | 15% | 0% | 0% |
| **C** | 0.43 | 0.00 | 0.24 | | 2.22 | 2.30 | 30% | 23% | 11% | 8% |
| **D** | 0.24 | 0.00 | 0.16 | | 1.88 | 1.68 | 21% | 19% | 9% | 8% |
| **E** | 1.31 | 0.24 | 0.55 | 0.51 | 5.55 | 5.00 | 43% | 46% | 19% | 21% |
| **F** | 0.98 | 0.60 | 0.06 | 0.28 | 6.58 | 5.09 | 20% | 29% | 5% | 8% |
| **G** | 0.42 | 0.30 | 0.03 | | 3.20 | 3.12 | 14% | 21% | 1% | 1% |
| **H** | 0.48 | 0.25 | 0.00 | | 2.81 | 1.93 | 17% | 20% | 0% | 0% |
| **I** | 0.22 | 0.00 | 0.09 | | 1.08 | 1.27 | 29% | 19% | 8% | 6% |
| **J** | 0.29 | 0.10 | 0.11 | | 1.98 | 1.84 | 20% | 22% | 5% | 6% |
| **K** | 0.86 | 0.38 | 0.03 | 0.22 | 6.16 | 4.91 | 18% | 16% | 4% | 4% |
| **L** | 0.64 | 0.30 | 0.00 | 0.01 | 3.83 | 2.59 | 17% | 21% | 0% | 0% |
| **M** | 0.26 | 0.20 | 0.00 | | 1.93 | 1.33 | 13% | 20% | 0% | 0% |
| **total** | 7.12 | 2.36 | 2.20 | 1.08 | 43.16 | 35.49 | | | | |

As detailed in the table, the calculated imperviousness value for some catchments is zero or less than 10% after removing roofs, but probably, there are some other impermeable surfaces in the area which are not considered in the equation IV (Imperviousness formula). Therefore, the imperviousness is assumed 10% (the same as green area) for the catchments with lower imperviousness than 10%.

As evident from Figure 40, after removing the roofs runoff from the sewerage system, the flooded nodes (CDS, T=10, SF=1.43) extremely decreased in the DemFil area.


**Figure 40, flooded nodes before and after removing roofs runoff (CDS, T=10, SF=1.43)**

Furthermore, Figure 41 displays the total flow in the node BSE0100 (for finding the node place see Figure 37). As anticipated, the peak flow decline from 0.3m$^3$/s to 0.25m$^3$/s in this scenario (CDS, T=10, SF=1.43). The accumulated flow volume is decreased to 763m$^3$ (see Appendix E).

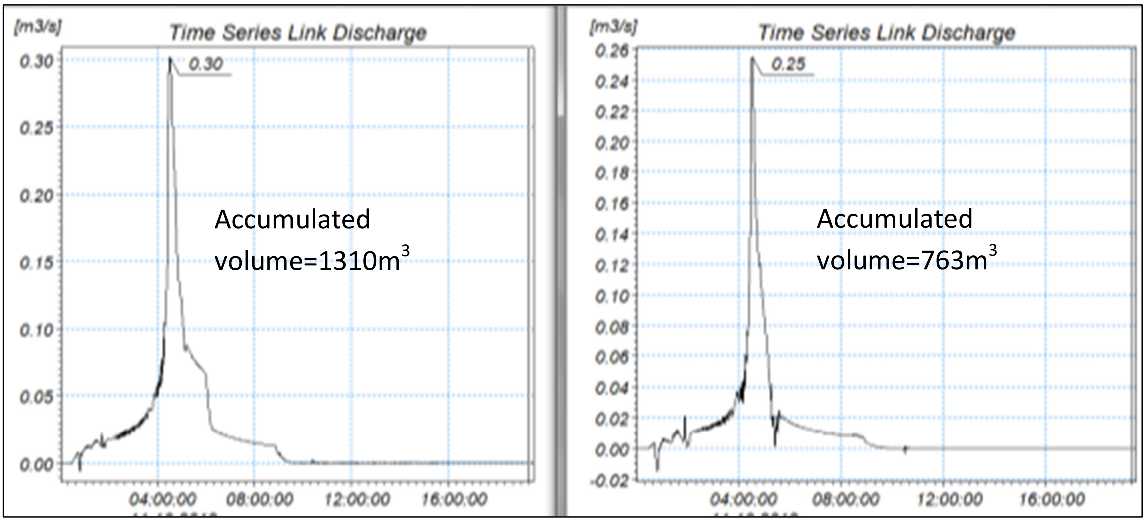


**Figure 41, flow in the node BSE0100 before and after removing roofs runoff (CDS, T=10, SF=1.43)**

In addition, it is evident from Figure 42 the flow has more reduction in node BSE2000, because these pipes are covered more houses and apartments (for finding the node see Figure 37). The peak flow is dropped from 0.77m$^3$/s to 0.41m$^3$/s (CDS, T=10, SF=1.43). The accumulated volume of water in the system decreases from 3201m$^3$ to 1409m$^3$.

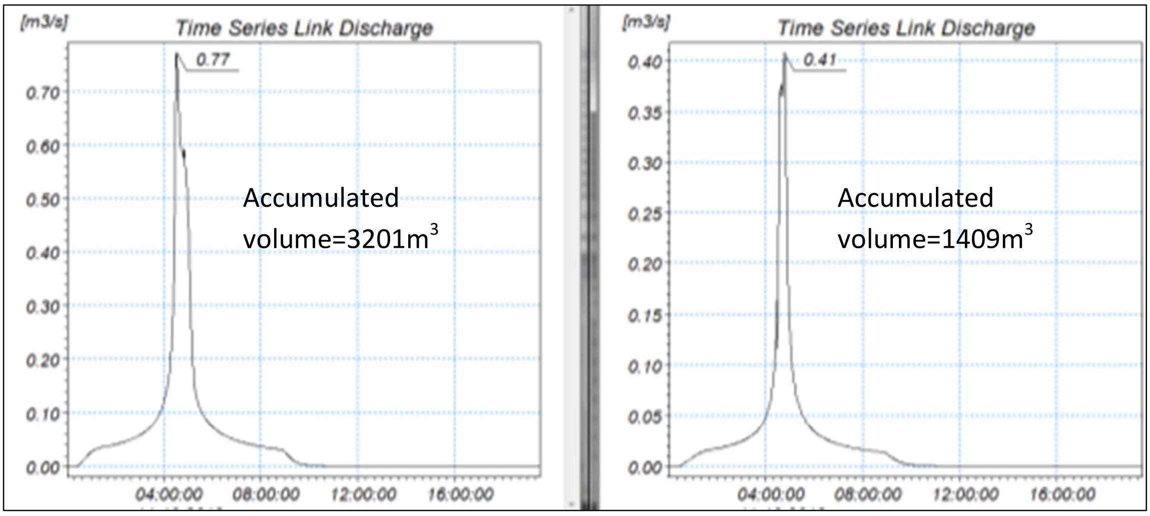


**Figure 42, flow in the node BSE2000 before and after removing roofs runoff (CDS, T=10, SF=1.43)**

#### *4.1.3.3. Making Basin*

In order to decrease the flooding in the catchment F, water utility company (Nordvand) has decided to make a basin in this part of the sewer system in the future. This basin will contain $250m^3$ volume of water during the heavy rain. Then the water will pump back into the main system when the water level reduced in the combined system.

In this part of the project, the efficiency of this measure is taken to the account. As illustrated in Figure 43, the basin was modeled in MU without defining any pump to make a simplified model (CDS, T=10, SF=1.43). The weir is installed, between the manhole BSE2022 and basin, for deriving wastewater into the basin when it reaches the certain level. There is a limitation in MU to connect the basin to the weir without any pipes; therefore, the extra manhole is created to connect the basin and weir.


**Figure 43, adding basin in the DemFil area**

As detailed in Figure 44, the invert level of manhole is 25.03m and the crest level of the weir is 26m, so the extra water than 26m is going to the new basin via the weir. This action probably reduced the water level and flooding in the neighboring manholes.


**Figure 44, invert levels of manholes and crest level of weir**

It can be seen from Figure 45, the flooded nodes (CDS, T=10, SF=1.43) in the catchment F are reduced after making basin in this area.

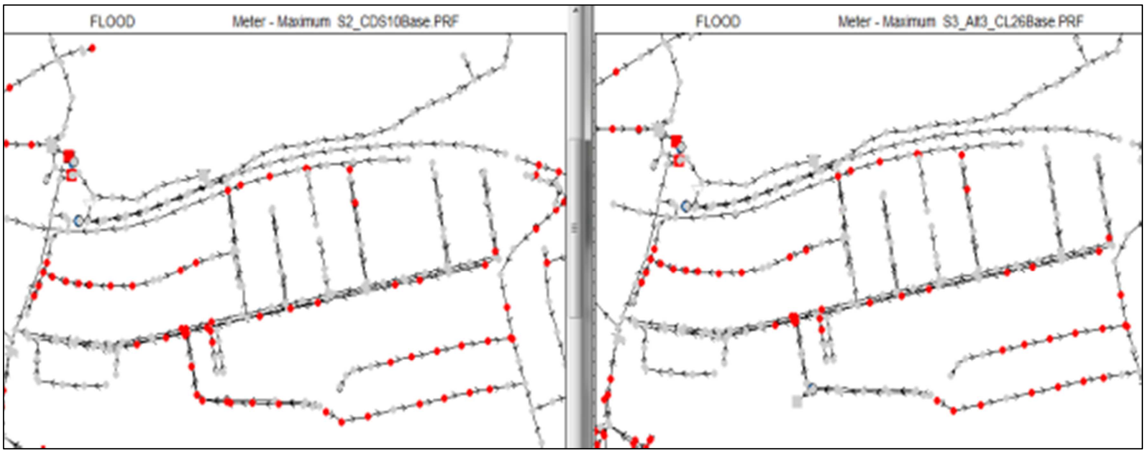


**Figure 45, flooded nodes before and after making basin (CDS, T=10, SF=1.43)**

As it can be seen in Figure 46, the manholes were typically flooded (CDS, T=10, SF=1.43), before making basin in catchment F.

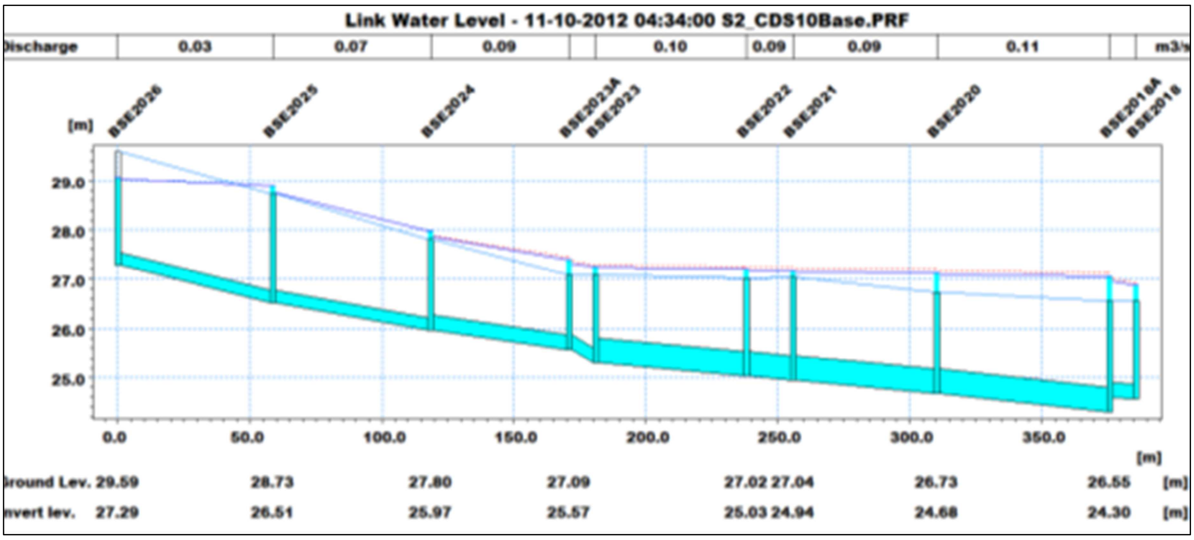


**Figure 46, maximum water level before making basin in catchment F (CDS, T=10, SF=1.43)**

Additionally, Figure 47 indicates that the maximum water pressure level does not exceed the ground level at the same profile plot, but it still is high in most of the manholes. However, there is no flooding in this area after making basin, the risk of flood is high in this catchment. It was predicted that the flooded nodes (CDS, T=10, SF=1.43) are remain unchanged in other catchments after making basin in catchment F.

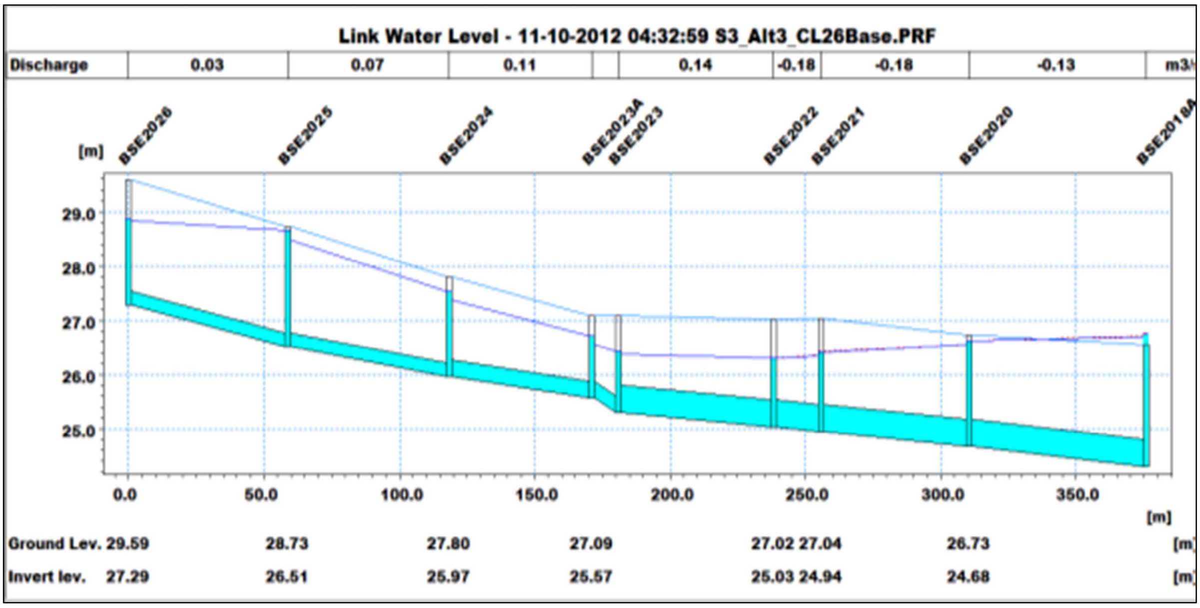


**Figure 47, water level in the pipes near the basins (CDS, T=10, SF=1.43)**

#### *4.1.3.4. Enlarging the Pipes*

Enlarging the pipes is one of the methods to increase the sewer system capacity which leads to have less flooding and water level in the manholes. As it can be seen in the previous alternatives, some nodes are flooded even after removing the roads or roofs runoff (CDS, T=10, SF=1.43). It seems probable that enlarging the pipes inevitable in some catchments to reduce flooding from the sewer system.

In this scenario, the pipes are enlarged in different stages to find appropriate dimension for having no flood in the system. Initial simulation shows that, enlarging the downstream pipes are more efficient than enlarging the pipes locating in the flooding area. The enlarging process was continued by trial and error until no flooded nodes can be seen in the sewer system.

Figure 48, indicates the initial size of the pipes before enlarging, and Figure 49 shows the ultimate up sized pipes. It is evident from the figures that, some pipes are enlarged even more than 3 times.


**Figure 48, initial size of pipes in the DemFil area**

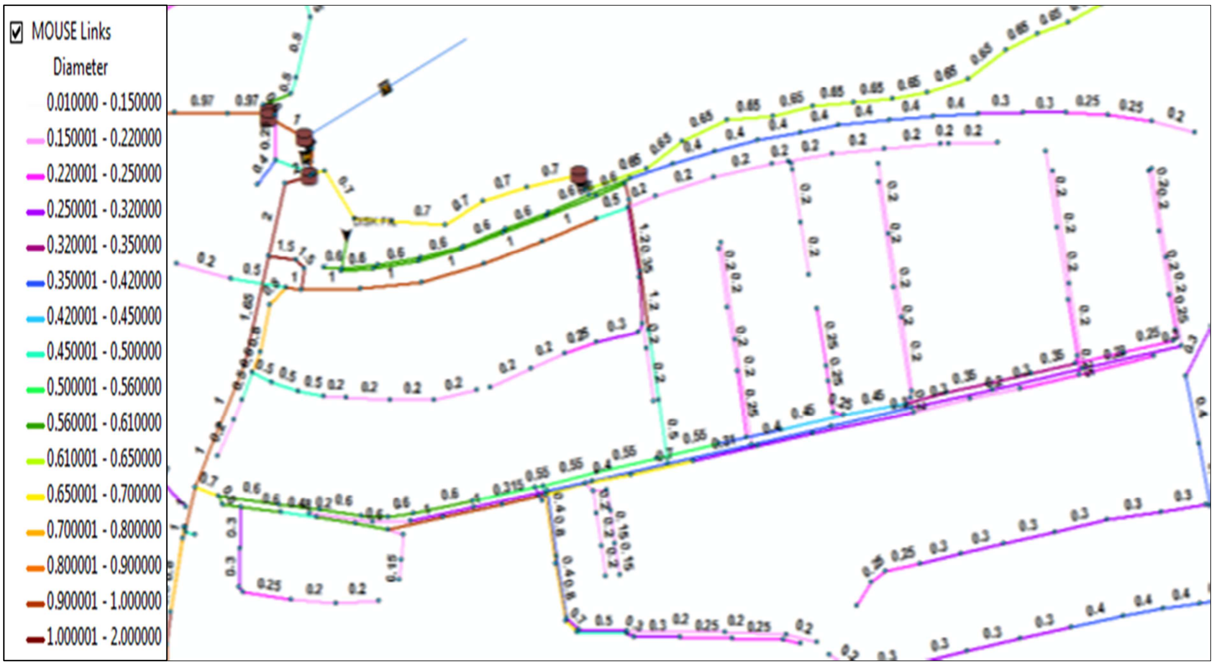


**Figure 49, after optimum enlarging**

Figure 50 compares the results of flooding computation in MIKE VIEW (CDS, T=10, SF=1.43). It is evident that, enlarging pipes could be an efficient way to remove flooding in the area, but it needs time to try different size and position of pipes to find optimum dimension.

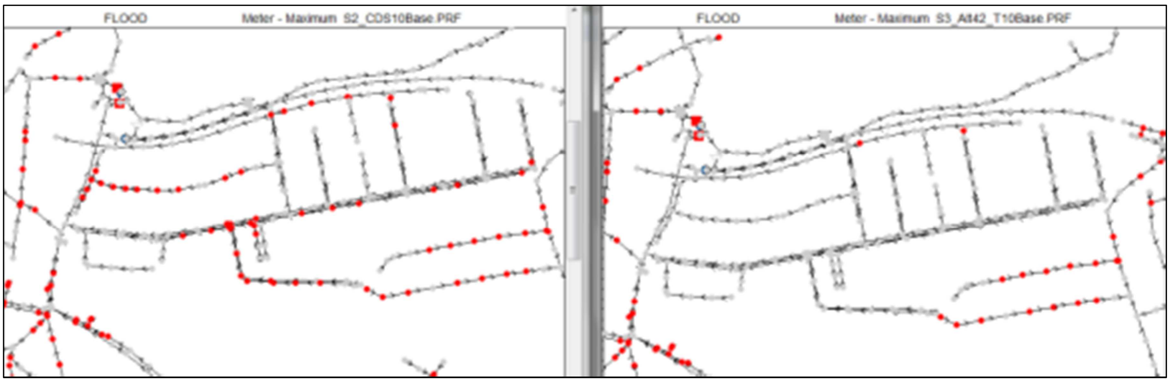


**Figure 50, flooded nodes before and after enlarging the pipes (CDS, T=10, SF=1.43)**

Figure 51 shows the initial pipe section in catchment A, where the red dashed-line represents the maximum water pressure level. Figure 52 illustrates the same profile plot after enlarging the pipes. It can be seen that the maximum water pressure level does not exceed the ground level at any node. The other changed pipe sections can be checked in Appendix J (DVD).

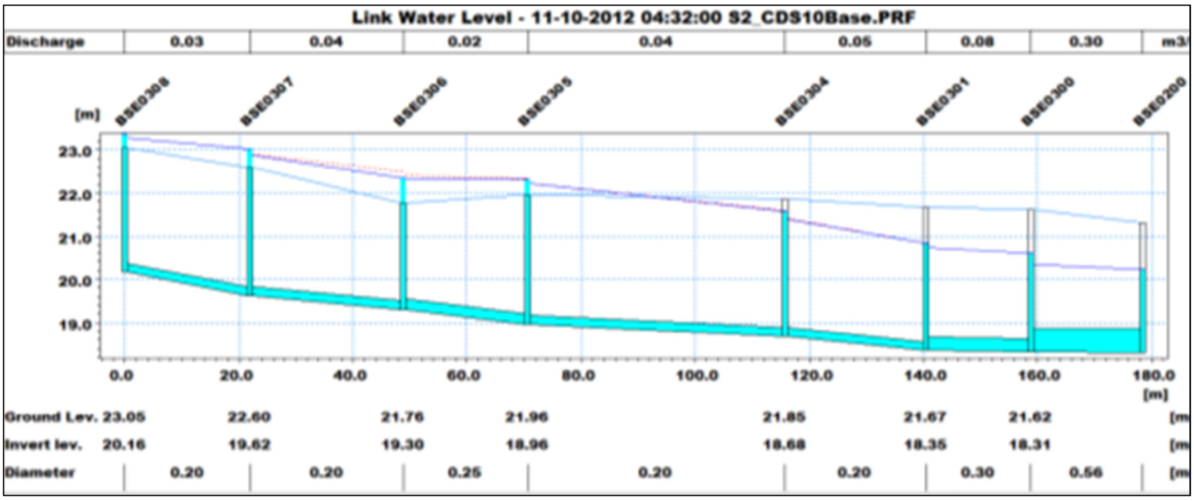


**Figure 51, Maximum water level in catchment A before enlarging the pipes (CDS, T=10, SF=1.43)**

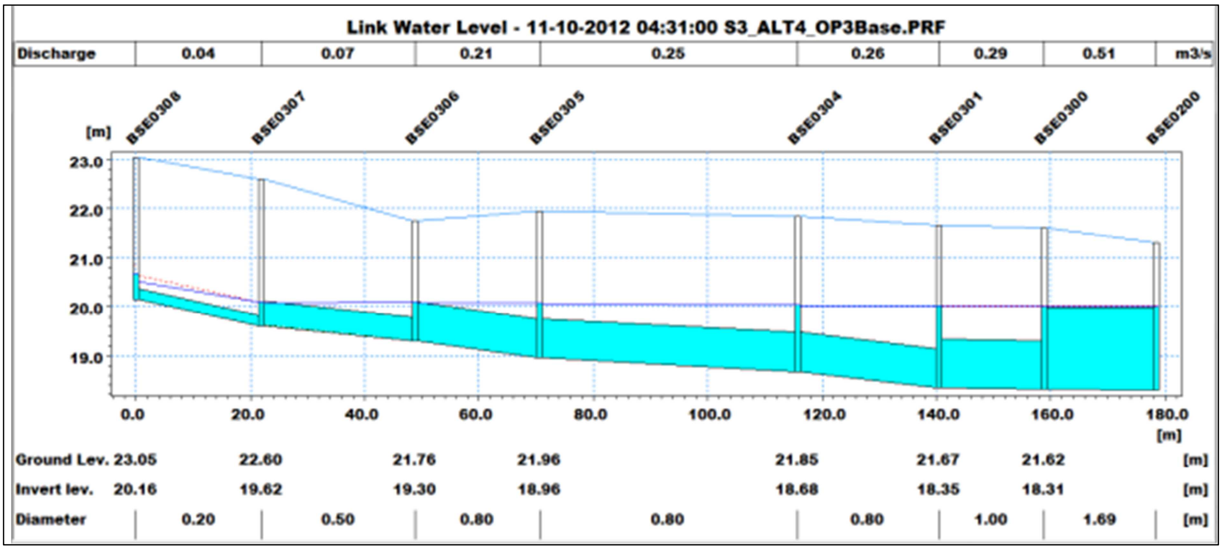


**Figure 52, Maximum water level catchment A after enlarging the pipes (CDS, T=10, SF=1.43)**

## 4.2. Quality Analysis Results

The pollutants loads and concentration for each activity were determined based on the municipality data and some assumption via SCF database. Table 5 represents the total loads and concentrations of each pollutant in the DemFil roads runoff, which obtained from SCF database.

**Table 5, total pollutants concentration from SCF database**

| Substances | Release Load Low (Kg/year) | Release Load (Kg/year) | Release Load Hi (Kg/year) | Con[2] low (µg/L) | Con (µg/L) | Con Hi (µg/L) | General Quality[3] (µg/L) | short-term Quality[4] (µg/L) |
|---|---|---|---|---|---|---|---|---|
| Anthracene | 0.174 | 0,0 | 20.295 | 8.3E-09 | 1.4E-12 | 9.7E-07 | 0.1 | 0.4 |
| Atrazine | 0,0 | 0,0 | 0,0 | | | | 0.60 | 2 |
| Benzene | 0.008 | 505.713 | 0.078 | 3.7E-10 | 2.4E-05 | 3.7E-09 | 10 | 50 |
| Benzo(a)pyrene | 0,0 | 0.003 | 0.001 | 1.9E-13 | 1.39E-10 | 6.0E-11 | 0.05 | 0.1 |
| C10-13 chloroalkanes | 0,0 | 0,0 | 0,0 | | | | 0.40 | 1.40 |
| Cadmium | 0,0 | 0.029 | 0,0 | | 1.4E-09 | | 0.45 | 0.45 |
| Chlorpyrifos | 3.660 | 0,0 | 10.295 | 1.8E-07 | | 4.9E-07 | 0.03 | 0.10 |
| Dichloromethane (DCM) | 0,0 | 0,0 | 0,0 | | | | 20 | not used |
| Diethylhexylphthalate (DEHP) | 0,0 | 14.058 | 0,0 | | 6.7E-07 | | 1.30 | not used |
| Diuron | 0,0 | 0,0 | 0,0 | | | | 0.20 | 1.80 |
| Endosulfan (thiosulfan) | 0,0 | 0,0 | 0,0 | | | | 0.005 | 0.01 |
| Endrin | 0,0 | 0,0 | 0,0 | | | | 0.005 | not used |
| Hexachlorobenzene (HCB) | 0,0 | 0.00002 | 0,0 | | 1.1E-12 | | 0.01 | 0.05 |
| Hexachlorobutadiene (HCBD) | 0,0 | 0,0 | 0,0 | | | | 0.10 | 0.60 |
| Hexachlorocyclohexane (HCH) | 0,0 | 0,0 | 0,0 | | | | _ | 0.04 |
| Lead | 0,0 | 0,0 | 0,0 | | | | | 0.80 |
| Mercury | 0.018 | 8.007 | 0.051 | 8.7E-10 | 3.8E-07 | 3.7E-08 | 0.05 | 0.07 |
| Nickel | 0.003 | 4.583 | 0.007 | 1.4E-10 | 2.19E-07 | 3.3E-10 | _ | not used |
| Nitrate | 0.827 | 0,0 | 1.655 | 4.0E-08 | | 7.9E-08 | _ | _ |
| Nonylphenols (NPs) | 0.003 | 0,0 | 0.009 | 1.5E-10 | | 4.4E-10 | 0.30 | 2.00 |
| Pentabromobiphenylether (PBDE) | 0,0 | 0.165 | 0,0 | | 8.0E-09 | | _ | _ |
| Pentachlorobenzene (PeCB) | 0,0 | 0,0 | 0,0 | | | | 0.007 | not used |
| Tetraethyl lead (TEL) | 0,0 | 0,0 | 0,0 | | | | _ | _ |
| Tributyltin compounds | 0,0 | 0,0 | 0,0 | | | | 0.0002 | 0.0015 |
| Trichloroethylene (TCE) | 0,0 | 0,0 | 0,0 | | | | 10.00 | not used |

[2] Concentration
[3] standard values for fresh water in general case from ”Forurenende stoffer med EU-miljøkvalitetskrav for overfladevanda”
[4] standard values for fresh water in short-term quality case from ”Forurenende stoffer med EU-miljøkvalitetskrav for overfladevanda”

According to Table 5, benzene is significant chemicals contribute to stormwater pollution. Transportation activity and roads are the main source of this chemical. The second highest concentration is related to anthracene. This substance is released to the environment by combustion of car fuel and households heating. It is expected to do not have any “C10-13 chloroalkanes” in the DemFil, since there is not any metal or other manufacture industry in the area. Atrazine is zero in the catchment area, because it was banded to use as well as diuron. The endrin release to the environment via using the pesticide, insecticide, and rodenticide; however, its concentration is zero in the Table 5 due to not available release factor. Furthermore, the concentrations of lead, tetraethyl lead (TEL), and pentachlorobenzene (PeCB) are zero as the same reason as endrin. The concentration of tributyltin compounds are not considered because they mostly discharge into the environment by painting on the small boats and yachts, but the target of this study is finding the roads runoff quality. Also, Dichloromethane (DCM) is zero, since it is mostly spread into the air during collecting and treatment of wastes and processing of tea and coffee. Therefore, they are not relevant to stormwater quality in the DemFil area.

Additionally, the Table 5 contains the standard values of each substance. Indeed, there is not any criteria for stormwater quality; consequently the computed values are compared with “environmental quality standards for water bodies and requirements for the discharge of pollutants into rivers, lakes or the ocean”[5] [39]. The calculated values are compared with chapter 3 “pollutants with EU environmental quality standards for surface water”[6] of the mentioned legislation. There are two options for evaluating values in this legislation. One of them is general quality values, and the other one is short-term quality values. For comparing the results, the short-term values are used since the stormwater is not continuous event. As it can be evident from the Table 5, there is no exceeding from standard values in the legislation.

In order to find the most significant source of pollutants, the substances were sorted by the emission source type in the SCF database. The result is briefly shown in the Table 6. In the SCF, the pollutants from the construction process or erosion of metals in the urban area are classified as construction yard pollutants. Moreover, the pollutants from washing and dry-cleaning also carwash activities are categorized as facility sources. The diffuse sources covere the pollutants from gasoline evaporation or other mobile sources.

This table revealed that roads and supply activities (electricity- gas and water) are the principal sources of pollutants in the DemFil region. These sources include combustion of fuel, erosion of tires and asphalt, and distribution of electricity and gasoline.

[5] Bekendtgørelse om miljøkvalitetskrav for vandområder og krav til udledning af forurenende stoffer til vandløb, søer eller havet1)
[6] Forurenende stoffer med EU-miljøkvalitetskrav for overfladevanda (a)

**Table 6, emission source type**

| Emission source type | Concentration low (µg/L) | Concentration (µg/L) | Concentration Hi (µg/L) |
|---|---|---|---|
| **Total agriculture** | 2.08E-07 | 2.49E-11 | 5.53E-07 |
| **total building** | | 8.13E-09 | |
| **Total construction yard** | 1.72E-12 | | 4.59E-12 |
| **Total diffuse sources** | | 6.83E-07 | |
| **Total electricity, gas and water supply** | | 1.57E-06 | |
| **Total facility** | | 2.19E-07 | |
| **Total household** | 1.48E-08 | 3.92E-07 | 9.89E-07 |
| **Total road** | 1.75E-09 | 2.26E-05 | 4.22E-08 |

Table 6 just reveals that which sources release more pollutants into the roads runoff in DemFil area. It does not mean that these sources are released more toxic pollutants and they are more harmful for environment. For instance according to Environmental Quality Standard (EQS), the allowable concentration of Tributyltin compounds in water is only 0.0015(µg/l), on the other hand, the allowable concentration of Nonylphenols is 2 (µg/l). Therefore, Tributyltin is more toxic than Nonylphenols in the environment. Consequently controlling the sources of releasing Tributyltin is more necessary than controlling the sources of Nonylphenols.

# 5. Discussion

As mentioned previously, this thesis has investigated the hydraulic situation of the DemFil sewerage system located in the Bagsværd area. The roads runoff was disconnected from the combined sewerage system and it is supposed to be discharged into the nearby lake. It will result in some changes in the hydraulic status of the downstream sewerage system. Additionally, discharging rods runoff into the lake leads to releasing pollutants via stormwater into the nearby lake. Therefore, this chapter is divided into a hydraulic and a water quality part as in the previous chapters.

## 5.1. Hydraulic Analyses

The main purpose of this part of the study was assessing the different situation of the sewerage system in the DemFil area. Furthermore, some suggestions are made to improve the function of the sewerage system in this catchment area. It should be note that, the catchments IDs are displayed in Figure 17. Moreover, all these situations are assessed based on CDS with 10 years return period and safety factor of 1.43 since the combined sewerage systems in Denmark are designed for 10 years return period.

### 5.1.1. Assessing the Previous and Current Situation

According to result from 4.1.1.1(the previous situation) and 4.1.1.2 (the current situation), the number of flooded manholes are remarkably decreased after separating the roads runoff from the initial sewerage system in the DemFil area (CDS, T=10_SF=1.43). Figure 22 and Figure 23 illustrates the flooded nodes in these two situations respectively. Disconnecting the roads runoff in the area causes the less connected area into the combined sewer system in the DemFil area. Therefor the flow decreases in the main sewerage system and the emerging water on to the urban area reduced (CDS, T=10_SF=1.43). In addition, surcharging in the houses basement decreased in the DemFil area. The model for previous situation was not available to compare the impervious areas of catchments and water level in the pipes.

### 5.1.2. Assessing the Current and Future Situation

Comparing the results from simulation of the situation before and after discharging stormwater into the lake (see Figure 30), reveals that the numbers of flooded nodes are remained unchanged in the downstream area (CDS, T=10_SF=1.43). It may happen because the disconnected area is small compared with the total catchments connected to the downstream combined system. Figure 53 displays the pipes in the selected polygon which are connecting to the basin BRXOVF1 in downstream. The DemFil area is very smaller than the polygon area.

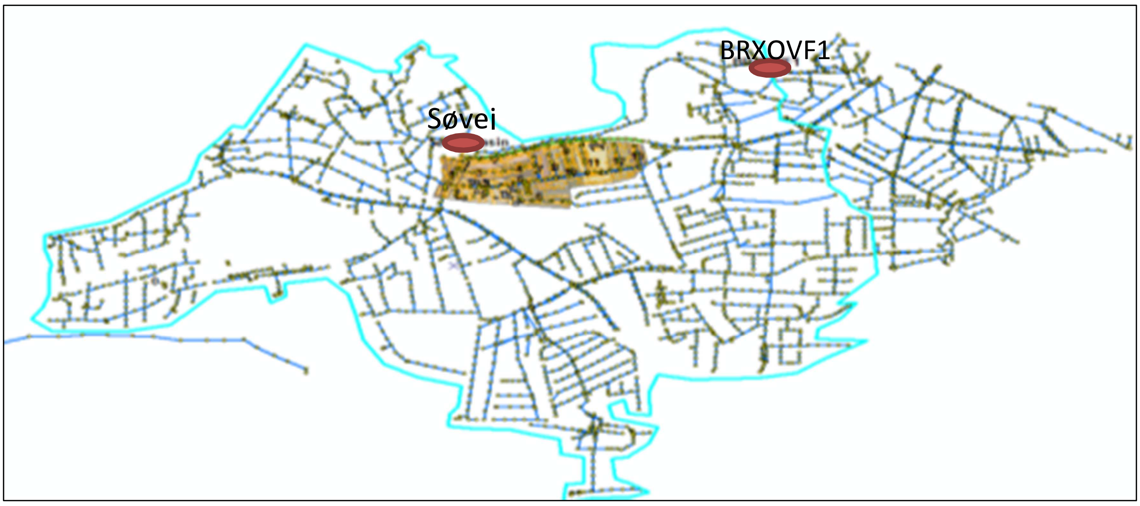


**Figure 53, catchments area which connect to BRXOVF1 in downstream**

The total area of this polygon is approximately 947 ha from GIS model and its imperiousness is assumed the same as mean imperviousness of the DemFil area (26%). Therefore, the total impervious area is 247 ha and the separated catchments area (separated roads area) is approximately 2 ha (See Appendix F).

As evident from Table 7, only o.8% of the total impervious area is separated and the remaining 99.2% still contributes to generate stormwater in the combined system.

**Table 7, proportion of separated stormwater connected to BRXOVF1**

| Region Basin | Total Area (ha) | %Imp | Total Imp Area (ha) | Not Separated (ha) | Separated Area in DemFil (ha) | Ratio |
|---|---|---|---|---|---|---|
| **BRXOVF1** | 947 | 26% | 247 | 245 | 2.01 | 0.8% |

The variation of maximum water level has been studied in some of the downstream pipes, before and after discharging stormwater into the lake. The maximum water level, from simulation with CDS rain data (T=10_Sf=1.43), dropped after discharging stormwater into the lake (see Figure 32 and Figure 33).  Less reduction of water level can be seen in further pipes from separation node (Figure 34). This is reasonable since the further pipes collect the more catchments runoff than earlier pipes. Therefore, removing roads runoff in a small area such the DemFil does not have much influence on water levels in further pipes.

Moreover, discharging stormwater into the lake leads to overflow reduction from Søvej basin in the downstream (CDS, T=10, SF=1.43). The location of Søvej basin was represented in Figure 53. Annual overflow from the basins can be determined by performing long term simulation (LTS). Although LTS simulation has not been done, the regular simulation (CDS, T=10_SF=1.43) reveals that the overflow from Søvej basin was decreased after discharging stormwater into the lake (see Figure 35).

### 5.1.3. Potential Improvements

Although large numbers of flooded nodes were removed after disconnecting the roads runoff in the DemFil area, there are still a few flooded nodes even in 5 years return period rainfall event. Therefore, suggestions have been made to improve the sewerage system function in the DemFil area.

The first alternative is disconnecting the additional roads runoff which have not yet disconnected from the combined sewer system in the area. As it can be seen in the Figure 54, 17% of the total impervious area is related to the roads catchments which have not yet been separated from the sewer system. Moreover, 19% of total impervious area is related to the separated roads in the DemFil area.

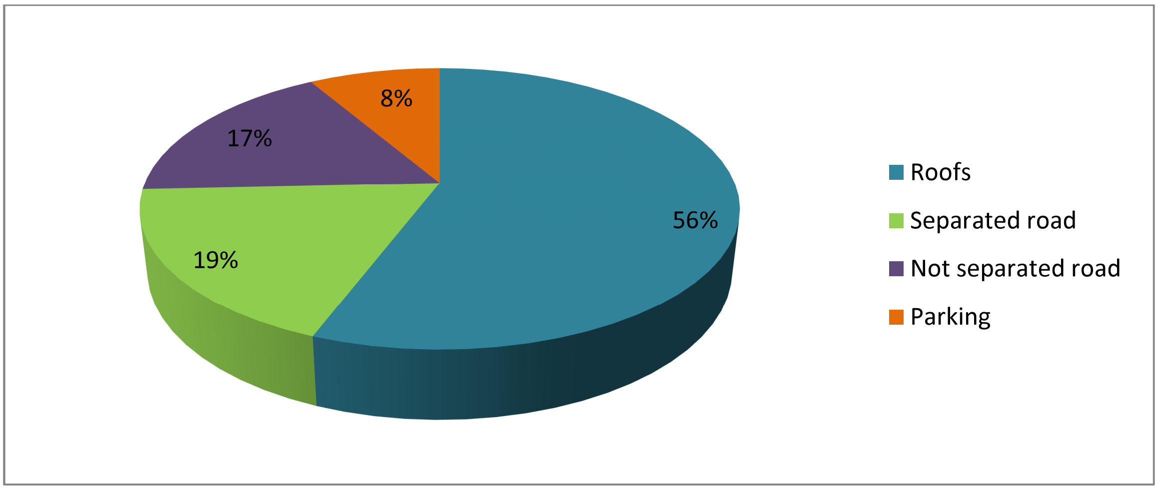


**Figure 54, impervious areas in the DemFil region**

After removing additional roads runoff in this situation, the combined system will have less connected impervious area. Consequently the results from simulation (CDS, T=10_SF=1.43) demonstrated that the flooded nodes relatively decreased in the DemFil area. On the other hand, this measure was not effective enough to reduce the number of flooded nodes in the catchment A, C, and horizontal pipes in Aldershvilevej Street (See Figure 36 and Figure 37). Furthermore, the stormwater volume was checked in the last two nodes of the sewer system in the DemFil (BSE0100 and BSE2000). These nodes are shown in Figure 37. The results revealed that the volume of stormwater in the sewer system decreased by 733 $m^3$ after disconnecting the additional roads runoff (CDS, T=10_SF=1.43).

The second possibility is disconnecting the roofs runoff from the main sewer system. As indicated in Figure 54, the roofs area is 56% of the total impervious area in the DemFil region. Therefore, it was expected to have considerable flood reduction in the area. The results of simulation (CDS, T=10_SF=1.43) are in well agreement with this prediction (Figure 40). Even in this situation, some flooding in the catchment A can be observed. Moreover, the results from simulation (CDS, T=10_SF=1.43) indicates that 2339$m^3$ of stormwater reduced from the main sewer system after disconnecting the roofs runoff (see Figure 41 and Figure 42).

The third option is making a new basin in the catchment F. Doing this measure in the model with CDS rain data (T=10_SF=1.43) resulted in reducing the flooded nodes in catchment F; however, the risk of flooding is still high in this area (Figure 47). The number of flooded nodes in the other catchments was unchanged after doing this measure. Consequently, this measure should be examined by combination with another method to decrease the risk of flooding in the entire DemFil region.

The last but not the least possibility to reduce the flooding risk, is enlarging the pipe size in the DemFil area. The most problematic pipes are related to the catchments A, C, and F since the manholes in these catchments are flooded even in simulation with 5 years return period. Since doing other measures could not help to reduce flooding in these catchments, it seems that enlarging pipes are inevitable. In order to prevent flooding in these catchments, some pipes were enlarged even 3 times more than the initial size in the model (CDS, T=10_SF=1.43). Upsizing the pipes were done based on trial and error until no flood was observed in the area. Moreover, the combination of this method with one other method could possibly lead to less pipe enlargement in the DemFil region.

### 5.1.4. Multi Criteria Analysis (MCA)

Each of these alternatives has their own pros and cons. Therefore, a brief assessment is done here to find which of these measures is more suitable for the DemFil region. This evaluation is made with simplified MCA (Multi Criteria Analysis) method. It should be mentioned that, all these measures simulation are done with CDS rain data with 10 years return period and safety factor 1.43.

As listed in Table 8, different parameters are considered to evaluate the alternative measures. Each of them is valued by plus and minus symbols.

**Table 8, Simplified Multi Criteria Analysis (MCA) for alternative methods**

| Alternative | | Reduced Flood | Reducing SW | Construction Cost | Treatment Cost | Environment | Social Independent | Total Value |
|---|---|---|---|---|---|---|---|---|
| 1- Additional roads | Separate Pipes | ++ | + | – – | – | +++ | + | ++++ |
| | Infiltration | | | – – | + | ++++ | + | ++++<br>+++ |
| 2- Roofs | Separate Pipes | ++++ | ++++ | – – | – | ++++ | – | ++++<br>++++ |
| | Infiltration | | | – – – – – –<br>– – – – | + | +++++ | – | +++ |
| 3- Basin | | + | – | – | – – – | + | + | – – |
| 4- Enlarging | | +++++ | – | – – – – – | – – – – | ++ | + | – – |

The first item of this table is related to reduce number of flooded node. For every 10 reduced flooded nodes after doing each measure, one plus is added for that measure. After doing these alternative measures the numbers of flooded nodes reduced to 13, 38, 7, and 42 respectively (CDS, T=10, SF=1.43).

The second column of Table 8 is reducing the stormwater load from the combined sewerage system in the area. After disconnecting the additional roads runoff from the combined sewerage system, the volume of total flow was reduced by $733m^3$. Furthermore, disconnecting the roofs runoff caused $2339m^3$ of total flow in the combined system was decreased. The total flow is combination of stormwater and wastewater, but in these two cases the wastewater flow does not change. So the change in the total flow equals the flow of stormwater. These measures lead to fewer overflows from downstream basin and less volume of wastewater in the treatment plant. Therefore, it can be considered as one of the evaluation parameters. In Table 8, each plus represents $500m^3$ reductions in the volume of stormwater. Making basin and enlarging the pipes may not contribute to reduction of stormwater volume in the combined sewerage system in the area.

As far as construction cost is concerned, the cost of each alternative (separating the roads and roofs runoff, and upsizing the pipes) is calculated based on the length of required pipes, and the corresponding cost from Figure 55. Since the range of dimension of separated pipes in the DemFil sewerage system is between 0.3m to 0.6m, the average construction cost for collecting the roads and roofs runoff is considered to be 4500DKK/m. It is also assumed that, the existing separate pipes have enough capacity to collect the roofs runoff in separated area. Therefore, the length of required pipes for disconnecting the roofs is equal to the length of the demanded pipes for collecting additional roads runoff in the area. According to GIS model the length of required pipes for collecting the additional roads and roofs is 1370m. Therefore, the total cost of construction the separate pipes for additional roads and roofs runoff are 6 million DKK for each method (Appendix G). As illustrated by Figure 49, the diameters of enlarged pipes are typically between 0.5m and 1m and a few of them are 1.5m. Therefore, the average construction cost is considered 8000 DKK/m from Figure 55. In this alternative almost 1500 m of pipes are upsized. As a result the enlarging pipes cost 12 million DKK.

According to the Nordvand Co. the construction cost for a closed basin is approximately 5000-6000 DKK/$m^3$. Therefore, making basin in catchment F cost approximately 1.5 million DKK (Appendix G).

The infiltration cost for each square meter is considered as 250 DKK according to Matthiesen et al thesis report [40]. In this part for estimating the infiltration cost, rough approximation is made due to two main reasons; lack of the information about the soil, and existence of various types of infiltration trench. The cost of applying infiltration unit for removing the additional roads runoff in the area is approximately 4million DKK. Moreover, infiltration cost depends on the roofs area and the collection pipe system needed to transport water from rooftops to the infiltration unit. Consequently the total cost of infiltration roofs runoff is about 24million DKK.

The details of cost calculation are available in Appendix G. Each minus sign shows 2.5 million DKK.

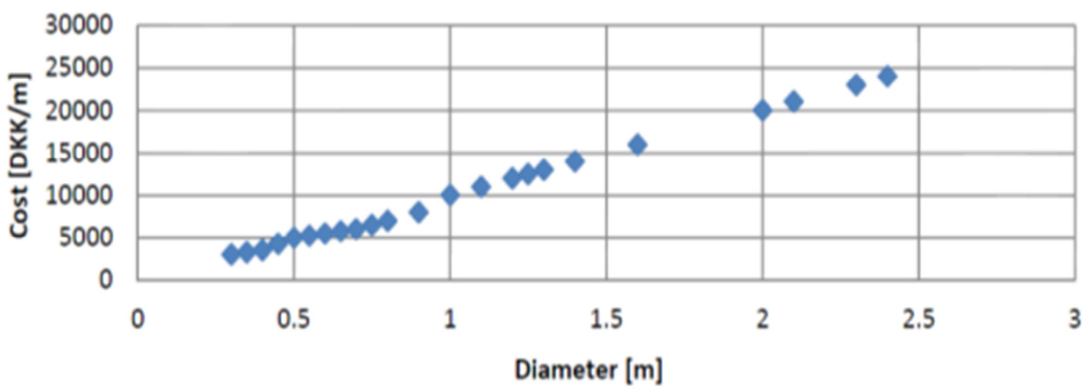


**Figure 55, relation between the cost and pipe size [41]**

The next column of MCA table is the treatment cost. The alternatives are evaluated qualitatively, since there is no relevant data according to the author knowledge. Enlarging the pipes size probably result in the highest treatment cost due to a larger amount of influent passage through the treatment plant than other alternatives. Moreover, in this method more chemicals are demanded to purify the influent of treatment plant. The second expensive alternative for treatment is making basin. The stored wastewater in the basin may contain fewer pollutants because some pollutants are settled in the basin; however, the stored water in the basin is very small in comparison to the total influent of the treatment plant. The separated systems for roads and roofs runoff require some treatment processes before releasing into the receiver water. It is expected to have less treatment process and cost, due to lower concentration of pollutants in roads and roofs runoff than the wastewater. As far as infiltration is concerned, the water is passing through the different layers of the infiltration device as well as soil; consequently many pollutants get stuck in these layers before reaching a groundwater layer. Therefore, this technique probably does not need too much treatment cost.

The next item, in the Table 8, is environmental effects of these alternatives. The alternatives are compared with each other based on fewer pollutants emission to the environment. Therefore, the alternatives receive plus for less risk of emission pollutants in the environment. The pollutants can be released to the environment from the sewerage system by flooding, overflow from basin, leakage from pipes, and problems in the treatment process. The best alternative is infiltration roofs runoff because it reduces the risk of flooding and overflowing from the basin. In addition, roofs runoff may contain fewer pollutants than other surface runoff. On the contrary, making a basin in the area might have less efficiency than other methods in the environmental issues, since it could not reduce the risk of flooding and overflow from the downstream basin.

The last item is social effects of each measure. One of the advantages of separating the roads runoff instead of roofs runoff is that the municipality can decide and apply this method independent from house owners contribution. Furthermore, for separating the roofs runoff municipality as a decision maker should convince house owner to contribute to implement this measure and it may take a lot of time. Moreover, using the infiltration method for collecting the roofs runoff may cause a problem for foundation and walls of houses because of high dampness in the soil.

According to this simplified evaluation, disconnecting the roofs runoff to a separate system is recommended for improving the sewerage system in DemFil area. The next appropriate alternative measure is infiltrating the roads runoff.

This evaluation was made based on a simplified Multi Criteria Analysis (MCA) and it can be a good start point for more investigation. The simplified MCA evaluation demonstrated that making separate system for collecting the roofs runoff is the best option for improving the DemFil sewerage system, but choosing the best measure depends on the priorities of decision makers in this area. For instance environmental issues can be more important than the cost of measure for one decision maker or vice versa.  Moreover considering more items helps decision makers to have better overview about the advantage and disadvantages of each alternative measure.

Additionally, the combination of these methods were not simulated and evaluated in this study, due to time limitation. Therefore, further investigations on combination of these methods seem desirable to find optimum solution.

## 5.2. Quality Analysis

Pollutants in the DemFil roads runoff have been estimated via Source Classification Framework (SCF). The advantage of SCF is that, all the potential sources of pollutants for a specified substance or urban structure are revealed by the SCF. As a result, finding a better solution for minimizing the released pollutants is more feasible [35].

The result of database calculation demonstrates that the pollutants load in the DemFil area is not exceeding the Danish standard values for water bodies (environmental quality standards for water bodies and requirements for the discharge of pollutants into rivers, lakes or the ocean)[7].

In addition, benzene has the highest concentration in the DemFil roads runoff. The main source of this pollutant is transportation in the area. Moreover, sorting the pollutants based on the emission sources demonstrates that road and supply activities have a significant contribution to released pollutants in the DemFil area.

There are many uncertainties in this method, due to lack of data about consumption habits of inhabitants (wood, paint, fertilize, etc.). Moreover, there is not available data about the release factor for many pollution resources. In addition, some of the release factors are gained from Stockholm or Germany. Despite of making reliable assumption during this study, more investigation and experiments are recommended to find the precise concentration in the DemFil region.

[7] Bekendtgørelse om miljøkvalitetskrav for vandområder og krav til udledning af forurenende stoffer til vandløb, søer eller havet1)

# 6. Conclusion

## 6.1. Hydraulic Analysis

Extreme rainfall is one of the climate change outcomes which affect the sewerage system function. In a recent incident, the heavy rain caused flooding in Copenhagen in July 2011. Therefore, more research is highly recommended to find appropriate adaptation measures in order to decrease the risk of flooding in the urban areas. Recently, Gladsaxe municipality decided to disconnect roads runoff from parts of the combined sewerage system in the DemFil area, in northern Copenhagen, to solve the flooding problem. This study attempts to investigate the efficiency of the applied solution and other alternative measures via modeling.

In the first part of this thesis, the hydraulic conditions of the DemFil sewerage system were studied in the different situations. In the current situation, the roads runoff was separated from the combined sewerage system in the area. This separated water was not allowed to be discharged into the nearby lake; therefore, it links to the combined system again in a downstream manhole. According to the results of this study, disconnection of roads runoff significantly decreases flooding in the area in comparison with the past situation with CDS rain data (T=10, SF=1.43). There are still some flooded nodes in the DemFil area.

In order to make a real separate stormwater system in the DemFil area, the disconnected water should be discharged into the lake after passing through a disc filter. This action dropped water level in the downstream manholes which are close to the disconnection node (CDS, T=10, SF=1.43). Conversely, discharging water into the lake could not be efficient to decrease the number of flooded nodes in the downstream sewerage system (CDS, T=10, SF=1.43). Besides, discharging treated water into the lake from disc filter, result in fewer untreated overflows from the downstream basin.

Four measures were investigated in this thesis in order to improve the sewer system function and diminish the flooding in the DemFil region. All these potential measures were simulated with CDS rain data with 10 years return period. In the first alternative, disconnection of additional roads runoff was examined via the model. The number of flooded nodes was moderately reduced, but this measure was not efficient to decrease the flooding in all parts of the catchments. The second alternative was disconnecting the roofs runoff from the sewerage system. Since the roofs area has a large proportion of the total impervious area connected to the combined system in the DemFil region, the flooding was significantly reduced by applying this measure. The third one was making a basin in one of the catchments. It results in fewer floods from neighboring manholes, but the water level in the manholes, and the number of flooded nodes was unchanged in further catchments. The last alternative was enlarging the pipes. Enlarging the pipe size has been done based on trial and error until no flooding was detected in the region. In addition, the combination of these measures in the area can be investigated in the future work to find the most efficient and optimum solution for the DemFil sewerage system.

Each of these measures has their own pros and cons. According to the results of simplified Multi Criteria Analysis (MCA), disconnecting roofs runoff to separate system is the best solution for improving the DemFil sewerage system. Disconnecting additional roads runoff via infiltration and separate system are good solution after disconnecting the roofs. Considering the simplicity of the MCA and its uncertainties, further investigations will be desirable; however this evaluation would be helpful for decision makers to have brief overview of advantage and disadvantage of potential measures.

Based on all above mentioned, disconnecting roads runoff in this small area cannot solve all the flooding problem in the whole area, but it can be a good start point for disconnecting more areas.

## 6.2. Quality Analysis

In the separate sewerage system, the stormwater is discharged into the water courses. In the DemFil region, the roads runoff has been collected by separated pipes and they should be discharged into the nearby lake. It may cause releasing pollutants into the lake. Therefore, the disc filter would be the appropriate technique to decontaminate the separated water before discharging into the lake. In this thesis the pollutants concentration of disconnected roads runoff are determined via Source Classification Framework (SCF). Although SCF has been developed during these years, more researches are needed in order to cover more pollutants and sources. Indeed, new technology and materials may bring new pollutants which should be added to the SCF database. Furthermore, the release factor for many substances is yet unknown.

The SCF calculation results indicate that, the highest concentration is related to benzene which it still is not exceeding the standard value. Moreover, the road (fuel combustion, erosion of tires and asphalt), and supply activity (gas, electricity distribution) are the major contributors to roads runoff pollution in the DemFil area.

In this study, there was much uncertainty about local data. Moreover release factor of many pollutants still were not defined. Although, much effort has been made to make reliable assumption, accuracy of the SCF result should be assured by doing the experimental tests.

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# 8. Appendices I:

## Appendix A (Mean Annual Rain Data)

These values are taken from www.dmi. dk ; [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52]

**Table 9, mean annual rainfall from 30222 Søborg station**

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | MIN | MAX | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jan** | 42 | 40 | 84 | 45 | 75 | 50 | 53 | 117 | 61 | 28 | 14 | 14 | 117 | 55 |
| **Feb** | 37 | 31 | 115 | 7 | 36 | 33 | 25 | | 25 | 44 | 33 | 7 | 115 | 39 |
| **Mar** | 78 | 23 | 31 | 10 | 51 | 32 | 33 | 28 | 66 | 44 | 47 | 10 | 78 | 40 |
| **Apr** | 33 | 52 | 35 | 52 | 31 | 12 | 55 | 18 | 39 | 15 | 34 | 12 | 55 | 34 |
| **Maj** | 28 | 35 | 68 | 96 | 28 | 65 | 66 | 89 | 61 | 69 | 60 | 28 | 96 | 60 |
| **Jun** | 76 | 56 | 78 | 46 | 89 | 46 | 9 | 149 | 45 | 132 | 62 | 9 | 149 | 72 |
| **Jul** | 38 | 26 | 104 | 69 | 118 | 91 | 33 | 207 | 32 | 57 | 195 | 26 | 207 | 88 |
| **Aug** | 50 | 108 | 9 | 52 | 65 | 45 | 182 | 66 | 144 | 45 | 34 | 9 | 182 | 73 |
| **Sep** | 99 | 116 | 17 | 34 | 42 | 23 | 42 | 68 | 24 | 29 | 51 | 17 | 116 | 50 |
| **Okt** | 68 | 41 | 123 | 46 | 31 | 58 | 84 | 42 | 75 | 80 | 65 | 31 | 123 | 65 |
| **Nov** | 60 | 41 | 75 | 50 | 41 | 42 | 86 | 38 | 56 | 98 | 96 | 38 | 98 | 62 |
| **Dec** | 48 | 54 | 38 | 68 | 71 | 55 | 80 | 48 | 71 | 52 | 24 | 24 | 80 | 55 |
| | **657** | **623** | **777** | **575** | **678** | **552** | **748** | **870** | **699** | **693** | **715** | **552** | **870** | **690** |

## Appendix B (Assumptions in SCF)

Assumptions for calculation pollutants load in SCF database are made as follows:

- Average consumption fuel per 100 km= 6 liter
- Average consumption fuel per 1 km= 0.06 liter
- Population of smoking person= 30% people
- Number of cigarette per day per person= 6 cigarette
- Density of asphalt= 1700 kg/$m^3$ (reference)
- Thickness of asphalt= 0.2meter
- Motor vehicles, under sealing paste per people= 10% inhabitants
- Floor and wall covering (floor and wall carpets)= 10% inhabitants
- Building installation, coated metal sheets= 10% inhabitants
- Tubes and profiles used for construction= 5% inhabitants
- Stainless steels used for architectural application and in building construction= 0.5% area
- Stainless steel and cast iron used in garden furniture and other outdoor applications=0.5% area
- Painting cover house= 10% inhabitants
- Total number of house which are relate to separate system in the DemFil area (from ArcGIS)= 220 house
- Birch wood consuming as household fuel= 15% inhabitant
- Percentage of area which use fertilizer for gardening= 10% area
- Daily using coin= 200 number
- Percentage of releasing hand wash ( polluted by coin)= 10%
- Wood consumption for stove=9000 Kg/year [53]
- People who use wood stove= 10% inhabitants
- Garden area=5516.2*3/10000=1.65 ha
- Construction activity for zinc= 5% inhabitants
- Carwash in the urban area not in the carwash place= 0.5% light cars
- Number of personal cars= 500 car
- Number of cars in Stockholm(each 3 person has 1 car)=260000
- Agriculture land in the world= 12.2 billion acres= 4.94E+09ha [54]
- World population in the world in 1984= 5E+09 [55]
- current world population= 7E+09 [55]

# Appendix C (SCF calculated database)

**Table 10, possible emission into the roads runoff in the DemFil area (SCF database)**

| ID_ES | Substance | NOSEP_code_and _description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2522 | Anthracene | 201 - Road transport | Release to the air due to combustion processes related to land based road transport (cars, buses, trucks) | roads | A 100 | 5.2_28 | µg/km | 3.E+06 | 0.0157_0.844 | 7.5E-10_4.4E-09 |
| 2536 | Anthracene | 101.07 - Other equipments (stoves, fireplaces, cooking,...) | Emission from fuel combustion for household heating (e.g. coal, oil and wood) | House | A 100 | 0.8_102 | mg anthracene/ kg birch wood combusted | 2.E+05 | 0.1584_20.196 | 7.58E-9_9.66E-07 |
| 2400 | Anthracene | 105.16.31 - Road paving with asphalt | Emissions from asphalt pavement | roads | W | 1.78 | µg/kg | 8.E+06 | 0.0145 | 6.95E-10 |
| 2389 | Anthracene | 113.01 - Household consumption and similar processes | Emissions from cigarette smoke | House | A 100 | 34 ± 8 | ng per cigarette | 8.E+02 | 0.00003 | 1.27E-12 |
| | Total Anthracene | | | | | | | | 0.01453 | 1.27E-12 |
| | Total Atrazine | | | | | | | | 0.0000 | 0.00E+00 |
| 1961 | Benzene | 201 - Road transport | Transport - road of person cars | Roads | A 100 | 110 | mg/km | 3.E+09 | 281.9930 | 1.35E-05 |
| 1968 | Benzene | 113.01 - Household consumption and similar processes | Smoking e.g. cigarettes | House | A 100 | 10_100 | µg/cigarette | 8.E+05 | 0.0078_0.0782 | 3.74E-10_3.74E-9 |
| 2000 | Benzene | 201 - Road transport | Use of gasoline engines - road transort | Roads | A 100 | 0.80 | Tg/yr | 2.E+11 | 190.4000 | 9.11E-06 |
| 2002 | Benzene | 201.06 - Gasoline evaporation from vehicles | Evaporation from motor vehicles | diffuse sources | A 100 | 0.06 | Tg/yr | 2.E+11 | 14.2800 | 6.83E-07 |
| 2005 | Benzene | 106.05 - Gasoline distribution | Evaporation losses during refining and distribution of gasoline - gasoline distribution | electricity and gas and water supply | A 100 | 0.08 | Tg/yr | 2.E+11 | 19.0400 | 9.11E-07 |
| | Total Benzene | | | | | | | | 505.7130 | 2.42E-05 |
| 1587 | Benzo(a)pyrene | 201 - Road transport | Emissions from road transport (with catalist) | Roads | A 100 | 1.10 | 10E-6 g/km driving | 3.E+06 | 0.0028 | 1.36E-10 |
| 1579 | Benzo(a)pyrene | 113 - Households | emissions from cigarette smoke | House | A 100 | 80 | ng BaP/cigarette | 8.E+02 | 0.0001 | 2.99E-12 |

| ID_ES | Substance | NOSEP_code_and_description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total Benzo(a)pyrene | | | | | | | | 0.0029 | 1.39E-10 |
| | Total chloroalkanes | | | | | | | | 0.0000 | 0.00E+00 |
| 1387 | Cadmium | 111.02.04 - Washing and degreasing | Emissions from transport, storage and transportation; car washing and degreasing | House | WI 100 | 0.01 | g/inhabitant/yr | 1.E+09 | 0.0119 | 5.69E-10 |
| 1405 | Cadmium | 110.01.04 - Market gardening | Release during growing of crops; market gardening; horticulture; Use of fertilizers in market gardening. Cultures with fertilizers, leaching erosion spills, direct drainage discharges | Agriculture | U 100 | 30 | g/km2 garden | 2.E+04 | 0.0005 | 2.38E-11 |
| 1476 | Cadmium | | Pollutant in Zn. Emission during use of Zn in construction material; Other activity; corrosion | House | W 100 | 0.000013_0.01 | g/inhabitant/yr | 6.E+07 | 0.0_0.0008 | 3.7E-14_3.7E-11 |
| 1482 | Cadmium | | Activities of housholds, release during use of artist paints | House | WI 100 | 4 | kg/yr | 6.E+06 | 0.0061 | 2.92E-10 |
| 1492 | Cadmium | 113.02 - Gardening | Release during use in houshold activities; Use of fertilizers in houshold gardens; via leaching, erosion, spills, direct drainage discharges. | House | U 100 | 30 | g/km2 garden | 2.E-03 | 0.0001 | 3.45E-12 |
| 1498 | Cadmium | 201 - Road transport | Emissions from road transport, storage and transportation; motor vehicles - break linings and tyres, fuel and asphalt; passenger cars, trucks and buses | roads | A 100 | 7 | kg/yr | 1.E+07 | 0.0107 | 5.11E-10 |
| | Total Cadmium | | | | | | | | 0.0293 | 1.40E-09 |

| ID_ES | Substance | NOSEP_code_and_description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2063 | chlorpyrifos | 113.01 - Household consumption and similar processes | Control of household pest (ants, bees, roaches) | House | U 100 | 8_22.5 | g/L | 2.E+07 | 0.14_0.39 | 6.67E-09_1.88E-08 |
| 2065 | chlorpyrifos | 110.06.01 - Agriculture | Control of insects (locust, termites, cockroaches, mosquitos, beetles, flies, moths) | Agriculture | U 100 | 8_22.5 | g/L | 4.E+08 | 3.52_9.9 | 1.68E-07_4.74E_07 |
| | Total chlorpyrifos | | | | | | | | 3.66_10.3 | 1.75E-07_4.93E-07 |
| | Total Dichloromethane (DCM) | | | | | | | | 0.0000 | 0.00E+00 |
| 1400 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Transports. Release during use of motorvehicles, undersealing paste | Roads | U 25 | 0.132 | g/inhabitant/yr | 1.E+02 | 0.0039 | 1.88E-10 |
| 1400 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Transports. Release during use of motorvehicles, undersealing paste | Roads | W 75 | 0.132 | g/inhabitant/yr | 1.E+02 | 0.0118 | 5.64E-10 |
| 1478 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release during use of other building installation, coated metal sheets | House | U 50 | 0.249 | g/yr/inhabitant | 1.E+02 | 0.0148 | 7.09E-10 |
| 1478 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release during use of other building installation, coated metal sheets | House | W 50 | 0.249 | g/yr/inhabitant | 1.E+02 | 0.0148 | 7.09E-10 |
| 1479 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release from tubes and profiles used for construcion | building | W 50 | 0.075 | g/yr/inhabitant | 6.E+01 | 0.0022 | 1.07E-10 |
| 1479 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release from tubes and profiles used for construcion | building | U 50 | 0.075 | g/yr/inhabitant | 6.E+01 | 0.0022 | 1.07E-10 |
| 1490 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release during use of clothing and footware, shoes (soles), housholds | House | U 50 | 0.19 | g/yr/inhabitant | 1.E+03 | 0.1113 | 5.32E-09 |
| 1490 | diethylhexylphthalate (DEHP) | 107.05.09 - Other | Release during use of clothing and footware, shoes (soles), housholds | House | W 50 | 0.19 | g/yr/inhabitant | 1.E+03 | 0.1113 | 5.32E-09 |

| ID_ES | Substance | NOSEP_code_and_description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1739 | diethylhexylphthalate (DEHP) | 107.05.08 - Electrical equipment | Release during distribution of electricity, electrical cables outdoor in soil. | electricity and gas and water supply | U 100 | 0.01 | kg/yr/inhabitant | 1.E+03 | 13.3280 | 6.38E-07 |
| 1740 | diethylhexylphthalate (DEHP) | 107.05.08 - Electrical equipment | Release during distribution of electricity, electrical cables outdoor in air. | electricity and gas and water supply | A 100 | 300 | kg/yr | 2.E+06 | 0.4577 | 2.19E-08 |
| | Total diethylhexylphthalate (DEHP) | | | | | | | | 14.0580 | 6.73E-07 |
| | Total Diuron | | | | | | | | 0.0000 | 0.00E+00 |
| | Total Endrin | | | | | | | | 0.0000 | 0.00E+00 |
| 2113 | Hexachlorobenzene (HCB) | 110.06 - Use of pesticides and limestone | Use of the fungicide quintozene (as an impurity) | Agriculture | W 20 | 694 | kg/yr | 2.E+02 | 0.000005 | 2.23E-13 |
| 2113 | Hexachlorobenzene (HCB) | 110.06 - Use of pesticides and limestone | Use of the fungicide quintozene (as an impurity) | Agriculture | U 80 | 694 | kg/yr | 2.E+02 | 0.000019 | 8.90E-13 |
| | Total Hexachlorobenzene (HCB) | | | | | | | | 0.000023 | 1.11E-12 |
| | Total Lead | | | | | | | | 0.0000 | 0.00E+00 |
| 1585 | Mercury | 201 - Road transport | Emissions due to erosion of tiers | Roads | WD 100 | 4_240 | g mercury released per 1,000,000 km driving | 3.E+06 | 0.0121_ | 3.46E-09 |
| 1586 | Mercury | 201 - Road transport | Emissions due to erosion of roads | Roads | WD 100 | 2_17 | g mercury released per 1,000,000 km driving | 3.E+06 | 0.006_0.0513 | 2.89E-10_2.45E09 |
| 1705 | Mercury | 101.07 - Other equipments (stoves, fireplaces, cooking,...) | Emissions from wood burning stoves | House | A 100 | 0.04 | g mercury released per ton dry wood burned | 2.E+05 | 7.9200 | 3.79E-07 |
| 1719 | Mercury | 201 - Road transport | Emissions from transportation devices (land transport) running on distillated fuels (jet fuels, diesel fuels, heating oil, and kerosene) | Roads | A 100 | 0.0001 | g mercury released per liter fuel used | 7.E+07 | 0.0000 | 3.56E-13 |
| | Total Mercury | | | | | | | | 8.0075 | 8.66E-10_2.45E-09 |

| ID_ES | Substance | NOSEP_code_and_description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2286 | Nickel | 111.02.04 - Washing and degreasing | Release of Ni to wastewater from car washes | facilities | W 100 | 690 | kg/year (1999) | 7.E+06 | 4.5779 | 2.19E-07 |
| 2460 | Nickel | | Release to sweat on hands of people handling nickel alloy coins, followed by washing of hands | House | WI 100 | 2 | µg of Ni per coin released to artificial sweat after 2 mins contact with cupro-nickel coins | 7.E+03 | 0.00001 | 6.99E-13 |
| 2470 | Nickel | 112.09.12 - Leakage and spillage from equipment | Release of Ni due to runoff from stainless steels used for archictural application and in building construction | construction yard | W 100 | 0.3_0.8 | mg Ni/m2 stainless steel / year | 1.E+02 | 0.00004_0.0001 | 1.72E-12_4.59E-12 |
| 2270 | Nickel | 201 - Road transport | Emission from the use of a gasoline engine for road based transport (e.g. cars) | Roads | A 100 | 21_107 | ng km−1 | 3.E+06 | 0.0001_0.0003 | 2.58E-12_1.3E-11 |
| 2272 | Nickel | 201 - Road transport | Emission due to combustion processes associated with the use of a diesel engine for road transport (e.g. bus, car, truck) | Roads | A 100 | 3.2_2310 | ng km−1 | 5.E+05 | 0.000001_0.001 | 6.93E-14_5E-11 |
| 2280 | Nickel | 201.07 - Automobile tyre and brake wear | Release from runoff from Ni containing parts such as brake linings, tyres etc | Roads | U | 2 | kg / 1100 000 000 vehicle km | 3.E+06 | 0.0055 | 2.63E-10 |
| 2408 | Nickel | 105.16.31 - Road paving with asphalt | Release due to degradation/abrasion of asphalt | Roads | U | 1_2 | kg / 1100 000 000 vehicle km | 3.E+06 | 0.0027_0.0055 | 1.3E-10_2.63E-10 |
| | Total Nickel | | | | | | | | 0.0028_0.0069 | 1.36E-10_3.3E-10 |
| 2164 | Nitrate | 110.06.03 - Market gardening | Herbicide in horticulture | Agriculture | U 100 | 0.5_1 | kg/ha | 2.E+00 | 0.83_1.65 | 3.96E-08_7.92E-08 |
| | Total Nitrate | | | | | | | | 0.83_1.65 | 3.96E-08_7.92E-08 |

| ID_ES | Substance | NOSEP_code_and_description | ESS- Description | ES_Type | COMP | RF | RF Unit | Size | Load Release (kg/year) | Conc (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1572 | nonylphenols (NPs) | 107.01 - Paint application | Emission from application of paints, lacquer, engineering industry, glue, concrete, plastics, building material. | House | WI 5 | 0.03_0.08 | g/inhabitant/yr | 1.E+02 | 0.0002_0.0005 | 7.4E-12_2.22E-11 |
| 1572 | nonylphenols (NPs) | 107.01 - Paint application | Emission from application of paints, lacquer, engineering industry, glue, concrete, plastics, building material. | House | UI 95 | 0.03_0.08 | g/inhabitant/yr | 1.E+02 | 0.0029_0.0088 | 1.41E-10_4.22E-10 |
| | Total nonylphenols (NPs) | | | | | | | | 0.0031_0.0093 | 1.48E-10_4.44E-10 |
| 1397 | pentabromo biphenylether (PBDE) | 107.05.09 - Other | Losses during lifetime use of articles containing polyurethane foam (furniture/upholstery and automobile) where flame retardant PBDE is added, due to volatilisation. | building | A 100 | 0.14 | g/yr/inhabitant | 1.E+03 | 0.1654 | 7.91E-09 |
| | Total pentabromo biphenylether (PBDE) | | | | | | | | 0.1654 | 7.91E-09 |
| | Total tributyltin compounds | | | | | | | | 0.0000 | 0.00E+00 |
| | Total Trichloroethylene (TCE) | | | | | | | | 0.0000 | 0.00E+00 |

# Appendix D (Overflow from Søvej basin)

Overflow from Søvej basin before and after discharging stormwater into the lake.

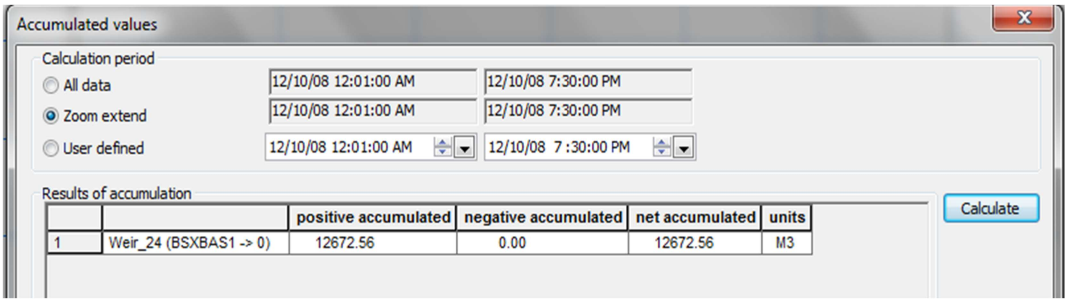


**Figure 56, volume of overflow before discharging water into lake**

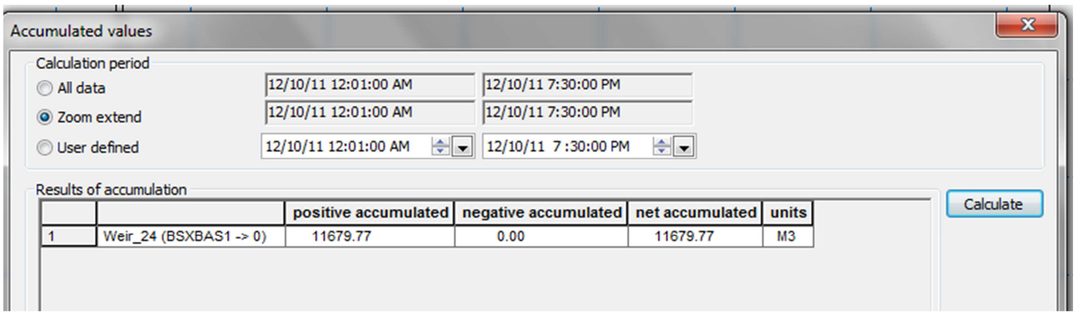


**Figure 57, volume of overflow after discharging water into lake**

# Appendix E (Accumulated volume)

Accumulated volume before and after doing improvement measure

### 1- Disconnecting additional roads runoff

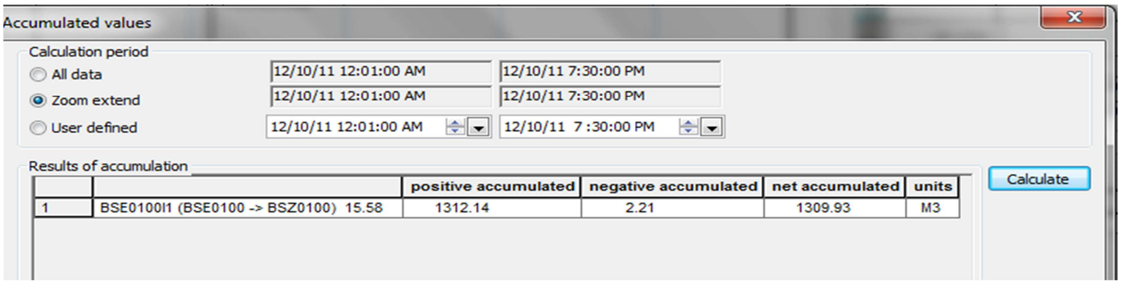


**Figure 58, before disconnecting additional roads runoff in node BSE0100**

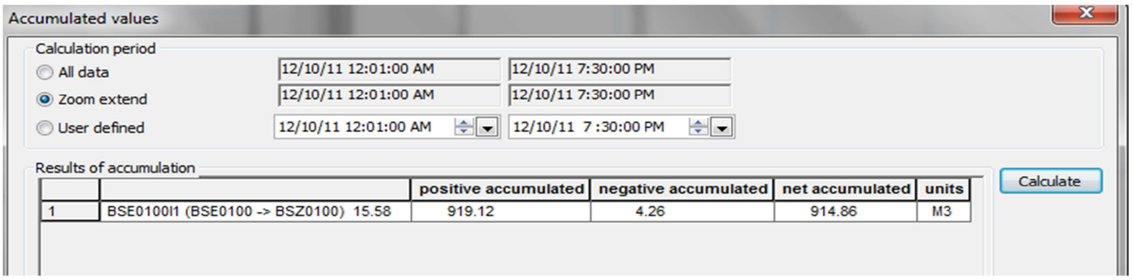


**Figure 59, after disconnecting additional roads runoff in BSE0100**

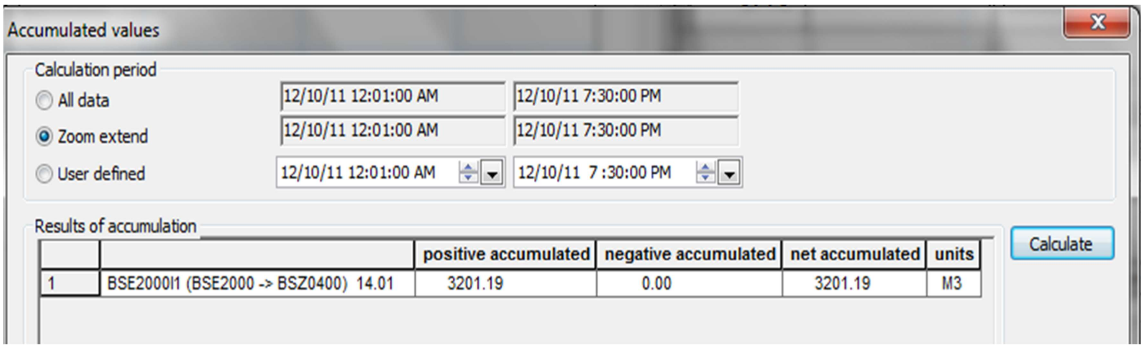


**Figure 60, before disconnecting additional roads runoff in BSE2000**

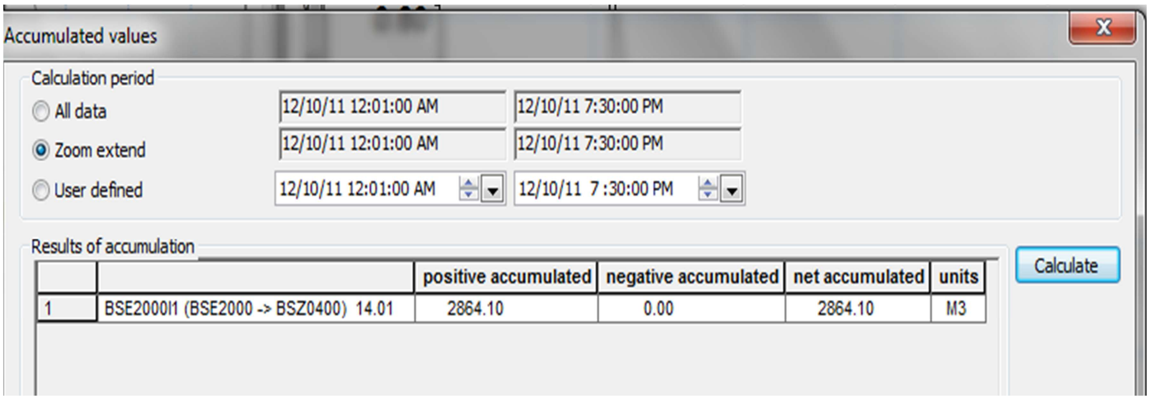


**Figure 61, after disconnecting additional roads runoff in BSE2000**

## 2- Disconnecting roofs runoff

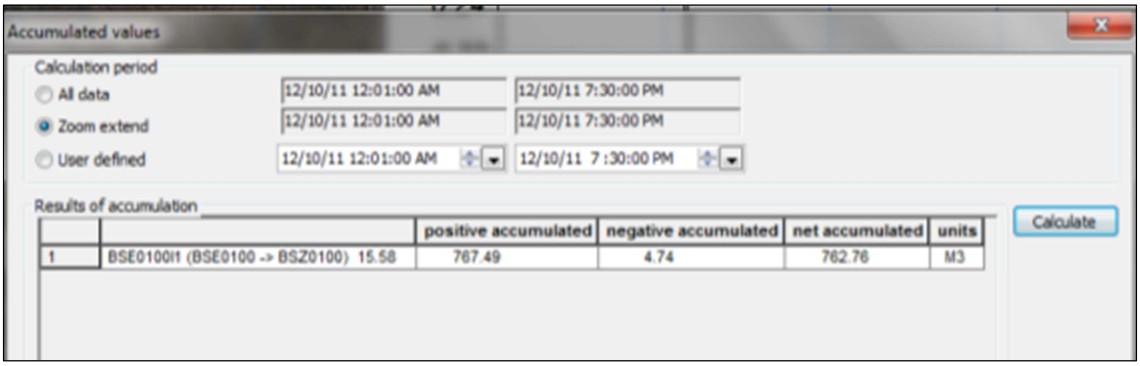


**Figure 62, after disconnecting roofs runoff in node BSE0100**

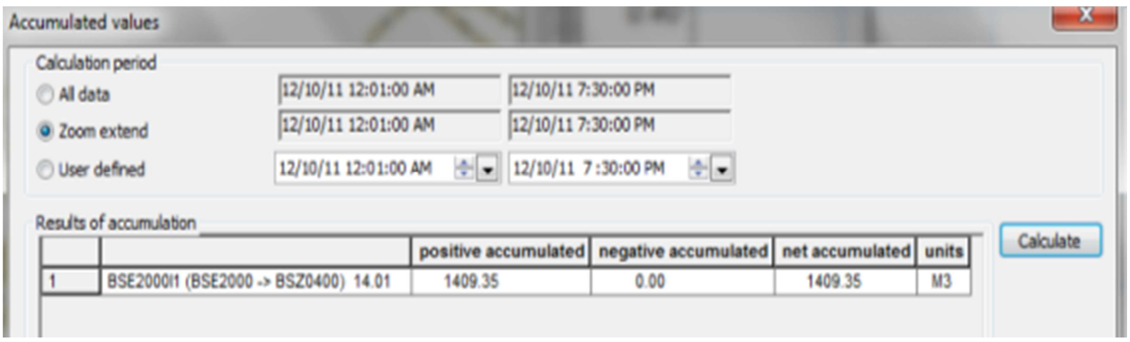


**Figure 63, after disconnecting roofs runoff in node BSE2000**

# Appendix F (Impervious area in DemFil)

**Table 11, impervious areas in DemFil catchment**

| Catch ID | impervious area in GIS (ha) | | | | Total Imp Area (ha) GIS | percentage of | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Roofs | Separated road | Not separated road | Parking | | Separated Roads | Not Separated Roads | Roofs | Parking |
| 1 | 0.73 | 0.00 | 0.92 | 0.05 | 1.70 | 0% | 54% | 43% | 3.1% |
| 2 | 0.27 | 0.00 | 0.00 | | 0.27 | 0% | 0% | 100% | 0.0% |
| 3 | 0.43 | 0.00 | 0.24 | | 0.67 | 0% | 35% | 65% | 0.0% |
| 4 | 0.24 | 0.00 | 0.16 | | 0.40 | 0% | 40% | 60% | 0.0% |
| 5 | 1.31 | 0.24 | 0.55 | 0.51 | 2.61 | 9% | 21% | 50% | 19.6% |
| 6 | 0.98 | 0.60 | 0.06 | 0.28 | 1.92 | 31% | 3% | 51% | 14.7% |
| 7 | 0.42 | 0.30 | 0.03 | | 0.75 | 40% | 4% | 55% | 0.0% |
| 8 | 0.48 | 0.25 | 0.00 | | 0.72 | 34% | 0% | 66% | 0.0% |
| 9 | 0.22 | 0.00 | 0.09 | | 0.31 | 0% | 28% | 72% | 0.0% |
| 10 | 0.29 | 0.10 | 0.11 | | 0.49 | 20% | 22% | 59% | 0.0% |
| 11 | 0.86 | 0.38 | 0.03 | 0.22 | 1.50 | 25% | 2% | 58% | 14.9% |
| 12 | 0.64 | 0.30 | 0.00 | 0.01 | 0.95 | 32% | 0% | 67% | 1.1% |
| 13 | 0.26 | 0.20 | 0.00 | | 0.46 | 44% | 0% | 56% | 0.0% |
| total | 7.12 | 2.36 | 2.20 | 1.08 | 12.76 | | | | |

# Appendix G (Alternatives costs)

**Table 12, construction cost of disconnecting runoff and pipes enlargement**

| pipe cost | | | |
|---|---|---|---|
| **Alternatives** | Pipes length (m) | Cost (dkk/M) | Total price (dkk) |
| **roads** | 1370 | 4500 | 6,165,000 |
| **roofs** | 1370 | 4500 | 6,165,000 |
| **enlarging** | 1500 | 8000 | 12,000,000 |

**Table 13, construction cost of basin**

| Basin cost | | | |
|---|---|---|---|
| **Basin** | Volume (m3) | Cost (dkk/m3) | Total Cost (dkk) |
| **1 basin** | 250 | 5500 | 1,375,000 |

**Table 14, infiltration cost**

| infiltration cost | | | |
|---|---|---|---|
| **Alternative** | area m2 | cost | total cost |
| **roads** | 16595.43 | 250 | 4,148,858 |
| **roofs** | 56933.61 | 250 | 14,233,402 |

**Table 15, additional cost for collecting the roofs runoff**

| Additional cost | house/property | cost per property/house | cost |
|---|---|---|---|
| **collection system for roofs** | 320 | 60,000 | 9,600,000 |

Total cost of disconnecting the roofs runoff: 9,600,000+ 14,233,402 = 23,833,402 DKK

# Appendix H (List of Tables)

List of tables in the report are as follows:

# Appendix I ( List of figures)

List of figures in the report are as follows:

# 9. Appendices II

DVD contains the following files:

## Appendix J (MU simulations)

MIKE URBAN Simulation

## Appendix K (SCF database)

Source Classification Framework database (initial data base and calculated database)

## Appendix L (Calculation files)

Calculation of areas and cost for hydraulic parts