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I can't forget to acknowledge this work to my mother's sole and my father.

Runoff water quality from a green roof and in an open storm water system

Abstract:

Augustenborg storm water system has become well known for its incorporation of urban green spaces. Open storm water system was developed in late 1990s by disconnecting impervious surfaces from combined sewers as a result of flooding problem in the basements after heavy rain events. The open storm water management system consists of open channels and ponds, a small wetland, green infiltration areas, green roofs, and permeable paving surfaces. The Augustenborg catchment area includes council offices, residential apartments separated by parking places, a school, courtyards and roads. This study consists of two parts. In the first one the storm water quality in Augustenborg storm water system is investigated and the degree of water pollution is assessed by comparing with other studies of storm water quality in urban areas. In the second part the changes in green roof influence on runoff water quality depending on roof age are assessed by comparing current results with the previous studies on the same green roof in Augustenborg. Water samples are taken from four different locations after the four different rain events; these are rain water sample, green roof runoff sample, runoff sample from the open channel and finally the sample from the last pond situated on downstream of the Augustenborg storm water system. All samples are analysed for nutrients and heavy metals. Analysed nutrients are potassium (K), nitrate nitrogen (NO3-N), total nitrogen (Tot-N), phosphate phosphorus (PO4-P), total phosphorus (Tot-P), dissolved organic carbon (DOC) and analyzed metals are; Cd, Cu, Zn, Pb, and Ni.

The study revealed that the influence of green roof on runoff quality changes with the roof age. The major trend is that the phosphorus and potassium concentrations in roof runoff water are less the older the roof. The green roof keeps its ability to remove 60% of nitrogen from rain water so that the concentrations in green roof runoff are less than the concentrations in rain water. Regarding the open storm water system in Augustenborg the study found generally that the storm water quality was better comparing with other urban sites as found by other studies.

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1. Introduction

Many catchments around the world are undergoing fast urbanization as a result of population increase. Increasing urbanization leads to an increase in runoff and this process concentrates fresh water flows to localized receiving waters including man-made systems such as retention ponds, detention basins and natural environments like lakes, estuaries and near shore coastal waters. The impact of urbanisation on terms of water resource management in combination with effect of climate change has been studied by Kleidorfer et al. 2009. They found out that 20% increase in rain intensity as a result of climate change has the same effect on average as a 40 % increase of the impervious area. They also concluded that the impact of increased urbanization is sometimes significantly higher than the one expected from the global warming.

During urbanisation some catchments experience water quality degradation due to high pollution loads from different non-point sources. Storm water runoff has been recognised as one of the major driving force of non-point source discharge such as heavy metals, polycyclic aromatic hydrocarbons, nutrients and other toxic compounds of anthropogenic activities (US EPA, 1995; Characklis and Wiesner, 1997). Non-point source pollutants have recently become the great concern for the scientists, decision makers and for public, greater that the point source pollutants. The reason is that the point source has been identified and remedied but the non-point sources are complex to identify and manage.

Storm water pollutants have different characterised depending on the land use. As storm water runoff pollutants are generated and transported in a diffuse manner and their sources are related to physiographic factors of individual catchment thus storm runoff pollution usually presents spatial variation with land use being one of the most important factors (Tong and Chen, 2002; Yusop et al., 2005). The storm runoff pollution has negative consequences on our aquatic resources (streams, lakes, estuaries, rivers, aquifers and other water bodies) which are most valuable assets of every nation. The resulting negative impact includes change in flow, increased sedimentation, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic populations, and decreased water quality due to increased level of nutrients, metals, hydrocarbons, bacteria and other constituents (Karlsson, 2006).

Generally, storm water is conveyed in two ways. One is conventional storm water systems which include combined and separated storm water sewers through pipe arrangements and the second approach is open storm water system which includes wetlands, ponds, infiltration systems, open channel etc.

Objectives

In this thesis an example of an open storm water system from Augustenborg, Malmö, Sweden is studied. The purpose of this study is to investigate the storm water quality in

Augustenborg open storm water system and to compare it with the urban storm water quality as found by other studies. In addition to this, performance of green roof in Augustenborg on runoff quality with the passage of time is also investigated.

The study was done on small scale area where storm water system was only managed so sanitary waste water has not been discussed and only open storm water system was studied instead of conventional sewer system.

2. Background

2.1 Storm water systems and elements

Urban drainage

Human activity interacts the natural water cycle in two ways. One way is the abstraction of water for water supply and other way is by creating obstruction to the natural rainfall cycle through impervious surfaces. These two ways lead to the development of different drainage systems in urban areas, namely wastewater and storm water (Butler and Davis, 2004). Urban drainage systems handle these two types of water in order to minimize problems to human health and to the environment.

When rain falls on a surface it is either evaporated or infiltrated while rest water becomes runoff. In urban areas infiltration is very little as a result of large extension of more impervious surfaces. Infrastructures in urban areas obstruct infiltration and concentrates runoff (Villarreal et. al, 2005). The principles of how urbanization influences the urban water cycle are shown in figure 1.

The conversion of roof runoff into the waste water in terms of its entry into the sewer system means not taking advantage of this resource. The potential uses of storm water runoff from roofs may otherwise be irrigation, drinking water or different uses at household.

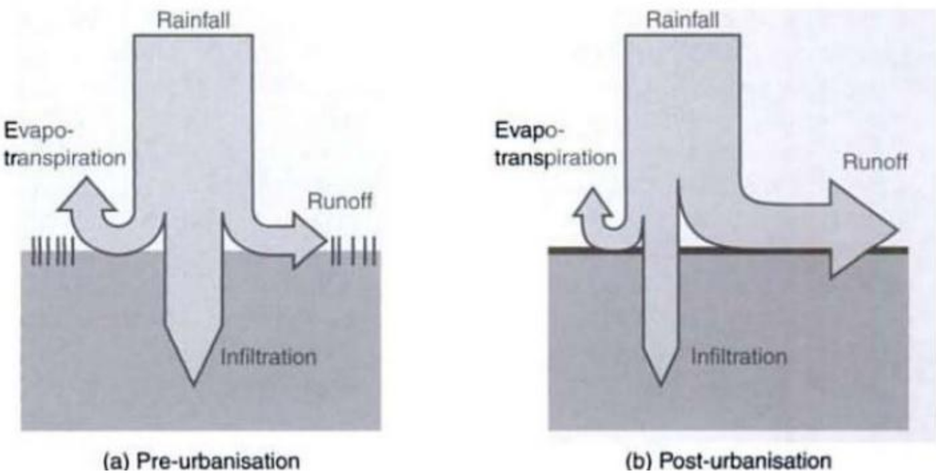

Fig. 1. Effect of urbanization on runoff (taken from Butler and Davis, 2004).

Drainage systems are categorized on base of their means of drainage. The means of drainage can be natural or conventional. Natural mean of drainage is the drainage through infiltration and storage properties of semi natural features. For example swales, ponds, detention basins, ground depression, pervious pavements etc. These will be discussed in detail later. Conventional mean of drainage is pipe drainage.

There are two types of piped storm water systems: Combined and separate. In the combined sewer system storm water and waste water are carried together in the same pipe. The pipe is normally loaded 10 % of the total volume and the rest is only filled in the wet weather. Thus most of the time the system is not used in its full capacity. This is the main drawback of combined sewer system. In addition, combined sewer overflow (CSO) is occuring in case of heavy storms to reduce load on the tretment plant. CSO diverts untreated waste water into natural water courses. It is diluted with storm water but still carrying gross pollutants into recipients. In cold climate during snow melt period CSO has been seen often (Thorolfsson, 2000).

The separate system consists of two separate sewers, storm water sewer and waste water sewer, usually laid side by side (Davis and Butler, 2004). The advantage of separate system is that the storm water does not mix with waste water and thus it can be discharged to the water body at any suitable place in the vicinity of the sewer system. Nevertheless, the storm water is now recognised as polluted because it is washing off the pollutants from the urban impermeable surfaces. As two pipes are required the system is more expensive than the combined sewer system. The cost however does not need to be doubled as both pipes may be laid in the same excavation. During dry weather the storm sewer is to large extent empty. There might be some inflitration or inflow from storm sewer to waste water sewer due to some crackes at waste water sewer joints or along the length. On the other hand the inflow to the sewer can be sometimes a result of wrong connections between storm sewer and wastwater sewer; for example it is found that many households connections of garden drains are made through manhole for waste water. There may also be illiegal connections from some households conecting household wastewater to storm water drains. In many European countries like Germany, France, UK the majority of sewer systems is combined (Butler and Davies, 2004). In Sweden about 15 % of the sewer systems is combined and the rest is separate (Berggren, 2007).

The separate storm water system can be conventional (piped), open, or a combination of those two. An open system may, among others, contain following elements: ponds, channels, wetlands, green roofs, green infiltration surfaces and porous paving. The common advantages of open systems are storm water treatment and slowing runoff thus minimising risk of flooding. The elements of open systems and other structural and non-structural measures aiming at improving water quality and minimising the environmental impact of the systems are called BMPs (best management practices). BMPs are considered as the sustainable urban drainage approaches in many countries (Scholes et. al, 2007).

Urban runoff quantity

The amount of runoff from a catchment depends upon its characteristics size of the area, land use, shape, slope, soil type and soil cover, roughness, wetness and storage (Butler and Davis, 2004). Among all of them the land use and size of the catchment are main important parameters to predict the runoff of a catchment.

The boundries of the catchment are fixed either by the field survey or elevation maps as the drainge takes place towards low level area. Land use can be categorized into impervious and perviuos areas (roads, buildings, parking area and green areas). The contribution of pollutant load in storm water runoff stems from the nature of the impervious surface. Impervious surface has many characteristics in terms of pollutant load

- Impervious surface contribute to hydrological changes that degrade waterways
- Prevent percolation and infiltration processing into soils.
- Serve as an efficient conveyance system for the delivery of pollutants into waterways (Arnold and Gibbons 1996).

Thus a small rainfall may cause high runoff as a result of impervious surfaces. This runoff will carry pollutants if they are not removed during street cleaning, by wind action or any other mechanical approach.

Climate is an important factor to determine the timing and magnitude of the water inputs to the surface of the water body (Moore, 1991). Storm water peak flow is an example of it and is determined by the intensity and duration of a rain event in the surrounding areas. In addition impervious surface, it is soil moisture condition, tributaries, wetlands and upstream lakes that play role in urban runoff.

The runoff coefficient expresses the percentage of rainfall that becomes runoff. The remaining part of water from a rainfall event infiltrates and evaporates . The runoff coefficient depends on land use type, soil type and vegetation cover (Table 1). It is always less than 1 (Svenskt Vatten P90, 2003). It is also effected by rainfall intensity, duration and antecedent conditions (Butler and Davis 2004; Svenskt Vatten P90, 2003). It depends on the slope of an area: For example for flat areas it is lower and for steep areas it is higher (Svenskt Vatten P90, 2003).

Table 1. Typical values of runoff coefficient in UK by Davis and Butler (2004).

Area Description	Runoff coefficient	Area Description	Runoff Coefficient
City centre	0,70-0,95	Parks and gardens	0,05-0,30
Suburban	0,50-0,70	Concrete and asphalt paving	0,70-0,95
Industrial	0,50-0,90	Roofs	0,75-0,95
Residential	0,30-0,70	Lawns	0,05-0,35

Table 1 shows the runoff coefficients for UK but this according to Svenskt Vatten (2003) can be used in Sweden as well.

The volume of a rainfall with depth *I* falling on an rectangular impervious area A with edges of impervious wall can be expressed as *Volume=I*A.* In a steady state conditions in time *t* the flow rate of this rainfall will be *Q=I*A/t*. As the area is not completely impervious and there will be some runoff losses in terms of infiltration and evaporation the runoff coefficient can be introduced and the formula will become as follows *Q=C*i*A* (Butler and Davis 2004; Svenskt Vatten P90 2003). This is often referred to as a rational formula.

Below, the elements of storm water systems, including swales, infiltration systems, porous surfaces, gully pots, above ground water storage facilities, constructed wetlands and green roofs are described.

Swales/Filter strips

Filter strips are the grass or vegetated strips of ground that storm water flows across and swales are the vegetated broad shallow channels for transporting storm water (Revitt et al., 2003). Both of these systems have potential to recharge ground water and pollutants removal but the swale has lower removal rate than the filter strips because filter strips has the higher hydraulic detention time. Further, swale has higher flow velocity and also require less space. Both systems are the common BMPs in cold climate to control storm water and melt water with the additional snow deposit advantage. However, swale reduces conveyance as a result of ice blocks at its inflow and outflow (Revitt et al 2003; Westerlund, 2007).

On the other hand pollutants removal efficiency of swale is positive co-related to the incoming pollutants mainly as a result of sedimentation of particles. The study of Bäckström

(2003) showed that during snow cover period pollutant removal rate of swale for TSS and total concentration of Cu, Pb, Zn was 78-99% at three different locations. He also showed in the same study that the dissolved Cu and Zn was washed away during snow melt while 30-40 % of Pb retained, as Pb has higher adsorbness. However, swale pollutant removal rate does not remain same all the time. Bäckström (2002) also showed that 45 % removal rate was reduced from rainy period to snow period as a result of reduced flow resistance and filtering ability because of the deterioration of vegetation layer during snow cover.

Infiltration systems

Soakways are the underground structures which are designed to soak the water in the ground through base and sides of the structure. They are normally hidden structures and are preferred due to les space coverage. Soakways also pose a potential risk to the aquifer as they let the water directly into the ground water.

Infiltration basins collect and keep surface water runoff and allow it to infiltrate through soil or constructed drain with gravel and sand filter beds (Revitt et al., 2003). According to Revitt et al. (2003) infiltration basins can be used in cold climate but the limitation is the reduced system performance during snow melt period when hydraulic capacity is lower and there is possibility of ice formation in the system.

Infiltration trenches are very similar to infiltration basin but they are designed in linear form filled with stone or rubble medium. Infiltration trenches are also similar to soakway but they provide more infiltration surface area and thus higher treatment efficiencies. The infiltration trench can also be laid out as a filter drain where storm water is not infiltrated into the ground but intercepted by a perforated pipe. The perforated pipe is laid out in the trench backfilled with gravel and the main purpose is to convey water to a desired outlet.

Porous surfaces

Porous pavement consists of layers of porous pavements, a sand layer or a granular filter, sub base layer and the filter fabric protecting the soil. All layers must be constructed properly to avoid fine particles from entering into the sub surface during construction phase. Porous pavement can reduce both the amount of runoff and pollutants. Porous pavement is a permeable pavement surface with an underlying stone reservoir that temporarily stores surface runoff before infiltrating into the subsoil. These kind of porous surfaces replace traditional pavement, allowing parking lot runoff to infiltrate directly into the soil and receive water quality treatment. However it is not recommended for heavy traffic areas because of potential of clogging, nor is it a good idea for storm water hotspots which generate high pollutants. Further their installation should be avoided at the area of low soil permeability, seasonal high ground water table, and areas close to drinking water supply wells. Porous pavement cannot be used in areas with high amounts of sediment in the storm water due to clogging of the pores (Butler and Davies, 2000).

Gully pots

Gully pots collect material from road runoff in the grit chambers. They retain not only the sediment but also other substances like metals and organic substances. The gully pots are connected either to the storm sewer or to the sanitary sewer. Gully pots are one of the most common BMPs (Karlsson, 2006). Vacuum cleaners are normally used to clean gully pots once or twice a year and removed materials are disposed to landfill.

Above ground water storage facilities

Ponds are of different types depending on their function. The examples of different type ponds are sedimentation basins, sedimentation ponds, detention ponds and infiltration ponds. The common processes taking place in ponds are sedimentation, uptake of substances by plants, bacterial decomposition of organic matter and chemical precipitation. Sedimentation is one of the most important mechanisms for pollutants reduction in storm water ponds as most of the pollutants are attached with solid even though chemical and biological processes also take place simultaneously. Particle size distribution is an important parameter influencing pollutant removal capacity in ponds. Many studies revealed that the major part of the particulate bound pollutants is attached with the smallest particles. To achieve as high as possible pollutant removal efficiency following factors shall be considered during design: Flow regime, capacity, and residence time. Improper design may lead to short circuiting of flow or creation of dead zones (Petersson, 1999).

Retention basins are ponds which always possess water and retain storm water during storm period. On the contrary, the detention basins are empty most of the year except in wet weather. Detention basins are less efficient in removing pollutants than retention basins (Revitt et al. 2003). Detention ponds can be used as snow deposit during winter but this causes problems during snow melt period when there is heavy load and they cannot retain water properly (Bakstrom and Viklander, 2000). Pettersson et al. (1999) in their study of retention ponds in Sweden showed that retention ponds effectively controlled pollution; However, during winters due to freezing conditions the amount of dissolved oxygen was reduced because of flow blockages and these in turn caused increased concentrations of heavy metals (Zn, Pb, Cu, and Cd).

Constructed wetlands

Wetlands are natural vegetated impounding systems. In storm water treatment wetlands the storm water runoff is stored above the permanent pool of water and is released to the recipient constantly after the rain event. In wetlands the pollutants are removed from water through various processes including adsorption, plant uptake, filtration, decomposition, adhesion. The water residence time in wetlands may vary between several days and several weeks. Generally the longer the residence time the higher pollutants removal rates.

Constructed wetlands are effective for flood control and also for removing pollutants. To remove coarser sediments that can deteriorate the performance of a wetland, a pre-treatment pond should be included before the wetland (U.S. EPA, 1999).

Green roofs

In this thesis green roofs are mainly considered as a storm water management measure.

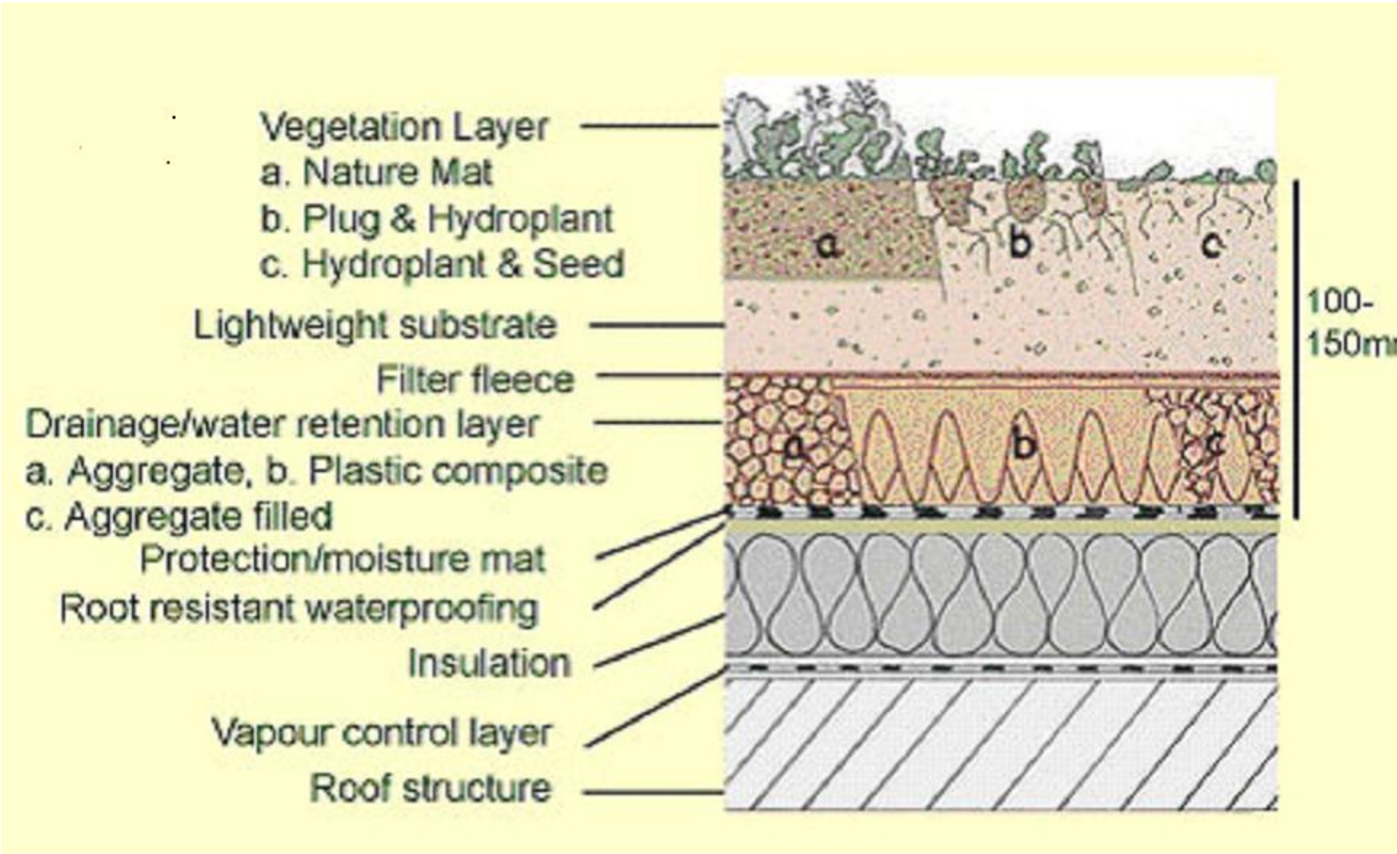

Fig. 2. Green roof structure (Blackdown Horticulture). Available at http://www.greenroof.co.uk/index.html#consultancy

The urban development results in establishment of more and more impermeable surfaces. This in turn increases urban storm water runoff. There are different approaches suggested and tested to cope with the growing problem of both urban flooding and impact on receiving waters. These approaches commonly referred to as SUDS (Sustainable urban drainage systems) and BMP's (Best management practices) have generally large space requirements. However, the available space is often limited in densely populated urban areas. The space that is often available is the roof space. Some of this space can be utilised for storm water management measures. It is shown that extensive green roofs can reduce annual runoff by 50 % (Villarreal and Bengtsson, 2005). Green roofs also contribute to increasing time of concentration and help to some extent reducing the load on storm water systems. In addition to this some studies also predict that due to global warming the occurrence of intense precipitation events may increase and in some areas may cause severe urban flooding (Arnell, 1999; Bates et.al., 2008). Green roofs may become a useful technology to reduce urban flooding.

Green roofs are complex layered structures (Fig.2). They generally consist of a water proofing membrane, root barrier layer, drainage layer, a filter fabric layer and finally the growing medium and plants.Water proof membrane prevents the moisture from entering the building. Root barrier layer prevents the roots from entering in water proof membrane and the roof deck. Filter layer prevents the soil particles to be washed away from the substrate medium and compromising with the drainage layer supports draining the excess water from the roof, soil substrate layer and vegetation layer.

The green roof are of two main types as suggested by the majority of studies: intensive and extensive. The intensive green roof is similar to a roof-top park consisting of large plants and shrubs and may be paved with walk ways established. The intensive green roof requires deeper substrate layers while extensive roofs are established with thin substrate layers. Extensive roofs are designed to be maintenance free. The vegetation on extensive roofs are typically ground covering such as sedums, moss and herbs. The definition of extensive and intensive substrate depths varies between different studies. For example a green roof of 100-150 mm thickness can be regarded as intensive or extensive by different authors (Berndtsson, 2010).

Except of playing an important role in storm water management green roofs may have many other advantages including the following: :

- Green roofs block solar radiation and enhance the thermal protections of the buildings;
- Green roofs improve the climate by reducing the heat island effect;
- Green roofs can be prime habitats for many plants and animals (including the protected species) and thus contribute to enhancing biodiversity;
- Green roofs reduce noise pollution;
- Green roofs contribute to mitigating air pollution.

The risks linked with the establishment of green roofs include:

- Green roofs can be source of pollutants that are released from soil, plants and fertilizers
- Green roofs may increase risk of fire during dry seasons
- Green roofs when improperly designed and managed can become unaesthetic.

Water retention capacity of green roofs depends mainly on the type of vegetation, substrate thickness, rain intensity and slope. Retention volume is inversely proportional to the slope and rain intensity in the initial dry weather conditions (Villarreal and Bengtsson, 2005), the greater the slope and rain intensity the lower will be retention volume. However some studies do not find significant influence of the roof slope on roof runoff. In water retention process water is held by in the substrate layer and then later a part of it drains and some part evaporate. Thickness of the substrate layer plays an important role in holding water. Thicker layer have more water holding capacity than the thin substrate layer (Teemusk and Mander, 2007).In addition to this the preceding weather conditions and the substrate moisture influence the green roofs water retention capacity. Green roofs can retain light rain or moderate rain depending on initial substrate moisture conditions.

2.2 Storm water pollutants

In the past storm water has been considered clean. That is why it was disposed of directly to the recipients wherever possible. With the passage of time as development progressed, the increased impervious areas raised the pressure on the recipients in terms of pollutants load and flooding. Subsequently infiltration to the ground was also reduced as a result of increased impervious surfaces. This further led to drying of small water courses which, in the period of dry weather, were mainly fed by ground water. In addition to this it was also realized in the later years that the storm water is a big source of pollution to recipients.

The storm water pollution load to the Swedish coastal waters was estimated to equal 140 tons of phosphorus and 710 tons of nitrogen per year corresponding to the 8 and 2% of the total pollutant load. The following estimates of heavy metals load to coastal waters are also made: 38 tons of lead and 30 tons of copper, 76 tons of zinc, 760 kg of cadmium and 2.4 tons chromium (Hogland et al, 1993). The emerging pollution leads to initiating the major rethink of the storm water pollution control. On site storm water solutions are promoted as having many advantages including reducing the storm water pollutant load to recipients (Larm, 1994).

Storm water carries the pollutants from the surface on which it travels and it is more polluted in urban areas than rural areas. Determination of sources of storm water pollutants is very complex: they are numerous and sometimes unknown. For example the wash off metals is characterized by following parameters: regional dust amounts, storm water intensities, duration of storm water events, duration of dry weather periods and the formation of the drainage surfaces (Xanthopoulos and Hahn, 1989). Larm (1994) described three basic parameters influencing compositions of runoff: type of the surface on which it travels, antecedent dry period and original pollution load in rainfall. Antecedent dry period is considered the key factor in determining the storm water pollutants deposited on the catchment surface available for wash off during storms (Lee et al., 2002; Soller et al., 2005). Anything that alters the chemical balance of our waterways may be detrimental for aquatic plants and animals. PH is actually an indicator of this imbalance. Sources of this imbalance are metal plating, printing/graphic industries, cement/concrete production, cleaners, and others.

The pollutants which are often investigated in storm water are nutrients, oils and grease, suspended solids, heavy metals, organic compounds, microbial contaminants. These are described below.

Nutrients

The primary nutrients are nitrogen and phosphorus. Nitrate enters the storm water from different land use activities. It comes from fertilizers, decomposition of natural rocks and soils, detergent used to wash car on the streets and from the animal faeces. Nitrogen (N) and phosphorus (P) released from the arable land in dissolved or particulate form not only degrade the soil nutrients stock and lower soil productivity (Pimentel et al., 1995), but also cause eutrophication in water bodies (Foy et al., 1995). Nitrogen in soil lies as NO3-N and NH4-N. Soil erosion as a result of heavy storm events are the main source of N and P. Erosion depends on the soil texture and its ability to resist whether phenomenon and storm strength as well. It has been found that the uncommon heavy storm events are the main cause of soil erosion (Hussein, 1996; Cai and Wu, 1998; Hollinger et al., 2001; Spaan et al., 2005). The N and P are the main nutrients that nourish the algal biomass in water. As to maintain the algal biomass for avoiding any nuisance total nitrogen should be less than 350 µg/l (Smith et al., 1999).

Excess nutrient levels can over-stimulate the growth of algae and other aquatic plants, resulting in unpleasant odour, unsightly surface scums, and lowered dissolved oxygen levels from plant decay. Nutrients are most likely to pose a problem in slow moving water such as lakes or sluggish streams. Nutrients indirectly are problematic in different way for example as nutrients support algae growth and some forms of algae are toxic to fish and other aquatic organisms and may even cause death in animals that drink affected water (Kovacic et al., 2000). Algae can also cause taste and odour problems in drinking waters, foul-smelling odour in ponds and lakes, and problems with clogged water intakes, drains, and pipes. Heavy loading of nutrients into slow-moving waters can adversely affect many beneficial uses of the water. Forms of nitrogen (ammonium), in combination with pH and temperature variations, can cause water quality problems and be toxic to fish. This process consumes large amounts of oxygen in the water and subsequently stresses or kills fish and other aquatic organisms when oxygen levels are reduced. Ammonia toxicity, due to nitrogen in its ammonium form, can harm fish and other aquatic organisms.

Fertilizers, animal wastes, failing septic systems, detergents, road de-icing salts, automobile emissions, and organic matter such as lawn clippings and leaves are all contributors to excessive nutrient levels in urban and agricultural storm water runoff.

Oils and grease

Oils and grease are common components of storm water runoff pollutants because their sources are abundant: streets and highways, parking lots, food waste, storage areas, heavy equipment and machinery storage areas, and areas where pesticides have been applied. The familiar sight of a rainbow-colored puddle or trickling stream in parking lots, driveways, and street gutters is a reminder of the presence of oils and greases in storm water runoff. Oils and greases can be petroleum-based such as in transport industry or food-related (such as cooking oils). Oil and grease are known to be toxic to aquatic organisms at relatively low concentrations. They actually form a film over water which spreads and make oxygen transfer difficult and toxic to aquatic ecosystem; they can coat fish gills, and clog drainage facilities (leading to increased maintenance costs and potential flooding problems).

Sediment/solids

Suspended solids are the largest pollutant constituents in storm water. They accumulate and have significant negative impacts on the environment, including: increase in turbidity, making it difficult for aquatic ecosystem to function normally; decrease in light for photosynthesis; contamination of gills in fish and aquatic species; reduction in spawning of fish and general survival; increase in the transportation of heavy metals, phosphorous and other pollutants through waterways as they attach to the sediment particles and harm water quality. The sources of sediment in urban run-off are numerous, including: sand and gravel storage, construction sites, unpaved areas, agriculture/livestock, and wash-off of dirt from paved surfaces. Sediment - often originating as topsoil, sand, and clay - is the most common pollutant in storm water runoff by volume and weight. Sediments are washed off paved surfaces and exposed earth during storms. Sediment may seem harmless, but it poses serious problems in the water. Sediment is of particular concern in fish bearing streams where it can smoother trout and salmon eggs, destroy habitat for insects (a food source for fish), and cover prime spawning areas. Uncontrolled sediment can also clog storm drains, leading to increased private and public maintenance costs and flooding problems. Cleared construction sites and exposed earth are generally the greatest contributors of soil particles in surface water and change the physical appearance of the water. Other sources include erosion from agricultural lands, application of sand and salts to icy roads, fallout from pressure washing and sandblasting operations, dirt from equipment and vehicles, and dirt and grit from parking lots, driveways, and sidewalks.

Heavy metals

The most common heavy metals in storm water are Lead, Zinc, Cadmium, Copper, Chromium and Nickel (Karlsson, 2006). Many studies agree that the sources of heavy metals are abundant and a single source cannot be associated with heavy metals. However, some typical relations between sources and metals can be established as of result of many experimental data. Typical sources of heavy metals are industrial wastes, solid wastes, landfill leachate, corroding metal pipes and storage tanks. Numerous metals are life essential micronutrients. However, excessive supply and persistent exposure to these metals may be dangerous to health (UNEP, 2006).

The fate of heavy metals in environment is characterized by the incorporating system. For example in the combined sewer system major part of the heavy metals first flow to the treatment plant and it is further transferred from an aqueous or suspended phase into the sludge. If the sludge is used as fertilizer to the agriculture land then these heavy metals also deposit as dry sludge or slag. On the other hand in separate sewer system a substantial part of the total mass flow of heavy metals is discharged into the receiving waters where the accumulation takes place in the solid phase of the sediments.

Heavy metals are normally present in storm water. They are not biodegradable and are harmful to the aquatic environment. Heavy metals show a distinct accumulation behavior on solid surfaces. Heavy metals in dissolved form in the storm water runoff are adsorbed on the solid surfaces (Kern et al., 1992) and are comparatively easy to determine. Rain water is slightly acidic which increases the solubility of heavy metals.

The toxicity and the negative environmental impacts differ between different metals. High exposure to lead may cause neurological damages which further lead to neurological diseases, loss of short memory, poor coordination and learning disabilities, low birth weight and poor immune responses. In adult it is also revealed that the lead exposure causes behavioral inhibition and also tooth decay (Masters, 1998, Gil et. al., 1996). High concentration of mercury is associated with nervous system damage, deformities in early exposure, partial blindness, muscles wasting, and low learning abilities, low coordination and low fertilities in males (Dickeman et. al, 1998). According to World Health Organization report Arsenic may cause cardiovascular disorder, skin related disease, kidney damage and peripheral neuropathy. Cupper is life essential but a high exposure may cause anemia, liver and kidney damages, stomach and intestinal problems. Improper amount of cadmium may cause renal dysfunction, kidney and liver failure, lungs cancer, bone abnormalities such as osteomalacia and osteoporosis as a result of long term exposure (BRF, 2005).

Organic compounds

Plant debris, food waste, and some chemical wastes fall into a category of water pollutants known as oxygen demanding substances. Such substances use dissolved oxygen in water when they decay or chemically react. If dissolved oxygen levels in water become too low, aquatic animals can become stressed or die. Salmon and trout are particularly at risk because they need high dissolved oxygen levels to live.

Animal wastes, food wastes, leaves and twigs, and other miscellaneous organic matter carried by storm water runoff into surface water can lead to reduced oxygen levels. Slow-moving waters are particularly susceptible to oxygen depletion because aeration of the water by turbulence is lacking. Therefore, oxygen that is depleted in slow-moving waters due to the presence of excess organic matter or unnatural chemical compounds is not replaced. Reduced oxygen levels in these waters are often particularly severe after a storm (Kohler et. al,2004).According to European water framework directive priority pollutants need to be focused in order to achieve good surface water quality (Bjorklund 2011). The priority pollutants list consist of five metallic compounds and the rest are 28 toxic organic compounds. Organic compounds have not been given proper attention in our society except some polycyclic aromatic hydrocarbons, aliphatic and aromatic hydrocarbons. It might be a result of lack of knowledge of their occurrence in products and thus low awareness of emissions of these toxic organic compounds into the environment. As they are very toxic to environment it is of prime concern to find their sources and do remedies to avoid their detrimental effects in ecosystems (Bjorklund, 2011).

Microbial contaminants

As the storm water passes through impervious surfaces it carries many human and non-human pathogenic bacteria. The degree of pathogens bacteria pollution is more or less directly proportional to the imperviousness of the surface. Makepeace et. al, (1995) revealed that the E-coli bacteria in the storm water from parking lot was as high as 50,000 Cfu/100ml. The animal traffic in parking area is believed to be source of microbial pollution as people leave dogs faeces and do not dispose them off. Ellis (2004) estimated that the dogs produce daily fecal 100-200 g/dog. On the other hand storm sewer system can be a source of this pollution due to several reasons like illicit connections, storm sewer leakage and domestic pets etc.

In table 2 the summary of typical storm water pollutants and their sources is presented.

Table 2: Storm water pollutant sources and their impact (Sources: Butler & Davies, 2000; Campbell *et al*, 2004; Harrison, 1990; Larm, 1994; Luker & Montague, 1994).

Sources	Pollutants	Potential impact on pollutants
Anthropogenic activities such as heating, Industrial pollution, Tire wear; road wear; lubricants; auto body and engine corrosion; brake linings; corrosion of road furniture and building materials; atmospheric deposition.	Heavy metals (Cd,Cu,Pb,Zn) and most reported metals (Co, Cr, Fe, Mn, Ni)	The speciation determines the toxicity and bioavailability of the metals; many metals have toxic effects on aquatic plants and animals
-Vehicles Fuel emissions, abrasion of tyres, corrosion of materials used in vehicle formation. Road pavements, brake linings. Erosion from construction sites, driveways and footpaths; car washing; corrosion of building materials; winter road maintenance; organic matter from plants and animals.	Suspended solids, heavy metals, organic compounds and sediments	Increased turbidity; reduced light penetration; interference with fish and aquatic invertebrates; important for transport of other contaminants through water systems.
De-icing activities in winter for snow melting (road salt)	Ions of (Ca,Cl, and Na) and small amounts of chromium and cyanide.	Potential ground water contamination.
Atmospheric deposition; degradation of organic material; animal and human waste; fertilizers and waste from gardens and parks.	Nitrogen and Phosphorus.	Eutrophication: excessive plant growth, which can choke streams and lead to fluctuations in dissolved oxygen levels; increase in algal blooms reduces the amount of light and oxygen in the water.
Spills and leaks of lubricants, petrol and diesel; road runoff; car parks; car washing.	Petroleum hydrocarbons (aliphatic and aromatic hydrocarbons), oil and grease.	Wide range of toxic effects, from less toxic to carcinogenic; may form emulsions and films on water surfaces, which reduces re-aeration and makes it difficult for animals and plants to breathe.
Incomplete combustion of organic material including vehicular emissions, oil, combustion, wood burning, waste incineration; lubricating oil; bitumen and asphalt; tire rubber.	PAHs.	Some of the PAHs are classified as carcinogenic, mutagenic, and teratogenic.
Animal and human faeces.	Bacteria, viruses, Fungi and particles with high biochemical oxygen demand.	May cause disease in plants and animals, including humans; concern for contact recreation, such as swimming.

2.3 Legislative Framework

Water Framework Directive is a legal regulation for all water management practices in European Community. It was initiated in the year 2000 and it regulates river basin management.

The overall objective of this framework is to acquire good ecological status and good water quality for surfaces water on catchment scale by the integrated river basin management (Scholes et al, 2007).

To achieve the objectives by 2015 it requires the implementation of Water Framework Directive with a program of measures by 2012.

Objectives are as follows:

- Prevention of further deterioration; protection and enhancement of status of aquatic ecosystem and the water needs of terrestrial and wetland ecosystem.
- Sustainable water use based on the long term protection of existing water resources.
- Enhancement of the protection and improvement of the aquatic environment.
- Ensuring the progressive reduction of pollution of groundwater.
- Contribution to mitigate the floods and droughts (Scholes et al., 2007).

According to Scholes et al. (2007) urban runoff quality mainly affects the aquatic ecosystem. As the BMPs are considered better approaches than the traditional approaches so WFD also supports them.

In Sweden there is no legislation specifically about storm water treatment (Skibicka, 2003). However by the collaborations of municipalities and the Government agencies there are environmental fundamental rules in the environmental code (1998:808). Storm water treatment is regulated by the Swedish environmental code (1998:808) which came into force in 1st January 1999. According to Skibicka (2003) road administration and county administration prepared the list of Protective measures to avoid recipients along the road network from being polluted by runoff (Skibicka ,2003). The Stockholm city has a policy of runoff treatment for the roads over 20,000 vehicles/day.

The definition of waste water in environmental code 9.2:

1. Discharge water, sewage or other liquids with impurities.
2. Water which is used for cooling.
3. Diverted water used to drain the public land which is part of detailed development but not the specific property.
4. Water that is used for the drainage of a burial ground (Skibicka, 2003).

According to the section 3 it is clear that storm water from public places is also waste water and its discharge is a hazardous activity. Thus storm water should be dealt under same provisions (rules) as the waste water. In addition to this the chapter 9§7 in the code states ”Waste water should be treated in a way that it may not cause any detrimental effect on the environment. Appropriate sewerage systems should be applied for this purpose”.

3. Methodology

3.1 Study site description

Augustenborg is an inner-city high density housing district suburb of Malmö, Sweden. It is a typical residential area with prevailing apartment houses and small commercial and service utilities. However, through the area runs a major road (Ystadsvägen, Malmö) with an average daily traffic density of 24200 cars with the share of heavy vehicles being 7% (measurements and estimates of year 2010) (Malmö municipality, personal communication).

Until late 1990s a combined sewer system has been used to handle storm water runoff. However combined sewer system could not handle the heavy storm events and it resulted in flooding in basements and garages of residents. The major property owner in this area Malmo municipal housing (MKB) together with Malmo Water and Waste Water Works suggested to construct an open storm water system to avoid flooding risk (Villarreal et al., 2004). Thus an open storm water system was constructed during December 1999 and summer 2000. En element of the open storm water system in Augustenborg – a wet pond – is shown in picture 1.

Picture 1: Wet pond in Augustenborg.

Open storm water system in addition to other advantages, proved cheaper than the conventional sewer system provided available space in Augustenborg. Bengtsson et al. (2004) simulated a conventional sewer system as a part of the combined sewer system instead of an open storm water system. He considered a return period 5-10 years with a maximum flow velocity of 1.5 m/s and minimum concentration time of 10 min. He discovered that a pipe network of total length 295 m and concrete pipes with dimensions between 250 and 525 mm will be required for the area (Bengtsson et al., 2004) which is more expansive than the open storm water system.

One of the obstacles towards establishing an open storm water system was the limited space as the land owners did not want their property to be affected under this development. Therefore green roofs were established as a part of the storm water management system. Green roofs help to attenuate the runoff and create aesthetic values in the area. Green roofs were not bound to specific vegetation as different types of green roof covers and different vegetation were used for the green roof construction. The idea was to use the vegetation which can sustain on less water for example sedum, mosses and grasses. The major substrate used on green roofs in Augustenborg is 3 cm thick soil mixture of clay 5 %, crushed lime stone 5 %, crushed ceramic roof tiles 43 % and 10% organic matter (Bengtsson et al., 2004). Bengtsson et al. (2004) performed study on hydrological function of the extensive green roof in Augustenborg. The results of his study showed that the green roofs reduced 50 % of the runoff. Monthly precipitation, runoff, and evapotranspiration which were analyzed are given in Table 3 below. The measured daily runoff was always less than the precipitation event except for few days when soil in the roof reached its field capacity. In such a situation, runoff was equal or close to precipitation. It was because the soil pores were filled with water and had no capacity to retain further coming water. The study confirmed the ability of the soil on the roofs to store the water; for instance for 13 mm rainfall on a dry roof only 1 mm runoff was generated. It can be concluded from those studies that the green roof can detain and reduce the runoff; moreover, the runoff in many cases does not occur until the soil reached the field capacity (Bengtsson et al., 2004).

Table 3. Monthly water balance for extensive green roof in Augustenborg and the runoff for small water rural basin for 12 months (Bengtsson et al., 2004).

Month	Precipitation (mm)	Runoff (mm)	Evapotranspiration
August-01	89	48	41
September-01	110	76	34
October-01	43	17	26
November-01	50	29	21
December-01	37	25	12
January-02	76	62	14
February-02	69	56	13
March-02	29	13	16
April-02	28	5	23
May-02	52	13	16
June-02	64	8	56
July-02	58	26	32
12 month	705	378	327

The other major elements of Augustenborg open storm water system are surface channels (Picture 2), ponds, wetlands, swales and green infiltration surfaces. In the downstream of Augustenborg open storm water system there are school buildings, swale, parkland and a pond. The parkland helps to reduce runoff by infiltration in case of heavy storms. In the parkland small area has been meandered as swale which leads to the last pond of the Augustenborg system and further towards the inlet of city storm water sewer.

Most upstream area has commune offices, paved yard with cobblestones and car parking area. There are two BMPs elements in this area; green roofs and a pond complex. The green roofs cover 31% of the upstream area and is able to retain 10 mm rain before it is released (Begtsson 2004). The second BMP element in this area is, a small pond, actually located in the upper reach of main surface channel. This pond is of round shape with an outlet structure consisting 12 rounded weirs on both sides of the upper reach of main surface channel. There are two dry ponds in immediate downstream area. These ponds take the runoff from adjacent buildings and thus regulate the water in the main channel by some orifices arrangement.

Main channel takes water from upstream and from its surrounding area either through dry and wet ponds or through small storm drains. A small wetland runs along the main channel. Wetland regulates the water into the main channel via round orifices with the weir. The wetland acts as a detention system. Water is evaporated following the dry period. The main channel is further connected with a downstream two-courtyard-ponds-system. The water from open channel flows down to the two-courtyard-ponds. These two ponds are connected by a somewhat meandering open channel. The water is circulated between the ponds and aerated. If the water level becomes too low the additional water is provided to the two-pond-system from mains supply. It is done due to aesthetical reasons and to avoid drying of the ponds.

3.2 Methodology of sampling and analyses

To assess the water quality in an open storm water system and in the runoff from green roof, four water samples were collected after four different rain events during the autumn 2010 from the following points: rain water sample at the roof, runoff from a green roof through a plastic pipe, sample from surface channel in the residential area and a sample from a pond located at the end of the open storm water system in Augustenborg (Figure 3). The samples were collected after four different precipitation events; on 19 October, 26 October, 04 November and 10 November 2010. Samples were taken manually, after a rain event. Bulk rain water samples (at sampling point 1 or MP1) and green roof runoff water sample (sampling point 2 or MP2) were collected. Grab storm water samples were taken from the channel and the pond (sampling point 3 or MP3 and sampling point 4 or MP4 respectively).

Picture 2: Open channel in Augustenborg (sampling point 3).

The studied vegetated roof plot from which sample was taken is 1.25 m wide and 4 m long, sloping 2.6 %. It was fertilized during spring 2001 and spring 2002 and there was no fertilization since 2003 (Czemiel Berndtsson, 2008).

Rain water and green roof runoff were collected in HDPE containers. The rain water HDPE container was with an open water catching surface of 0.1 m² with 5 liter capacity. The volume of container for green roof runoff was 30 l and it was connected to a roof drain through a plastic pipe. Before each sampling containers were rinsed with rain water and distilled water. Immediately after a rain event a rain water sample and green roof water sample were collected in 100 ml HDPE bottles. Grab storm water samples from the pond and the channel were collected also in 100 ml HDPE bottles. After being collected samples were delivered to the laboratory for analysis.

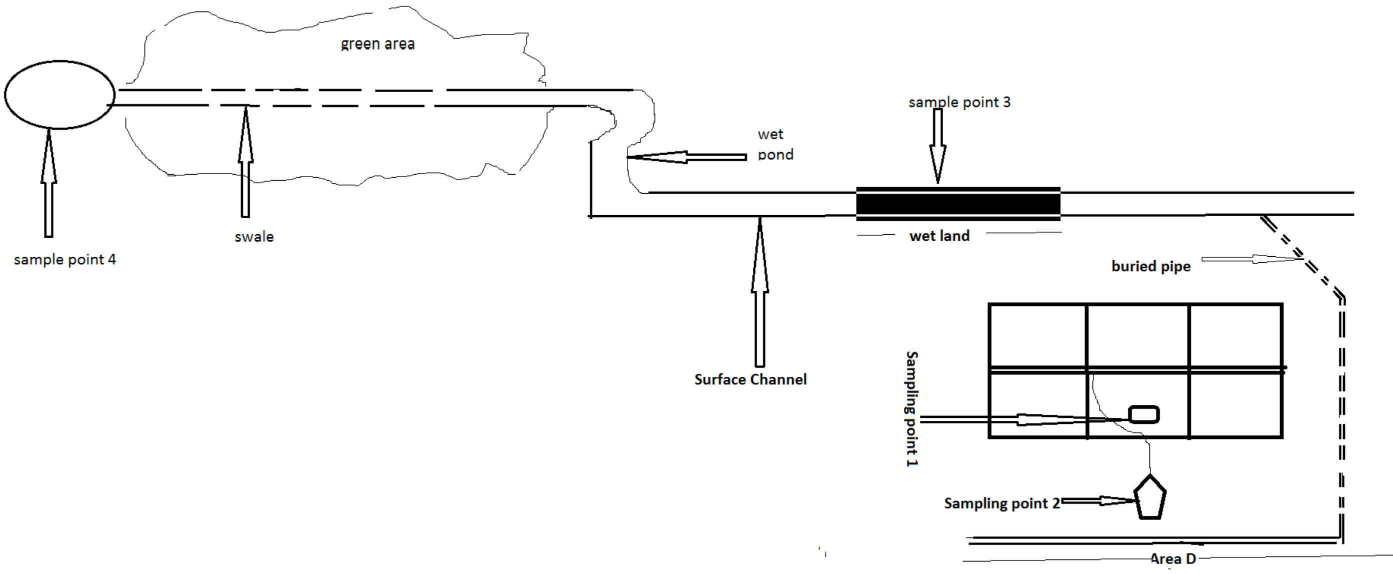

Fig. 3. Schematic representation of Augustenborg open storm water system with sampling points.

Sampling bottles (300 ml) were new. From each sampling point one plastic bottle was filled by submerging in the water. All samples were analyzed against nutrients and heavy metals. All the Samples were analysed for potassium (K), nitrate nitrogen (NO3-N), total nitrogen (Tot-N), phosphate phosphorus (PO4-P), total phosphorus (Tot-P), and dissolved organic carbon (DOC), and following heavy metals Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, Pb, Zn.

Samples were analysed for metals with the optical ICP AES technique using a Perkin-Elmer OPTIMA 3000 DV instrument; analyses were performed following the instrument manuals; Samples were analysed for NO3-N nitrate nitrogen according to ISO 13395 and PO4-P phosphate phosphorus according to ISO 15681-1 with detection limit (DL=1 µg/l); for Tot-P (DL=8 µg/l) with the optical ICP AES technique using a Perkin-Elmer OPTIMA 3000 DV instrument; for Tot-N (DL 5 µg/l) with Tot-N measuring unit TNM-1 from Shimatzu.

Methodology of load calculations

Loads of contaminants from green roofs and from rainwater per unit area are also calculated. This is done using measured average concentrations of studied compounds during autumn 2010 and the precipitation data for autumn 2010 as recorded by SMHI at the Malmö metheorological station. The Autumn season is defined here as the period between 1^{st} September and 31^{st} November. Loads of contaminants per 1 m^2 surface area in precipitation during the whole Autumn season are calculated by multiplying an average concentration of the substance as measured in precipitation (mg/l) and the amount of precipitation falling on $1m^2$ during months of September, October and November.

Note that precipitation data is in mm: 1 mm rainfall on one square meter area corresponds to 1 l.

The contaminants loads in green roof runoff are calculated accordingly however with regard given to a fact that on annual basis only 50% of the rainfall creates runoff while the rest of precipitation either absorbs or evaporate from the surface (see table 1, as found by Bengtsson et al., 2004). It is assumed that here that runoff volume reduction as compared with precipitation volume is 50 % also during the Autumn season.

4. Results and discussion

Bulk samples of rainwater, runoff from the vegetated roof, storm water runoff in open channel and runoff collected in the pond were analyzed for potassium (K), nitrate nitrogen (NO3-N), total nitrogen (Tot-N), phosphate phosphorus (PO4-P), total phosphorus (Tot-P), dissolved organic carbon (DOC) and heavy metals (Cd, Cu, Mn, Zn, Pb) in Autumn 2010. These results are presented in table 4 and later discussed under following three categories:

4.1 Evaluation of the green roof influence on runoff water quality with the passage of time. Load of contaminants in rain water and green roof runoff.
4.2 Comparisons of water quality between rain water, storm water quality in green roof runoff, open channel, and pond in Augustenborg open storm water system.
4.3 Comparison of the findings of this study with literature.

Table 4. Measured average storm water pollutant concentrations in Autumn 2010 from Augustenborg, data in mg/l .

	Cd	**Cu**	**K**	**Ni**	**Pb**	**Zn**	**TOT-P**	**PO_4-P**	**TOT-N**	**NO_3-N**	**DOC**
MP1 19/10	0.00008	0.0054	0.1	0.0006	0.0025	0.033	0.01	0.00	3.8	1.75	1.2
MP1 26/10	0.00002	0.0017	0.1	0.0002	0.0002	0.008	0.01	0.00	0.6	0.17	0.4
MP1 4/11	0.00002	0.0019	0.2	0.0003	0.0005	0.007	0.01	0.00	2.2	0.75	0.7
MP1 10/11	0.00004	0.0057	0.2	0.0016	0.0004	0.031	0.02	0.00	3.3	1.54	2.6
Average MP1	**0.00004**	**0.0036**	**0.1**	**0.0007**	**0.0009**	**0.020**	**0.01**	**0.00**	**2.5**	**1.05**	**1.2**
MP2 19/10	0.00003	0.0311	1.4	0.0017	0.0005	0.049	0.24	0.16	3.6	0.04	18.1
MP2 26/10	0.00000	0.0061	0.8	0.0005	0.0004	0.005	0.08	0.00	0.8	0.02	17.5
MP2 4/11	0.00001	0.0084	1.1	0.0009	0.0008	0.008	0.08	0.00	0.9	0.04	19.2
MP2 10/11	0.00000	0.0126	1.0	0.0011	0.0014	0.007	0.09	0.00	0.5	0.04	13.7
Average MP2	**0.00001**	**0.0145**	**1.1**	**0.0010**	**0.0008**	**0.017**	**0.12**	**0.04**	**1.5**	**0.03**	**17.1**
MP3 19/10	0.00003	0.0029	3.7	0.0009	0.0001	0.040	0.25	0.18	2.8	1.27	8.9
MP3 26/10	0.00001	0.0030	2.6	0.0005	0.0002	0.019	0.06	0.00	0.5	0.00	11.2
MP3 4/11	0.00001	0.0031	5.8	0.0008	0.0003	0.011	0.34	0.22	0.7	0.01	14.6
MP3 10/11	0.00023	0.0159	18.0	0.0047	0.0012	0.107	4.09	4.10	4.1	0.82	15.0
Average MP3	**0.00007**	**0.0062**	**7.5**	**0.0017**	**0.0004**	**0.044**	**1.19**	**1.12**	**2.0**	**0.52**	**12.4**
MP4 19/10	0.00001	0.0027	4.2	0.0015	0.0002	0.013	0.06	0.00	2.3	1.05	8.8
MP4 26/10	0.00000	0.0028	6.0	0.0009	0.0002	0.010	0.14	0.00	1.7	0.00	12.5
MP4 4/11	0.00000	0.0018	7.2	0.0015	0.0004	0.010	0.16	0.00	1.8	0.02	15.9
MP4 19/10	0.00000	0.0019	5.4	0.0013	0.0005	0.010	0.08	0.00	2.0	0.14	14.6
Average MP4	**0.00000**	**0.0023**	**5.7**	**0.0013**	**0.0003**	**0.011**	**0.11**	**0.00**	**1.9**	**0.30**	**12.9**

In table 4 the measured concentrations of studied compounds have been presented and different substances show different behavior. For example Cd and Pb measurements are very similar in all samples which ensures trend of Cd. Cu concentrations show variability. K has the large fluctuation and variability in different samples. Ni shows less fluctuation and thus small variability. Zn concentration shows the variability. PO_4-P, Tot-P, Tot-N , NO_3-N and DOC show the variability.

4.1 Evaluation of the green roof influence on runoff water quality with the passage of time

Results of concentration measurements of studied substances in roof runoff and rainwater during five different seasons (Autumn 2003, Spring 2005, Autumn 2006, Spring 2007 and

Autumn 2010) are presented in figures (1-12) below. The results for Autumn 2003, Spring 2005, Autumn 2006 and Spring 2007 are taken from the study done by Berndtsson (2008) whereas Autumn 2010 is the current study.

Measured concentrations of studied compounds in rainwater (input) and roof runoff (output) water are compared. After water passage through the vegetated roof an increase of concentration is observed for PO4-P, Tot-P, K, and DOC during Autumn 2010 just like the previous studies. PO4-P increases about 10 times in spring seasons and more than 20 times in autumns during 2003, 2004, 2005 and 2007 (Fig. 4). No PO4-P is detected in rain water during autumn 2010; PO4-P found in green roof runoff during Autumn 2010 was substantially lower than the previous studies. Tot-P increases 5 to 8 times in springs 2005, spring 2007 whereas more than 10 times in autumns 2003, 2006 and 2010, however the average concentration of total phosphorus in green roof runoff during Autumn 2010 was substantially lower than in previous seasons (Fig. 5). Potassium (K) increases about 10 times in springs 2005, 2007 and autumn 2010, 20 times in autumn 2006, but much more in the first studied autumn 2003 (Fig. 6). The findings show that the amount of potassium released from green roof with runoff water is decreasing with time and is in Autumn 2010 about one third of what it was in studies from 2005, 2006 and 2007. Concentrations of PO4-P, Tot-P, and K in water after passing through green roof are still higher than concentrations in rain water but lower than found in roof runoff in previous studies. DOC concentration in roof runoff is 15 times higher than rainwater during autumn 2003 and 4 times during the autumn 2006; they are 19 times higher in spring 2005, and 11 times during the spring 2007 season (Fig.7). DOC concentration is 14 times higher in autumn 2010 just very close to the initial study Autumn 2003.

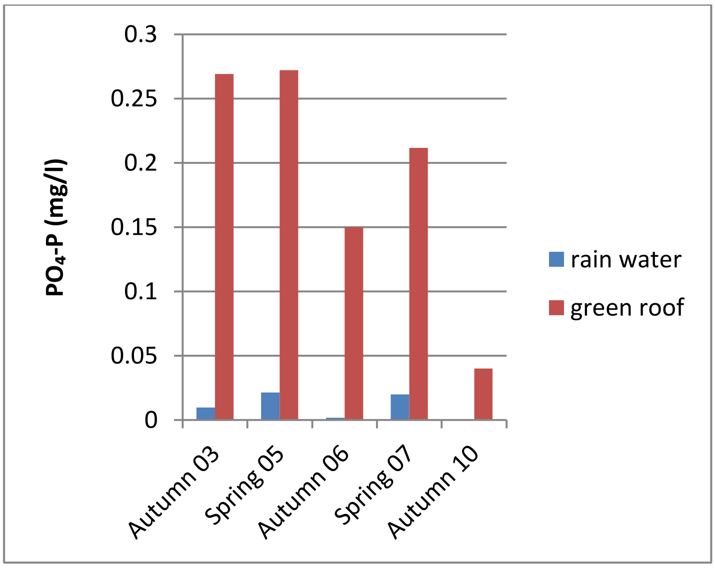

Fig. 4. Average concentration of phosphate phosphorous in rain water and roof runoff

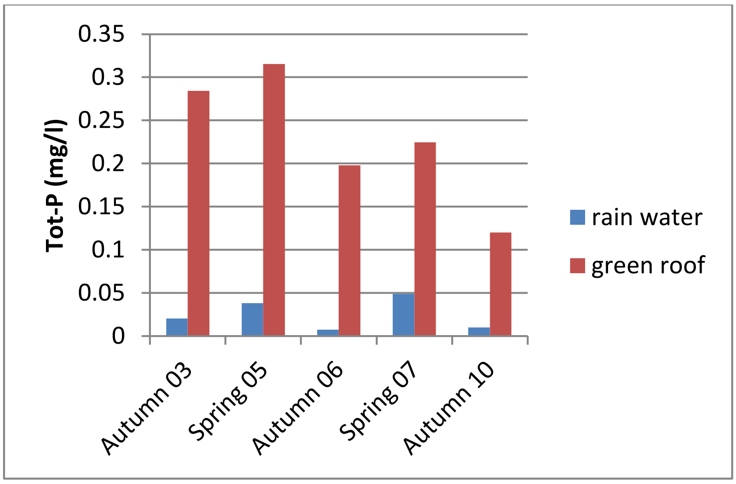

Fig. 5. Average concentration of total phosphorus in rain water and roof runoff in mg/l

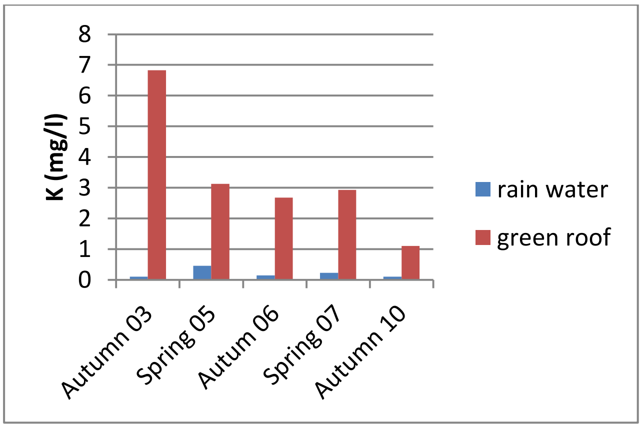

Fig. 6. Average concentration of potassium in rain water and roof runoff in mg/l

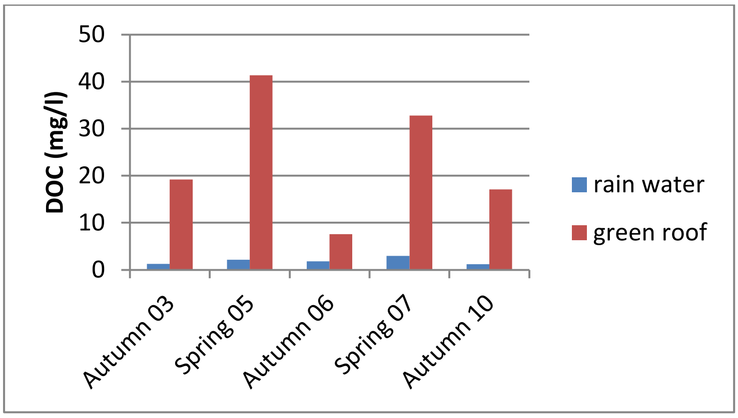

Fig. 7. Average concentration of DOC in rain water and roof runoff in mg/l

A substantial decrease of NO3-N concentrations was observed after water passed through the green roof (Fig. 8). The decrease is about 26 times in autumn 2003, and 19 times in autumn 2006 seasons and 14 times in Spring 2005, and 5 times in Spring 2007; however, in

Autumn 2010 there is a large (35 times) decrease of nitrate nitrogen concentration comparing rain water and green roof runoff. The results show that the green roof has the ability of lowering the water content of nitrate nitrogen and this ability remains during different seasons and is not reduced by the roof aging. Tot-N decreases somewhat in roof runoff comparing with the rain water concentrations (Fig. 9).

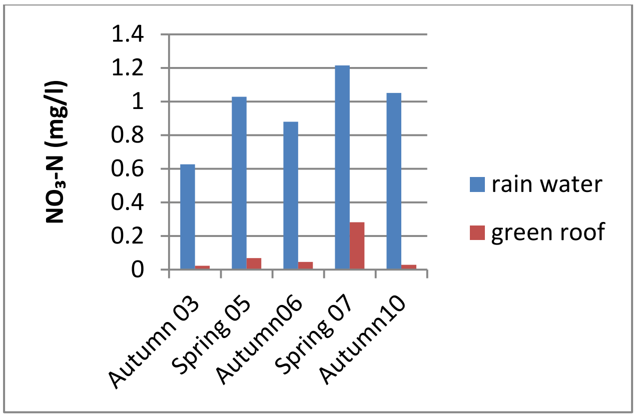

Fig. 8. Average concentration of nitrate nitrogen in rain water and roof runoff in mg/l.

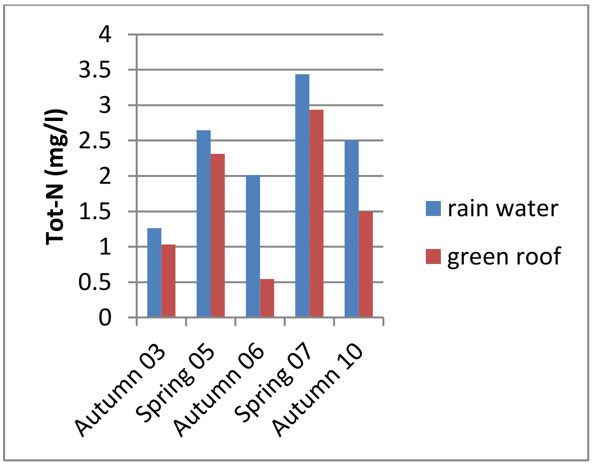

Fig. 9. Average concentration of total nitrogen in rain water and roof runoff in mg/l.

Amounts of Cd (Fig. 10) and Pb (Fig. 11) decrease while passing through the green roof – the concentrations of these metals are less in green roof runoff than in precipitation water. In the first study during autumn 2003 Cd have not been detected at all, however, this may be due to a different method of analyses that was applied then. During spring 2005, autumn 2006 and spring 2007 the decrease of Cd is only 1-2 times comparing rain water and green roof runoff; However, in autumn 2010, 4 times decrease is observed.

In autumn 2003, Pb concentrations in roof runoff are 7.5 times less than in precipitation; during Spring 2005 Pb is not at all detected in green roof runoff. Studies performed in 2006, 2007 and 2010 show that lead concentrations in green roof runoff are somewhat less than in precipitation.

There is no data available for Ni concentration on the study site during 2003 and 2005. The amount of Ni during autumn 2006 is somewhat less in green roof runoff water than in precipitation (Fig. 12). During spring 2007 the concentration of Ni increases about 3 times comparing between rain water and green roof runoff. In autumn 2010 nickel concentration in runoff from green roof is somewhat higher than in precipitation.

The concentration of Cu is substantially higher in green roof runoff than in precipitation. The results show that copper concentrations in green roof runoff are very similar in all studied autumn seasons and do not change with the roof age. Copper concentrations measured in roof runoff during spring seasons are substantially higher than in autumn seasons. The results show that zinc concentrations in rain water and green roof runoff water are very similar, with exception of spring 2005 (Fig. 14). In autumn 2010 the average zinc concentrations in runoff water are for the first time less than concentration in rain water.

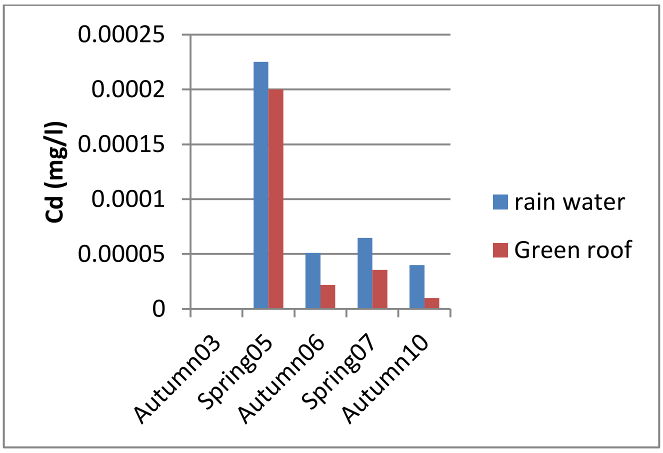

Fig. 10. Average concentration of cadmium in rain water and green roof runoff in mg/l.

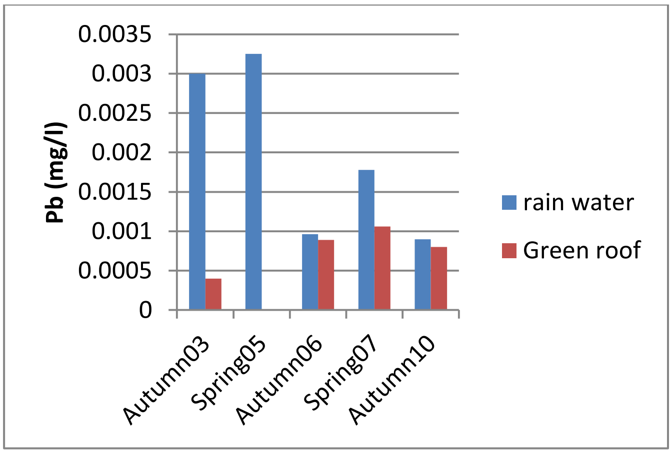

Fig. 11. Concentration of lead in rain water and green roof runoff in mg/l.

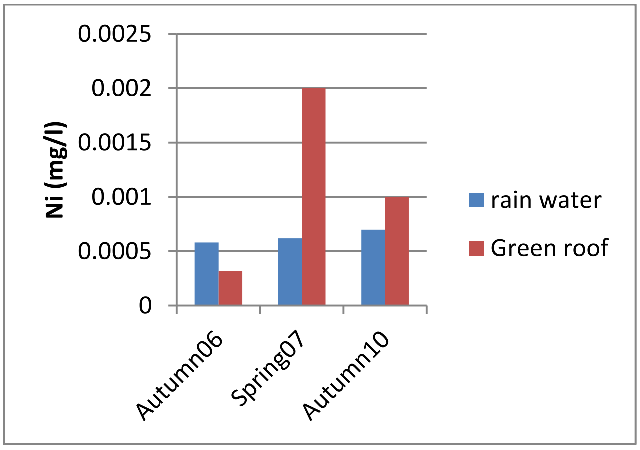

Fig. 12. Average concentration of nickel in rain water and green roof runoff in mg/l.

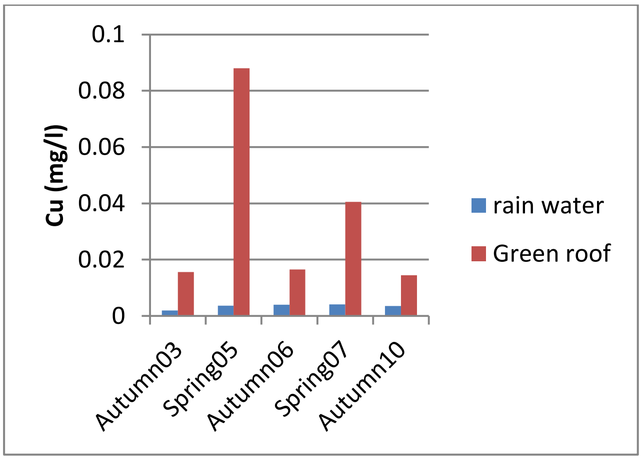

Fig. 13. Average concentration of copper in rain water and green roof runoff in mg/l.

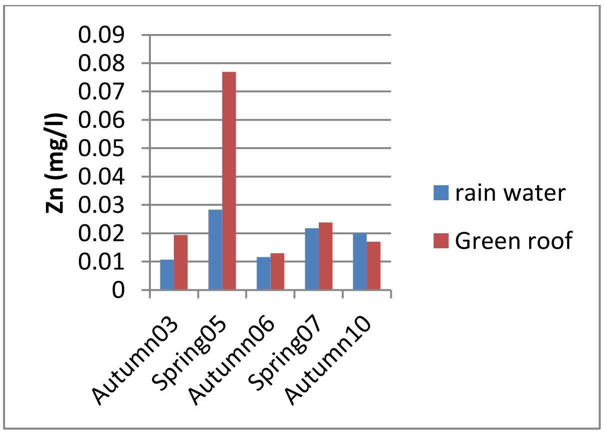

Fig. 14. Average concentration of zinc in rain water and green roof runoff in mg/l.

Load of contaminants in rain water and green roof runoff

The following precipitation data for Malmö was gathered from SMHI (2010): September 114 mm, October 60 mm, and November 54 mm. The sum of the monthly precipitation gives 228 mm and is used in further calculations as the total precipitation in autumn 2010. The comparison of loads of contaminants in rain water and loads of contaminants in green roof runoff gives different results than the comparison of respective concentrations. This is due to the fact that the amount of green roof runoff is less than the amount of precipitation, here assumed as 50% less (see discussion in section 3.3).

Table 5. Pollutants load in rain water and in green roof runoff in Autumn 2010.

	Cd	Cu	K	Ni	Pb	Zn	TOT-P	PO_4-P	TN	NO_3-N	DOC
Load in rain water (mg/m2)	0.005	0.41	11	0.08	0.10	2.2	1	0	285	120	137
Load in green roof runoff (mg/m2)	0.001	1.65	125	0.11	0.09	1.9	14	5	171	3	1949

Comparing loads of contaminants in rain water and in green roof runoff water from the surface of $1m^2$ during autumn 2010 shows that the green roofs contaminates the storm water with phosphorus, potassium, organic carbon and to some extent with copper. The loads of nitrogen are substantially less in green roof runoff than in rain water. The loads of studied heavy metals are generally the same in rain water and green roof runoff water with the exception of copper.

4.2 Comparisons of water quality between rain water, storm water quality in green roof runoff, open channel, and pond in Augustenborg open storm water system

The average concentrations of pollutants in samples of rain water, green roof runoff, storm water in an open channel and a pond are presented in figures 15-22 below.

The concentrations of Tot-P and PO4-P (Fig. 15) have been found largest in storm water runoff in surface channel. This may be a result of the pollutants washed off pollutants from the nearby surfaces: pavements, road, yard. The pollutants are dust, debris, animal feces and, most dominately, shreded leaves. The results show that phosphorus concentrations in green roof runoff are substially less than found in storm water in the open channel. Beside, almost all phosphorus is found in dissolvable form which may suggest that the source is fertiliser or fertiliser-enriched soil used in gardening.

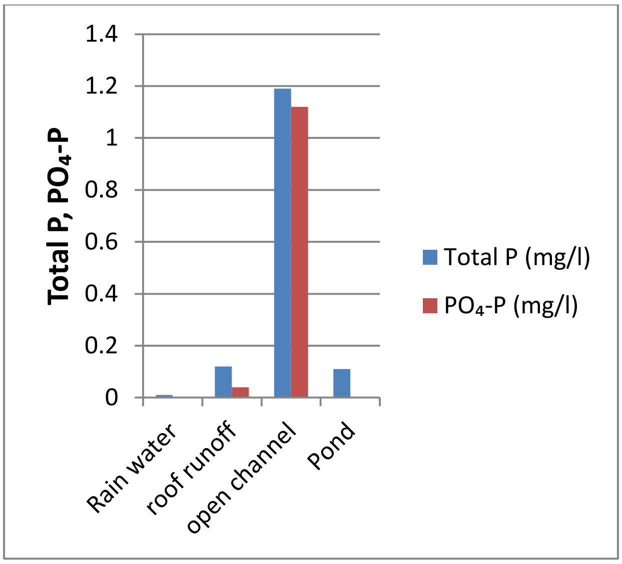

Fig. 15. Average concentrations of Tot-P and $P0_4$-P in rain water, roof runoff, open channel and pond in mg/l.

The concentration of total nitrogen (Fig. 16) in green roof runoff water is somewhat less than in storm water in the open channel and pond which in turn is still lower than concentration in rain water. Nitrogen in nitrate form is found in very low concentrations in green roof runoff and is still less in storm water in the open system than in rain water. The concentration of dissolved organic carbon (Fig. 17) in green roof runoff is somewhat higher than in storm water in the open channel and the pond. It is also found that storm water contains substantially larger amounts of dissolved organic carbon than rain water.

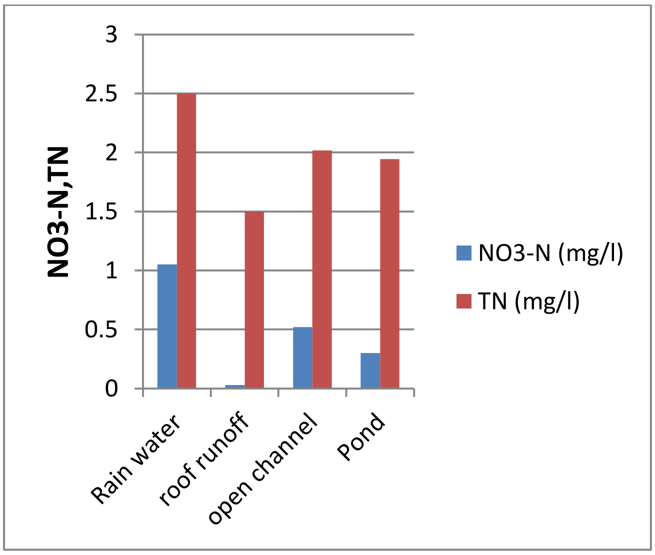

Fig.16. Average concentrations of NO3-N and Tot-N in rain water, green roof runoff, open channel and pond in mg/l.

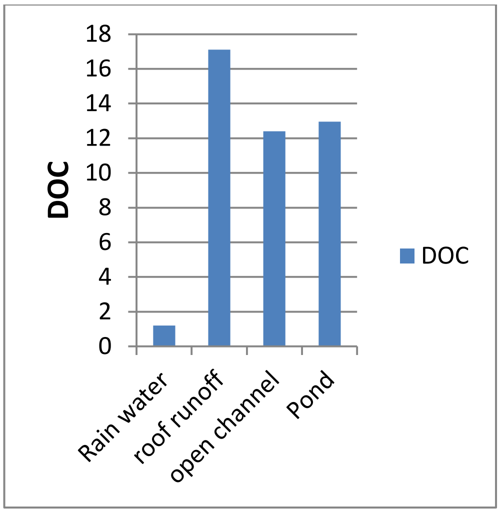

Fig.17. Average concentrations of DOC in rain water, green roof runoff, open channel and pond in mg/l.

The highest concentration of copper is found in green roof runoff (Fig. 18). The copper concentraitions found in rain water and storm water in pond were similar while storm water in open channel has a slightly higher copper content. The higher amount of copper found in green roof runoff maybe a result of copper presence in the soil.

The concentration of nickel is similar in rain water and storm water at all three sampling stations (Fig. 18).

Potassium is present in rain water in very small amounts (Fig. 19) and is found in substantially higher concentrations in storm water in open channel and pond. During present study the potassium concentration in green roof runoff was more than in rain water but much less than in storm water runoff in the open system.

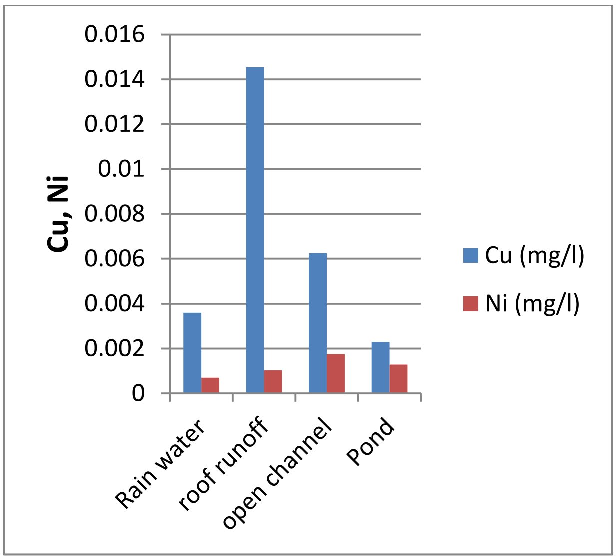

Fig.18. Average concentration of copper and nickel in rain water, roof runoff, open channel and pondin mg/l.

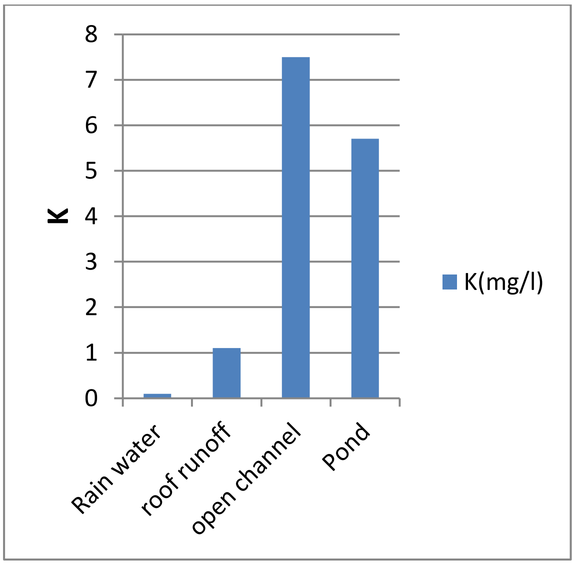

Fig. 19. Average concentrations of potassium in rain water, roof runoff, open channel and pond in mg/l.

The highest concentration of cadmium (Fig. 20) is found in storm water in the open channel. Cadmium concentrations in storm water in pond and green roof runoff are comparable and less than concentrations found in rain water. This study found that the largest lead concentrations were in rain water and all storm water samples showed in comparison smaller lead concentrations: somewhat smaller in green roof runoff and about half as large in storm water in open channel and pond (Fig. 21). The concentrations of zinc in storm water in open channel were twice as high as in rain water (Fig. 22). The concentrations of zinc in green roof runoff and storm water in open pond were somewhat less than the concentrations in rain water.

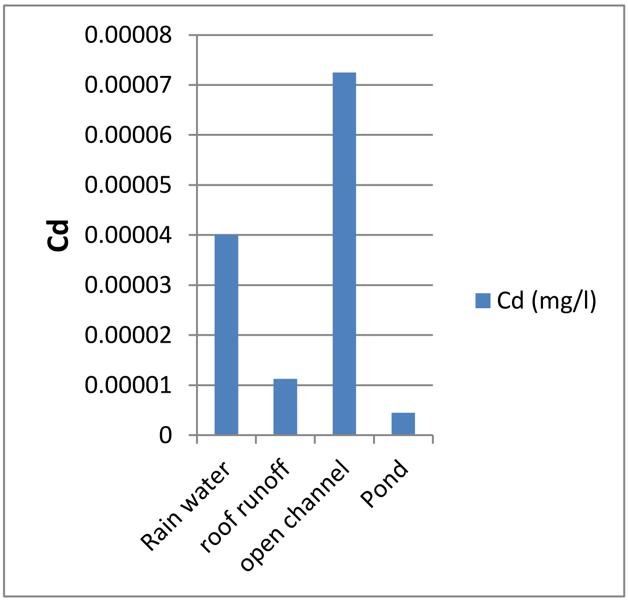

Fig. 20. Average concentrations of cadmium in rain water, roof runoff, open channel and pond in mg/l.

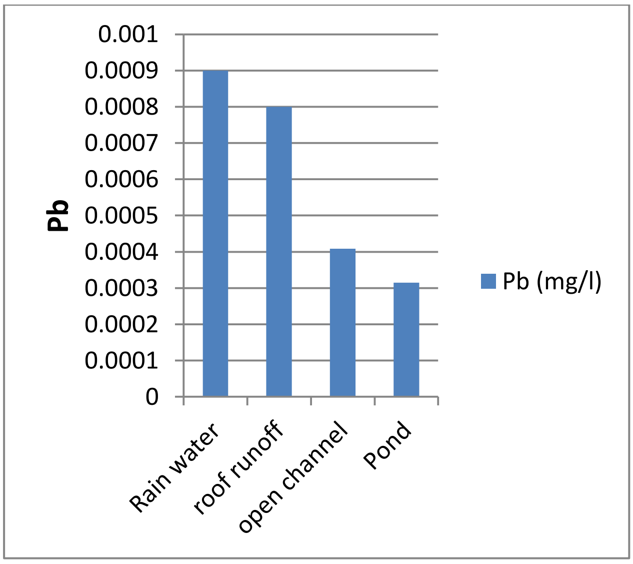

Fig. 21. Average concentrations of lead in rain water, roof runoff, open channel and pond in mg/l.

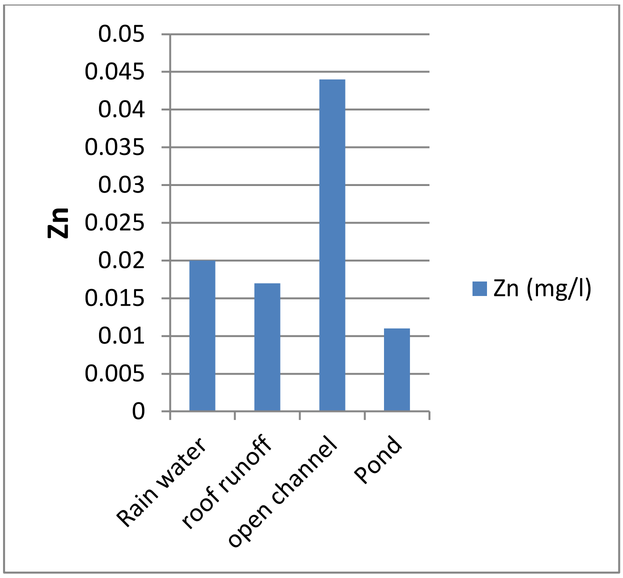

Fig. 22. Average concentrations of zinc in rain water, roof runoff, open channel and pond in mg/l.

4.3 Comparison of the findings of this study with literature.

In order to assess the quality of water in Augustenborg open storm water system and green roof runoff water with the storm water quality at other urban sites the findings of this study are compared with other studies as well as values suggested to be a guideline for storm water quality in Sweden (Regional planning and urban transportation, Stockholms läns landsting, 2009). The guidelines for the recommended storm water quality differ with regard to recipient; here the discharge directly into small lakes and indirectly into big lakes or the sea is regarded. The guidelines and findings from other studies and are summarized in Table 6.

Table 6. Pollutant concentrations in storm water runoff from different urban areas.

Parameter	Cd mg/l	Cu mg/l	Ni mg/l	Pb mg/l	Zn mg/l	NO_3-N mg/l	TN mg/l	PO_4-P mg/l	TOT-P mg/l
Guideline values[1]									
Small lakes	0.00004	0.018	0.015	0.008	0.075		2		0.16
Big lakes	0.00005	0.04	0.03	0.015	0.125		3		0.25
Rain water[2]	0.00004	0.0036	0.0007	0.0009	0.02	1.05	2.5	0	0.01
Green Roof	0.00001	0.0145	0.001	0.0008	0.017	0.03	1.5	0.04	0.12
Open channel	0.00007	0.0062	0.0017	0.0004	0.044	0.52	2	1.12	1.19
Pond	0	0.0023	0.0013	0.0003	0.011	0.3	1.9	0	0.11

Street[3]			-						
Min	0.0003	0.027	-	0.071	0.246	-	-	-	-
Max	0.0018	0.191		0.523	3.839	-	-	-	-
Median	0.0006	0.061	-	0.133	0.55	-	-	-	-
4 Roofs			-						
Min	0.0001	0.003		0.016	0.802	-	-	-	-
Max	0.032	0.247	-	2.764	38.061	-	-	-	-
Median	0.0013	0.037		0.493	3.422	-	-	-	-
Urban area[4]									
Site 1 Max	ND*	0.1	-	0.1	0.1	-	-	-	-
Site 1Mean	ND	0.01	-	0.01	0.04	-	-	-	-
Site 2 Max	ND	0.1	-	0.2	0.4	-	-	-	-
Site 2 Mean	ND	0.01	-	0.07	0.06	-	-	-	-
Highway[5]									
IC event 1	0.02	0.304	0.047	0.171	2.804	-	-	-	-
EMC event 1	0.0002	0.059	0.0006	0.017	0.505	-	-	-	-
IC event 2	0.043	0.62	0.056	0.567	7.639	-	-	-	-
EMC event 2	0.0003	0.1	0.0002	0.039	1.191	-	-	-	-
IC evevnt 3	0.0001	0.245	0.043	0.131	1.67	-	-	-	-
EMC evevnt3	0.0001	0.066	0.0009	0.039	0.468	-	-	-	-
IC evevnt 4	0.0007	0.211	0.013	0.13	3.51	-	-	-	-
EMC event 4	0.0001	0.039	0.0005	0.039	0.427	-	-	-	-
Motorway Raw									
runoff[6]	0.001	0.045	-	0.058	0.356	-	-	-	-
Mean	0.00074	0.043	-	0.043	0.254	-		-	-
Median							-		
Motorway Filtered	0.00053	0.025	-	0.0039	0.222	-	-	-	-
runoff	0.00033	0.019	-	0.0026	0.147	-		-	-
Mean									
Median									
Roof runoff water[7]	0.0001	0.003	0.0015	0.003	0.015	-	-	-	-
Road runoff	0.004	0.15	0.0044	0.3	0.5	-	-	-	-
Road 5000ADT[8]	0.00024	0.031	0.0015	0.014	0.062	-	1.65	-	0.14
Road 30000ADT	0.00044	0.072	0.0044	0.031	0.197	-	2.4	-	0.24
Apartment	0.0007	0.03	0.009	0.015	0.1	-	1.6	-	0.3
Parking Area	0.0003	0.015	0.002	0.006	0.025	-	1.2	-	0.12
Rain water[9]	0.0007	0.011	0.002	0.009	0.080				0.09
Motorway	0.0037	0.065	0.027	0.224	0.345				0.20
Roof runoff with Zinc gutters	0.0008	0.153	0.004	0.069	1.851				0.22

(1) Regional planning and urban transportation, 2009. Drafts guidelines for storm water discharges. (2) Ahmed (2010), 4 storm events have been sampled during Autumn 2010 at Augustenborg open storm water system located in Malmö,Sweden; (3) Gromaire-Mertz et al.(1999),measurements in central Paris, 16 rain events between July 1996 and May 1997. (4) Chui (1997), 9 storm events have been sampled at site 1 and six at site 2; both sites located at Stamford canal watershed, Singapore; (5) Shinya et al. (2000), 16 samples collected during four rain events in August-November 1997 from urban highway in Osaka, Japan, IC initial concentration; (6) Legret et al. (1997), 50 storm events have been sampled during 28 March 1995-26 February 1996 from the site located on the north bypass motorway of Nantes (Loire-Atlantique,France); (7) Boller (1997), measurements from road and roof runoff in Zurich city (Switzerland); (8) Larm,T (2009).Storm Tac Available at

www.stormtac.com/pages2_stormtac.htm; (9) Göbel et al. (2007), Journal of contaminant hydrology 91 (2007) 26-42.

Comparing with findings from other studies (Table 6) it is seen that the concentration of Cd is low in storm water in the Augustenborg open storm water system and less than even the minimum values as measured in other studies. The concentration of Cu in roof runoff is more than in rain water, open channel and pond system. By comparing the concentration of Cu on Augustenborg site with literature studies listed in table 6 it is seen that low concentrations have been found in Augustenborg open storm water system except in green roof runoff water. The Cu concentration in green roof runoff water is more than the concentration in roof runoff water as found by Boller (1997) but less than in the road runoff in the same study. As the open channel on Augustenborg site reflects the washed off pollutants it can be compared with road runoff quality. Comparing storm water from open channel in Augustenborg with road runoff in Boller (1997) it is seen that low Cu concentration was found in Augustenborg open channel water. Runoff from roof with zinc gutters as studied by Göbel et al. (2007) carried more Cu as compared to green roof runoff in Augustenborg.

The concentration of Ni in Augustenborg open storm water system as found by this study is similar to the storm water Ni content from other urban sites (Table 6). However, it is observed that concentration of Ni is higher in Augustenborg open storm water system than found by Shinya et al. (2000) in highway runoff. However, concentrations of Pb, Cu and Zn were found higher in study by ibid. than what this study found at the Augustenborg site. One reason behind this may be different traffic intensity at the sites (lower at Augustenborg).

The concentration of Pb was substantially lower in Augustenborg open storm water system than findings at other sites (Table 6). This might be a result of reduction in usage of leaded gasoline in transport industry. Nevertheless, the results as summarized in Larm (2009) show substantial higher Pb concentration at other sites than in Augustenborg system even with the same traffic density (as discussed in methodology section 3.2). Therefore unleaded gasoline cannot be the only reason and role of drainage system of Augustenborg seems to be the cause in reduction of Pb. Hvitved-Jacobson (1999) showed in his study that the soil behaviour also plays an important role in removing the heavy metals from runoff depending on soil sorption capacity. Thus the soil may adsorb pollutants before letting water into the open channel.

Zn concentration in Augustenborg storm water system was generally lower than findings by other studies at other sites except the storm water quality at parklands as summarized by Larm (2009). However the storm water quality found at sites with apartment houses and on roads sites (Larm, 2009) show higher Zn content in storm water than found by this study. If we compare the water quality in pond in Augustenborg - which also reflects the parkland -

then we see that lower Zn concentration was observed in this study than it is summarized in Larm (2009).

There are only a few studies analyzing nutrients in storm water runoff. Two studies presenting the results of Tot-N and Tot- P have been listed in table 6. The comparison shows that Tot-N concentration in green roof runoff in Augustenborg is less than typical values found in runoff from roads and pavements in apartment houses areas as summarized by Larm (2009) but more than in runoff water from parkland area. The concentration of Tot-P is less in storm water at the Augustenborg site than the values presented for storm water in Larm (2009) and findings by Göbel et al. (2007). The exception is storm water in open channel, Augustenborg which shows higher Tot-P concentrations than what is found by other studies (Table 6). Higher concentrations of Tot-N and Tot-P in storm water in the open channel in Augustenborg may be due to the presence of shredded leaves and debris in open channel which may be a source of those contaminants.

5. Conclusions

Runoff water quality from the green roof depending on the roofs age

After water passage through the vegetated roof an increase of concentration – comparing values in rain water and green roof runoff - is observed for PO4-P, Tot-P, K, and DOC during Autumn 2010 alike in the previous studies. Importantly, the previously observed decreasing trend of phosphorus and potassium concentrations in roof runoff (Berndtsson, 2008) is confirmed by the current study. DOC concentrations in roof runoff water found in this study are very similar to findings during 2003. No trend is observed for the changes of DOC in roof runoff water between different years. The results show that the green roof has the ability of lowering the water content of nitrate nitrogen and this ability remains during different seasons and is not reduced by the roof aging. Tot-N decreases somewhat in roof runoff comparing with the rain water concentrations.

Regarding heavy metals it is observed that cadmium concentrations are found less in runoff water than in rain water while the opposite is found for copper. Regarding zinc, lead and nickel there are only small differences of concentrations between rain water and the green roof runoff. Comparing the results of water quality analyses during different seasons it is seen that, with regard to copper, zinc and cadmium, the concentrations in runoff are substantially higher during spring 2005 than during other years. It may be due to the weather conditions and sampling occasions with longer dry periods between rain events during spring 2005 than during other study periods.

Comparing loads of contaminants in rain water and in green roof runoff water during autumn 2010 shows that the green roofs contaminates the storm water with phosphorus, potassium, organic carbon and to some extent with copper. The loads of nitrogen are substantially less in green roof runoff than in rain water. The loads of studied heavy metals are generally the same in rain water and green roof runoff water with the exception of copper.

Water quality within Augustenborg open storm water system

The concentrations of Tot-P and PO4-P have been found highest in storm water runoff in the surface channel. The phosphorus is mostly found in dissolvable form and the possible source may be fertiliser used in gardening of nearby green surfaces. The concentrations of NO_3-N and Tot-N were lowest in the green roof runoff. The green roof has the ability to reduce the content of nitrate nitrogen in water passing through it. However the green roof influence on the content of total nitrogen in water passing through it is much less. Concentrations of DOC in storm water runoff are similar at all three sampling sites. Potassium concentrations are similar in storm water in open pond and surface channel and these are substantially more than the potassium concentration in green roof runoff. Cadmium and zinc are found in highest concentrations in the open channel. Lead concentrations are somewhat less in storm water than what is found in rain water.

Comparisons between Augustenborg and literature study

The storm water in the Augustenborg open storm water system was generally found less polluted with heavy metals, Tot-N and Tot-P than what is reported for storm water at other sites. Regarding the nutrients the exception is water quality in the open channel at Augustenborg which is higher than what is reported for other urban sites.

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