VA-teknik Södra

Rapport Nr. 02
2014

Stormwater management in Malmö (Sweden) and Copenhagen (Denmark)

Salar Haghighatafshar

VA-teknik Södra

Foreword

In the light of IPCC reports as well as intensive research projects it is now clearer than ever that climate change initiated from global warming has already affected the life on earth and is expected to lead to more severe consequences in the future. Therefore it is necessary to take action plans not only to control the deteriorating trend but also to prepare to meet the present and future challenges with regards to climate change. All such actions and measures are regarded as *climate adaptation plans*. Scandinavian countries are amongst those which are expected to be exposed to intensive precipitation as well as sea level rising. Three strong storm events during the last 4 years have struck the Öresund region where the populated cities of Copenhagen/Denmark and Malmö/Sweden are located.

The extent of damages evaluated for the rain storm on 2nd of July 2011in Copenhagen, which corresponded to a once in a 1000 year rain event, counted up to about 1 billion Euros while critical infrastructures were damaged and the hospitals were just about evacuation. The storm Sven (5th-7th of December 2013) showed that the city of Malmö was prone to critical damages in case of severe rainfall events. During the storm the water level in the city canals of Malmö raised about 1.5 m the three year-old metro network of Malmö was only 15 cm (in water level) away from being flooded. The situation was even worse in other Swedish cities in the Öresund region. The amount of insurance compensation paid by Swedish insurance companies summed up to about 600 million Swedish kroner for the damages caused by the two consecutive storms in autumn 2013 which struck the Öresund region.

The severity of the situation concerning climate change in the Öresund region caused us to take a closer look into the current status of measures with focus on the measures and projects for management of storm water in two populated cities of the region, i.e. Copenhagen and Malmö. This study, financially supported by *Sweden Water Research*, presents a comparative approach towards the differences, similarities as well as the perspectives of storm water management on two sides of the Öresund Bridge.

May, 2014
Lund, Sweden

Salar Haghighatafshar

Acknowledgements

This project is financially supported by ***Sweden Water Research***. *Jes Clauson Kaas*, *Nis Fink* and *Rikke Nikolajsen* at HOFOR in Copenhagen are appreciated for their contributions. Special thanks are forwarded to *Sara Maria Lerer* at DTU for her kind help providing the information about responsibility shares in Denmark with regards to storm water management. I would also like to thank Professor *Jes la Cour Jansen*, Associate Professor *Karin Jönsson* as well as *Henrik Aspegren* and *Viveka Lidström* for their invaluable discussions and guidance. I am also grateful to *Henrik Sønderup* and Professor *Ann Mattsson* for their help and support.

Table of contents

Background

Climate change is believed to lead to more intense precipitation trends in future in the Scandinavian countries (Collins *et al.*, 2013). As illustrated in the IPCC 5th assessment report, global warming (i.e. higher average temperature), along with other consequences, would increase the global evaporation rate which would cause more intensive rain events in specific regions following the elevated water vapor content in the atmosphere (Figure 1). This would however make serious problems in urban areas where the surfaces are mainly covered by impermeable material, such as concrete, asphalt, buildings, etc. On the other hand, the existing storm water management systems are not designed to face extreme events. Tackling storm water problem has to be done from different aspects in order to be able to move towards sustainable development. The patter of sustainable development in which *social progress, economic development* and *environmental responsibility* interact within a well-balanced equilibrium (as illustrated in Figure 2) can be severely disturbed by mismanagement of storm water in urban areas regarding both its quantity and quality.

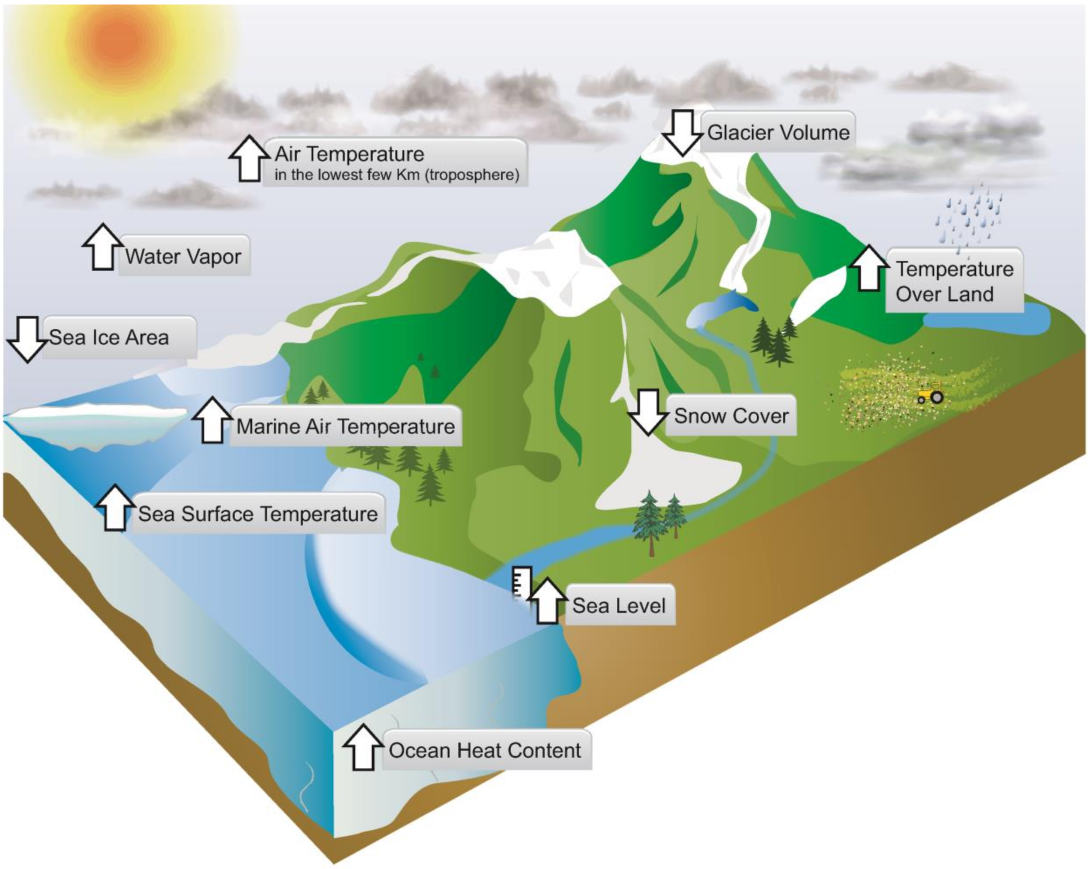

Figure 1. Effect of global warming on many different components of the water cycle. Arrow direction shows the expected change; i.e. higher (up), lower (down). This figure is adopted from Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), FAQ 2.1, Figure 1. [Cambridge University Press (in press).]- with permission.

Existing storm water handling systems in Scandinavian countries are mainly dominated by pipe networks, which can be regarded as the traditional approach towards management of urban runoff. As cited by US EPA the pipe-oriented systems may have been originated based on the idea that *dilution is the solution to pollution*. Consequently quick transport of wastewater to farther locations from the city was believed to be the answer to waste problem.

Figure 2. Sustainable development maintains a well-balanced world with respect to social, environmental and economic values.

Combined sewer networks are normally associated with severe problems with combined sewer overflows (CSO) or increased influent to the wastewater treatment plant (WWTP) in case of intensive precipitations; while separate sewer systems, though more convenient in many ways, are regarded as expensive solutions with limited handling capacity.

Best management practices (BMP) are the alternative to the traditional pipe-oriented systems. BMPs (open systems, blue-green solutions) are also known as key actors within sustainable urban development systems (SUDS) and low impact development (LID). The idea with the alternative approach is to mimic the natural processes in the urban areas in order to handle the storm water (see the picture on the front page taken at Gyllins garden, Malmö). Slow transport, detention ponds and lakes, green roofs, etc. are considered to be methods within the context of BMPs. The definition of sustainability in storm water management in Sweden, and especially southern Sweden, is to a great extent influenced by *Peter Stahre* who made intensive studies on this field. The books written in 2006 by Peter Stahre "*Sustainability in urban storm drainage*" as well as "*Blue-green fingerprints in the city of Malmö, Sweden: Malmö's way towards a sustainable urban drainage*" in 2008 shaped the framework of a sustainable approach towards urban drainage issues.

The definition of "Blue-Green" has to be discussed further since it is not completely well-developed. Basically all the storm drainage techniques that blend the following three aspects can probably be called "blue-green" solutions:

1- Hydraulic control of storm water
2- Quality control of storm water regarding organics, pathogens, biocides, micro-pollutants, heavy metals, etc.
3- Added value of the system i.e. storm water shall play an aesthetic role in the urban landscape and contribute to biological diversity

Almost none of the above stated points have been perfectly implemented anywhere in the world. Traditional piping network for handling the storm water in some occasions does not meet the incoming flows leading to flooding of urban areas (separate networks), discharge of untreated combined sewer overflows (CSO) at combined networks or both. Even development of open solutions for enormous volumes of storm water, such as the 1000-year storm in Copenhagen 2011, is an ongoing process with lots of debates on unsolved problems concerning social, legislative, economical, and political aspects. Quality of storm water varies a lot depending on the surface the drops land on. Storm water flowing over industrial areas has different composition from that of a real-estate accommodation area. There is no available appropriate technique for treatment of storm water in advance to its release into receiving waters. Heavy-metals and biocides, polycyclic aromatic hydrocarbons (PAHs) are the most problematic fraction of the pollutants in the storm water compared to organics and nutrients. Even there is no clear evaluation of the current open solutions applied in cities i.e. retention ponds, swales and wetlands regarding nutrients uptake, organics reduction, heavy metals, biocides etc. in such systems. Considering the serious problems regarding management of quantity and quality of storm water, application of an aesthetic function seems to be far more problematic where the risk for human contact with the collected storm water is high.

Regardless of the techniques and methods used for handling of storm water in urban areas, urban flood risk management can be done at three different levels known as Three Points Approach (3PA) as suggested by Fratini *et al.* (2012). 3PA classifies rain/storm event into three different categories:*1) Design rain*, *2) Extreme rain*, *3) Little rain* based on their impacts on urban life quality and likely risks associated. Three levels of 3PA are shown in Figure 3 while further explanations and elaboration can be read through Fratini *et al.* (2012). Appropriate adaptation of the entire storm water handling system for meeting the needs in case of all three rain categories, as classified in 3PA, would be a considerable step towards a sustainable urban drainage. Therefore development of new methods and techniques for management of rain events at different intensities is one of the missing loops of the sustainable management chain.

Moreover there is a high degree of uncertainty regarding the future climate conditions which leads to less determinacy level in the selection of an appropriate act that in turn makes the decision process very sophisticated. Rare occurrence of extreme storms which cause catastrophes is another reason making it more difficult to realize the necessity of implementation of preventive-adaptive measures in urban areas. Figure 4 shows how uncertainty about future could obviously affect the determinacy level in the process of decision-making. Long term projections lead to less determinacy in decision making. This trend can be true for extreme storms which so far have been seen as too rare and/or uncertain events; hence less focus has been allocated by politicians and other decision makers.

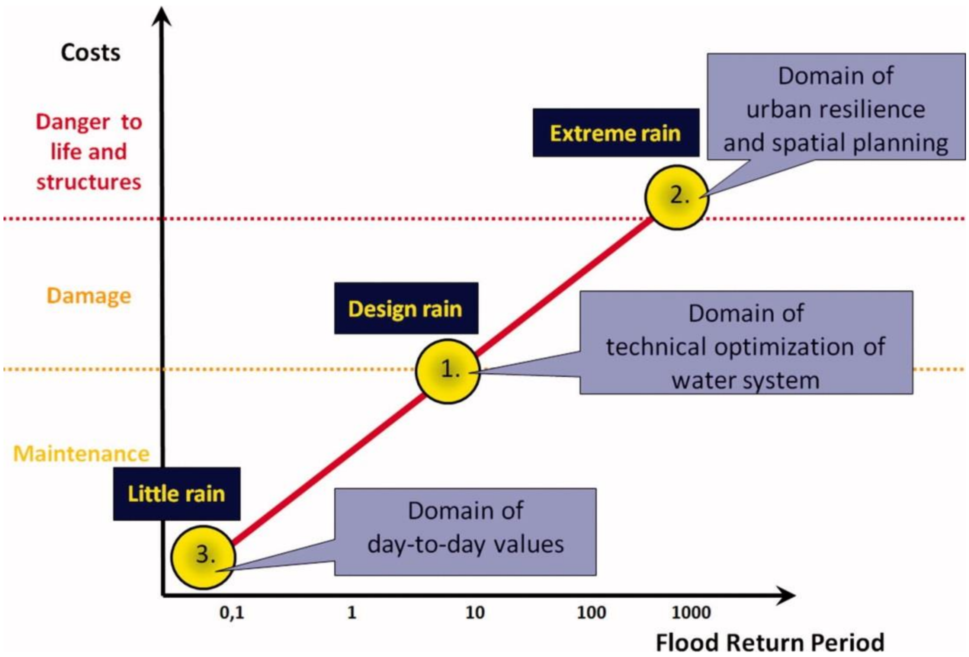

Figure 4. Illustrative scheme for the Three Point Approach (3PA) as introduced by Fratini *et al.* (2012).

Meanwhile legislations are passed, at both European and national levels, delimiting the water, wastewater, and storm water sectors within tighter requirements. European Flood Risk Directive (2007/60/EC) asks the member states to evaluate and assess flood risks with respect to flooding and its impact on public health and life, the environment, cultural heritage and economic activity. According to the plan all member states are required to generate flood risk management plans including assessments, risk maps and measures regarding prevention, protection and preparedness by 2015. The latest EU Bathing Water Directive (2006/7/ EC) is another example stipulating stronger requirements on *E. Coli* and *Enterococci* levels in the receiving waters used for bathing. Such legislations bring up an important discussion among different actors of the city regarding responsibilities. Who is responsible for flooding of a basement? Who is responsible for alleviation of the problem? Should the existing pipes in the

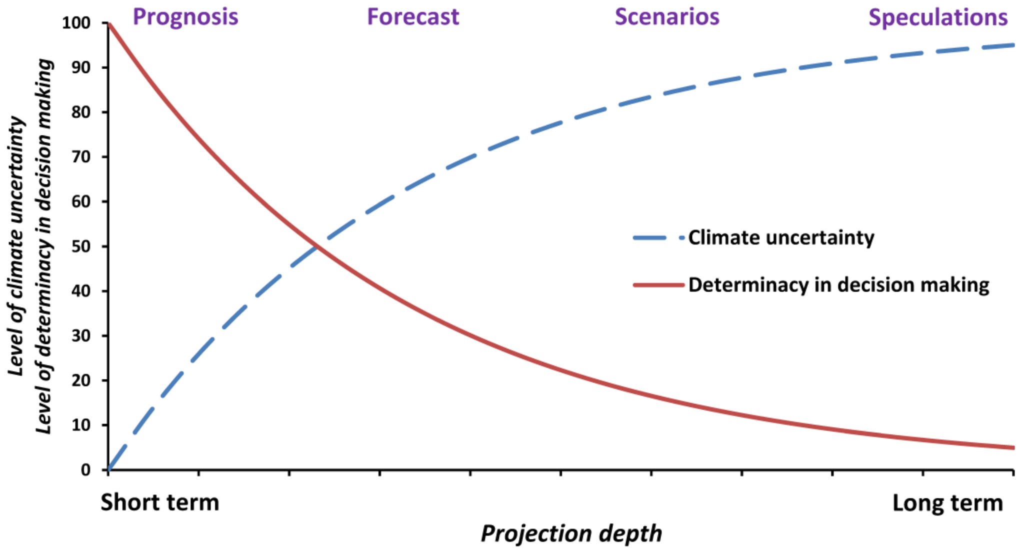

Figure 3. The relationship between climate uncertainty and the determinacy of decision making.

network be replaced by larger ones? Or should it be the land-owner thinking of possible solutions? Or is it only the tenant (in case of residential areas) that needs to adopt the needed measures? Is it fair to worsen the quality of storm or wastewater and hand it in to the sector that has traditionally been responsible for its quality?

In order to be able to tackle such discussions it seems necessary to know the current management system in an urban area. Malmö, largest city in southern Sweden, and Copenhagen, Denmark, are chosen for this study. It has been tried to describe the roles, responsibilities and cooperation between different actors.

Legislation in Sweden

Swedish legislative and regulative process is illustrated in Figure 5. In Sweden, the law is passed and issued by the parliament at the top of the pyramid and is then sent to the government for further implementation. The government subsequently assigns the task of interpretation and establishment of the relevant regulations to the authorities, normally without any significant elaboration.

Swedish law has not specifically addressed storm water issue in the cities. According to the law storm water (*dagvatten*) together with black- and gray water from households (domestic wastewater/domestic discharge/*spillvatten*) is classified as *wastewater*. The Swedish Environmental Code defines wastewater as:

"'Wastewater' shall mean:

> *1. Discharge water, sewage or other liquid impurities;*
> *2. Water used for cooling;*
> *3. Water that is diverted for the purpose of draining land included in a detailed development plan, where drainage is not carried out for the benefit of a specific property or properties; or*
> *4. Water that is diverted for the purpose of draining a burial ground. "*

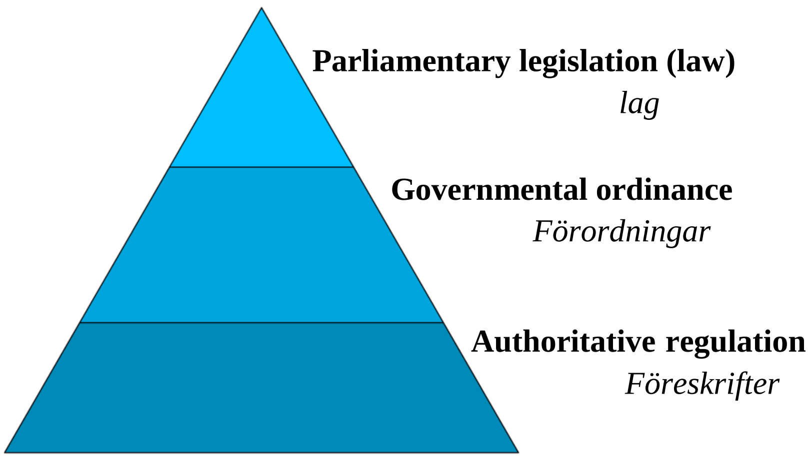

Figure 5. Swedish legislative and regulative process.

In which the notation number 3 can be interpreted as it includes storm water runoff as well. Assuming that the term "wastewater" in definition includes "storm water" it could in return

mean that all the regulations concerning domestic wastewater could probably apply to storm water as well. In order to keep the track of different definitions of terminologies used in this report an illustrative definition of *wastewater* and its components is given in **Appendix A**.
According to the section 12 in *Ordinance (1998:899) concerning Environmentally Hazardous Activities and the Protection of Public Health (Revision 2002:557)* wastewater is not allowed to be released to the water bodies if it is not treated further than sludge separation, under the condition that the wastewater is proven to be harmful to the environment and/or to the people's health.
Under section 47 of the same ordinance (1998:899) *The Swedish Environmental Protection Agency* (Naturvårdsverket) is enforced to stipulate further regulations with respect to treatment of wastewater (which in this context still includes storm water) from densely built-up areas.
Following the process towards the regulations of The Swedish Environmental Protection Agency it is found that the term "Storm water" (*Dagvatten*) is separately defined which is also considered as a contributor to the urban wastewater. The definition is exactly in-line with that cited in *Council directive of 21 May 1991 concerning urban waste water treatment*. This means that all the regulations for treatment of domestic wastewater (*spillvatten*) apply to storm water as well as stipulated both in the named directive as well as the regulations of Swedish Environmental Protection Agency.
Management of storm water in urban areas is an important issue that also needs to be addressed. Swedish law does not specify any roles and responsibilities for the actors of a city. However it is mentioned in Planning and construction law (capital 4, Skydd mot störningar, 12 §) that the municipality can require protective measures against surface pollution, accidents, flooding as well as erosion. However it does not clarify the roles of the water-services and the municipality in case of flooding. The relevant ordinance does not address capital 4, 12 § of the planning and construction law at all. Moreover, law (2006:412) about public water services describes the juridical cooperation between customers (i.e. real estate) and the main water utility company (VA SYD in this case). Governmental ordinance (2007:701) based on this law enforces the municipalities to coordinate and establish the authoritative regulations. These regulations, which could also be called *municipal provisions,* are known as ABVA (Allmänna bestämmelser för brukande av den allmänna vatten- och avloppsanläggningen) which in case of Malmö is generated by VA SYD as well as a few other regional municipalities (ABVA, 2009).

The storm water management in Malmö is driven by an official document (Storm water Strategy for Malmö) generated through mutual agreement of VA SYD and Malmö City (municipality). The first version of the document was published in 2000 where some basic principles were underlined regarding the storm water management:

- The natural water balance should not be affected negatively by urbanization.
- Sources that contribute to pollution of storm runoff should be limited.
- Storm water handling system shall be designed in order to avoid harmful flooding in case of intensive rainfalls.

- Storm water handling system shall be designed so that a large part of its pollution is removed on its way towards the recipient.
- Storm water shall be used as a positive resource in urbanization.
- Open solution for storm water shall be prioritized as much as possible in the new developments.

The latest version of the policy was published in 2007 which the above stated principles are deepened and practical approaches are explained. The major part of the current policy (published 2007) is dedicated to explanation of the responsibilities of different departments of the municipality as well as VA SYD. Severe difficulties were faced in late 1980s regarding cooperation of city actors which made it almost impossible to implement a storm water project with sustainability fingerprints. However, it could be assumed that the policy has been the outcome of about 10 years of experience in negotiation, collaboration and cooperation between different actors of city from 1989 to 2000. Today it seems that different departments of the municipality in Malmö have realized the importance of the storm water management as it is taken into consideration at very early stages of city planning. Consequently a framework for responsibilities associated with each department/actor is generated clarifying the role of different actors all the way from planning to maintenance of the system (**Appendix B**) in addition to some other acts such as classification of recipients. All the recipients in Malmö are classified based on their sensitivity to *flow*, *nutrients* and *pollutants*. The classification for each group is done at three levels of *very sensitive*, *sensitive*, *less sensitive*. Classification of storm water based on its quality running off different urban surfaces is addressed in the policy.

Figure 6 illustrates the whole process and the relations between decision makers at different levels of authority with regards to storm water management in urban areas.

In addition to all the relevant legislations stated above, Swedish parliament has passed a bill targeting the pressure reduction on the environment by 2020 and the climate change on 2050. The bill is known as Sweden's Environmental Quality Objectives which consists of 16 goals as shown in Figure 7. The bill aims to be the main driving force in achievement of a decent environmental quality in Sweden by initiating a holistic integrated movement through different governmental agencies, public agencies, NGOs, enterprises as well as individuals. A specific agency is assigned as the main responsible for each goal as shown in Table 1 while it is utterly understood that fulfillment of the goals requires public care and sometimes international collaboration. Ministry of Environment is the supreme responsible and the main supervisor of the status of the drawn vision.

It is also very interesting to investigate the 16 environmental objectives with respect to storm water. A glance at the objectives could reveal that fulfillment of some will lead to better storm water quality. Goals such as *Clean Air*, *Natural Acidification Only* and *A Non-Toxic Environment* would influence the storm water quality positively while control and management of storm water quality would help achieve other goals such as *Good-Quality Groundwater*, *A Balanced Marine Environment*, *Thriving Wetlands*, etc especially in urban areas. It seems that storm water quality plays a more important role in the Swedish Environmental Objectives than its quantity.

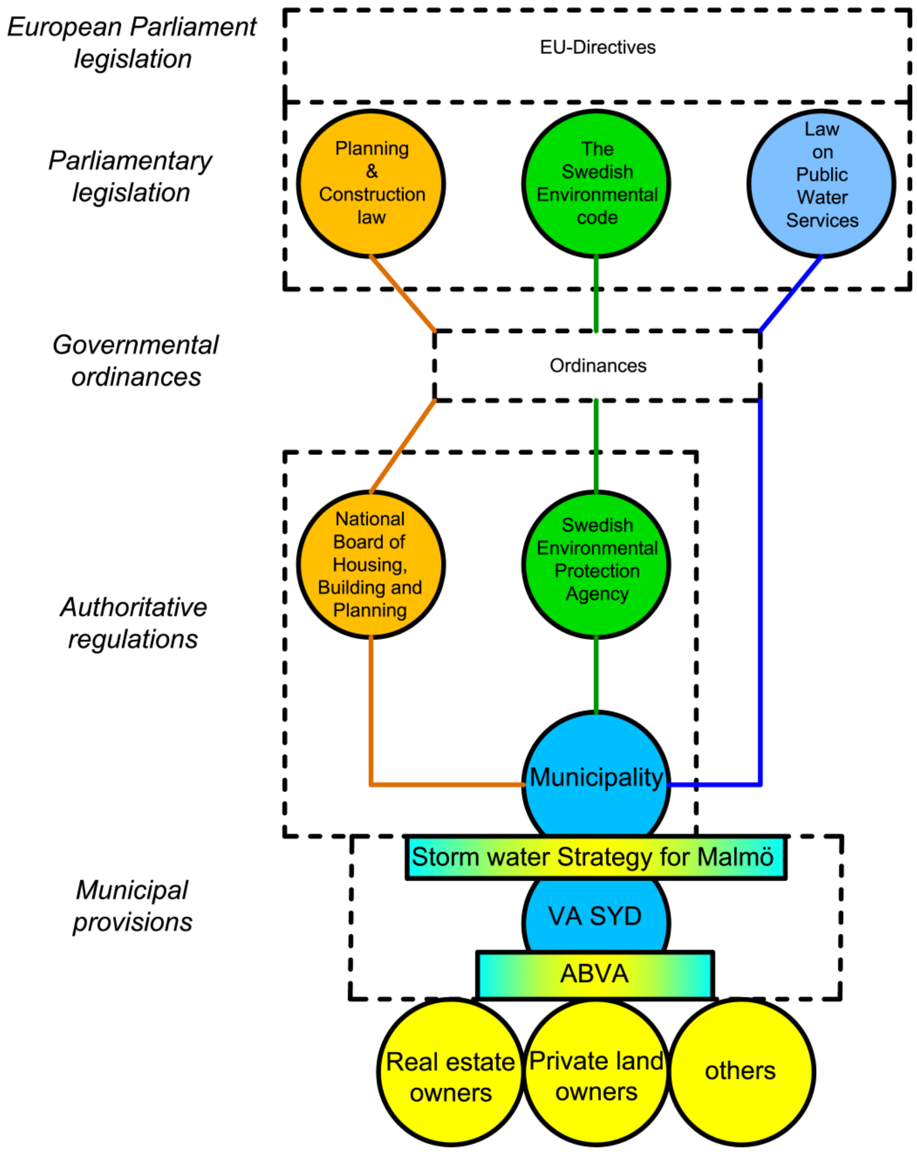

Figure 6. Legal hierarchy in Swedish system with respect to storm water management for city of Malmö.

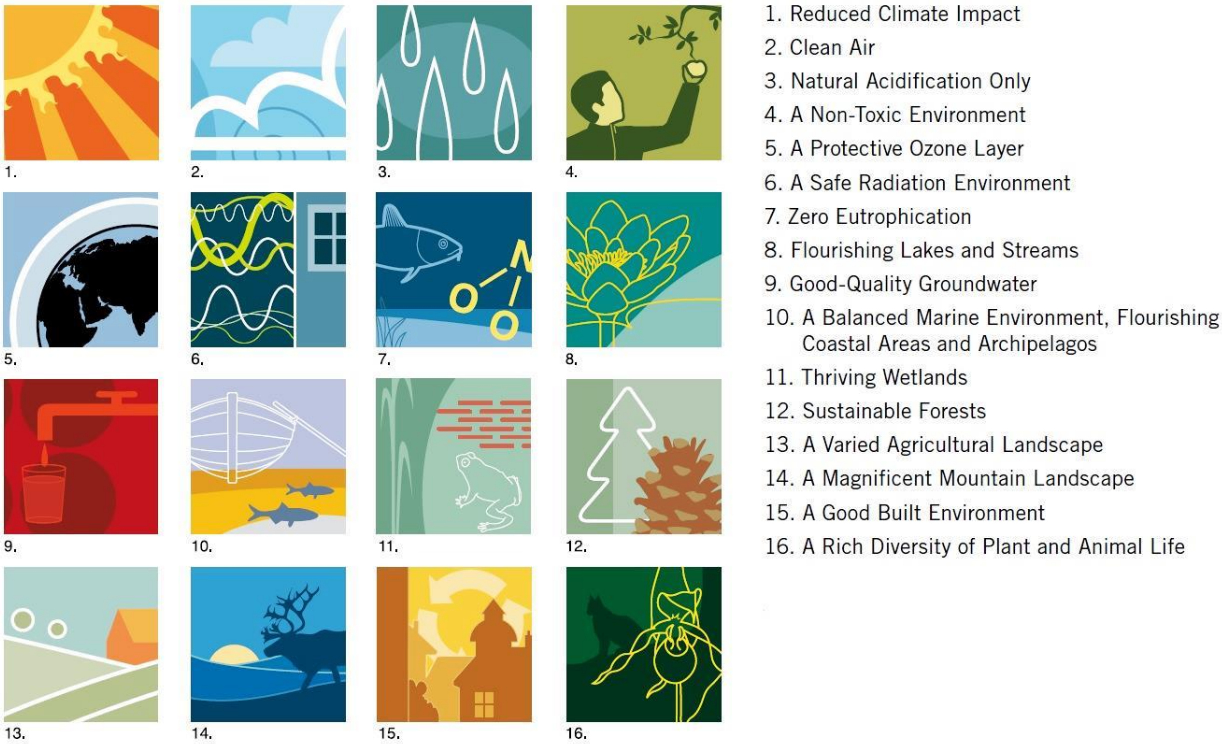

Figure 7. The 16 Environmental Quality Objectives illustrated by *Tobias Flygar*. Taken from Naturvårdsverket (2009) with permission. See http://www.miljömål.se for further information.

Table 1. The 16 Environmental Quality Objectives as well as the consequent responsible authority.

No.	Description	Responsible Agency
1	Reduced Climate Impact	Swedish EPA [a]
2	Clean Air	Swedish EPA
3	Natural Acidification Only	Swedish EPA
4	A Non-Toxic Environment	Swedish Chemicals Agency [b]
5	A Protective Ozone Layer	Swedish EPA
6	A Safe Radiation Environment	Swedish Radiation Safety Authority [c]
7	Zero Eutrophication	Swedish Agency for Marine and Water Management [d]
8	Flourishing Lakes and Streams	Swedish Agency for Marine and Water Management
9	Good-Quality Groundwater	Geological Survey of Sweden [e]
10	A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos	Swedish Agency for Marine and Water Management
11	Thriving Wetlands	Swedish EPA
12	Sustainable Forests	Swedish Forest Agency [f]
13	A Varied Agricultural Landscape	Swedish Board of Agriculture [g]

14	A Magnificent Mountain Landscape	Swedish EPA
15	A Good Built Environment	Swedish National Board of Housing, Building and Planning [h]
16	A Rich Diversity of Plant and Animal Life	Swedish EPA

a: Naturvårdsverket, b: Kemikalieinspektionen (KEMI), c: Strålsäkerhets Myndigheten, d: Havs och Vatten-myndigheten, e: Sveriges Geologiska Undersökning (SGU), f: Skogsstyrelsen, g: Jordbruksverket, h: Boverket

Responsibilities and obligations in Sweden/Malmö

In order to make a comprehensive picture of storm water management in urban areas the responsibilities of city actors for water management is explained with respect to storm water quantity and quality at different situations that storm water is located. The possible situation of a virtual rain drop is classified as illustrated in the following schematic drawing of an urban system (Figure 8).

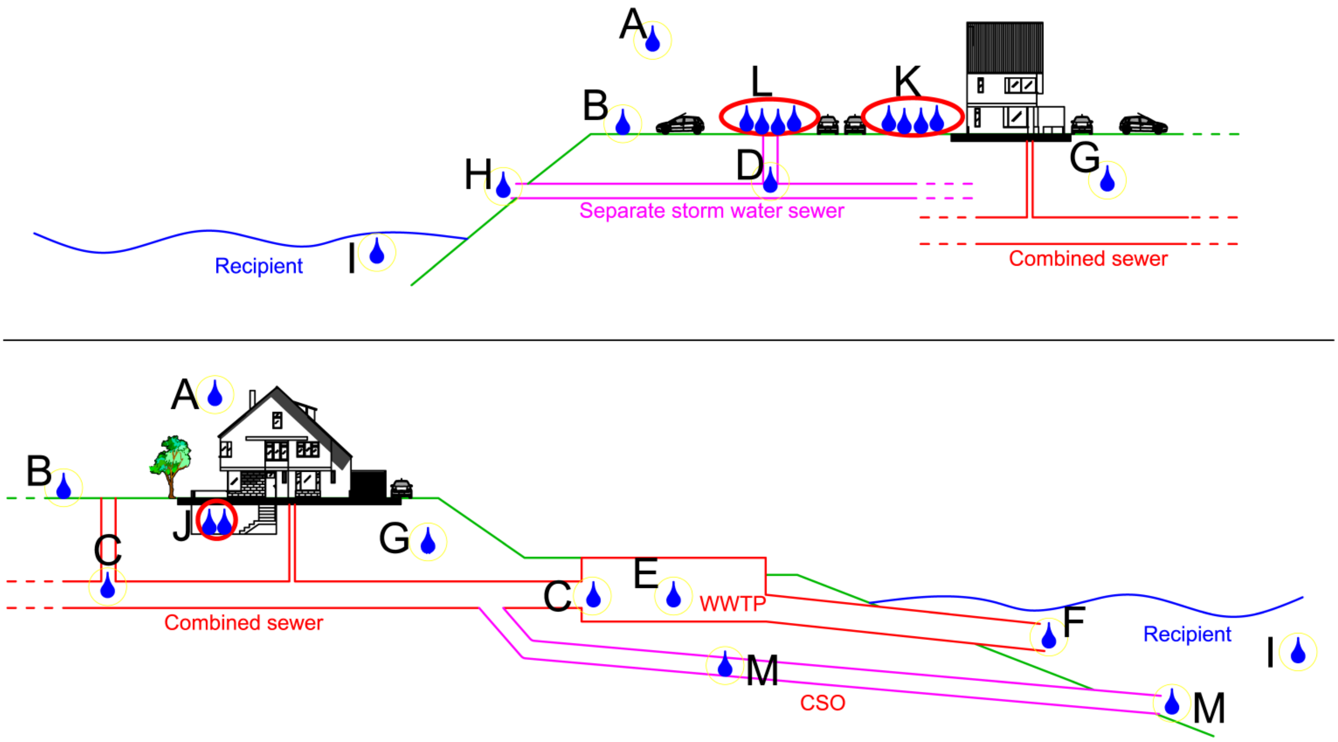

Figure 8. Schematic section of an urban area classified for different locations of rain drops. Several drop icons sitting together stand for flooding in the location.

A, in the sky while falling down
At this situation none of the actors of the city have any responsibilities in order to control the rainfall. However the rain drop is exposed to air pollution and is acidified (depending on the intensity of air pollution) which may dissolve more impurities when it reaches the ground.

B, on the urban surfaces moving towards storm drains
As soon as the rain reaches the ground in urban areas, it needs to be taken care of. According to Capital 4, 12 § in Planning and construction law, it is the municipality that needs to control the runoff in order to avoid any possible flooding (it is assumed that the municipality has a supervisory role in regulation of real estates within the detail plan of a city).

C and D, in the sewer system
As the runoff enters the sewer it is still owned by the land owner as long as it is moving in the pipes upstream the connection point (*förbindelsepunkten*). At the downstream of the connection point it gets off the local authority and is then owned by the owner of the pipe network. In case of Malmö it is VA SYD that owns the pipe network and needs to manage the storm water in the underground system. According to the ABVA, VA SYD is forced to accept the runoff from the real estates as long as there are no applicable alternatives for local management of storm water. However it is also mentioned that the drained storm water shall have a quality by which the water principal can meet its required criteria through treatment. It is not clearly defined what level of quality can or cannot be accepted but some measures are mentioned in the *supplementary material to ABVA*. Table 2 contains some of the measures indicated in ABVA that should be taken into considerations by the users.

Moreover water principal has the right to inspect and investigate the installations and their functions within a real estate. In this case the real estate is responsible for correction and reparation of any probable shortcomings or malfunctions.

E, in the wastewater treatment plant
All the wastewater inflow into the WWTP has to be treated by the owner of the plant (VA SYD)

F, in the outlet of the wastewater treatment plant
The owner of the WWTP is responsible for the water discharged into the recipient.

G, in the soil (percolating towards groundwater aquifers)
Lack of information. No responsible defined.

H, in the outlet of the separate storm water pipe-network
The owner of the network is responsible for the quantity and quality of the discharged storm water. The storm water collected via separate network is not exempted from treatment according to the Swedish law and regulations. Storm water in any system needs to be treated in order to meet the criteria stipulated by Swedish Environmental Protection Agency.

Table 2. Some guidelines indicated in ABVA in order to control the quality of storm water in urban areas.

Activity	Measure
Material	If copper (Cu) or lead (Pb) is used in roof or walls VA SYD has the right to force the owner to implement needed treatments before connection. Dyed material is environmentally better than galvanized material however the used dye should not contain heavy metals. Processed wood which is exposed to wind and weather should not be used since they emit environmentally hazardous substances.
Parking places	The runoff from such surfaces shall be connected to FOG (fat, oil and grease) separator.
Rain water from development/construction sites	Runoff from surfaces with no vegetation shall be conducted towards a sedimentation basin. The surfaces can alternatively be seeded with vegetation.
Storm water from streets	The frequency of street sweeping as well as maintenance of storm drains (wells) shall be adjusted depending on the traffic and littering.
Renovation	Construction materials which contain copper, lead or polychlorinated biphenyls (PCB) shall be replaced by environmentally friendly material at the most possible extent. Replacement and decontamination of PCBs shall be registered at the environmental administration (Miljöförvaltningen) at the municipality.
Car-wash on the streets and residential areas	Washing cars on the street is not allowed.
Slip control	Amount of spread salt on the streets has to be minimized.
Damaged vehicle	Reparation of damaged vehicles on the streets which can lead to release of oil or other pollutions to the storm drains, is not allowed

I, in the receiving water bodies

It seems that the water quality in the recipients is controlled by a number of authorities and organizations such as Swedish Agency for Marine and Water Management, the Swedish Environmental Protection Agency, National Food Agency, etc. However the objective for the long-term quality in the water courses of Sweden is settled by the County Administrative Board (*Länsstyrelsen*)

J, K, L & M, Flooding and overflow

Flooding of basements normally occurs in case floor-drains are installed at the basements of the connected to the combined sewer network (Figure 9). Flooding of basements can also be caused by separate systems as shown in Figure 9. These drains may release the head pressure of a full-flow storm water pipe, in case of intensive rains or snow melt, through flooding.

Even a separate storm water network may cause flooding in the basements via penetration through walls or even windows. In most of the cases the water principal is not found responsible for the flooding of the households as long as the designed system fulfills the requirements as stated in the Swedish Water Association (Svenskt Vatten) report P90 (earlier P28). P90 recommends 10-year storm as the design criteria for dimensioning the storm water network in confined city center areas. All the conflicts in the field of municipal water and wastewater management are handled by a relevant judiciary council known as VA-nämnden (www.va-namnden.se). In order to minimize the basement flooding cases VA SYD encourages the stakeholders to disconnect the roof drains from the combined sewer (in certain cases economically compensated) while other techniques such as choking storm drains on designated streets is also implemented. These approaches are explained more in the following paragraph. Moreover some regulations as well as guidelines are generated by The Swedish

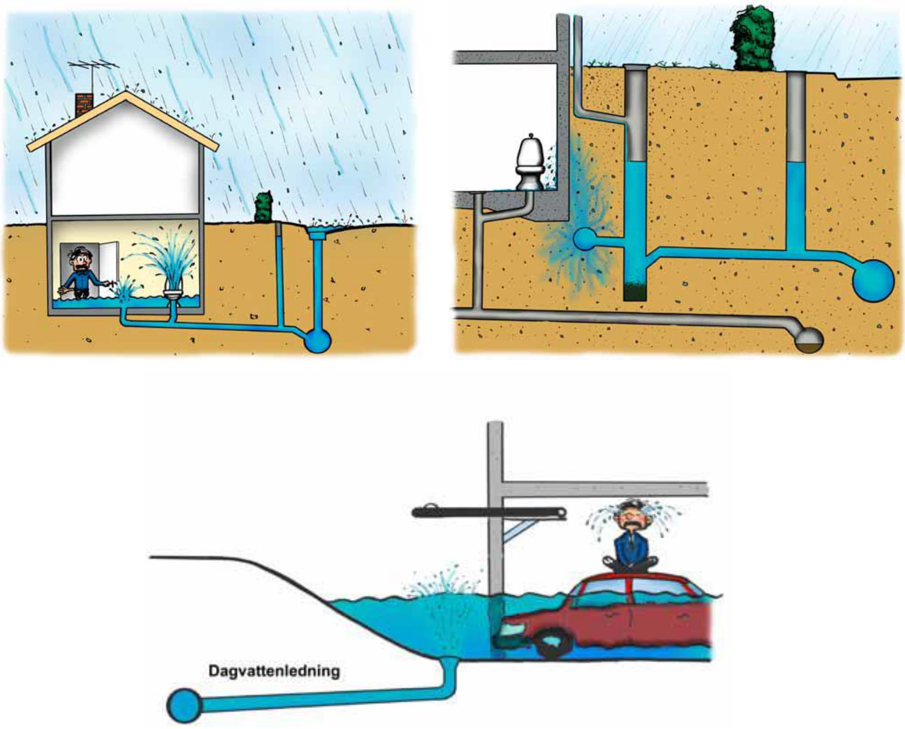

Figure 9. Basement flooding can be caused by both combined and separate systems. Pictures are taken from Kungsbacka Kommun (2011).

National Board of Housing, Building and Planning (*Boverket*) shall be followed which would decrease the risk of flooding in households.

CSO is a major contributor to the pollution of water courses as about one third of the pollution in the water courses are known to be caused by CSOs (Andoh, 1994). It is not clearly stated in the regulations who is responsible for combined sewer overflow (CSO) but VA SYD can be considered as the one responsible for control and management of CSO since they own the network. Therefore VA SYD has taken a policy in order to encourage the house owners within the combined sewer catchment areas to disconnect the roof drains from the sewer network and divert onto a lawn, infiltration trench, soakaway (dry well), etc. In this way the risk for overflow of combined sewer and flooding of basements is decreased. Disconnection of roof drains from a sewer network is found to decrease the in-pipe flow by 25-60% (Ellis, 2008). Temporary storage of storm water on the streets and alleys with considerably low traffic is another approach taken by VA SYD. This is done by blocking or partial choking of storm drains which will provide enough time (delay) for the already entered storm water and the domestic wastewater to be transported to the WWTP without any/considerable overflow. This can also be implemented at the separate storm water networks to avoid flooding of sensitive urban locations.

Storm water management in Malmö

Figure 10 shows the distribution of combined and separate sewer networks in the city of Malmö. About 35 percent (~2800 hectares) of the Malmö city has combined sewer system of which about 20% (~550 hectares) is non-effective separate system. Non-effective separate storm water system is a duplicate system which is not diverted to the recipient directly so the storm water eventually flows into the combined system and is then led to wastewater treatment plants.

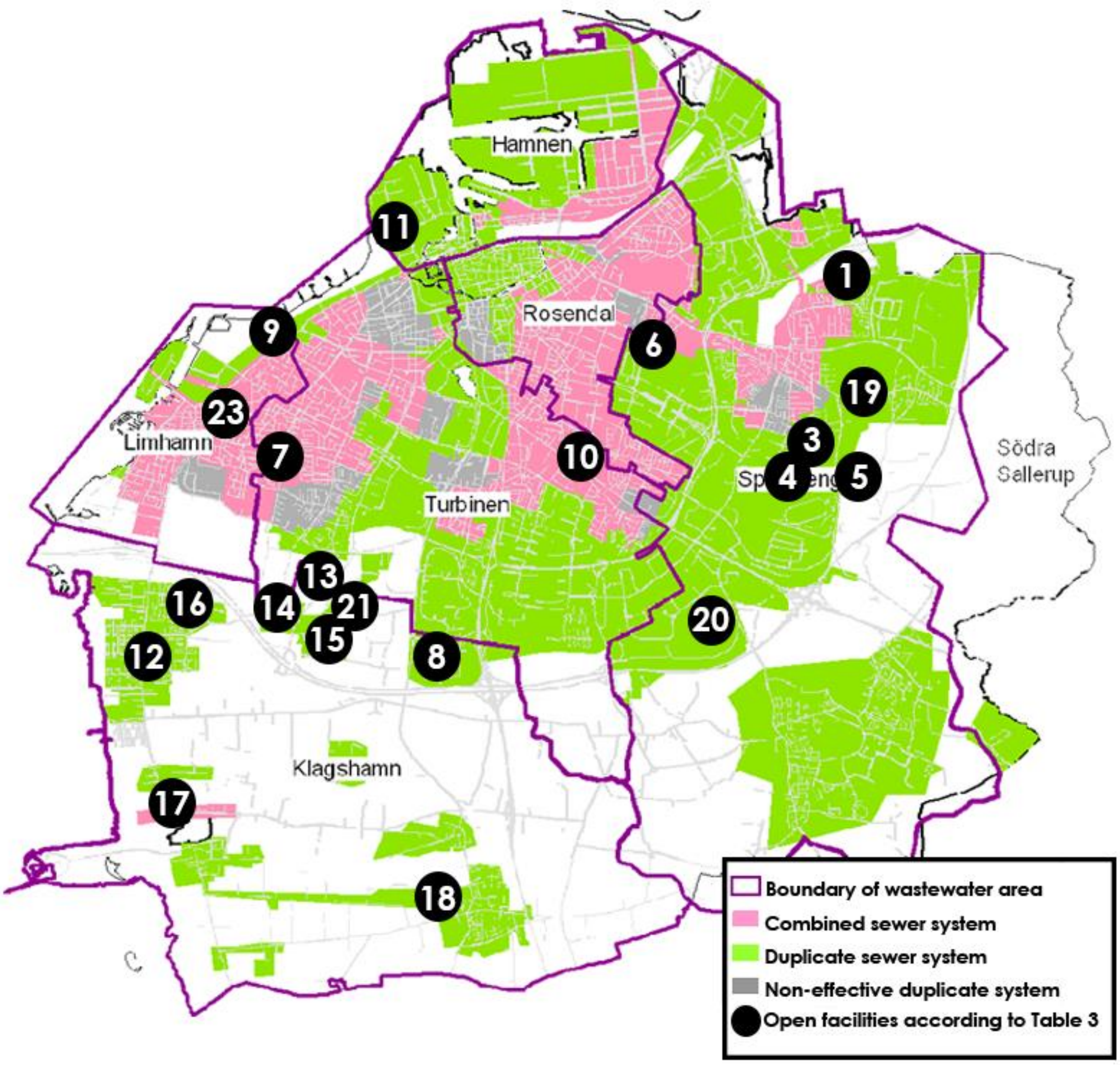

Figure 10. Different storm water collection networks as well as implemented open solutions in the urban areas of Malmö, Sweden. Measure No. 22 according to Table 3 is implemented within the combined sewer area wherever applicable. The basic map for generation of this figure is adopted from *VA SYD (2009)* with permission.

Table 3. List of the BMP implementations in the city of Malmö and their characteristics.

ID	Name	Year of implementation	Type of facility	Level of implementation
1	Toftanäs wetland park	1989-1990	Wetland, controlled flooding	Downstream control
2	Sallerupsvägen	1992	Pond, meandering creek, root zone	Slow transport/ Downstream control
3	Kasernparken	1992-1993	Pond, reed bed	Onsite control
4	Amiralsgatan	1995-1996	Ponds	Onsite control
5	Husie lake	1996-1997	Detention lakes	Downstream control
6	Olof Hågensens wetland	1997	Wetland, controlled flooding	Downstream control
7	Vanåsgatan	1999	Swales, inverted traffic bumps	Slow transport
8	Svågertorp	1998-2001	Soakaways (dry wells), ponds	Onsite control
9	Limhamnsfältet	1998	Swale	Slow transport
10	Augustenborg	1998-2005	Green roofs, canals, swales, ponds, permeable paving, controlled flooding	Source/onsite control
11	Bo 01 housing exhibition	2000-2002	Open canals, rain gardens, water artwork	Source control
12	Fjärilsparken	2000-2004	Eco-corridor (regional swale)	Slow transport/ Downstream control
13	Elinelund recreation area	2001-2002	Ponds, filter walls	Downstream control
14	Gottorpsvägen	2001	Ponds, filter walls	Downstream control
15	Vintrie	2001-2003	Detention ponds in series	Downstream control
16	Annestad	2005	Detention canal, controlled flooding	Onsite control
17	Växthusparken	2005	Eco-corridor (open watercourse and pond)	Slow transport
18	Tygelsjö eco-corridor	2004-2007	Eco-corridor (wetland, watercourse and ponds)	Downstream control
19	Gyllins trädgård	2009-2010	Green roofs, controlled flooding	Source control
20	Skogholms meadows	2011	Detention ponds in series	Downstream control
21	Hyllie Water Park	2014 (expected)	Detention pond	
22	Disconnection of roof drains from CS	-	Infiltration, controlled flooding	Source control
23	Choking of storm drains in CS (Limhamn)	2007	Controlled flooding	Onsite control

The combined sewer is traditionally present in the older parts of the cities which are normally tightly constructed and highly populated. These circumstances make the application of new solutions such as open systems almost impossible moreover substitution of combined sewer with a separate sewer seems to be an extremely costly and complicated process. However the outskirts of the city and new and relatively recent developments of Malmö city has been supplied with a duplicate sewer system together with a few open solutions in certain areas.

Since early 1990s there has been a shift towards open solutions in storm water management in Malmö. These solutions are mainly considered as *Best Management Practices* (BMP), *Sustainable Urban Drainage Systems* (SUDS) or *Blue-green solutions* for urban drainage. The process of the transformation from a traditional urban drainage towards a sustainable approach, with all the hurdles and difficulties faced at the time, is well described by *Peter Stahre* in his book "*Blue-green Fingerprints in the City of Malmö; Sweden*". As a result, Malmö is one of the leaders in application of sustainable urban drainage systems in Sweden. The main objectives of the BMP are to decrease and slow down the runoff flow in the urban areas so that the existing piping network does not get overloaded. These measures can be implemented on private lands (known as source control methods) and public lands. Figure 11 shows the different levels of implementation of open storm drainage together with some examples of the techniques and methods applicable at each level. Please note that the mentioned techniques under each level in Figure 11 are not specifically unique for that level but are most frequently implemented techniques. This means that for instance permeable paving or ponds can be a source control technique if implemented on private land. In many cases it is not easy to assign the project singly to one of the four levels of implementation since most of the projects include some slow transport at downstream control level.

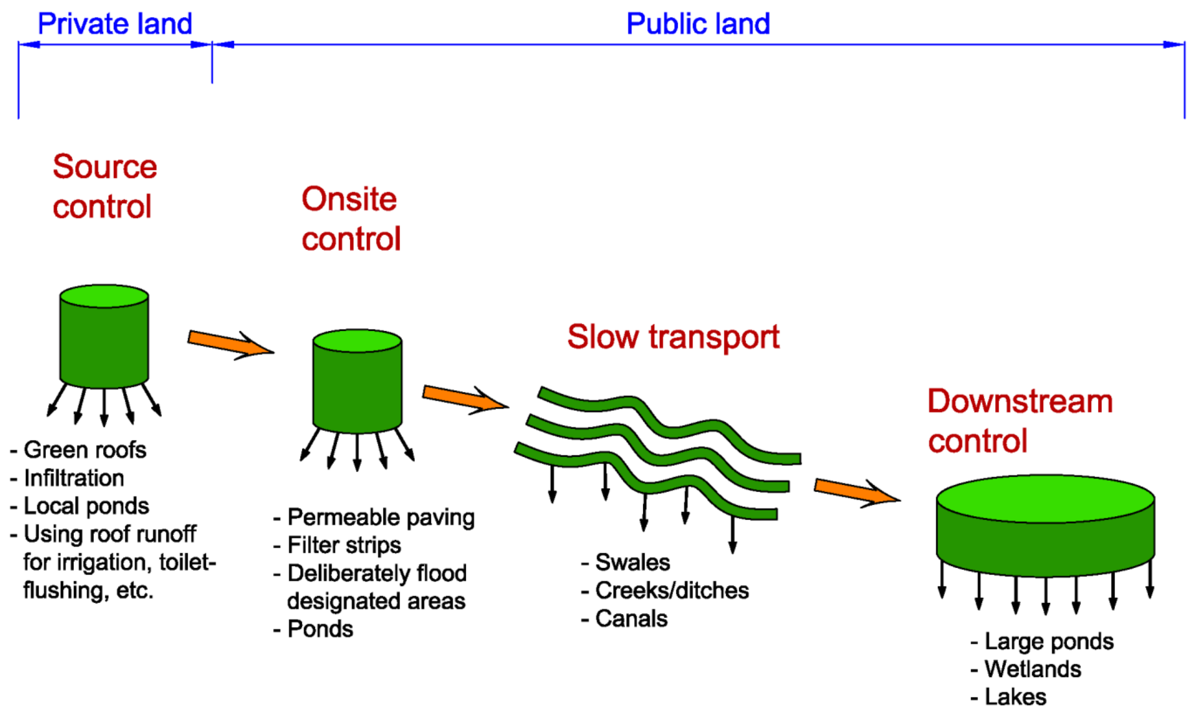

Figure 11. Implementation levels of open storm drainage systems and their applicable techniques [reproduced according to Stahre (2006) with permission].

According to the definition presented above as well as in Figure 11 the storm water management projects in Malmö are collected and classified based on the level of implementation in Table 3. Over 20 projects within the context of sustainable urban drainage has been defined and implemented in Malmö as stated in Table 3. Table 3 is adopted from the book "*Blue-green Fingerprints in the City of Malmö; Sweden"* and has been updated based on information from VA SYD.

However, despite all the implemented open systems in Malmö the storm Sven (5^{th}-7^{th} of December 2013) showed that the city was still prone to critical damages in case of severe rainfall events. During the storm the water level in the city canals of Malmö raised about 1.5 m the three year-old metro network of Malmö was only 15 cm (in water level) away from being flooded.

Studies have been done regarding the sea level rising concerning the coasts of Malmö which has led to re-consideration of a course of action for all new constructions to be at least 3 m above sea level (Dialog-pm, 2008:2) if no other flood-proof measure is available in the area. Previous guideline stated a minimum level of 2.5 m above sea level for new constructions.

The city of Malmö has been actively taking part in climate adaptation plans. The project "Bygga Bo-dialogen" initiated by *Boverket* has been run for Malmö in order to establish a framework of cooperation in the planning phase of new developments between the actors. Malmö has also taken part in two EU-projects "GRaBS" and "GreenClimeAdapt"which are EU *Life+* projects. Malmö together with some other European partners in GRaBS have shared their experiences regarding climate adaptation measures and open storm water handling systems. One of the main objectives of the project is to create a multidimensional regional planning strategy. As the result of the GreenClimeAdapt projects some areas along the Riseberg stream were chosen for construction of open storm water systems for hydraulic and qualitative maintenance of Riseberg stream as well as its erosive behavior. In addition to *Storm water policy for Malmö* a few other documents and reports can be found concerning climate adaptation in Malmö, such as *Klimatet, havsnivån och planeringen* (Dialog-pm 2008:2), *Handlingsplan för klimatanpassning Malmö 2012-2014* and *Faktablad om Malmös lokala klimatinvesteringsprogram (KLIMP 2003-2007)* in which both technical and social aspects of climate adaptation processes are addressed.

Legislation in Denmark

Legislative system in Denmark is very similar to that of Sweden. The Danish government is responsible for interpretation, elaboration and implementation of the law through announcement of relevant regulations while Danish EPA only suggests the guidelines related to the subject. Figure 12 below shows the terminologies used in the Danish system.

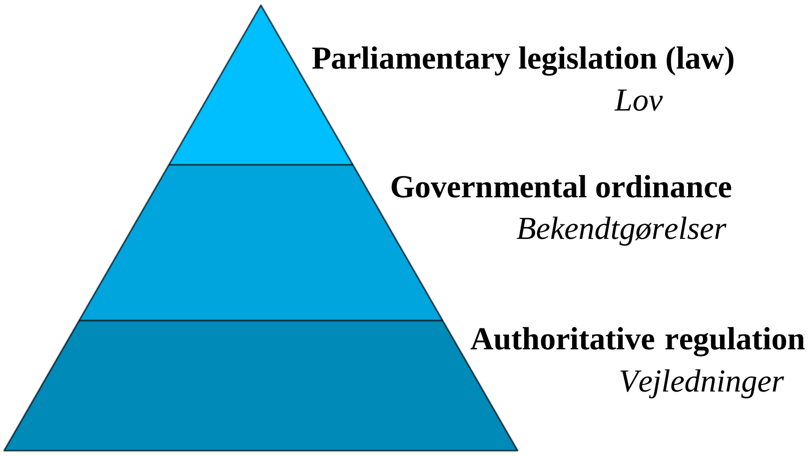

Figure 12. Danish legislative and regulative process.

The dominating law in Denmark regarding the environmental issues is "The Law of Environmental Protection" (*Miljøbeskyttelsesloven*). The law, in capitals 3 and 4, empowers the Danish Ministry of Environment to regulate further detailed requirements and obligations with regards to protection of soil, groundwater and surface water. It is also the Danish government which is responsible for the adaptation of the national ordinances with EU directives. The definition of wastewater according to the governmental ordinance BEK nr 1448 af 11/12/2007 Gældende (*Spildevandsbekendtgørelsen*) – based on capitals 3 and 4 of the law of environmental protection - is presented in three categories under capital 2, § 4 as below:

- Waste water means all water which is derived from residential, businesses, other buildings and paved areas.
- Domestic wastewater is sewage from households, including discharge from water closets.
- Roof and surface run-off means rainwater from roofs and other fully or partially paved areas, including railways. Roof and surface water must not contain substances other than those usually applied to storm water associated with runoff from such areas or have a significantly different composition.

The definition presented above is in principle the same as the Swedish definition of wastewater which contains storm water as well. It is however interesting that the Danish system has separately named and defined Roof and surface runoff and has requirements for its quality, while the specific quality requirements are not well-explained. The definition of wastewater is issued at the governmental level in Denmark while elaborated definition of wastewater is given at authoritative level in Sweden. Considering the fact that even the outlet requirements of the wastewater treatment plants are also stipulated at the governmental level (§17, Bekendtgørelse om spildevandstilladelser) may indicate that relatively detailed decisions are made at higher levels in Denmark compared to Sweden.

Responsibilities and obligations in Denmark/Copenhagen

Discussing the distribution of responsibilities and obligations in the Copenhagen area it can be mentioned that municipality holds the main role in management of urban drainage systems.

Considering the illustrations in Figure 8 the situation in Denmark (Copenhagen) can be described as below:

Responsibilities for storm water at points *A* and *B* are completely similar to that of Malmö (stated in the relevant section). Same as in Malmö, wastewater is owned and managed by the municipality as soon as it flows out of the private land (i.e. points *C* and *D*). *Wastewater plan for Copenhagen* (*Spildevandsplan)* is generated by the municipality every 4th year which identifies the areas of the city that have the right to discharge their runoff to the pipe network, as well as areas that first need to try to handle it locally or otherwise prove that local handling is not feasible. In this respect, the municipality (main water principal) has the right to investigate the quality of the installations within a private area, while the land owner is still the responsible for probable corrections or reparations.

E, in the wastewater treatment plant
Each wastewater treatment plant has a predefined flow that has to be treated. Therefore the wastewater treatment plant can legally bypass the excess inflow direct into the recipient without any treatment.

F, in the outlet of the wastewater treatment plant
Wastewater treatment plant is responsible for the discharged water quality as they could be punished in case they do not meet the requirements as defined by law.

G, in the soil (percolating towards groundwater aquifers)
There is no responsible defined in case of natural percolation. However, in case of designed infiltration/percolation facilities it is the municipality who has the responsibility of ensuring the function of the system so that it does not deteriorate groundwater quality.

H, in the outlet of the separate storm water pipe-network
It is similar to that described for Sweden.

I, in the receiving water bodies
The municipality is mainly responsible for the water quality in the receiving water bodies, while the national responsibility is held by Naturstyrelsen under the Ministry of Environment.

J, K, L & M, Flooding and overflow
Copenhagen Municipality is not considered as the responsible authority in case of basement flooding at rain events with return periods larger than 10 years since the pipe network is designed for a 10-year storm according to *Spildevandskomiteens skrift 27*. Therefore private land owners and real estate authorities are strictly asked to consider the required measures to protect their properties against flooding. On the other hand there are municipalities like Århus that accept the responsibility in case of flooding regardless of the cause. CSOs are mainly managed by the municipality as the main responsible authority.

Storm water management in Copenhagen

Copenhagen is mainly dominated by combined sewer system with exception of Ørestad and a narrow strip along the harbor which have separated sewer networks (Figure 13). Water quality in the Copenhagen harbor has always been an important issue for the Copenhageners. As reported by Lindegaard (2001) it was in 1930 that the local council representatives reacted against the environmental water quality in Copenhagen putting the blame on the city of Copenhagen (municipality) for releasing 370 000 tons of waste including domestic wastewater into the Sound. This argument brought up the demand for treatment of the municipal wastewater from Copenhagen (Politiken, 1932). The municipality decided to build a WWTP at Kalvebod and implemented chlorine disinfection to the treated wastewater from Helgoland. However it was in 1932 that the municipality closed down the bathing locations

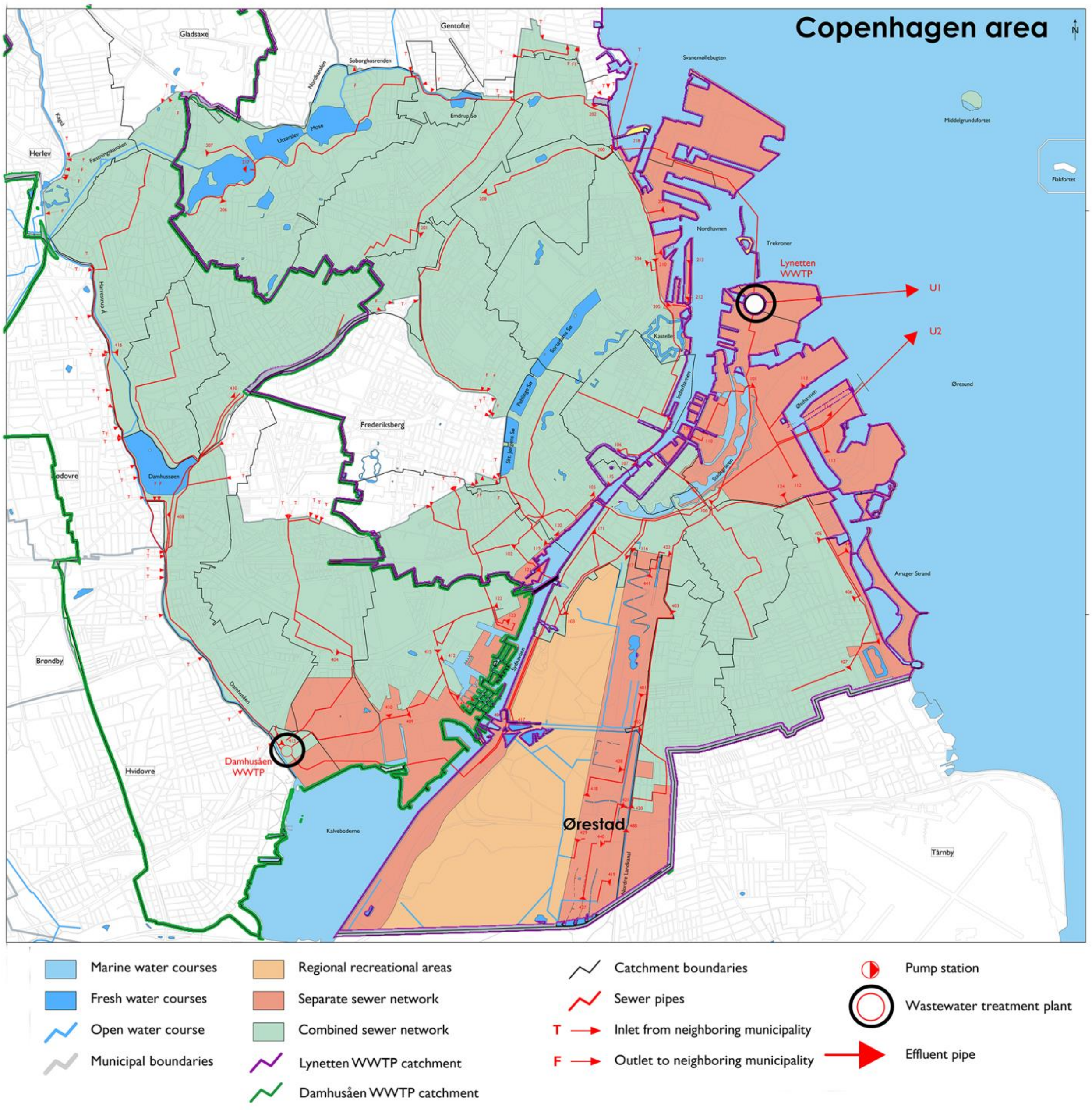

Figure 13. Overview of Copenhagen area illustrating locations of separate and combined sewer networks. This map is adopted from *Københavns Kommunes Spildevandsplan, 2008 (with permission).*

due to high bacterial content in the water.

Back in 1990s improvement of water quality in the Copenhagen harbor has been a driving force to control flooding and sewer overflows into the harbor. Heavily polluted water caused by industrial impacts and combined sewer overflows had made it completely impossible to use the harbor for water-based recreational purposes for decades. Totally 93 outlets for CSO were released into the harbor and its neighboring coasts in case of heavy rainfalls.

The aim to achieve a water quality for swimming in the harbor initiated a plan in the municipality of Copenhagen in order to decrease the release of pollutants into the harbor. Many retention basins were built in the overflow points which could detain the overflow water for a certain time until the network could handle it back. Construction of retention basins was a great progress in line with the defined aim which decreased the number of the outlets down to 38. Current CSOs occur at very extreme rainfalls (i.e. overflow takes place at higher hydraulic gradients in the pipe system compared to the original conditions) while an online warning system controls the bathing water quality in the harbor. Figure 14 shows people bathing in the harbor area in Copenhagen.

The intense storm on 2nd of July 2011 in Copenhagen has probably been a turning point in the history of storm water management in Denmark. Over 150 mm rain in about 2 hours, corresponding to a 1000-year rain, led to approximately one billion euros insurance claims in the Copenhagen area. Moreover, critical infrastructures were damaged, hospitals were close to evacuation point and the emergency services were threatened seriously. Since then the storm water management has been considered as one of priorities in the urban planning in

Figure 14. Improvement of water quality in the Copenhagen harbor has been a major achievement for the municipality. This photo is taken from *Københavns Kommunes Spildevandsplan, 2008 (with permission).*

Copenhagen.

The *Cloudburst Management Plant* (October 2012) can be regarded as the guideline and policy for storm water management in Copenhagen. Since implementation of the mentioned measure requires a holistic perspective, Cloudburst Management Plan has been worked out by the City of Copenhagen via cooperation with Københavns Energi (Copenhagen Energy), the city of Frederiksberg, Frederiksberg Forsyning (Frederiksberg utility company) as well as neighboring local authorities whose storm water is diverted to the common water courses through Copenhagen. The document is an offshoot to the *Copenhagen Climate Adaptation Plan* (August 2011) with some changes initiated from the experiences of the 2^{nd} of July 2011 extreme storm. *Climate Adaptation Plan* suggests two measures in order to mitigate flooding in case of extreme events: **a)** Changing the current combined sewer network to separate network (long-term plan), **b)** Using public surface with low sensitivity e.g. parks, sport fields and open spaces for temporary storage of storm water (known as *Plan B*). However the 2^{nd} of July 2011-event proved that the maximum volume contained on such surfaces in Copenhagen area would only cover a minor proportion of the flood during the extreme rainfall events. Therefore, *The Cloudburst Management Plan* is issued by introducing additional measures which could lead the storm water to the sea via roads, canals, urban waterways and underground tunnels. The legal problems for financing such inter-institutional provisions are identified and asked to be solved by the Danish Ministry of Environment. Moreover, environmental impacts of such water outpourings into the water courses are planned to be investigated.

The Cloudburst Management Plant also recommends a new risk dimensioning criteria. The suggested criteria allows the sewer water level reach the ground surface once in a 10-year course (i.e. the former criteria) as well as 10 cm flooding above ground level once every 100 years. 100-year storm is selected based on economical evaluation of different approaches. Figure 15 shows that for implementation of preventive measured for storm events larger than 100-year, the initiative (implementation) cost goes far beyond damage costs resulting in diminishing net gains. Controlling the flood level of maximum 10 cm above ground level in case of a 100-year storm would be done via combined adoption of storage measures, fast transport via designated surfaces and tunnels all together with public awareness and preparation of their properties against 10 cm of water above the ground level. This means that in future every individual should be prepared to manage 10 cm of storm water above the ground level without any substantial flooding in their properties. According to the plan the owner is the only responsible for flood-proofing his/her property with respect to 10 cm flood depth.

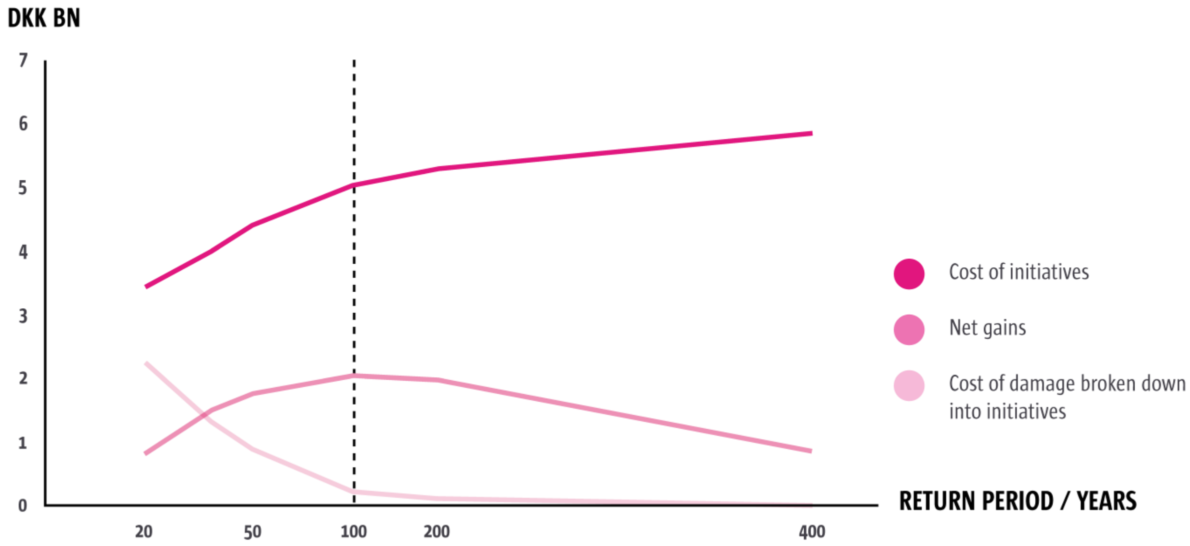

Figure 15. Cost versus gain evaluation of adaptation initiatives with different time-spans in the city of Copenhagen (taken from *Cloudburst Management Plan* with permission).

On the way towards large scale adaptive measures for the city of Copenhagen, as discussed above, blue-green solutions are one of the major available alternatives. The City of Copenhagen has expressed its determinacy for implementations of blue-green solutions concerning storm water management for alleviation of urban flooding problem. Unlike the situation in Malmö, Copenhagen does not have as many large-scale open storm water implementations. The only large-scale implementation is available at Ørestad area in Copenhagen where a series of interconnected canals is recipient to the storm water runoff from the roofs of the surrounding buildings (Figure 16). There are several projects in the planning phase in Copenhagen which address the common use of urban surfaces e.g. streets, parks, etc. for storm water control in case of intensive rains. H.C. Andersen's Boulevard, Sankt Annæ Plads, Istedgade, Sankt Jørgens Sø and Sønder Boulevard are some these conceptual plans under consideration for Copenhagen area as presented in Figures 17 and 18.

Figure 16. Open channel for storm water collection in Ørestad, Copenhagen.

Figure 17. Open storm water solution plans for Copenhagen. ***Top: Sønder Boulevard , Bottom: Istedgade.*** **Pictures are taken from Jørgenssen (2013) and are accredited to Copenhagen Municipality.**

Figure 18. Open storm water solution plans for Copenhagen. ***Top: Sankt Jørgens Sø (accredited to Copenhagen Municipality), Bottom: H. C. Andersen's Boulevard (accredited to Tredje Natur architecture company). Visit http://tredjenatur.dk/portfolio/indre-by-skybrudsplan/ for further illustrations.***

Summary and discussion

Malmö and Copenhagen, despite of close neighborhood, have substantial differences with respect to storm water management procedures. The review of the Danish and Swedish legislations revealed that the Danish Ministry of Environment takes a great deal of role and responsibility with regards to management and handling of urban wastewater while in Sweden it is the Swedish EPA that issues the crucial regulations. Considering the pyramid of law, it can probably be told that details of the law and the guidelines for fulfillment of the requirements are at higher elaboration level in Denmark. Discharge limits from the wastewater treatment plants are clearly mentioned by the Danish Ministry of Environment while Swedish EPA has introduced general regulations and the actual discharge requirements are given by *County Administrative Boards of Sweden (Länsstyrelsen*). Although the definition of wastewater is recognized in both Danish and Swedish laws but there are no clear statements specifically for storm water management and flood prevention.

The nature of storm water management in two cities is completely different. In Malmö, many large-scale open storm water handling implementations (over 20 facilities) are already present in forms such as ponds, wetlands, swales, canals, detention lakes, green roofs, etc. while there is only one large-scale project realized in Copenhagen (Ørestad). Open blue-green solutions in Malmö have been constructed followed by individual efforts as well as overwhelming anxiety of *Peter Stahre* who succeeded to affect the overall perspective of storm water management in Malmö. Current inter-organizational cooperation framework in Malmö owes a lot to *Peter Stahre*. In other words the existing full-scale implementations of open systems in Malmö can more or less be accredited as *Peter Stahre*'s heritage. The City of Malmö has generated a storm water policy (*Dagvattenstrategi i Malmö*) in which responsibilities of different departments, classification of different recipients according to their sensitivity to high flow/pollution, as well as different sources of pollution in storm water are addressed. This means that the administrative framework for alleviation of storm water in Malmö already exists while lack of an in-depth evaluation of the existing system and its behavior in case of different scenarios for extreme storm events in Malmö as well as its probable consequences is obviously realized.

Improvement of harbor water quality to make it suitable for bathing and recreation has been the main ambition and driving force for wastewater management (including storm water) in the city of Copenhagen for over two decades until the extreme rain event on 2nd of July 2011 which influenced the concept of management fundamentally. Comparing the evolution of the two cities regarding storm water plans it can be observed that most of the large-scale projects in Malmö are fulfilled in the suburbs of the city while no substantial adaptation plan has either been implemented or planned for the inner city areas. Copenhagen, on the other hand, has studied the most vulnerable areas of the city and concentrated to rehabilitate the system by implementation of a holistic approach including all different actors such as utilities, municipalities and public. Quick transport of storm water to the sea by a network of roads, canals and subterranean tunnels, storage of storm water on open areas, sport fields, parks as well as multipurpose streets has all been mentioned as possible solutions in the *Cloudburst Management Plan* in Copenhagen. Adoption of such an approach requires active engagement of different city actors, as well as legal adaptations. However, inter-organizational cooperation has not been practiced in reality in Copenhagen yet as lack of mutual understanding as well as framework of responsibilities and contributions were found to be major hurdles on the way of implementation of new techniques, as told in Malmö's experience.

Considering the Three Points Approach (3PA) suggested by Fratini *et al.* (2012) – discussed earlier in this report- it might be concluded that the concentration of the city actors in Copenhagen during last years have been on solving problems associated with extreme rain (*Point 2*); while design rain (*Point 1*) and maintenance of the system for little rain (*Point 3*) have been more underlined in Malmö.

Table 4 shows the summary of the evaluation of storm water management in Malmö and Copenhagen.

Table 4. Summary of storm water management situation in Malmö and Copenhagen.

No.	Phase	Malmö	Copenhagen
1	Political engagement/commitment	○	●
2	Evaluation of the existing system for future scenarios	○	●
3	Evaluation of different adaptation plans	○	●
4	Choice of a feasible action plan/rehabilitation roadmap	○	●
5	Identify obstacles/suggested solutions	○	●
6	Sensitivity study of recipients	●	○
7	Experience of inter-organizational cooperation	●	○
8	Experience of large-scale blue-green implementations	●	○
9	Experience of extreme rainfall/flooding	○	●
10	Fulfilled climate adaptation plan/flood-proofing	○	○

●: *available*, ○: *not available*

References

- Andoh, R.Y.G. (1994). Urban runoff: Nature, characteristics and Control. *Water and Environment Journal* 8(4), 371-378.
- ABVA, Allmänna bestämmelser för brukande av den allmänna vatten- och avloppsanläggningen. Accessible via: http://www.vasyd.se/sv-SE/Artiklar/Avlopp/Lagar-och-regler
- VA SYD (2009). Åtgärdsplan för Malmös Avlopp. Accessible via: http://www.vasyd.se/~/media/Documents/Broschyrer/Vatten%20och%20avlopp/%C3%85tg%C3%A4rdsplan%20f%C3%B6r%20Malm%C3%B6s%20avlopp%202009.ashx
- Cloudburst Management Plan (2012). The City of Copenhagen.
- Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Dagvattenstrategi för Malmö (2008). Malmö Stad.
- Directive 2006/7 /EC (2006). Concerning the management of bathing water quality and repealing Directive 76/160/EEC. Official Journal of the European Union, 64, 37-51.
- Directive 2007/60/EC (2007). On the assessment and management of flood risks. Official Journal of the European Union, 288, 27-34.
- Ellis, J. (2008). Third generation urban surface water drainage; from rooftop to the receiving water sub-catchment. 11th International Conference on Urban Drainage, Edinburgh, Scotland.
- Fratini, C.F., Geldof, G.D., Kluck, J., Mikkelsen, P.S. (2012). Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality. Urban Water Journal 9(5); 317-331.
- Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai, (2013). Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Jørgenssen, Steen A. (2013) http://www.b.dk/nationalt/se-de-flotte-billeder-saadan-skal-koebenhavn-sikres-mod-skybrud.
- Københavns Kommunes Spildevandsplan (2008). Accessible via: http://www.hofor.dk/wp-content/uploads/2012/06/spildevandsplanKE.pdf
- Kungsbacka Kommun (2011). Översvämning i Källare; Råd & Tips.

- Lindegaard, Hanne (2001). The Debate on the Sewerage System in Copenhagen from the 1840s to the 1930s. AMBIO - A Journal of the Human Environment; Vol. 30, Issue 4/5, Page 323.
- Naturvårdsverket (2009). Wastewater Treatment in Sweden. ISBN 978-91-620-8416-5.
- Politiken, 24. 05.1932 (In Danish).
- Stahre, P. (2006). Sustainability in Urban Storm Drainage, Planning and Examples. Svenskt Vatten, ISBN: 91-85159-20-4.
- Stahre, P. (2008). Blue-Green Fingerprints in the city of Malmö, Sweden – Malmö's way towards a sustainable urban drainage. VA SYD.

Appendix A – illustrative definition of *Wastewater* interpreted based on the Swedish Environmental Code