Urban, pluvial flooding
Appended papers


IV. M. Wihlborg, J. Sörensen and J. Alkan Olsson. (n.d.) Drivers and barriers for implementation of blue-green infrastructure in Swedish municipalities – what could be done to overcome them [manuscript]

V. Johanna Sörensen, Johanna Alkan Olsson and Anna Persson. (n.d.) A framework for city planning with nature-based solutions (NBS) [manuscript for *Land Degradation and Development*, special issue on Nature-based solutions]

Author’s contribution to appended papers

I. The author coordinated the writing process. All co-authors contributed with texts and ideas. The author synthesised the material into an article.

II. The author collected data, developed the method, analysed the data and discussed the results independently. The author wrote the article, with supervision on the structure and with proof-reading help.

III. The author collected data, developed the method, analysed the data and discussed the results independently together with the co-author.

IV. The study was conducted by a master’s student (first author of the article). The author supervised the thesis of which the article is based on together with the other co-author. All three authors developed the theory for the study further during the article writing process.

V. The author took the initiative for collaboration on blue-green infrastructure and nature-based solutions. A couple of brainstorming sessions were conducted together with the co-authors. The author, together with one of the co-authors, made three interviews with in total six practitioners.
Urban, pluvial flooding
Blue-green infrastructure as a strategy for resilience

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Urban, pluvial flooding

Blue-green infrastructure as a strategy for resilience

Johanna Maria Lykke Sörensen
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Det går ett träd omkring i regnet,
skyndar förbi oss i det skvalande grå.
Det har ett ärende. Det hämtar liv ur regnet
som en koltrast i en fruktträdgård.

Då regnet upphör stannar trädet.
Det skymtar rakt, stilla i klara nätter
i väntan liksom vi på ögonblicket
då snöflingorna slår ut i rymden.

_Tomas Tranströmer_
_Trädet och skyn_
_ ur Den halvfärdiga himlen, 1962_
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Introduction

Floods cause enormous damage around the world and were the second largest natural cause of economic loss (after storms) and account for 47% of all weather-related disasters between 1995 and 2015 (CRED & UNISDR 2015). During 1980–2010, floods affected almost 90 million people worldwide. 15% of the world’s population will live in flood-prone areas by 2050, not taking climate change into account, meaning they are threatened by flooding (Ligtvoet et al. 2014). Floods have a large impact on human well-being and economy (CRED & UNISDR 2015). Besides loss of human life and human health effects (Hajat et al. 2005), flooding leads to ecosystem degradation and damage to economic, historical and cultural values, as well as decrease of socio-economic welfare (REF Jongman, Appleton från Jonkman). Most of the death tolls from natural disasters are reported from low-income countries, while the economic losses are higher in high-income countries, reflecting the accumulation of economic wealth there (CRED & UNISDR 2015).

The worldwide frequency of floods has been demonstrated to already have increased during the twentieth century (Milly et al. 2002) and several reasons for the increase have been suggested, such as climate change (Milly et al. 2002), increased population and economic growth (Ligtvoet et al. 2014), and land use changes (REF). In Europe, a small increase in flood frequency between 1970 and 2005 is reported for major floods (direct damage larger than 0.005% of the EU GDP and/or more than 70 casualties), while number of total floods (including smaller events) shows a greater increase (Barredo 2007). The total losses in Europe are estimated to approximately €4.9 billion annually (2000–2012) and expected to increase to approximately €23.5 billion by 2050 (Jongman et al. 2014). The projection is how-ever highly uncertain (ibid.).
Severe flooding has hit highly developed cities like Prague, Dresden, and several other cities (2002), Bern and several other cities (2005), New Orleans (2005), Copenhagen (2010, 2011, and 2014), and New York (2012), as well as areas like Queensland (2010), south-western England (2013–2014), and the French Riviera (2015). The societal consequences are severe and flooding in urban areas is costly, especially in central areas. In Nordic countries recent floods have caused severe losses. In 2002, several villages on the island Orust outside Gothenburg, Sweden were isolated, and the damages covered by insurance companies were estimated to 123 million SEK (~15 million €) (MSB 2013). The insurance costs after the pluvial flood in Copenhagen, Denmark in 2011 was estimated to more than 800 million USD (~580 million €) (Swiss Re 2011). The direct economic losses of an extreme rainfall event in Malmö, Sweden in 2014 was estimated to 600 million SEK (~60 million €) (Malmö Stad 2016). There are few flood events reported to the EM-DAT from Nordic countries between 1970 and 2005, compared to countries like Italy, Spain, France and Germany (Barredo 2007). One major event was reported from Sweden, a spring flood in Bergslagen 1977. River floods, flash floods, and storm surge cause most damage and casualties in Europe (Barredo 2007).

Urban flooding problems are increasing due to numerous reasons. Extensive urban and suburban growth (UN 2015, Ligtvoet et al. 2014) in combination with insufficient sewer systems (Swan 2010) as well as climate change (Semadeni-Davies et al. 2008a,b) aggravates the problem. The effects associated with global warming, such as sea level rise, more intensive precipitation and higher river discharges, may increase the frequency and the extent of flooding on a worldwide scale. Global average precipitation is projected to increase, but both increases and decreases are expected at the regional and continental scales (REF IPCC). In northern Europe, both annual precipitation and extreme rainfall events during summer is projected to increase (REF IPCC, REF Olsson).

In this work, focus is on pluvial flooding because of its close connection to stormwater management and the urban landscape. The situation in small cities, like Malmö, where some of the studies in this work have been conducted, is different from the most vulnerable megacities, like Dhaka, Kolkata, Shanghai, Mumbai, Jakarta, Bangkok and Hoh Chi Minh City (Ligtvoet et al. 2014). While the megacities mentioned are threatened by both riverine and coastal flooding, Malmö has no major river and is, in comparison, well protected from storm surge. It is therefore natural to focus on pluvial flooding, which has led to large damages several places in Malmö and other cities in Nordic countries and elsewhere (REF MSB, Houston et al. 2011). Despite the difference in urban density compared to the megacities, there have been several casualties reported during urban floods in Europe (REF MSB, REF), adding on to the importance to manage urban flooding also in developed countries. Pluvial flooding has in common with fluvial flooding the climatological (Glaser et al. 2010) and hydrological (Berghuijs et al. 2016) drivers as well as the
effect of human activities (Zhang et al. 2014). However, pluvial flooding acts on a different scale than fluvial flooding, where mechanisms and characteristics are functioning differently. Consequently, research is needed to investigate mechanisms and characteristics also for pluvial flooding, despite extensive research on causality of fluvial flooding. Also, the measures to control pluvial flood differs from those to control fluvial and coastal flooding.

Adaptation of systems for urban drainage

The traditional engineering approach to manage urban drainage is by combined or separate sewers. In urban catchments, drainage systems may include different types of storage and detention facilities to cope with floods. However, during recent decades alternative ways to manage floods have evolved since traditional methods often harm the riverine ecosystems in urban as well as in rural areas and increase the flood risk (Liao 2012, REF Smits). The current, centralised sewers put a pressure on urban areas and their surroundings, both by increased flood risk and by high pollution loads related to combined sewer overflow (CSO) as well as stormwater runoff from polluted surfaces.

Densification has become a dominating urban planning strategy, as many cities strive to reduce their negative, environmental impact (REF Ståhle, REF Talen). With a high amount of impermeable surfaces, urban land is more vulnerable to flooding than the surrounding environment (REF). To mitigate negative effects of densification, such as loss of ecosystem functions and services, alternative stormwater management solutions have been used since the 1970s. During later years, green infrastructure planning with the social perspective in mind has been called for. Schifman (2017) claims that the perspective must be shifted from hydrologically driven to an integrated, socio-hydrological approach, where values such as increased property value, greenspace aesthetics, heat island amelioration, carbon sequestration, and habitat for biodiversity are included. In this thesis, the term blue-green infrastructure is used to clarify the need of integrated solutions with holistic water cycle as well as ecosystem perspective.

Another problem with current stormwater management is related to aging sewers and/or lack of proper maintenance. Many pipes have begun to show signs of deterioration and it expensive to meet the need for new investments (REF SVU-rapport) with new pipes and enlarged capacity. To avoid replacement of existing pipe network, some areas can be disconnected from the sewers to reduce load from them, and mains and distribution pipes can be rehabilitated with no-dig methods like pipe lining. These methods are often less expensive than traditional open cut replacement methods.
The combination of climate change adaptation, densification, the call for more green spaces, and a need to restore aging sewers, leads to strong interest in retrofitting of urban areas with blue-green infrastructure.

Blue-green infrastructure as a sustainable urban drainage solution

Blue-green infrastructure can contribute to the urban environment with multiple benefits: water supply, flood mitigation, terrestrial biodiversity, urban cooling, resilience to climate change, urban agriculture, and human well-being (Walsh et al. 2016). In this work, the main focus is on how blue-green infrastructure can contribute to improve the urban water cycle by detention (REF), infiltration (REF), and evapotranspiration (REF) of urban stormwater to reduce pluvial flood risk (REF). These hydrological processes act differently for different time scales, i.e. precipitation durations. As this work concerns urban, pluvial flooding, the most extreme rainfall events are considered, typically with short duration.

Incorporation of blue-green infrastructure and resilience into decision-making and ways to handle integrative and multi-criteria aspects in the legal and organisational system are still to a great extent undeveloped. The current regime for stormwater management, through piped drainage, is dominating (Ashley et al. 2011, REF Cettner). An urban planning approach integrating technical, social, environmental, legal, and institutional aspects of stormwater management is crucial (Zhou 2014). Introducing such an approach is faced with barriers that are largely socio-institutional rather than technical (Brown & Farrelly 2009).

Objectives

This study has its base in a hydrological perspective on urban, pluvial flooding. From this perspective, it reaches further to study socio-technological transition in the context of changed urban environment and climate change. Strategies for retrofit of urban areas and urban drainage systems in a decentralised manner with the use of blue-green infrastructure are examined. The overall purpose is to better understand if urban, pluvial flooding could be mitigated with blue-green infrastructure and how wide-spread implementation of such measures could be done. While the studies have been conducted in Sweden, most of the conclusions are applicable in other regions with similar socio-technical circumstances.
Through elaborated analysis of flood insurance data, in combination with study of drainage system, elevation, and land use, characteristics and mechanisms of pluvial flooding are examined. While the study is limited to temperate climate, many of the conclusions are applicable also in other parts of the world. Drivers and barriers of the socio-technological transition from pipe-bound to blue-green drainage is investigated through interviews with municipal officials. A similar method is used to propose a framework for data collection and management for planning of blue-green infrastructure.

The detailed objectives are:

- to analyse the spatial distribution of flooding and its spatial relation to drainage system, flow paths, rainfall patterns, and sea level (Paper2),
- to understand the characteristics and mechanisms that governs the effect of flooding (Paper2),
- to understand the role of blue-green infrastructure for risk reduction (Paper3),
- to investigate the barriers and drivers for a socio-technological transition from pipe-bound drainage to blue-green structures for stormwater management (Paper4), and
- to develop a framework for data collection and management for planning of blue-green infrastructure in urban areas (Paper5).

Structure of this thesis

After the introduction in chapter 1, a theoretical background is given in chapter 2 that serves as a foundation for the studies (Paper2, Paper3, Paper4, and Paper5) presented and discussed in the following chapters, including some of the concepts presented in Paper1. The work is based on five scientific papers (appended). Paper1 presents a framework for flood risk management. Effects of extreme precipitation in urban areas are then studied in full city scale (Paper2) and in a neighbourhood retrofitted with blue-green infrastructure (Paper3). In Paper4, barriers and drivers for implementation of blue-green infrastructure are assessed and in paper5 a framework for GIS data management in the planning of blue-green infrastructure is presented. The studies in Paper2, Paper3, Paper4, and Paper5 are described in chapter 3. Methodology, 4. Study area, 5. Data, and 6. Results, while Paper1 serves as a theoretical framework presented in chapter 2.8. Flood risk management. In chapter 7, the results from the studies are analysed in relation to findings from other studies and in chapter 8, some implications of the work and my deliberate suggestions for the future are discussed. In chapter 9 the work is finally concluded.
Theoretical background

Extreme precipitation

An extreme event is only extreme in relation to the normal. Extreme precipitation cannot be defined by its impact on the society, i.e. how severe hazard it leads to, or what the systems normally are designed for, i.e. the design standard. Both these perspectives would lead to a definition where an event would be considered less extreme as the society gets more well-prepared, or as the standards are changed. It is more correct to define the extremeness in relation to how common the precipitation in itself is; the lower frequency the more extreme. In urban hydrology, a 100 years event is often considered extreme (Hoang and Fenner 2016, Madsen et al. 2014). However, even this definition is problematic. As the climate changes and heavy precipitation gets more common, the pillars also of this definition shake. This, common, definition needs to be re-evaluated as climate changes.

For extreme precipitation to fall, either sufficient moisture must be available for a convective thunderstorm to be developed by solar heating, or moisture must be advected into the region and released by an uplift mechanism (Gustafsson et al. 2010). Extreme daily summer rainfall in Sweden from advection is governed by atmospheric circulation characterised by air-masses that collect moisture over the European continent and the Baltic Sea (Gustafsson et al. 2010). While convectional rainfalls are typical for the tropics, they are also common at higher latitudes, particularly in the summer. As the ground gets heated, air bubbles raise 10–12 km and form cumulonimbus clouds from which intense rainfall is released when it cools to condensation temperature (Shaw 1988). The rain cells are often too small to be captured
by point measurements (Wern 2012). The most severe downpours in Sweden typically hits Scania, eastern Götaland, Svealand and the southern coast of Norrland (Wern 2012). There is no correlation between high annual precipitation and extreme daily rainfall in Sweden (Wern 2012, Bengtsson & Rana 2014). Most events of extreme precipitation in Sweden are reported in July and August and a weak correlation between high summer temperatures and number of days with extreme daily rainfall was found in a study by Wern (2012).

In Sweden, about 70% (range 52–81%, but most often within 70–80%) of the extreme events occurred during cyclonic weather type, compared to only 45% for the non-extreme events (Hellström 2005). However, the southernmost region of Sweden, including Scania, differed from the other regions. Here the difference in weather type is less distinct (ibid.). Extreme events were in the southernmost region to 52% related to cyclonic weather (non-extreme 27%), to 39% related to anticyclonic weather (non-extreme 23%) and to 10% related to directional weather types (non-extreme 50%) (ibid.).

The Swedish Meteorological and Hydrological Institute (SMHI) mainly measures daily precipitation. Therefore, most Swedish studies are based on daily precipitation. Only 120 of 750 stations uses automatic registration, where typically registration is done every 15 minutes since the 1990s. For the rest, manual registration is done once a day (SMHI 2017). As the measurements are registered as 24 hours totals recorded at 0700 local time, it is difficult to compare studies done with these data with statistics from other places (Hernebring & Salomonsson 2009). High resolution data from e.g. tipping buckets are only registered by municipalities, utility companies and on private initiative. In Sweden, extreme precipitation is often defined as 40 mm of daily precipitation (Hellström 2005, Gustafsson et al. 2010). The return period for such an event is between 1 and 5 years (Wern 2012). The 10-years event is in the range 45–55 mm/day and the 100-years event in the range 60–100 mm/day (Bengtsson & Rana 2014). SMHI defines downpour (in Swedish: skyfall) as minimum 50 mm in an hour or minimum 1 mm in a minute (Wern 2012), which in Malmö corresponds to a return period between 50 and 100 years (Hernebring et al. 2015).

Many studies from Northern Europe have found an increased number of extreme rainfall events (Madsen et al. 2014). However, in Sweden no significant trend has been found (Bengtsson & Rana 2014). The 1970s were a very dry period in Sweden, especially in southern Sweden (Lindström and Bergström 2004). During 1807–2002, the years of 1951 and 1924 stand out as most notable (riverine) flood years, but also during the 1990s several big floods where noted (Lindström and Bergström 2004). Future precipitation patterns cannot be predicted from analysis of historic data. Instead, climate models must be used (Wern 2012), projecting an increase in short-duration extreme intensities of 5-10% in Stockholm, Sweden by 2011-2040.
Pluvial flooding

Floods are usually categorised by the governing mechanism. The most common flood types are coastal (from storm surge, sometimes in combination with high tide), fluvial (or riverine) and pluvial (rain induced) flooding. Flooding can also appear as groundwater flooding or flooding caused by dam breaks, damage to water supply or drainage system. Riverine floods in mountainous landscape is often called flash floods, because of their sudden appearance. (REF) In this work, pluvial flooding includes surface water flooding and flooding by exceedance water from the drainage system.

Runoff from both pervious and impervious surfaces (Boyd et al. 1993) is the governing hydrological process for urban flooding (Berggren et al. 2013). The effect of impervious surfaces is constant for all storms, while runoff from pervious surfaces are related to the depth of rain. For storms larger than 50 mm, soil saturation before the storm was also important (Boyd et al. 1993). During extreme rainfall, the green/pervious areas contribute to runoff (Berggren et al. 2013). Changes in the infiltration capacity impact the urban runoff (ibid.).

In urban areas, flooding may be associated with inadequate sewer systems. With high property values of buildings and other structures, potential damage from flooding can easily extend into large amounts. However, drainage systems designed to cope with the most extreme storms would be too expensive to build and operate (REF 3PA). In establishing tolerable flood frequencies, the safety of the residents
and the protection of their valuables must be in balance with the technical and economic restrictions. The response of the drainage system to rain events in the urban environment is characterized by two main components (Bengtsson et al. 1993). The first is the surface runoff on natural slopes, i.e. the major system. The second component consists of the artificial drainage system, i.e. the minor system. In most of the cities, the artificial drainage system is controlled by a combined sewer network, which collects both stormwater and wastewater and leads it to the treatment plant. While the major system often is neglected in the urban planning, leading to construction in low-laying, high risk areas, the minor system is typically designed according to a certain, locally or nationally set design standard (REF butler). However, the way to set design levels has been criticised (Knighton & Walter 2016).

To write: Precipitation events prior to extreme rainfall events have a significant impact on insurance claims (Torgersen 2015).

### Historical development of urban drainage systems

![Historical development of urban drainage systems](image)

Figure XXhist. Stages of development of urban drainage systems in Sweden. A) sewerage deposited to street, B) drainage of streets through piped sewers, C) pipe system connected with interceptor sewers, D) wastewater treatment plants to treat sewerage, E) separate foul and surface water sewers, F) detention and treatment of stormwater in vegetated swales, canals and ponds.

Urban drainage in Sweden has gone through a long development, from the first piped solutions, to introduction of wastewater treatment and later separation of sanitary sewers and stormwater pipes. Similar development is seen worldwide (Brown...
et al. 2009, Cettner et al. 2012, de Feo et al. 2014). Before pipes were constructed for drainage in urban areas, sewerage was deposited through a hole in the wall, the door, or a window and flushed away with rain. Faeces were stored in the backyard, collected, and used as fertiliser on agricultural land (Figure XXhist, A). The cities were smelly and hygiene was bad. After several outbreaks of diseases like cholera, action was called for and pipes were constructed to drain the streets. During 1930s outhouses were replaced by water closets in many homes (REF SKBL Agnes Hedvig Charlotta Lagerstedt [2018-03-10]). At this time, sewers were also seen as a way to promote civic pride (Cettner et al. 2012). Through construction of pipelines for drainage, cities could be promoted as well developed and with future perspectives (REF Cettner). In the beginning, the outlets were typically located in a nearby canal, stream or lake (Figure XXhist, B). Later, about 19XX, outlets close to the city were shut down and interceptor sewers were constructed, often incorporating stretches of polluted, urban watercourses, which lead the sewage further away to bigger rivers, lakes, or to the coast (Figure XXhist, C). Still, sewage was discharged without treatment. In 1950s and 60s, pollution of streams and waterborne diseases lead to public health interventions for treatment of sewage in waste water treatment plants (Figure XXhist, D). As sewerage and … started to construct separated sewers, with a foul sewer to carry contaminated wastewater and a surface water sewer to carry rainwater to receiving waters (Figure XXhist, E). In the 1970s, ideas of environmentally friendly drainage of stormwater started to develop (Cettner et al. 2012, Fletcher et al. 2014). The main idea was to retain and treat stormwater in retention and detention basins, urban wetlands, etc. (Stahre 2006) (Figure XXhist, F). The piped drainage has a central role for clean and modern cities (Cettner et al. 2012), but the fast and efficient conduit of stormwater from urban spaces also leads to problematic pollution of downstream recipients like rivers, lakes and coastal water (Weibel et al. 1964), increased risk of flooding in urban areas (REF, not mine) and erosion and other disturbances to aquatic wildlife (Walsh et al. 2016).

To write: Piped network works fine under most circumstances.

At present about 54% of the global population live in cities and by 2050, two thirds of the world’s population will live in urban environments (UN 2015). In Europe, the current, urban population is 73% (ibid.). The hydrology in urban areas differs from the surrounding landscape. While infiltration and evapotranspiration are significantly reduced with urbanisation, both overall discharge and peak flow increase. The rapid flow, caused by shorter lag time to peak flow, leads to increased flood risk. For receiving waters, erosive flow frequencies increase, at the same time as base flow in urban streams are reduced because of the low infiltration rates. Urbanisation leads to changes in the aquatic ecosystems by i.e. reduction of fish population, and decreased diversity of algae and macrophytes. Pollution from heavy metals, PAHs, PCBs, pesticides, and pharmaceuticals as well as macronutrients (N/P/K)
increases. (McGrane 2016) Urban areas pollute with more heavy metals, but with less nutrients, compared to farmland (Berndtsson & Bengtsson 2006).

**Problems related to current stormwater management**

To write: Pollution from CSO and stormwater

To write: Floods – little capacity and centralised sewers

To write: Runoff from impervious land

To write: Loss of ecosystem functions and services

To write: Degraded pipes. Aging system. Need for new investments.

To write: Need to develop urban green

Misconnections, where wastewater is discharged into surface water sewers, are common (Ellis & Butler 2015). In some parts of London, as many as one in three households lead their wastewater untreated to rivers and streams because of such domestic misconnections (REF Thames Water) The misconnections are difficult to find and correct, as the sewers are hidden underground. The opposite kind of misconnections, where stormwater runoff is discharged into foul sewers, leads to unintentionally high pressure on wastewater treatment plants (REF Ashley, NORIS project) and increased risk of flooding.

The development of urban drainage over time has led to inclusion of more and more different perspectives (Brown et al. 2009). Blue-green infrastructure is highly complex (Hoang & Fenner 2016) and it is a challenge how we best organise the management among a diverse group of professionals and stakeholders. There is today a need for stakeholders to understand more than one discipline or perspective, such as hydrology, ecology, landscape architecture, urban planning, etc. (Brown et al. 2009).

**Blue-green infrastructure**

Blue-green infrastructure is a concept for landscape planning where urban stormwater is controlled in a decentralised manner with vegetated structures (Liao et al. 2017, O’Donnell et al. 2017). There are a vast number of concepts to describe decentralised and sustainable drainage of stormwater through vegetated measures, e.g. Low Impact Development (LID), Sustainable (Urban) Drainage Systems (SuDS/SUDS), Green Infrastructure (GI), and Water Sensitive Urban Design (WSUD) (Fletcher et al. 2014). The concept blue-green infrastructure is chosen in
this work, as it emphasises the importance of both blue (water) and green (vegetation) and the interaction between them. The word infrastructure underlines that different elements need to be interlinked to work as a connected web of measures (Lennon 2015). Water obviously follows flow paths, natural or constructed, but urban ecological networks and connectivity is also important in perspective of ecology (Ahern 2013), where it benefits spread of flora and fauna between the different green elements (REF se referenser från Anna). The connected parts are more than the sum of the single elements. Sandström (2002) similarly choose the concept green infrastructure, instead of the traditionally more commonly used green space, to signal the multiple purpose of green space. The word infrastructure gives the concept the same dignity as other kinds of (technological) infrastructure (Sandström 2002, Lennon 2015). In countries with a neoliberal agenda, the concept shows that such measures complement rather than prevent economic development (Matthews et al. 2015). Every element of blue-green infrastructure is in itself a nature-based solution and mimics natural ways to handle water (European Commission 2015). The economic benefits of such solutions have been put forward by the European Commission as well as through research (ibid., Ossa-Moreno et al. 2017).

Stahre (2006) categorises the different elements of blue-green infrastructure depending on their role in the stormwater control system and on the stakeholder that can allocate space for them. Most upstream, source control is used to describe small scale facilities, like green roofs, permeable paving and local ponds, typically on private land. On public land, onsite control measures for detention, infiltration and evaporation, such as soakaways, special surfaces for temporary flooding, and smaller ponds, are found. Water from these structures are retained in canals, swales, and other structures for slow transport. Larger retention ponds, lakes and wetlands serve as downstream control.

Green spaces are important in urban areas for six reasons, according to Boverket (1992) (REF From Sandström 2002): recreation, maintenance of biodiversity, city structure, cultural identity, environmental quality of the urban area, and as biological solutions to technical problems in urban areas. Swedish cities are recommended to develop a green plan where urban green spaces are identified together with their value to the public (Sandström 2002). This plan should be a part of the mandatory structure plan. However, Sandström (2002) showed that these plans do not take into consideration the multiple purposes of green spaces in the urban environment. The relation between urban green and water is only to a limited degree mentioned and discussed in the evaluated plans. The importance to work integrated with water and green spaces have been mentioned also by others (REF, REF, REF). The European Commission defines Green Infrastructure as “a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings.” (European Commission 2013). This
definition does not explicitly include a focus on water. On the other hand, the US Environmental Protection Agency use Green Infrastructure as the narrow, water-focused concept to describe vegetated, stormwater technologies. They claim that “green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits.” (US EPA, webpage) and exemplify with technologies like rain gardens, bioswales, downspout disconnection, urban tree canopy, green streets, and rainwater harvesting.

Stormwater control measures are known for their ability to treat stormwater from polluting particles and solved compounds. Nutrition uptake in urban wetlands reduces pollution of downstream recipients (REF) and XXXX are degraded by XXXX (REF). However, caution must be taken as stormwater carriers heavy metals from the urban fabric (REF Lars). These metals are not treated or degraded but detained by the stormwater control measures. They will therefore stay in the water or the vegetation of the control measure, or infiltrate and potentially pollute the groundwater.

To write: Challenges with the multi-disciplinary basis of the concept.
To write: Hur hydrologin påverkas generellt
To write: Vad sägs om översvämning och blå-grönt?

Stormwater control measures of different kinds have been shown to reduce flood risk, like swales (Qin et al. 2013), green roofs (Qin et al. 2013), permeable pavement (Qin et al. 2013, Zahmatkesh et al. 2014), ponds (REF), urban wetlands (REF Miklas?). For instance, swales can lower the flood risk as they can store large volumes of water (Qin et al. 2013). Initial wet conditions reduce the ability of blue-green infrastructure to handle a large storm (Villarreal et al. 2004). A combination of stormwater control measures are often recommended in the literature (Qin et al. 2013, Liu et al. 2014).

Transition theory

Blue-green infrastructure is a fairly new technology that goes outside the currently dominating socio-technological structure for stormwater management. Research has shown that barriers for transition is institutional rather than technical (Brown & Farrell 2009). In this work, transition theory with a multi-level perspective is used as an analytical tool to explore barriers and drivers that may exist in relation to an altered management of stormwater in Sweden. Transition theory sees socio-technological systems, in this case the stormwater management system, as composed of three constellations: regime, niche and niche-regime. Surrounding these is the landscape that forms the prerequisites for the system (de Haan & Rotmans 2011). The
three constellations and their surrounding landscape is shown in Figure XXtrans. While Rotmans et al. (2001) relate the levels to bureaucratic levels (macro, meso, and micro level) or nested hierarchies, we perceive the levels as including organisational, technical as well as social systems as suggested by Geels (2011). In the following section the features of the multi-level perspective are briefly explained and thereafter the process of change according to transition theory is described.

Figure XXtrans. Transition theory according to Ashley et al (2011) and de Haan & Rotmans (2011).

The regime dominates the system and is the way that societal needs are met (de Haan & Rotmans 2011). A regime includes institutions, technologies, practical applications and social relationships (Geels 2002, Smith et al. 2005). The regime is the most powerful constellation of the system (de Haan & Rotmans 2011). In Sweden, the current regime of urban drainage management consists of a pipe-bound infrastructure with a centralised management. Several actors are involved in developing and maintaining it (Cettner et al. 2012). A shift to a new regime is more than just an evolutionary transformation of a previous regime. There is a significant difference before and after a regime shift. For instance, to change from combined to separate sewers is an evolutionary transformation, while the change from pre-sewered cities to sewered cities can be considered as a transition to a new regime (Ashley et al. 2011).

A niche is a system that only meets certain, specific societal needs (de Haan & Rotmans 2011). The niche level is mainly referred to where emerging innovations are developed that are fundamentally different from solutions at the regime level (Geels 2011).

A niche-regimes is a regime that is not currently dominating, while it has significant power to compete with the regime for the functioning of the system (de Haan &
Rotmans 2011). Thus, a niche-regime is somewhere between niches and the regime in strength.

The landscape represents the wider context (legal systems, demography, economy and the natural environment) that in a long term perspective is able to influence and affect the development of the practices at regime, niche-regime and niche levels (Geels 2002; Geels 2011; Koppenjan et al. 2012).

A central idea of the transition theory is that change emerges from niche through alternative solutions to niche-regime to displaced or replaced regime, but a regime can also be influenced by actions and ideas emerging from landscape level (Koppenjan et al. 2012, Geels 2011, Smith et al. 2005). The challenges of the regime emerge from the dispersal of new social norms concerning how to solve a problem, know-how and motivation that alternative solutions bring with them when developed and implemented at the niche level (Koppenjan et al. 2004; Van de Bruges et al. 2005; de Haan & Rotmans 2011; Ashley et al. 2011 Farrelly & Brown 2011).

Drivers for this type of socio-technical transition has been divided into three categories: pressure, stress, and tensions (de Haan & Rotmans 2011). Pressure comes from alternative technologies that become viable competitors to the regime. Stress emerges when the regime is inadequate or internally inconsistent in meeting the needs of the system. Tension is when the system compromises in its relation to its natural or social environment. The tensions can either be structural, related to physical aspects of the regime, legal or cultural, related to cognitive or discursive aspects of the regime (ibid.). Structural tensions are more frequently related to pressures from the landscape level where as the cultural tensions can emerge from both niche and landscape level (Ashley et al. 2011).

Due to entrenched technological path dependency and cognitive lock-in, actors may be unable or hindered to implement new solutions (Brown & Farrelly 2009a). Such implementation barriers, have different origins and can be technological, legal, organisational, financial, social, educational or related to political will (Holtz et al. 2008; Brown & Farrelly 2009a; Brown & Farrelly 2009b; van de Meene et al. 2011; Cettner et al. 2013; Cettner et al. 2014; Mguni et al. 2015). As a consequence, a transformation of a regime must consist of both physical, administrative and structural changes in the regime (Bettini et al. 2015) and change usually has to occur at multiple levels for a regime to alter (Geels 2002).
Flood risk and resilience

To write: In this work, risk is seen as a potentially negative deviation from a preferred, expected development over time (Paper1). Increased resilience through construction of measures, increased awareness, ...

Since planners must cope with uncertainty (Godschalk 2003) and a flood event always can be bigger than what the system is designed for (Liao 2012), cities must be built resilient. An urban resilience to floods could be conceptualized as the capacity to remain in a desirable regime while experiencing a flood (Liao 2012). While a flood resistant city can resist floods to a certain degree, but not bigger floods, a flood resilient city is flexible and adaptive, and learning from historic events. It is in many cases not possible for a city to be both resistant and resilient. A city that accepts smaller floods, will be better prepared when a bigger flood occurs. To be able to handle floods, floodable areas are needed in the city (Liao 2012), i.e. areas that can store or convey water without incurring damage.

To write: Hur risk kan beskrivas genom hazard, exposure, vulnerability

To write: Risk som en kombination av sannolikhet och konsekvens

To write: Filosofin om risk – Johannes Perssons bok

To write: Risk som en avvikelse från den önskade utvecklingen

To write: Koppling till hållbarhet

Future uncertainties and strategies for adaptation

Nothing written yet, only a list with references to use:

Refsgaard et al. (2013) reason that there are three kinds of uncertainty: epistemic uncertainty, uncertainties related to ambiguity and aleatory uncertainty.

Hallegatte (2009) proposes different strategies to handle large uncertainties:

- No-regret: The solution is beneficial even in absence of climate change. Multiple problems are solved with such a solution, like energy saving or urban green.
- Reversible strategies: Flexible solutions that can be adjusted depending on the outcome. Waiting to urbanise is an example, which is much easier than first constructing and then retreat.
- Safety margin: Make a little bigger while designing new infrastructure. Be overpessimistic.
- Build resilience (soft strategies): Creation of institutes that can manage risks, insurance schemes to cover losses, early warning systems, etc.
• Reduce decision-making time horizons: Construct cheap houses that is made to be rebuilt after some time.

From fail-safe to safe-to-fail strategy (Ahern 2011)

Payo et al. (2015) about lock-in effects

Robust decision making

Flood risk management

To write: Paper1 serves as a background for the thesis. Describe how the other papers relates to flood risk management by presenting them on Figure XXmanage.

To write: Different aspects of flood risk management. Reduce hazard, exposure and vulnerability.

Figure XXmanage. The three systems involved in urban flooding. (A) The hydrological system; (B) The impact system; (C) The management system.

Urban flood management can be described with a system-analytical approach (Figure XXmanage) where three major systems are included: 1) the hydrological system (where the water physically flows through the urban space, intendedly or not), 2) the impact system (all parts of the society that are affected detrimentally during a flood event), and 3) the management system (the features of the society that deals with flood management to decrease the effect of a flood event). (Paper1) During an event the impact system is affected by processes governed by the hydrological system. These negative effects are to be reduced by the management system, both on the long term and on the short term, by reducing the societies vulnerability to flooding. Processes in the management system can also impact the hydrological system,
especially on the long term, by construction, control and improvement of the urban drainage system and watercourses, and changes in elevation in the urban landscape. Such changes will have an impact on the severity of coming flood events.

To write: Knowledge of the social system and its vulnerabilities is still weakly developed, even though it is a key element of the social response to a flood and of the urban dynamics (Hall et al. 2003).

In Europe, EU Water Framework Directive (WFD) (Directive 2000/60/EC) and the Floods Directive (FD) (Directive 2007/60/EC) have forced the countries to work more extensively with the urban waters. The WFD commits all member states to achieve good qualitative and quantitative status of all water bodies, such as watercourses, lakes and marine environment as well as ground water. The FD calls for actions to mitigate flood risk by first making risk assessments in two steps and then develop flood risk management plans. Implicitly the FD focuses on riverine floods. However, pluvial floods, also constitute a formidable threat to cities around the world. In Sweden, one of the first outcomes of the FD implementation was flood risk mapping of all major rivers (REF), but also pluvial flood risk gains increasing attention (REF). Together, these directives call for new ways to manage urban stormwater, preferably with a holistic view including both water pollution and flood risk mitigation, however this is not explicitly spelled out in the directives (REF).


In Paper1 five challenges related to flood risk management from a transdisciplinary view were identified: 1) To build flood resilience cities, while not forgetting to meet other climate change related impacts such as water scarcity, drought, and heat waves in the municipal planning. 2) To jointly consider the water, energy, land use, transportation, and socioeconomic nexus from a multi-stakeholder perspective. 3) To use flexible flood protective measures in the view of uncertainty regarding future climate. 4) To solve questions regarding responsibilities and improved communication between stakeholders and authorities. 5) To secure critical infrastructures. Blue-green infrastructure was identified as a key concept to meet challenge number 1 and 3 above.
Malmö in southern Sweden is at the centre of this work. For the analysis of flood mechanisms and characteristics on city scale (Paper2), Malmö inside the Outer Ring is used as study area. To study flooding and blue-green infrastructure (Paper3), the study area was focused on one district: Augustenborg Eco-City, an area that was retrofitted with stormwater control measures in early 00s. For the interview studies of transition to blue-green infrastructure regime (Paper4) and for the framework development (Paper5), the study area was zoomed out to include municipalities and water utilities in the region of Scania, including Helsingborg, Lund, Tomelilla, and Simrishamn, besides Malmö.
City of Malmö

The city of Malmö, Sweden, was selected as study site since, in the Scandinavian context, Malmö is a large city, where there have been several flood events in recent years. Like in many other cities, the more densely built areas have sewer systems where stormwater and sewerage are drained with one single pipe (combined system), leading to high risk of basement flooding. The sewer system in Malmö is representative for Scandinavian cities, with a mix of combined and separate sewers. Good quality data on flood extent, precipitation, topography, sewerage system, etc. are available. Malmö is also well known within the field of urban hydrology, as the city was an early starter in the work with integrated water management (Niemczynowicz 1999, Stahre 2008).

Augustenborg Eco-City

In Augustenborg, a 31 hectares residential area in Malmö, stormwater is controlled by blue-green infrastructure consisting of detention in ponds and areas for temporarily flooding, infiltration on green roofs, lawns and parking, as well as slow transport in swales, ditches and canals. The stormwater drainage was disconnected from the old combined sewers that are only used for wastewater now. The retrofitted blue-green infrastructure was constructed by the end of the 1990s by VA Syd (utility company) and MKB (housing company) as a part of the project called Eco-City Augustenborg. For a detailed description of the blue-green infrastructure in Augustenborg, see Villarreal et al. (2004). About 3,000 people live in the area in 3–6 storeys apartment blocks built in 1948–1952. The area continues to be developed and in 2016 a 14-storeys building with eco-friendly profile named Greenhouse was finished.

Municipalities and water utilities in Scania

For the two interview studies, the study area was zoomed out to include municipalities and water utilities in the region of Scania. Swedish municipalities are legally responsible for stormwater management on public land. The practical responsibility is frequently delegated to public water utilities which often are co-owned by several municipalities. In the first interview study (Paper4), on transition to blue-green infrastructure regime, municipal and water utility company bureaucrats in Malmö and Helsingborg was interviewed. The two municipalities use two different water utility companies, VA-syd (Malmö) and NSVA (Helsingborg), to provide stormwater
management and water treatment services to a total of 730,000 persons (Figure XXskane). Malmö (330,000 inhabitants) and Helsingborg (140,000 inhabitants), are the two largest cities in the region and have a long experience of working with blue-green solutions.

Figure XXskane. Municipalities covered by the water utility companies in the study, NSVA (dark grey) and VA Syd (light grey). Gôra figur som visar alla study areas för samtliga artiklar?

Interviews for the framework development (Paper5) was done with five municipal and water utility company bureaucrats in Malmö, Lund, Tomelilla and Simrishamn, and one GIS researcher. In this study, two of the interviewees worked with GIS data collection, management and support (the researcher and one of the bureaucrats).
Methodology

One of the main purposes of this work is to analyse the physical mechanisms and characteristics of urban, pluvial flooding (Paper2). Through this analysis, the spatial distribution of flood risk related to these mechanisms and characteristics are evaluated. According to Crichton’s Risk Triangle (e.g. Crichton 2008), risk comprises hazard, exposure, and vulnerability. The flood claims are used as a measure of spatial extent and severity of different flood events, which can be related to all three sides of the Risk Triangle. The vulnerability and exposure of individual households are not assessed as the study focuses on city-scale patterns.

Insurance claims as a measure of flooding

How insurance claims are used to analyse flood damage during historical flood events. Risk is a perceived measure (REF Becker book), and in this work flood damage through registered insurance claims is used as a representation for flood risk in different areas.

Insurance claim data have been used for various other studies to analyse the relation between rainfall and pluvial flooding in Denmark (Zhou et al. 2013; Spekkers et al. 2013b), and in the Netherlands (Spekkers et al. 2013a, Bouwens et al. 2018).

One catastrophic event might lead to many claims. For statistical analyses of insurance data, where independent random variables are needed, single claims must be aggregated into common losses for each event (Smith and Goodman 2000). However, in this study, where the hydrological process behind the losses is investigated,
the individual claims provides essential information about the spatial extent of the damage.

**Flow path analysis**

In Paper2, the minor and the major drainage systems of Malmö were investigated. The minor system was based on a sketch of the main sewers by VA Syd (water utility company), while the major system was derived from a simple analysis of the topography where the flow from an eight-direction flow model (Jenson and Domingue 1988) is accumulated into each cell. No validation of the analysis was done. The main sewer system follows the main flow paths in the major system to a high degree. Old maps from Malmö was studied in relation to the derived minor and major system. The main pipelines are found along the stretch of Hylliediket in western Malmö, Södervärnsstråket in southern Malmö, and the Riseberga Brook in eastern Malmö.

**Selection of nearby areas for comparison**

In Paper3, flood risk in Augustenborg was compared with flood risk in five nearby areas, Lindgatan, Lönngården, Norra Sofienlund, Södra Sofienlund, and Persbort. The areas were selected as they are similar to Augustenborg in several ways, like land use, building coverage, time of urbanisation, and original sewer system (combined). Stormwater control measures have only been implemented in Augustenborg, while the other areas still mainly have combined system, which make them suitable for comparison with Augustenborg in this study. Lindgatan is an exception, as the combined system has been reconstructed with a separate system here.

**Interviews**

Semi-structured interviews with staff in water utility companies and municipal water offices. Interviews used both to better understand the barriers and drivers for implementation of blue-green infrastructure and to develop a framework for data use in city planning with blue-green infrastructure. For the first purpose, water engineers and planners where interviewed, and for the latter purpose, water engineers, ecologists, planners, and GIS experts where interviewed.
The interviewed persons work at different departments, as environmental administration and planning office, and have a varied academic background. For both studies, a majority though have a background in natural and technical science. In total, 20 persons were interviewed in the first study and 6 persons in the second.

Data

Data and material used in the study are presented shortly here. Further details are found in the publications.

To write: Paper1, paper2, paper3…

To write: For Paper4 and Paper5, empirical material was collected through interviews, as described in section 3.3. Interviews.
Results

The main findings are here presented shortly. Further details are found in the publications. As Paper1 serves as a background for the thesis, no results from this article is presented here.

Mechanisms and characteristics of urban, pluvial flooding (Paper2)

Pluvial flooding is the most common kind of flooding in Malmö. Only a very few flood claims have been registered during high sea level caused by storms and there is only one watercourse in Malmö (Risebergabäcken/Sege å). Three severe, pluvial flood events are presented in the study: 5 July 2007 with 150 and 169 flood claims to VA Syd and LF Skåne respectively, 14 August 2010 with 210 and 148 flood claims, and 31 August 2014 with 2,109 and 2,649 flood claims within the study area. These flood events were all caused by heavy rainfall distributed over the entire city. The 2010 and 2014 events were both intense and with a quick development, while the 2007 event were less intense, but with a long period of rainfall before (Figure XXrain). The 2014 event was heavier than a 100-year event for durations between 3 and 16 h (average for all stations in Malmö).
Figure XIXrain. Accumulated rainfall (SMHI station A) for the three flood events in Malmö on 5 July 2007, 14 August 2010, and 31 August 2014. The accumulation curve is centred on the peak rainfall (maximum 15 min intensity) and the volume is accumulated for 20 days before the peak and 1 day after.

There is a relation between large-scale topography and flooding in Malmö. Areas within 100 m from the major system are more than twice as affected by flooding, compared to areas further away. During the severe flood events in 2010 and 2014, areas close to the major system was even more affected by flooding (3.0–4.2 times), compared to areas further away. During such downpours, runoff is quickly directed towards low-lying areas, both through the pipe system and by overland flow. In Malmö, like probably in most other places, the trunk sewers (minor system) are located under the main overland flow paths (major system), as they follow the topography. The spatial distribution during these two, highly intensive rainfall events (2010 and 2014) were different than during other events, including the 2007 event, with more flood claims clustered around the trunk sewers.

The combined system is more exposed to flooding than the separate system. Even if only 31% of the urban land in Malmö is connected to the combined system, 70% of the flood claims are reported from these areas. During the 2010 and 2014 events, the combined system was 3.8–4.2 times more affected by flooding compare to the separate system. Similar figures are found if all flood events are included. The 2007 event shows a different pattern: the combined system areas were only slightly more than twice (2.3 times) as severely affected by flooding during this event, compared to the areas with separate system. One reason why the 2007 event differs from the other events might be the difference in flood causality, where continuous rainfall during the preceding weeks saturated the ground with water. Flooding during this event was therefore less related to type of drainage system. The dataset is biased as
more people live in areas with combined system. However, the difference in reported flood claims still exists when adjusted for bias.

Locally, some flooding is caused by breakdown of the system, e.g. when a sewer pump stops pumping due to system error. On the one hand, the phenomenon with local breakdowns could be seen as unique incidents that are not likely to happen during future flood events. On the other hand, and in reality, it seems inevitable that a few of these unique incidents happen during every flood event.

Flood risk reduction with blue-green infrastructure (Paper3)

Little data is available from before implementation of the blue-green infrastructure in Augustenborg. However, the data available indicate decreased flood risk after implementation.

Flood reduction after stormwater retrofit in Augustenborg was evaluated by comparison with the five nearby areas (Lindgatan, Lönngården, Norra and Södra Sofielund, and Persborg) with similar age, land use, and imperviousness as Augustenborg. All five areas have combined sewer systems, corresponding to what Augustenborg had before the blue green stormwater retrofit. The flood magnitude (number of flooded properties per hectare) was more than 10 times smaller in Augustenborg compared to the other areas both during the extreme 2014 event and during the other events in 2007–2015. The difference was confirmed with a bootstrap analysis and found significant (99% bootstrap confidence interval).

The flood event on 31 August 2014 is considered as extreme, as more than 80% of the flood claims (2007–2015) were reported this day. The event makes it possible to evaluate the blue-green infrastructure under extreme conditions. In Augustenborg, 116 mm was measured, and most of the rainfall (100 mm) fell within 3.5 hours. This was the biggest rainfall event since measurements started in Malmö in the late 1800s and led to severe flooding in most of the city as well as in neighboring villages and in some parts of Copenhagen, Denmark. For durations longer than two hours the rain event exceed the 100 year return period. Compared to the five nearby areas without blue green infrastructure, approximately 10 times less properties were flooded in Augustenborg during the event. Lindgatan, which was the least flooded area, apart from Augustenborg, was 6.4 times more flooded than Augustenborg, while the most heavily flooded area, Södra Sofielund, was 18.4 times more flooded than Augustenborg.

It should be noted that the number of reported flood claims was also low in Augustenborg before the blue green infrastructure was implemented. However, it
seems that the number of reported flood claims has increased in general, while this is not the case for Augustenborg.

Barriers and drivers for implementation of blue-green infrastructure in Swedish municipalities (Paper4)

From the interviews with 20 practitioners, four types of drivers for implementation of blue-green infrastructure were identified, where the focus on ecosystem services and climate change were mentioned by all or almost all of the respondents respectively. Eight types of barriers were identified, where economy, roles and responsibilities, and lack of knowledge also were mentioned by almost all of the respondents. In addition, legislation and municipal organisation were mentioned as barriers by ¾ of the respondents. The barriers are closely related to the current stormwater management regime as understood from the theory, where the whole system, including technical, legal, organisational and other aspects, target the needs in the current regime. It was found that the economy of, the responsibilities within and the organisation of Swedish municipalities and their water utility companies are directed to fulfil the goals of the current, pipe bound stormwater management, rather than widespread implementation of blue-green infrastructure.

All of the interviewees mentioned ecosystem services as a driver. Their suggestion for the most important service is however diverse and includes services as recreational value, delay and treatment of stormwater, biodiversity, and cultural services like aesthetics. The second most mentioned driver was climate change, which was mentioned by all but one interviewee. The interviews show that there are awareness and knowledge about that the climate is changing and that the actors need to adapt urban areas to be able to handle the increased precipitation.

The most mentioned barrier is economy, as maintenance costs are uncertain, and the financial structure of Swedish municipalities does not support blue-green infrastructure. It is however interesting that economy also was mentioned as a driver by a third of the interviewees. They argue for instance that replacement of old pipes will be expensive, and that blue-green infrastructure can be a less costly alternative in many cases. Some also mention that it will be costly if flood mitigation related to climate change are done with conventional methods.

In the studied municipalities, there are several players with different skills, knowledge and training involved in the stormwater management chain, from the strategic and overall planning to detail planning for building permits and to private individuals. In the interviews the lack of clarity of roles and responsibilities emerged as an issue. Almost all interviewees also mentioned lack of knowledge as a barrier.
There is widespread awareness of the idea behind blue-green infrastructure in Sweden, but still knowledge about questions regarding for instance design, inclusion of ecological expertise, and maintenance are lacking.

Legislation and municipal organisation were also mentioned as barriers by many practitioners. They claim that the current legislation in Sweden and the municipal organisation do not support blue-green infrastructure in the planning process. The lack of legal support increases the uncertainty for involved stakeholders and as each municipal department has their own budget, interest and responsibilities, cooperation between them are difficult. Without such cooperation, widespread implementation of blue-green infrastructure is not possible.

A framework for city planning with blue-green infrastructure and nature-based solutions (Paper5)

From the brainstorming sessions, several perspectives on data availability and data management in the urban spatial planning of blue-green infrastructure and nature-based solutions were discussed. Three main areas of problems were identified: the multiple need of data, lack of GIS data, and problems related to data management. The latter includes technical issues, like incompatibility between database structures, and human resources issues, like low priority in the municipal organisation, lack of knowledge among practitioners and competition, prestige and difficulties to cooperate between departments. Data is collected and processed on both national, regional, and local level and in relation to the responsibility of the authority. Therefore, the collected data seldom comprise a comprehensive ground for planning blue-green infrastructure and its elements.

In the study, nine categories of data needed in the planning process of blue-green infrastructure were identified: cadastral, technical, geological, biological, environmental, risks, social, administrative, and meteorological.

From the interviews, six themes of problems related to GIS data in the planning process were found: 1) lack of data, 2) data access and rights, 3) lack of knowledge, 4) data storage tools not adapted to users’ needs, 5) organisation of data storage, and 6) strategic data use.

A framework for strategic use of data to aid the development of blue-green infrastructure was proposed (Figure XXframe). Three boxes lie outside the main flow in the figure: citizen’s needs, the fact that values change over time and scientific evaluations and support. Appropriate data to develop new NBS, or maintain current ones, is essential to ensure a strategic development to benefit both people and nature (biodiversity) itself. Hence the step evaluation and data collection, is essential and
can be seen as both the starting and end point of the framework. It is here essential that the evaluation and data collection step includes links to broader municipal goals to ensure a relevant collection of data. It is also essential to keep track of time related changes in data needs. A structured and continued evaluation of implemented structures is essential to assess their success. However, if the collected data is not stored in a proper way, access to it may in reality be limited. Moreover, as urban areas change quickly, data maintenance is essential to ensure its relevance and quality. This step has to include both data maintenance in a more technical meaning as well as information on how collected data has been collected.

As the main purpose of the data discussed here is to be used in further analysis, there is a need for both tools and structures for proper use once data is collected. If different types of models are used it may be important to save and store analyses of different scenarios in a structured way. The collected data and performed analysis thereafter has to serve as a basis for planning which need some type of visualisation of the data at a scale that is useful for spatial planning but also form smaller project.

Figure XXframe. Framework for improved information flows in urban planning of blue-green infrastructure.

To write: Better description of figure in caption and bodytext.
Discussion

The discussion is under progress. No text is finished yet!

Analysis

Runoff is the governing hydrological process for urban flooding. However, the study from Malmö shows that soil saturation through long-lasting rainfall impact flood extent in some occasions (Paper2).
Measures to decrease flood risk and increase resilience

Measures used to mitigate urban, pluvial flooding, such as conduit, detention, levelling of building and landscape.

Sea level rise will make storm surge more common in the future.

Redfern et al. 2016: Hydrological behaviour of urban surfaces are complex, depending on age, slope, maintenance, etc. Roads infiltrate more than often expected, up to 50–60% of rainfall, while green space, when compacted in different ways, can generate up to 60–70% runoff when newly established and 5–30% after some years.

Redfern et al. 2016: Precise definition of urban surfaces are important to better model hydrological processes in urban areas. It is a priority to develop methods for upscaling of small-scale results to city-scale hydrological behaviour.

Redfern et al. 2016: When studying effects of improved infiltration, realistic infiltration rates from already established urban surfaces must be assumed, as older road pavement often infiltrate more than expected.

Urban trees are sometimes mentioned as an important feature in flood risk reduction (Ahern 2013), as a large part of precipitation is taken up by the root network. This feature is probably of minor importance during pluvial floods with quick progress, like the 2010 and 2014 events in Malmö, but during pluvial floods with slow progress, like the 2007 event in Malmö, urban trees might play a role by reduction of soil water content.

Future stormwater control

While fluvial flooding is projected to decrease in southern Sweden due to less snow accumulation during winter months (REF Rojas), pluvial and coastal flooding are projected to increase due to increased extreme rainfall during summer months (REF Ohlsson) and rising sea level (REF) respectively.

Need for increased capacity in sewer if current design level should still be met.

All projections of future climate are highly uncertain, meaning that design of flood defence as well as stormwater management must be done with care. Implications for design…

Mission impossible to use quick conduits for drainage. The capacity in the system will also be too low at some point. Crucial to detend stormwater control. Need to elevate the land accordingly.

Need to reduce pollution from urban spaces. Polluter pays principle
Need for space. Inner yards in Copenhagen.

Transition towards increased resilience

Barriers and drivers that were found

Tratalos et al. (2007) raise the question whether it is possible to build compact cities with dense urban environments and still maintain urban habitats and biodiversity, and the resulting ecosystems services.

The transition theory, as described in section 2.5, aims to describe the full transition from one regime to a new regime through a regime shift. In the case of mainstreaming blue-green infrastructure, such a transition is probably not realistic and might not even be desired. A continuation of the continuous development described by Brown et al. (2009). While there are successful examples of implemented blue-green solutions in dense urban areas, complete removal of existing pipe-bound system is probably unnecessary. In many cities, like in Malmö and Copenhagen, main sewers are led through or close to the city centres. Extensive blue-green infrastructure can more easily be constructed outside the most innercity areas. Because of direct linkage, blue-green infrastructure in upstream areas outside the city centre can reduce stress on piped infrastructure in downstream areas inside the city centre. But, for mainstreaming of blue-green infrastructure to a more extensive implementation both in retrofitted and newly developed urban areas, a regime shift is essential. The current regime, with pipe-bound stormwater management, is too stable to allow widespread implementation of blue-green infrastructure.

Discuss what is needed for a transformation to take place.

How to work with data in municipalities and water utility companies.

Ambiguity and conceptual confusion

Det sokratiska perspektivet:

- **Begreppsbildning** – Viktigt att ha klara begrepp, risk annars att man inte kommer framåt
- **Kunskapsstabilitet** – Vad vet man och vad vet man inte? Vad är kvaliteten i den kunskap vi tror oss ha? Hålla ett vakande öga på vår kunskaps gränser och begränsningar.
Further research

Relation between rainfall and flooding
During the study of flood characteristics and mechanism, analyses of the data material indicated that sub-daily rainfall durations are governing for severe precipitation in Malmö. This relationship is worth to spend more time to investigate, as the rainfall patterns have implications for design standards and flood prevention.

Responsibility, policy changes, and updated guidelines
In relation to climate change adaptation and development of urban environment.

Mainstreaming of blue-green infrastructure in urban planning
Blue-green infrastructure has been shown to be efficient to locally control stormwater (Sun et al. 2014) and reduce flood risk (Sörensen 2016, Paper3) and these nature-based solutions are therefore widely promoted (Københavns Kommune 2012, European Commission 2015, Bai et al. 2018). However, the downstream effects of large-scale implementation have not yet fully been understood. There are a few studies, but they are often based on modelling with vague or symbolic parameterisation of important hydrological features (Stovin et al. 2013, Viavattene & Ellis 2013, Sun et al. 2014) or without any calibration and validation (Siekmann & Siekmann 2015, Locatelli et al. 2015). As IPCC conference steering committee recently claimed in Nature, more knowledge on different measures effect on urban water balance is needed (Bai et al. 2018). They claim that performance of green infrastructure for heat wave and flood risk reduction should be investigated, and that new standards and designs should be developed (ibid.). Here, one major challenge is to mainstream implementation of blue-green infrastructure (Liao et al. 2017).

More…
Conclusions

To write: A few, main conclusions based on the objectives.
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Re-Thinking Urban Flood Management—Time for a Regime Shift

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Abstract: Urban flooding is of growing concern due to increasing densification of urban areas, changes in land use, and climate change. The traditional engineering approach to flooding is designing single-purpose drainage systems, dams, and levees. These methods, however, are known to increase the long-term flood risk and harm the riverine ecosystems in urban as well as rural areas. In the present paper, we depart from resilience theory and suggest a concept to improve urban flood resilience. We identify areas where contemporary challenges call for improved collaborative urban flood management. The concept emphasizes resiliency and achieved synergy between increased capacity to handle stormwater runoff and improved experiential and functional quality of the urban environments. We identify research needs as well as experiments for improved sustainable and resilient stormwater management namely, flexibility of stormwater systems, energy use reduction, efficient land use, priority of transport and socioeconomic nexus, climate change impact, securing critical infrastructure, and resolving questions regarding responsibilities.

Keywords: urban flooding; resilience; climate change adaptation; blue-green urban solutions

1. Introduction

Urban flooding problems are increasing due to numerous reasons. Urbanization is an accelerating trend. At present about 54% of the global population live in cities [1] and by 2050, almost two thirds of the world’s population will live in urban environments [2]. Thus, urban areas are growing and in many cases, they are becoming denser [3]. Many cities are striving to reduce their negative, environmental impact and densification of existing urban areas has become the dominating urban planning strategy in order to meet a rapid urbanization with limited expansion on agricultural land [4,5]. The large proportion of impermeable surfaces makes built-up land more vulnerable to
flooding than the surrounding environment. Moreover, the risk of being flooded due to sea level rise or river discharge is threatening 15% of the world’s population [2]. Recently, severe flooding hit highly developed cities like Prague, Dresden, and several other cities (2002), Bern and several other cities (2005), New Orleans (2005), Copenhagen (2010, 2011, and 2014) (Figure 1), and New York (2012), as well as areas like Queensland (2010), South-western England (2013–2014), and the French Riviera (2015). The societal consequences are severe. In Europe only, the average cost of flood damages between 2000 and 2012 has been estimated to about 4.9 billion euros per year. It is estimated that this figure may increase to about 23.5 billion per year by 2050, i.e., with almost 400% [6].

![Figure 1](image_url)  
**Figure 1.** Pluvial flooding on the 31st of August 2014. Photos were taken at three different flood affected locations in Copenhagen (photo by Johanna Sörensen).

The traditional engineering approach to manage urban drainage is by combined (sewage water and stormwater in the same pipe) or separate pipe systems. In semi-urban catchments, urban drainage systems may be combined with dams, levees, and other types of storage and detention facilities to cope with floods. However, during recent decades alternative ways to manage floods have evolved since traditional methods often harm the riverine ecosystems in urban as well as rural areas and increase the long-term flood risk [7,8]. Alternative methods relate to resilience theory and address the city’s capacity to mitigate flooding in particularly sensitive urban areas, tolerate controlled flooding on assigned areas, and to re-organize in case of damage. This means that adaptive, multifunctional infrastructure in combination with water sensitive urban design are seen as means to reinforce resilience against climate change [9–11]. However, incorporation of these measures into decision-making and ways to handle integrative and multi-criteria aspects in the legal and organizational system are still to a great extent undeveloped. In general, a design framework integrating technical, social, environmental, legal, and institutional aspects is crucial [12]. Introducing such a framework is faced with barriers that are largely socio-institutional rather than technical [13].

Sustainable and resilient water management thus needs to involve water supply access and security, public health protection, as well as flood protection in densely built urban areas with many types of important urban infrastructure [10]. In view of the above, it is clear that urban water management systems need to become integrated elements in a multifunctional urban environment. Increasingly urgent and complex problems have to be solved by the city, where the water sector management systems should be developed in close collaboration with regional and municipal planning authorities.

The traditional thinking is that resilient societies bounce back from the state they were in before a devastating event. However, lessons learned, from for example the Hurricane Katrina in 2005, show that this may not the case. Ten years after the catastrophe, the area is still suffering from reduced long-term population and low economic activity [14]. Thus, instead of viewing the drainage design as a static process and to cope with floods of a certain recurrence, a contemporary interpretation of urban resilience needs to encompass a more flexible and adaptive approach to flood management. A flexible flood management system may be defined as measures for a given level of flooding, but with
an integrated ability to modify it later [15]. Urban resilience should be viewed as an adaptive process where the society continuously learns how to cope with changing socioeconomic conditions and urban land use as well as a changing climate. Since the urban space and flooding are complex, it is necessary to adopt a systems-analytical approach. Figure 2 outlines the three systems involved in urban flood problems, namely (1) the hydrological system; (2) the impact system; and (3) the management system. For a systematic approach to flood resilience, the dynamic character of all three systems needs to be considered.

**Figure 2.** The three systems involved in urban flooding. (A) The hydrological system is the terrestrial part of the hydrological cycle with both natural and man-made components; (B) The impact system is the part of urban society that may be affected in a detrimental way by a flooding event; (C) The management system is the part of urban society that deals with floods in order to decrease the detrimental effects of flood events.

A new adaptive approach to urban water management has to be integrated among stakeholders and authorities and by using sustainability criteria. It should secure a higher level of resilience to climate change and water services, while at the same time enhancing attraction and social inclusion of urban environments. In this regard, the complex function of urban areas needs to be weighed into the design process. In view of the above, the objective of this paper is to bring forward the concept of urban flood resilience into a context of sustainability and risk management. We elaborate on these concepts according to the concept graph in Figure 3 and point out areas where an updated approach serves to cope with changing risks and increase urban resilience through integrated flood management.

**Figure 3.** Outline of concept chart for improved urban flood resilience followed in this paper. The marked area in the middle of the chart denotes sustainable stormwater management solutions.
2. Resilience in Flood Management

As mentioned above, resilience is a key notion in sustainability science and contemporary urban flood management. For this purpose, we give a brief account of this concept in relation to risk below.

2.1. Concepts of Risk and Resilience

Although risk is a contested concept with numerous definitions [16], most characterizations have three aspects in common [17], namely (1) The assumption that the future is uncertain [18,19] and that any future event is possible to influence [20]; (2) the uncertain future has a potential impact on humans [18,21], or can at least be so perceived [22]; and (3) risk is defined in relation to a preferred outcome [20,23,24]. Thus, risk is a potentially negative deviation from a preferred expected development over time. This definition may at first appear as merely complicating more conventional approaches to risk, such as a combination of probability and consequence or of events and consequences and their associated uncertainties, but even so may serve its purpose [16].

The notion of resilience is usually used to describe (1) the ability of a system to “bounce back” to a single equilibrium [25,26]; (2) a measure of robustness or buffering capacity before a disturbance forces a system from one stable equilibrium to another [27,28]; or (3) a system’s ability to adapt in reaction to a disturbance [29]. It has been suggested that human beings have the ability not only to react to disturbances but also to anticipate and learn from them [17]. Resilience can be regarded as a purely descriptive concept in relation to systems behavior, or if it is normative in the sense of relating outcomes to human values and objectives. Both approaches have merits, but if resilience is to have any meaning in relation to risk and sustainable development, which are both inherently normative concepts, it becomes equally normative [17].

2.2. Flood Resilience

Urban flood risk management aims at assessing and reducing flood risk, as well as preparing for effective response to, and recovery after, actual floods, with the purpose of minimizing disturbances, disruptions, and associated costs in relation to a city’s preferred development over time. Thus, resilience is the capacity of a system, such as a city, to continuously develop along a preferred and expected trajectory [17], while remaining within human and environmental boundaries [30]. This approach to resilience is suitable when focusing on the sustainable development of cities, which entails human beings with preferences and expectations for their future as well as agency to strive to meet them. City authorities develop visions and plans for the future use of urban areas. Plans may span over years and even decades, during which the city changes more or less continuously and most often significantly due to purposeful and proactive human activities, also often reducing the applicability of all three main approaches to resilience previously listed. If a city’s resilience instead is its capacity to continuously develop along its preferred expected trajectory, then this resilience is an emergent property determined by the city’s ability to anticipate, recognize, adapt to, and learn from variations, changes, disturbances, disruptions, and disasters that may cause harm to what human beings value [17]. Sustainable development thus means to manage risk and resilience is the capacity for doing so in an uncertain, ambiguous, complex, and dynamic world.

2.3. Time Perspective on Flood Management

Long-term strategies are needed to facilitate cost-effective and rapid implementation of integrated flood management [31]. The aim is fast recovery from flooding and restoration to good living conditions. Sustainability should not only be achieved economically, but also socially and environmentally [32]. Cities are challenged by climate change, and according to the European Environmental Agency report [33] immediate action is needed since delaying adaptation actions will be much more costly in the long-term. Climate change will not only affect the economy but also increase the number of possible hazardous events to citizens. When planning for climate change,
however, also other related climate change effects such as, water scarcity, drought, and heat waves, need to be considered in the municipal planning. Cities should thus, not wait for a larger flood event or a large-scale catastrophe to act. Instead, city planners need to study front-runner cities that are dealing with flood challenges such as New York, Copenhagen, and Rotterdam. Learning from the experiences of others, and ourselves is of crucial importance and saves energy, resources, and time [34]. Thus, it is a long-term process to achieve a flood resilient city, and it is vital to ensure synergy between urban development and urban drainage strategies [35]. It is dangerous to make long-term decisions based only on experiences of a recent severe flood event. Doing so might lead to lock-in effects where irreversible decisions are made [36].

2.4. Flood Management Strategies

After a series of catastrophic floods in Europe, the EU Flood Directive was ratified in 2007 [37]. The Flood Directive gives two design levels, namely the 100-year event, and the “worst case scenario”. Implicitly the Flood Directive focuses on riverine floods. However, pluvial floods, i.e., flooding generated locally by an overload of the urban drainage system by extreme rainfall, also constitute a formidable threat to cities around the world. Since traditional urban drainage systems rely on underground pipes, they have, in order to avoid huge dimensions, typically been designed to cope with rainfall of 10 year recurrence period or less. More extreme events are deliberately allowed to generate inundation of selected areas such as streets, infrastructure, and building basements. Even with design level of 100 year recurrence period, the risk of exceeding critical conditions during a period of 50 years is 40%. On top of that, the uncertainty associated with recurrence periods based on existing, limited data is quite large [38]. The EU Flood Directive highlights that, irrespective of the recurrence period chosen, there is always a non-negligible probability of system failure. Unfortunately, it remains to make this an accepted public fact and a component of the strategic thinking among all stakeholders including especially the general public.

As climate change continues and the sea level rises [39], concerns regarding coastal flooding are growing. Three different strategies have been suggested [40,41], i.e., to retreat (slowly move buildings to higher elevations), to defend (secure areas with measures like dikes and floodgates), or to attack (build on the water, with buildings and infrastructures that can endure the water). From an environmental perspective, retreat or attack is most suitable, while defend is found less advisable. From an economical perspective, defend or attack is most suitable if there are high assets in the area, and defend will minimize the construction and maintenance costs. From a social perspective, the retreat might be a good solution [41]. Mathur, A. et al. [42] discussed flooding and sea level rise for Mumbai (India) and suggested that the sea should be seen as a friend rather than an enemy from which to be protected. Further, the islands of Mumbai should more correctly be called estuary and Mithi River a river rather than a part of the sewage system. They argued that the change in naming and understanding are important for how we reflect upon the nature as well as the city and that this influences how we plan the city and prepare ourselves for flooding.

In general, coastal flooding is different from riverine (from river) and pluvial (from intense rainfall) flooding with respect to physical planning. Cities are often experiencing a combination of riverine and pluvial floods. The pluvial flood type is generated locally and the result of exceedance of natural infiltration and drainage as well as exceedance of the capacity of the urban drainage system [43]. On the contrary, riverine floods are usually generated at a much larger rural catchment scale. Consequently, the flood problem for riverine cities may often be a result related to scale and upstream rainfall-runoff processes. Consequently, upstream flood management will also affect the downstream water level and discharge. In this regard sustainable flood management for urban areas needs to consider larger, often rural catchments that discharge nearby or inside urban neighborhoods as well as direct stormwater runoff from impermeable areas. This can be seen as a scale problem where both quantitative and qualitative aspects of runoff need to be considered. Nevertheless, the problem is similar when it comes to organizational strategies and the understanding of resilience and risk.
3. Integrated Approach to Urban Planning and Design

To manage floods in a sustainable way it is necessary to apply a holistic viewpoint and employ an integrated approach for the different functions that a modern city entails.

3.1. Water Management beyond the Traditional Pipe System

Continuous urbanization will result in increasing nutrient and contaminant emissions of watersheds, putting human health and ecosystems in danger [44,45]. Due to the absence of trans-scale thinking, drainage and flood protection systems mostly rely on expensive and inflexible underground solutions. High-intensive rainfall is causing more frequent overloading of pipes resulting in flooding of public and private property [46]. As most cities still are using combined sewage systems for drainage, more frequent overflow of untreated sewage may be expected in the future [46]. At the same time, urban areas are getting denser, and thus less space will be available for underground infrastructures including extensive use of drainage pipes. Developing the underground water infrastructure will thus be even more costly in the future. Urban transition should instead lead towards less and slower surface runoff, which requires more soil and surface infiltration. Accordingly, applying surface solutions and evolving the drainage systems are essential steps for the reduction of flood impacts [47]. Utilizing urban areas as integrated parts of the drainage system provides promising opportunities.

Geldof, G.D. [48] suggested the Three Point Approach (3PA) as a tool for how to move from only focusing on design standards for rainfall events that occur with a return period of 1 in 10 years (first point) to including extreme rainfall events (second point), and at the same time consider the impact on every-day life (third point). Fratini, C.F. et al. [49] found this tool useful in discussions with stakeholders. Rather than seeing the 3PA as going from a one-point to a three-point approach, the present flood management could be developed from a single-purpose view with a one-point approach to a multi-disciplinary view with a full spectra approach. This means that the whole range, from the everyday system and processes in the city to the functionality during the most extreme events, is incorporated. The whole system can be integrated and treated in unison, including also extremes. It is no longer appropriate to focus separately on the water issue solely when planning water infrastructure. For economical as well as environmental reasons, an integrated approach is needed. New large-scale single-purpose construction projects, such as huge sewerage tunnels in old combined sewerage systems, have been strongly criticized, for example in Philadelphia [50,51], London [52] and Copenhagen. Integrated flood management calls for solutions with multiple purposes, which has a valuable function every day, not only once in 50 or 100 years. With climate change and rapid urbanization, there is also a need to increase the capacity of the stormwater system. At the same time, since urban areas are becoming more complex including more and more high-tech and sensitive infrastructures, the economic value is increasing leading to larger flooding sensitivity. Therefore, more flexible systems are needed that can adapt to future changes.

3.2. Integrated Approaches to Flood Management

Designing open water management solutions in the urban landscape is a multi-disciplinary task that requires a combination of scientific and artistic approaches and a new kind of interaction between green and blue assets is called for [53]. Different mechanisms for infiltration, storage, transport, evapotranspiration, and treatment are usually applied in surface solutions [54]. In blue-green infrastructure, the urban greenery and water management are combined in order to protect the urban landscape and its ecological and hydrological values [55,56]. In successful examples, blue-green infrastructure not only mitigates flood impacts [57] and improves adaptation to climate change, but also increases the quality and living conditions of urban environments in terms of improved heat alleviation, increased biodiversity, and better air quality. It may even have the potential to provide for food and energy production, improve local economy, and benefit social life [58]. Ecological urbanism makes it possible for both water flow and urban landscape to act as mutual drivers and at the same
time, values are added to the public urban space. Due to historical reasons, most cities have today mainly piped drainage and a flood control system for pluvial flooding [13,59]. Transfer towards blue and green solutions will be slow and many challenges regarding responsibility, economy, and maintenance are yet to be solved.

Increased frequency and intensity of heavy rainfall are affecting private and public stakeholders and municipal authorities. Compact solutions and efficient land use are called for in both new areas and redevelopment in urban areas. Densely built urban areas should provide easy and convenient access to a multitude of functions such as retail, service, and public transport, thereby contributing to reduced energy use and CO₂ emissions [5]. This means that a wide range of everyday activities is carried out simultaneously in densely built urban environments. The value of urban land is high and thus urban space has a multitude of functions (Figure 4). Strategies to address water challenges at early stages and implement integrated site-specific urban drainage solutions in all urban projects are essential [35].

![Figure 4](image-url)  
**Figure 4.** Floodable areas with multifunctional use. (a) A pond in Augustenborg Eco-City, Malmö. During heavy rainfall, the area can store water up to the stone edge near the trees to the right (photo by Johanna Sörensen); (b) The Water Plaza in Rotterdam. The multifunctional basins prevent surrounding streets from being flooded. The plaza is also used for performances, skating, studying, and group meetings (photo by Misagh Mottaghi).

Several critical considerations need to be taken when introducing flood preventing measures above ground to assure that retention ponds, permeable surfaces, and open swales are adding to, rather than subtracting from, the experiential and functional quality of everyday living environments for urban dwellers (Figure 5). For instance, sustainable urban environments need to prioritize non-motorized travel modes such as walking, bicycling, and the use of public transport [60]. Special attention needs to be given to vulnerable and less mobile groups such as children, elderly people, and those with physical or visual impairment. It is therefore crucial to include designers with expertise in urban landscaping and social structures in the design process, to make sure that new designs meet the requirements for all users. With multipurpose solutions, increased complexity in the design process will follow. Water planning and urban planning integration are thus keys to flood resilience. The focal points should be at improving the spatial and economical values of the use of water in the city, protecting the city against sea level rise and river discharge, and increasing resilience to stormwater. Solutions should consist of the combination of planning, technology, and design. Accordingly, merging different urban projects and taking advantage of various sectors, working groups, and experts are necessary [61].
Flood events pose special threats to society through the effects on infrastructure. Large quantities of water may flood buildings and cut off roads. Flooded buildings with sensitive equipment such as electrical and IT systems may have devastating societal effects. Moreover, since sensitive infrastructure systems usually are connected and interdependent, effects may cascade to other systems and over a much larger area than the initially affected one [62,63]. Additionally, the consequences may occur instantly or show up later making it very difficult to assess the consequences that a flood event may have on society as a whole [64,65]. This is serious since the infrastructure is often critical for society’s function to work properly and deliver basic services and supplies to its inhabitants, such as fresh water and electricity. This is especially true for urban environments with no or few alternatives to the failed infrastructure. Moreover, vital societal functions, such as hospitals, may not tolerate interruptions in water supply, electricity, as well as transportation. Hence, it is paramount that effective planning measures for protecting the infrastructure are developed and implemented. Considering the damages flooding causes worldwide there is still much to do when it comes to protecting the sensitive infrastructure from being damaged or affected by flooding.

From the above, it is clear that planning is essential for protection of vital infrastructure when dealing with disaster risk management. Not only flooding, but also other potential threats to a functional society, have to be taken into account when designing and building infrastructure. We have to make sure that water, transportation, energy, and other important infrastructures are protected in non-normal situations, like during flood events. A way to prepare the society is to simulate different scenarios by applying disturbing factors. Using modern technology, like up to date spatial planning techniques, makes it possible to integrate a large number of societal threats and optimize solutions [66]. Solutions can also be based on different priorities, such as cost-benefit, time, or environment [67]. For this purpose, adequate and high quality data are a necessity to make simulations trustworthy, as even small errors in these datasets will highly influence the results [68]. The scale and accuracy challenge makes the planning site specific, and does not allow for spatial generalizations. Coombes, P.J. [68] noted that an appropriate policy framework is required that integrates land and water management with design processes at spatial scales from local to regional and that also applies to urban renewal and asset renewal or replacement choices. However, integrative aspects may as well lead to competing scales of issues and inertia of existing systems may severely challenge innovative facets of solutions [69].
4. Flood Management with Multiple Stakeholders

4.1. Roles and Responsibilities

The water supply and water sector is arguably the local activity that is first to be exposed by a changing climate and increased flood risk. However, the water sector cannot be expected to handle the complex problems by itself only. To find cost-effective solutions, public and private actors at the local and national level must cooperate and share the responsibility to reduce the negative effects of flooding. For the water sector, this would call, e.g., for measures to integrate water management with a wider planning system, such as land-use planning and development of transport systems, and decentralized blue-green solutions to handle stormwater. Future effects of climate change are also expected to vary considerably, due to, e.g., variation in local climate as well as variation in natural and social conditions. These characteristics make adaption to climate change and flood control a local task [70]. There is, thus, a need for differentiated and flexible measures. For example, giving responsibility to different sectors at the local level can motivate them to seek cross-sector cooperation where they find this relevant [70]. For this to function, stricter central government regulations may be necessary. Adopting a highly decentralized organization is not without problems. [71,72] studied the effects of introduction of a revised system of funding flood management schemes in England, the ‘Partnership Funding’ [73]. The results suggested, e.g., that the economic efficiency did not increase. Instead, higher costs resulted due to longer decision-making practices. In addition, the scheme increased social inequality, where rural middle-class groups with local capacities, such a networks, skills, and cultural capital, gained from the funding scheme. Hovik, S. [72] concluded that there is not necessarily a contradiction between strong vertical links and a strengthening of horizontal cooperation in a system of network governance. Although in the resilience literature decentralized and deregulated risk management systems have been suggested, often as part of a neoliberal policy agenda [74–76], there is nothing in the concept itself that disqualifies all levels to take active part. In other words, just because individuals, households, and communities become involved, the state is not restrained from a central role in a resilient city. A characteristic of the 20th century was development of utility services that did not require the citizens’ active behavior. With regard to solid waste, citizens need to and are willing to interact with this system on a wider basis. It may well be that we now see changes also with regard to water, where the citizens have to interact and be part of the system. For this to take place, support by legislation is required. The Danish law on sky burst management may well be the first example of this. The concept requires an environment where different techniques are allowed to co-exist as different possible ways to solve multifunctional goals.

4.2. Multi-Stakeholder Planning

To facilitate multi-stakeholder planning, it is first necessary to identify all relevant stakeholders in a given area and create forums in which they can communicate their specific interests and needs to each other [77]. There is also a need to increase the stakeholders’ knowledge and understanding about flooding as phenomena as well as how flooding may affect specific urban locations. The stakeholders need to work with and see the result of reliable flow models that can visualize how flooding may develop at these locations. The stakeholders also need to increase their understanding on how flooding may affect the infrastructure in these places and how the effects may spread from one system to another. This calls for solutions where it is possible to illustrate and visualize how exposed the infrastructure is to flooding and collectively analyze what the effects flooding may have on infrastructure and society. The analysis can be refined by clarifying the sensitivity of the different infrastructures, their interdependencies, and the functions they support. An exciting way to perform this analysis may be to use social media and techniques in virtual reality (VR) or augmented reality (AR). A common denominator is to improve the communication between stakeholders before, during, and after flood events.
A major challenge concerns the implementation of effective measures. Although the infrastructure is connected, the responsibility, ownership, and competence are often separated, adding to the difficulties to obtain a holistic perspective and a general understanding among the stakeholders. This is further complicated by the fact that information about infrastructure may be sensitive and therefore cannot be openly communicated. Moreover, the divided responsibility makes it difficult to implement cost effective measures since cost and effect may be separated for different actors and systems. Hence, there is a need to encourage formation of joint priorities and objectives among all stakeholders. For a holistic flood risk planning to function, the planning process must be imbued by a high degree of communication and collective learning. Collective learning can be defined as “... a broad term and includes learning between dyads, teams, organizations, communities, and societies” [78]. It stresses “... characteristics such as relationships, shared vision and meanings, mental models and cognitive and behavioral learning” [78].

Zhou, Q. [12] provided a general summary of the capacity of various models and software in terms of water quantity and quality simulation, sustainable drainage device modeling, and spatial planning. It is important that the multi-stakeholder planning involves a presentation and motivation of selected models for the quantitative and qualitative modeling. A general concern, however, for these models is the lack of a shared interface/platform for integrated use. Many models are specialized for only one or a few aspects of SUDS (Sustainable Urban Drainage System) and therefore the simulation is often performed in isolation and thus only partially reveals all effects of SUDS. For a detailed discussion of models see [12]. A possible way to better integrate hydrological and hydraulic model results into multi-stakeholder planning is the use of Geographic Information Systems (GIS).

4.3. Information Sharing between Stakeholders

Geographic Information Systems (GIS) is an effective tool for building databases and analyzing spatial data, and may be of great help for accomplishing learning across organizational boundaries. GIS enables numerous types of analyses based on, e.g., proximity and network. In addition, the effective visualization capability of a GIS makes it highly suitable for learning and communication activities. As a result different forms of collective GIS-approaches have emerged, e.g., community mapping and participatory GIS. GIS is also used and developed for improving (flood) risk management. GIS has, e.g., been used for identifying interdependencies between local infrastructures [65], modeling and simulation of infrastructure elements interdependencies [79], and modeling urban surface water balances [80].

Shared responsibility and access to databases and analysis results are essential for successful planning as discussed above. One way of implementing this is by the use of a spatial data infrastructure (SDI) that is available on the Internet [80]. Integrated systems and integrated spatial data infrastructures (see e.g., [81–83]), are essential to make information available and create possibilities to include various types of data from different stakeholders. SDI makes it possible for data providers, including participatory data collection made by the broad society, to contribute in building information databases, to be used for planning as well as for awareness and protective measures. Web-based solutions make it possible for responsible parties (like municipalities) to retrieve data and information on a detailed level and for the public to get up-to-date information when needed. All stakeholders are also able to feed the system, through database writing permission set by the authorities [84,85]. This means that parts of the system are publicly available, while other parts are restricted to planners and officials only.

5. Discussion and Conclusions

In the above, we elaborated on concepts related to urban flood resilience and pointed out several areas where the society needs to change the thinking to reach our goal: an integrated flood management system that can cope with changing risk by increasing urban resilience. In addition to an active civil society, effective urban water governance is also required. It is crucial to realize that cities are urban socio-ecological systems where multiple stakeholders can jointly develop multiple-purpose solutions to
the complex problem of flood prevention in densely built urban areas. There are several challenges that still call for a solution, and the more important ones are summarized below. Transdisciplinary research has the potential to identify obstacles, learn from successful examples, promote the development of new processes, and to support progress in the mentioned areas.

1. Climate change and related impacts

Future flood protective measures should be climate change resilient. However, also other related climate change effects such as, water scarcity, drought, and heat waves, need to be considered in the municipal planning.

2. Water, energy, land use, transportation, and socioeconomic nexus

The urban water system has traditionally been regarded as a stand-alone system. To develop flexible, resilient, and multipurpose flood protection systems, the water, energy, land use, transportation, and socioeconomic nexus need to be jointly considered from a multi-stakeholder perspective (see also e.g., [86]).

3. Flexibility of different kinds of stormwater systems

Flexibility of flood protective measures is paramount. Urbanization as well as the changing use of urban areas imply that flexibility in measures against floods becomes very important. Flexibility is also needed in view of uncertain future climate change impact.

4. Unresolved questions regarding responsibilities and improved communication between stakeholders and authorities.

Sustainable flooding and resilience thinking to flood prevention need better integration among stakeholders and authorities managing flooding. Flooding, like other sudden events, may change the city from one state to a new, different one (especially for catastrophic events). This understanding opens up for new approaches to urban planning. In this process, the responsibility of different sectors of city and planning authorities needs to be clarified.

5. Securing critical infrastructures

Important societal sectors may be highly dependent on certain infrastructure and different flows of supplies, e.g., the health care sector. Methods and tools to clarify the infrastructures’ vulnerability to flooding can involve simulations, which are efficient in visualizing and have predictive capability; integrated databases; broad participation of many stakeholders with varying interests; and collective learning efforts that enhance information sharing. There is a need to reflect carefully on these and other methods and tools, and consider how they can be implemented effectively in the flood risk management work.

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Pluvial, urban flood mechanisms and characteristics – Assessment based on insurance claims

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**ABSTRACT**

Pluvial flooding is a problem in many cities and for city planning purpose the mechanisms behind pluvial flooding are of interest. Previous studies seldom use insurance claim data to analyse city scale characteristics that lead to flooding. In the present study, two long time series (~20 years) of flood claims from property owners have been collected and analysed in detail to investigate the mechanisms and characteristics leading to urban flooding. The flood claim data come from the municipal water utility company and property owners with insurance that covers property loss from overland flooding, groundwater intrusion through basement walls and flooding from the drainage system. These data are used as a proxy for flood severity for several events in the Swedish city of Malmö. It is discussed which rainfall characteristics give most flooding and why some rainfall events do not lead to severe flooding, how city scale topography and sewerage system type influence spatial distribution of flood claims, and which impact high sea level has on flooding in Malmö. Three severe flood events are described in detail and compared with a number of smaller flood events. It was found that the main mechanisms and characteristics of flood extent and its spatial distribution in Malmö are intensity and spatial distribution of rainfall, distance to the main sewer system as well as overland flow paths, and type of drainage system, while high sea level has little impact on the flood extent. Finally, measures that could be taken to lower the flood risk in Malmö, and other cities with similar characteristics, are discussed.

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1. Introduction

Extreme rainfall leads to pluvial flooding in many cities, affecting many people (Houston et al., 2011). Extensive urban and suburban growth in combination with insufficient sewer systems (Swan, 2010) as well as climate change (Semadeni-Davies et al., 2008a,b) aggravates the problem. Pluvial flooding is becoming less accepted as society is becoming more reliant on highly developed, power supply dependent technology and as cities are becoming more densely populated. Property owners pay service fees and expect that the drainage system shall work properly (Schmitt et al., 2004). Where flooding earlier was seen as an unforeseen event that cities could not afford to prevent from happening, awareness is rising that cities can be better prepared for flooding by using flood warning systems, by implementing measures that can lower peak runoff through retention, and by leading excess flow to less vulnerable places. It is however expensive to increase the drainage capacity in cities, even when multiple-purpose solutions, e.g. blue-green infrastructure, are used. For strategic reasons, it is therefore necessary to identify in which environments rains of different characters, or combinations of rain and high receiving water levels, contribute to flooding and what the characteristics of flood-threatened areas are. Thus, it is our objective to investigate the mechanisms and characteristics of urban, pluvial flooding.

Several studies have sought mechanisms behind urban flooding. Akukwe (2014) collected data from questionnaires and interviews. Two thirds of the flooding in Port Harcourt Metropolis, Nigeria, could be explained by human-induced factors like unplanned urban development and poor drainage capacity, which can be influenced by city planners, while the biggest factor, rainfall, cannot. While information from the public can be used to identify problems in the drainage system, the physical drivers behind pluvial flooding can barely be understood by questionnaires and interviews solely. ten Veldhuis et al. (2009) analysed data from a complaint register, which might give a better understanding of the mechanisms. They found that the most important contribution to flooding in Haarlem, the Netherlands, was gully pot blockage (79% of reported complaints), while the contribution of heavy storm events were much lower (5%). Torgersen et al. (2015) used insurance data to study the relation between extreme rainfall and urban flooding and found that long-lasting, but less intensive,
rainfall lead to more flooding than shorter, intensive rainfall in Fredrikstad, Norway.

Studies on causality of fluvial flooding are more prevalent, as there are more data available from rivers and more methods of analysis developed than for urban, pluvial flooding. There are interesting lessons to learn both about climatological (Glaser et al., 2010) and hydrological (Berghuijs et al., 2016) drivers as well as the effect of human activities (Zhang et al., 2014). Every river catchment is unique and flood frequency patterns must be understood independently (Glaser et al., 2010). Pluvial flooding acts on a different scale than fluvial flooding, where mechanisms and characteristics are functioning differently. Consequently, research is needed to investigate mechanisms and characteristics also for pluvial flooding.

In the present study of pluvial, urban flooding, two long time series (~20 years) of flood claims in Malmö, Sweden, have been collected and analysed. The data come from a municipal water utility company and from an insurance company that covers property loss from overland flooding, groundwater intrusion through basement walls and flooding from the drainage system. The flood claims are used as a proxy for flood severity for different events. As the addresses for all claims are included in the datasets, they are suitable for spatial analysis. The flood claim data give a good measure of flood extent during both minor flood events and more severe flood events, and in combination with climatic data and characteristics of urban drainage, topography, etc., the mechanisms of urban, pluvial flooding are analysed and discussed.

Insurance claim data have recently been used for various other studies, e.g. statistical analysis to determine distribution of extreme events (Smith and Goodman, 2000), and to explain flood variability related to sewer flooding with rainfall data in Aarhus, Denmark (Spekkers et al., 2013b). Spekkers et al. (2013a) analysed the relation between flood claims and rainfall extremes for the Netherlands. They were able to explain some of the spatial variance in flood magnitude with spatial distribution of the rainfall, while a considerable fraction could not be explained. Zhou et al. (2013) tried to find a relation between hourly and daily rainfall and flood related costs, but could only explain some of the flood related costs variance by rainfall intensities. Spekkers et al. (2013b) suggest that further research is needed where factors that may potentially influence the severity of flooding, such as topography, building and household characteristics, urban drainage characteristics and spatial distribution of rainfall are evaluated. Some of these parameters, i.e. topography, urban drainage and spatial distribution of rainfall, are analysed and discussed in the present article together with other parameters, such as sea level and historical existence of watercourses in the urban landscape.

The main objective of the present study is to analyse mechanisms and characteristics of urban, pluvial flooding on city-scale. It is discussed which rainfall characteristics result in most flooding and why some extreme rainfall events do not lead to severe flooding. The relation between topography and flood extent under different rainfall characteristics are analysed, and the influence of high sea level is also discussed.

The detailed research questions are

- Which are the most important mechanisms and characteristics that influence flood extent and its spatial distribution?
- Can any spatial patterns of flooding be identified?
- Is the spatial pattern consistent for different rainfall events with similar distribution?
- What are the consequences of extreme rainfall with different spatial and temporary patterns?

In the following sections, we first introduce the study site, Malmö, Sweden, and the data used in the study. Second, we present the methodology by which the data are analysed. Then, the relation between flooding and different mechanisms and characteristics, i.e. rainfall, sea level, topography, and drainage system type, are analysed and discussed. After these sections, three severe and recent flood events are described and discussed. A flood hazard map from City of Malmö is discussed. Finally, after a summary of the most important results, potential strategies for Malmö and data reliability are discussed.

2. Study site and data

The city of Malmö, Sweden, was selected as study site since, in the Scandinavian context, Malmö is a large city, where there have been several flood events in recent years. Like in many other cities, the more densely built areas have sewer systems where stormwater and sewerage are drained with one single pipe (combined system), leading to high risk of basement flooding. The sewer system in Malmö is representative for Scandinavian cities, with a mix of combined and separate sewers. Good quality data on flood extent, precipitation, topography, sewerage system, etc. are available. Malmö is also well known within the field of urban hydrology, as the city was an early starter in the work with integrated water management (Niemczynowicz, 1999; Stahre, 2008).

As the focus is urban, pluvial flooding, only urbanised areas of Malmö were included in the study. A boundary of the study area was drawn, restricted by the outer ring road in south and east, by the municipal border in northeast and by the coastline in north and west (Figs. 1 and 3).

In the following section, data are described that relates to urban, pluvial flooding, including meteorological factors (e.g. rainfall depth and duration), hydrological factors (e.g. topography and watercourses) and factors related to the drainage system (e.g. type of system).

2.1. The urban landscape

Malmö is the third biggest city of Sweden with a population of 320,000 (SCB, 2015), situated in the very south of the country (Fig. 1). The city of Malmö went through a rapid urbanisation from mid-19th century until the 1970s and again after the 1990s. Land between smaller villages that were located outside Malmö in 1940, during the first period of urbanisation, is today (2017) urbanised. Places like Limhamn, Bunkeflo, Fosie and V. Skrävlinge are now well-integrated parts of Malmö and the population has doubled since 1940. The urban part of Malmö has an area of 7681 hectares, where approximately half of it is impermeable (SCB, 2016).

2.2. Geology and watercourses

Malmö is situated in a flat landscape where the highest elevation is 37 m above sea level. The bedrock consists of limestone, which generally is covered with clayey till (Länstyrelsen Skåne, 2016). The Riseberga Brook runs from south to north in the eastern part of the city connecting to the Sege Brook short before it reaches the sea north of Malmö. The two brooks can be seen in some of the oldest maps of Malmö (Provincial map, late 1600s; Bjurman, 1752). In addition to these, presently open brooks, a watercourse in western Malmö is shown on the old maps, reaching from Bunkeflo in southwest to Slottsstaden. A map from 1940 shows that (probably) the same watercourse was still noticeable at this time, as well as a watercourse reaching from Mariedal/Kulladal in south to Pildammssten. None of these watercourses is visible in the urban landscape anymore, as they have been drained in pipes. A canal surrounding the inner part of the city tracks back in history to at least late 17th century and is culturally an important landscape feature in the city. Many combined sewerage overflows (CSOs) pollute the canal during rainfall. There are no lakes in Malmö.
2.3. Climate, precipitation and sea level

Situated in northern Europe, Malmö has a temperate climate. Intense rainfall is most common during late summer (Gustafsson et al., 2010), when humid air from the sea reaches the warm land, while stormy weather with extreme waves and water levels is most common during autumn and winter (Hanson and Larson, 2008). The maximum hourly rainfall is 26.1 and 53.4 mm, for 10 and 100 years return period respectively (Hernebring et al., 2015). The mean annual precipitation is 605 mm.

The main flood events appear primarily during the late summer months (July–August). In Malmö, snowmelt is not an important mechanism behind flooding.

Rainfall data were collected from SMHI (Swedish Meteorological and Hydrological Institute) and VA Syd, the local water utility. SMHI has one station in Malmö (Station A) and VA Syd has eight stationary stations (MA01 Turbinen Pumping Station, MA02, Limhamn Strandgatan, MA03 Augustenborg Ystadvägen, MA04 Djupadalsskolan, MA05 Bulltofta Water Work, MA06 Hammers Park Pumping Station, MA07 Bellevue Vikingagatan and MA08 Hoga Högatorpsvägen). Fig. 2 shows the locations of these stations. Sea level data were collected from the SMHI station Klageshamn, 10 km south of Malmö, and the SMHI station Barsebäck, 18 km north of Malmö, from November 1995 until December 2014.

SMHI measures volume of precipitation during 15 min while all VA Syd stations use tipping buckets with 0.2 mm bucket. Data from VA Syd were converted to 5 min precipitation volume before further analysis. In 2015, Hernebring et al. updated the precipitation statistics for Malmö based on data from 1980 to 2013. The statistics is based on the formula (Eq. (1)) suggested by Hernebring (2006), which is often used by practitioners in Sweden for design and modelling, where i intensity (l/s/ha) can be calculated from tr precipitation duration (min), T return period (year), and six coefficients
\[ i = \left( k_{11} + k_{12} \right) \times T^{k_{21}} \times \frac{i_{p}}{C_{0}} \times \frac{1}{T_{r}} \times \frac{1}{(T_{r})} \]

2.4. Drainage system

The urban drainage can be divided into major and minor systems, where the minor system reflects the constructed drainage system underground, while the major system reflects flow on streets, in channels and streams as well as detention basins above ground (Bengtsson et al., 1993). In Fig. 3, the major and minor drainage systems of Malmö are shown. The minor system is based on a sketch of the main sewers by VA Syd (water utility company), while the major system was derived from a simple analysis of the topography where the flow from an eight-direction flow model (Jenson and Domingue, 1988) is accumulated into each cell. No validation of the analysis was done. The main sewer system follows the main flow paths in the major system to a high degree. The main pipelines are found along the stretch of Hylliediket in western Malmö, Södervärnssträket in southern Malmö, and the Riseberga Brook in eastern Malmö.

The current main drainage pipes closely follow the open watercourses like Hylliediket, Södervärnssträket, and Pildammsdiket which can be seen on a map from 1940. No parts of these watercourses are open anymore, except for the ponds Pildammarna, which are not connected to the drainage system. These watercourses do however still exist as major overland flow paths, according to the simple analysis of the topography.

Data on drainage system type (combined sewer, separate sewer and semi-separate\(^1\) system) were provided by VA Syd: one dataset from 2016 and one older dataset from an unknown year (probably 2000–2010). Areas developed during early urbanisation are still connected to the combined sewer system today, except for the most central area close to the canals, which was constructed with separate system. Until the 1950s, mainly combined sewer systems, with sewerage, stormwater, and groundwater drainage in the same pipe, were built in Malmö. From 1950s, separated sewer and stormwater systems were built in newly developed districts. In Malmö city, 31% of the urban land has combined system, 5% has semi-separate system and 64% has separate system (Fig. 3). Within the inner ring road, where the city is more densely built, 40% of the area has combined system, 7% has semi-separate system and 53% has separate system.

\(^1\) Semi-separate system is a separate system where the stormwater pipes are connected to the combined system downstream. The stormwater is thereby led to the wastewater treatment plant due to lack of a local recipient.
Several areas with semi-separate system has been reconstructed to separate system during recent years. In total, 4400 hectares are connected to the drainage system within the inner ring road, and further 2600 hectares between the inner and the outer ring road (mostly separate system). According to Swedish law, the pipe system should be designed so that flooding occurs less than once every ten years over a longer period. This corresponds to a rainfall volume of 16 mm in 15 min, 26 mm in one hour, and 30 mm in two hours in Malmö (Hernebring et al., 2015). The system is nevertheless, according to Swedish design standard, designed to handle stormwater from more extreme events in some places (Svenskt Vatten, 2016).

As the topography of Malmö is flat, pumping is needed in the sewerage system. The catchments of Turbinen and Rosendal, the two main pumping stations, include both separate and combined systems. Because of inflow from the combined system, they are affected by rainfall. The portion of combined sewerage is bigger in Turbinen catchment compared to Rosendal catchment, and therefore rainfall influences the flow more here. The pump capacity of Turbinenpst is 2.5 m³/s, Rosendalpst 2.7 m³/s, Spillepengenpst 1.6 m³/s, and from the harbour 1.5 m³/s. All these stations are connected to the wastewater treatment plant Sjölunda and the total maximum capacity of the pressurised system is 8 m³/s. In total, the utility company owns 134 smaller and bigger pumping stations.

There are several detention basins in Malmö for both stormwater and combined sewerage. The total volume is ~52,000 m³, where 9500 m³ of the volume is found in the combined system, 13,500 m³ is found as open basins and 29,000 m³ as underground basins in the separate stormwater system (VA Syd, 2009). The main function of detention in the combined system is to reduce CSO to the recipients.

2.5. Flood claims and reports

The general practice of insurance in Sweden is home insurance (‘hemförsäkring’), which a majority of homeowners have. The home insurance typically covers personal property, personal liability, and legal expenses, including flood related damage on the property. There are three categories of flood damages: via drainage system, overland flow into the building, and groundwater intrusion. Some home insurances cover all three types, while others only cover leakage and surcharge of the drainage system. Flood insurance is excluded from home insurances in some geographical areas with higher flood risk. It is not possible for homeowners to sign a separate flood insurance in Sweden.

Persons and companies affected by a flood event can make flood claims both to their insurance company and to the water utility company. If the drainage system is found to be insufficient, the water utility company covers the deductible for property owners. The water utility company also collects flood reports from other property owners and covers claims from insurance companies. For the present study, insurance claims and reports of flooded properties have been collected from the insurance company Länsförsäkringar Skåne (LF Skåne) (received 2015–03-24) and the water utility company, VA Syd (received 2016–03-14). The LF Skåne dataset contains 9704 reported flooded properties in the region Scania, Southern Sweden during a period of 28 years (1987–2015), where the first claim from Malmö is from March 1994. LF Skåne covers 40–50% of the private insurance market in the region. From this dataset, 3776 flood claims are from properties within the study area and a thorough quality control was made to ensure the right address of all claims. The VA Syd dataset includes in total 5868 claims and reports from Malmö for the period between June 1990 and March 2016 (26 years), whereof 5502 are from within the study area. Both datasets contain flood dates and therefore no adjustments of the dates are needed (see Spekkers et al., 2013b). There is no information in the two datasets that makes it possible to distinguish between floods of different kinds, like pluvial, fluvial or coastal flooding, to identify what part of the building that was flooded, or to identify the direct cause of the flooding (e.g. through drains, pipes, windows, etc.).

In general, there is consistency between the data from LF Skåne and from VA Syd. The LF Skåne dataset includes insurance claims from each affected insurance holder while the VA Syd dataset includes maximum one claim or report per property connected to the sewerage system. There are, as expected, more reports from VA Syd for most events. The biggest difference between the datasets is expected during coastal flooding, as it makes no sense for property owners to report such floods to the utility company, VA Syd. The spatial patterns of flood claims from most of the severe flood events are found concurring for the two datasets. However, for the event on the 26 August 1996, VA Syd received more than 900 claims, while LF Skåne only received 30 claims. LF Skåne has increased its number of customers in Malmö during recent years, which can explain why the number of LF Skåne flood claims are much lower compared to flood claims from VA Syd until 2006, while the number are more equal from 2007. For this reason, the dataset from LF Skåne is mainly used from 2007. After 2007, the number of customers has increased with 8% (2007–2014). In addition, the number of buildings connected to the sewerage system, and thus VA Syd customers, might have increased somewhat within the time period of the study. The increase is thus limited as most buildings are constructed where an old building has been torn down.

2.6. Topographic data and street maps

Data on topography in a 2 x 2 m grid were retrieved from the Swedish official digital elevation model (Ny Nationell Höjdmodell, NNH). The vertical error of the elevation model is 5 cm and the horizontal error is 25 cm on average for open, hard surfaces (Lantmäteriet, 2015). Street maps were received from the Swedish national mapping, cadastral and land registration authority.
mechanisms and characteristics are evaluated. According to Crichton’s Risk Triangle (e.g. Crichton, 2008), risk comprises hazard, exposure, and vulnerability. The flood claims are used as a measure of spatial extent and severity of different flood events, which can be related to all three sides of the Risk Triangle. The vulnerability and exposure of individual households are not assessed as the study focuses on city-scale patterns.

Some of the registered flood claims include information on economic losses for the property owners. While Zhou et al. (2013) used such information as a measure of flood severity, the information was excluded in this study. It might be misleading to use the information as a proxy for flood severity, as the losses are related to the economic value of the insurance holders’ belongings. Thus, high-income areas might seem to be more easily flooded, independent on the actual flood risk in these areas. Furthermore, the information tells little about the person’s vulnerability to flooding.

The relation between rainfall and flooding are analysed, followed by an analysis of the impact from high sea level, topography, and type of drainage system. Three severe flood events and the consequences for the city are then described. At last, results from a flood hazard model are compared with flood claim data.

3.1. Selection of events

Characteristics and mechanisms affecting flood extent and spatial distribution was assessed from a wide range of events. Firstly, three recent, severe flood events in Malmö were chosen for detailed analyses: 5 July 2007, 14 August 2010, and 31 August 2014. All of these flood events were caused by heavy rainfall. There were also severe flood events on 26 August 1996 and 9 August 1999, but these events were excluded, as little information on these events were available. Secondly, the biggest flood events, according to the VA Syd dataset, were selected for comparison. From these events, flood events that were highly localised to one part of the city, like the flood event on the 3–4 August 2014, were selected and analysed in a separate category. Thirdly, big rainfall events were selected for analysis of rainfall events that did not lead to severe flooding. The eight rainfall events with most precipitation volumes for 1 h, 6 h and 1 day were found and added to the list of events. The final selection of flood and rainfall events are presented in Table 2 together with precipitation during the most intense 1, 6, and 24 h. Return periods for the 6-h precipitation volume, calculated with Eq. (1), are also presented. According to Swedish design standards, the sewerage system must have the capacity to handle a 10-year rainfall event, which corresponds to ~40 mm precipitation during 6 h (Hernebring et al., 2015).

The selected events were categorised and assessed in four groups (Table 2): a) Severe flood events, i.e. the 2007, 2010 and 2014 events (flooding in more or less all of the city), b) Other big flood events (flooding of properties spread over bigger areas of the city), c) Highly localised flood events (big flood events that hit limited areas of the city), and d) Big rainfall events that did not lead to severe flooding.

3.2. Rainfall analysis

Maximum rainfall volumes for each day were calculated for durations from 15 min to 12 days with a moving window of the corresponding duration. The total rainfall volume within a window was dated according to the last time step of the window, where the maximum 1-h rainfall can fall any time from 23.05–00.05, starting the day before, until 23.00–24.00 during the date of interest. Intensity-duration curves were prepared and compared with intensity-duration frequency (IDF) curves from Hernebring et al. (2015), as mentioned earlier. Confidence intervals (95%) were constructed with the assumption that the mean precipitation for each duration is normally distributed.

3.3. Spatial analysis of flood claims

For spatial analyses of the flood claim data, a 50 × 50 m grid was positioned over the city and each grid cell was assigned flooded or not flooded for every flood event, where flooded was assigned to cells with one or more flood claims reported for an address within the cell and not flooded was assigned to cells with no reported flood claims. Similarly, each grid cell was assigned one of the system types separate, semi-separate or combined, given by the maximum cover of drainage system type in the cell, as well as distance to the major flow paths. In total, there are 35,746 cells, where ~13,200 has separate system, ~5800 has semi-separate system, ~9700 has combined system, and ~7200 are outside the areas connected to sewerage system (according to the old dataset, see Section 2.4).

The relation between drainage system type and flooding was analysed for different rainfall events. It is assumed that buildings connected to the combined system is more vulnerable to flooding than buildings connected to the separate and the semi-separate system. Toilets and sinks are often connected by gravitational flow

Table 2

Selected events, number of flooded properties reported to LF Skåne and VA Syd, maximum precipitation during 1 h, 6 h, and 1 day (average of all stations functioning during the event), return period for 6-h precipitation, and category of event: Severe flood events (a), Other big flood events (b), Highly localised flood events (c), and Big rainfall events that did not lead to severe flooding (d). Flood claims reported to LF Skåne before 2007 are shown in brackets, as these are considered more uncertain.

<table>
<thead>
<tr>
<th>Date</th>
<th>Flood claims from LF Skåne</th>
<th>Flood claims from VA Syd</th>
<th>Max. 1-h precip. [mm]</th>
<th>Max. 6-h precip. [mm]</th>
<th>Max. 1-day precip. [mm]</th>
<th>Return period for 6-h precip. [years]</th>
<th>Category</th>
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<tr>
<td>2001-08-07</td>
<td>(3)</td>
<td>1</td>
<td>15.9</td>
<td>22.3</td>
<td>24.3</td>
<td>1.4</td>
<td>d</td>
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<td>(12)</td>
<td>75</td>
<td>14.6</td>
<td>22.8</td>
<td>34.4</td>
<td>1.5</td>
<td>b</td>
</tr>
<tr>
<td>2003-05-24</td>
<td>(35)</td>
<td>105</td>
<td>8.2</td>
<td>8.2</td>
<td>14.3</td>
<td>0.04</td>
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<tr>
<td>2003-07-18</td>
<td>(30)</td>
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<td>19.1</td>
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<td>32.0</td>
<td>3.9</td>
<td>b</td>
</tr>
<tr>
<td>2006-08-26</td>
<td>(26)</td>
<td>121</td>
<td>17.2</td>
<td>20.1</td>
<td>20.2</td>
<td>1.0</td>
<td>c</td>
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<td>150</td>
<td>10.3</td>
<td>39.5</td>
<td>70.8</td>
<td>10.2</td>
<td>a</td>
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<tr>
<td>2007-07-22</td>
<td>1</td>
<td>1</td>
<td>9.2</td>
<td>31.1</td>
<td>37.9</td>
<td>4.4</td>
<td>d</td>
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<tr>
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<td>1.3</td>
<td>7.2</td>
<td>39.0</td>
<td>0.03</td>
<td>d</td>
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<tr>
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<td>210</td>
<td>20.8</td>
<td>50.8</td>
<td>55.3</td>
<td>24.3</td>
<td>a</td>
</tr>
<tr>
<td>2011-06-06</td>
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<td>13.9</td>
<td>15.0</td>
<td>15.0</td>
<td>0.3</td>
<td>c</td>
</tr>
<tr>
<td>2011-06-23</td>
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<td>10.8</td>
<td>28.5</td>
<td>31.0</td>
<td>3.3</td>
<td>d</td>
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<tr>
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<td>3</td>
<td>4</td>
<td>10.0</td>
<td>12.2</td>
<td>15.7</td>
<td>0.2</td>
<td>d</td>
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<td>19.1</td>
<td>27.3</td>
<td>0.8</td>
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<tr>
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<td>2109</td>
<td>30.1</td>
<td>83.0</td>
<td>96.0</td>
<td>134.5</td>
<td>a</td>
</tr>
</tbody>
</table>

* Includes claims from 2014-08-03 as the rain fell around midnight.
(no pumping) to the sewers, making the basements vulnerable to backwater flow from the combined sewerage pipe during heavy rainfall.

The effect of catchment scale topography on flooding was analysed as the relation between distance to the major system and reported flood claims per hectare. Cells without buildings were excluded from the calculations as flood claims only are reported for properties. There are roughly the same number of addresses per hectare near the major flow paths as further away from them (762 claims per hectare <100 m from the major flow paths and 716 claims per hectare >100 m away). VA Syd has approximately one customer for each address, indicating that the dataset is not biased in relation to distance to the major system. The spatial distribution of flood claims was analysed together with data about customers from other insurance companies.

### 3.4. Description of flood events and their effects on the city

The three severe flood events (2007, 2010, and 2014) were described in terms of how they affected the city, including the sewerage system. The main source of information was the insurance claims, information collected through personal contact² with VA Syd, the utility company in Malmö, and information from unpublished reports written by VA Syd after the flood events. The spatial distribution of flood claims was analysed together with data about the main sewer system and the topography of the city. The topography of flooded areas as well as a map from 1940, showing original path of watercourses before urbanisation of Malmö, were studied.

### 4. Results and discussion

#### 4.1. Relation between rainfall and flooding

The main cause behind the biggest flood events in Malmö is heavy rainfall (Table 3). The events in the table includes 76% and 83% of all claims reported by VA Syd and LF Skåne, respectively. As the flood claim data do not indicate causality for each flood event, this was derived from study of precipitation data (IDF curves), spatial pattern of the flood claims, and sea level data. A few flood events were caused by highly localised rainfall, as marked in the table, where the spatial extent both of the flooding and the rainfall were limited. Most flood events are noted in late summer months (July, August), which indicates that they are caused by convective rainfall. Out of the 64 events with at least 5 flood claims reported, 77% happened during June, July or August (June 16%, July 23%, August 38%). It cannot be assured that all flood claims during a certain day have the same cause, as there might have been a functional failure in the sewerage system at the same time.

During the six most intense hours of the 2014 event, approximately $3.2 \times 10^6 \text{m}^3$ of precipitation fell over Malmö city (Hernebring et al., 2015). The minor, ordinary drainage system could only handle a small part of this (separate system: $0.2 \times 10^6 \text{m}^3$; combined system: $0.25 \times 10^6 \text{m}^3$), while $1.2 \times 10^6 \text{m}^3$ infiltrated during these 6 h and about half of the total volume ran as overland flow to low-lying areas ($1.5 \times 10^6 \text{m}^3$). It took approximately four days before all low-lying areas were drained from inundated water (ibid.). The analysis shows that such extreme events cannot be handled only via pipe engineering, but has to be dealt with using appropriate spatial planning and urban design.

#### 4.1.1. Severe flood events (a)

In recent years, there were three severe flood events: 2007 (5 July), 2010 (14 Aug) and 2014 (31 Aug), see Table 2. They were all caused by heavy rainfall distributed over the entire city. As can be seen in Fig. 4a, the measured rainfall during the three events had a return period between 10 and 100 years for most durations. The 2007 event stands out with shorter return period for durations below 6 h, and the 2014 event was heavier than a 100-year event for durations between 3 and 16 h. These three, severe events, and the effects of them, are discussed in detail in Section 4.5.

#### 4.1.2. Other big flood events (b)

Three other big flood events were selected (3 Aug 2002, 18 July 2003, and 4 Aug 2014), see Table 2. These events flooded big parts of the city. The damages were, however, not as widespread as during the three severe flood events in 2007, 2010 and 2014. All the big events had reached their highest return period for shorter durations (up to 4–6 h), see Fig. 4b. From this figure, it can also be seen that these floods were caused by short, intense rainfall after several days with more or less persistent rainfall. The event on the 4 Aug 2014 was, according to VA Syd flood claim data, as extensive as the severe 2007 and 2010 events, while the data from LF Skåne indicates a flood extent less than half. The reason for the difference is unknown.

#### 4.1.3. Highly localised flood events (c)

Three highly localised flood events were selected, see Table 2. An event on 24 May 2003 affected areas with combined system mostly in the western parts of Malmö. The same areas were again hit on 26 August 2006, while an event on 6 June 2011 mostly affected areas with combined system in eastern parts of the city. As expected, most rainfall was measured at stations close to the most affected areas. On 24 May 2003 and 26 August 2006, the highest intensities were measured at Limhamn and Turbinen in west, while the highest intensities on 6 June 2011 were measured at SMHI A and Hjøra in east (for location of precipitation stations, see Fig. 2). In Fig. 4c, average precipitation from the two stations with highest intensities are shown (“Top 2”). The rainfall on 26 August 2006 was more intense than for the two other events (Fig. 4c). The lowest intensities were measured on 24 May 2003.

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* The second author worked for VA Syd for several years, hereunder during and after the 2014 event, where she made investigations of the pipe system (on site, through reports from property owners and insurance companies, as well as by modelling).

---

### Table 3

<table>
<thead>
<tr>
<th>Date</th>
<th>Flooded properties</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VA Syd</td>
<td>LF Skåne</td>
</tr>
<tr>
<td>2014-08-31</td>
<td>2109</td>
<td>2649</td>
</tr>
<tr>
<td>1996-08-26</td>
<td>882</td>
<td>(30)</td>
</tr>
<tr>
<td>2014-08-04</td>
<td>230</td>
<td>67</td>
</tr>
<tr>
<td>2010-08-14</td>
<td>210</td>
<td>148</td>
</tr>
<tr>
<td>2007-07-05</td>
<td>150</td>
<td>169</td>
</tr>
<tr>
<td>1999-08-09</td>
<td>144</td>
<td>(7)</td>
</tr>
<tr>
<td>2003-05-24</td>
<td>105</td>
<td>(35)</td>
</tr>
<tr>
<td>2003-07-18</td>
<td>105</td>
<td>(30)</td>
</tr>
<tr>
<td>2011-06-06</td>
<td>128</td>
<td>26</td>
</tr>
<tr>
<td>2006-08-26</td>
<td>121</td>
<td>(26)</td>
</tr>
<tr>
<td>2002-08-03</td>
<td>75</td>
<td>(12)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
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<th>Cause</th>
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<tr>
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</tr>
<tr>
<td>1996-08-26</td>
<td>882</td>
<td>(30)</td>
</tr>
<tr>
<td>2014-08-04</td>
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<td>67</td>
</tr>
<tr>
<td>2010-08-14</td>
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</tr>
<tr>
<td>2007-07-05</td>
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<td>169</td>
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<tr>
<td>1999-08-09</td>
<td>144</td>
<td>(7)</td>
</tr>
<tr>
<td>2003-05-24</td>
<td>105</td>
<td>(35)</td>
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<tr>
<td>2003-07-18</td>
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<tr>
<td>2011-06-06</td>
<td>128</td>
<td>26</td>
</tr>
<tr>
<td>2006-08-26</td>
<td>121</td>
<td>(26)</td>
</tr>
<tr>
<td>2002-08-03</td>
<td>75</td>
<td>(12)</td>
</tr>
</tbody>
</table>

Precipitation data are only available from VA Syd station MA01 Turbinen pst and at SMHI station A. At Turbinen station, 38.6 mm and 22.0 mm were measured on the 26 August 1996 and 9 August 1999, respectively, while only 7.6 mm and 0.3 mm were measured at SMHI station A on the 26 August 1996 and 9 August 1999, respectively. In both cases, the flood claims were reported from large parts of the city, indicating that the floods were caused by heavy rainfall. Sea level was low in both Klagshamn and Barseback.

² Includes claims from 2014-08-03 as the rain fell around midnight.
There were, however, no significant difference in number of flood claims.

4.1.4. Big rainfall events that did not lead to severe flooding (d)

Five big rainfall events that did not lead to flooding were selected for comparison (7 August 2001, 22 July 2007, 24 August 2008, 23 June 2011, and 25 September 2012), see Table 2. These events were all selected as they were ranked high on the list of events with high intensity for the 1-h, 6 h and 1-day durations. It is not possible to make a clear distinction in rainfall intensity between these events and the three bigger flood events (3 August 2002, 18 July 2003, 4 August 2014), as can be seen in Fig. 4d in comparison with Fig. 4b. The intensities for shorter durations (<8–10 h) seem to be slightly lower, but the difference is small. However, the spatial distribution is more even for the events that did not lead to flooding, indicating that the bigger flood events had higher intensities in some parts of the city. Therefore, even if the registered rainfall is similar on average, there might have been areas with more extreme precipitation during the events in category b (other big flood events) that were not captured by the metres.

4.2. Relation between sea level and flooding

As mentioned before, SMHI measures sea level 18 km north and 10 km south of Malmö. The closest station is Klagshamn, south of Malmö, but as the water level can differ at least up to 150 cm between the stations, data from both stations are useful for Malmö. The difference in level is an effect of the Saltholm–Malmö High, a large-scale, first order mound succession across the strait between Malmö and Copenhagen (Hansen, 1943; Bjerager et al., 2010). The water level in the strait is mainly governed by wind direction and stormy weather in the North Sea, leading to higher flood risk in most of Malmö when the water level is high in Barsebäck. During storms, waves might rise several metres higher than the actual water level (Sweco, 2017). There is little influence of tide.

There are 230 hectares of land in Malmö below +1 m, but no buildings, roads or other infrastructure. Below +2 m there are in total 580 hectares of land, including 50 hectares of housing and industrial land, and 12 km streets and 3 km railroad. Only half a metre higher, below +2.5 m, there are in total 1400 hectares of land, including 100 hectares of the city centre and 450 hectares industrial land. (Malmö Stad, 2008)

Out of the ten days with the highest water level measured at Klagshamn, flooding was only reported on one day, namely on the 20 January 2007 (Fig. 5). On the same day, about 20 mm of rain fell over Malmö. Two flood claims were made to LF Skåne and there were six claims or reports to VA Syd. All claims, except for one, came from properties close to the sea in Limhamn. It can be noted that the sea level was even higher in Barsebäck the day before, but on this day, no flooding was reported.

Out of the ten days with the highest water level measured at Barsebäck, flooding was reported on five days, namely on the 1 November 2006, when one property close to the canal was flooded, on the 27 and 28 November 2011, when four properties close to the canal were flooded, and on the 6 and 7 December 2013, during the storm named “Sven” by SMHI. In Fig. 5 it can be noted that out of the 30 biggest flood events, there was only one day with high sea level, namely on the 5 December 2013, also during storm Sven. On this day, 17 flood claims were made to the insurance company LF Skåne, while there were no claims or reports to VA Syd. From the latter fact, it can be assumed that there was no flooding related to the sewerage system during the storm Sven. All of the flood claims to LF Skåne, except one, came from property owners along the coast.

Only for a few events during the period of this study, stormy weather seems to have caused flooding. This is expected, as only areas of minor importance are located lower than the water levels measured during recent storms. The storm Sven was the only flood event with more than 15 claims that were caused by storm. A few streets along the coast and harbour were also flooded. Storms have so far caused much more wind related damage1, but with slightly

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Fig. 4. Intensity-duration curves for all nine rain gauges in Malmö, average for stations in function with confidence interval (95%) reflecting the spatial variation between the gauges. Note the different scale in figure a. Comparison with 10-, 50- and 100-year rainfall statistics from Hernebring et al. (2015). a) Rainfall that led to severe flooding in more or less the entire city. b) Rainfall events that led to flooding and 100-year rainfall statistics from Hernebring et al. (2015). c) Rainfall that did not lead to flooding. c) Rainfall events that did not lead to flooding. d) Big rainfall events that did not lead to severe flooding and 100-year rainfall statistics from Hernebring et al. (2015).
higher water level during Storm Sven, the railway tunnel under Malmö would have been flooded (Sweco, 2017). During the studied period, coastal flooding did not affect many property owners, compared to pluvial flooding, in Malmö. However, there are examples of more severe flooding from sea under current climate, like “the Christmas Storm” in 1902, with levels higher than +2 m (Sweco, 2017). With rising sea level in the future, coastal floods are expected more frequently (SMHI, 2007).

### 4.3. Relation between topography and flooding

Areas within 100 m from the major system are more than twice as affected by flooding, compared to areas further away (Table 4). During the severe flood events in 2010 and 2014, areas close to the major system was even more affected by flooding (3.0–4.2 times), compared to areas further away. During such downpours, runoff is quickly directed towards low-lying areas, both through the pipe system and by overland flow. In Malmö, like probably in most other places, the main sewers (minor system) are located under the main overland flow paths (major system), as they follow the topography. The pattern of flood claims during extreme rainfall can be noted on Fig. 6a, where claims from the 2010 and 2014 events are shown. While Fig. 6a shows claims from the two severe flood events in 2010 and 2014, Fig. 6b shows claims from all other flood events, including the severe, but slower, event in 2007. These claims are not as clearly localised along the major system, but there are still concentration of flood claims in some areas.

The number of flood claims per 100 hectares, as shown in Table 4, were calculated only for grid cells (50 × 50 m) where there is a building, as only claims from buildings are included in the two flood claim datasets.

### 4.4. Relation between drainage system type and flooding

Areas with combined or semi-separate system were more affected by flooding than areas with separate system for all flood events in total as well as the three severe flood events independently (Table 5). During the 2010 and 2014 events, the combined system was 3.8–4.2 times more affected by flooding compared to the separate system. If the “old pipe system” (see Section 2.4) is used for the analysis, instead of the pipe system according to the 2016 dataset, the combined system was as much as 6.3–6.8 times more affected by flooding compared to the separate system during these events. Similar figures are found if all flood events are included, indicating that the combined system is more exposed to flooding than the separate system. 70% of areas with separate system (in 2016) had a semi-separate or combined system before (according to older dataset). Many of these areas have been

![Fig. 5. Daily maximum sea levels in Klagshamn (x-axis) and Barseback (y-axis) between November 1995 and December 2014 in light grey. Maximum sea level during the 30 biggest flood events are marked with dark grey. Maximum sea level on the 1 November 2006 (cross), the 19 and 20 January 2007 (square), the 27 and 28 November 2011 (plus), and the 5, 6 and 7 December 2013 (ring, the storm Sven) are highlighted as they are of a certain interest (mentioned in the text).](image)

![Fig. 6. a) Flood claims reported by LF Skåne and VA Syd during two of the three severe flood events in Malmö (2010 and 2014). b) Flood claims reported by LF Skåne and VA Syd during all other events, except for two severe flood events (2010 and 2014).](image)

<table>
<thead>
<tr>
<th>All events in the datasets (20 years)</th>
<th>2007-07-05</th>
<th>2010-08-14</th>
<th>2014-08-31</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100 m</td>
<td>343</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>&gt;100 m</td>
<td>153</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 4

Number of flood claims per 100 hectares that has been reported within a distance of 100 m from the major system on 5 July 2007, 14 August 2010, and 31 August 2014 in Malmö (based on data from LF Skåne and VA Syd). Only grid cells (50 × 50 m) with a building are included in the calculations.
affected by flooding, which makes interpretation of the results difficult.

The 2007 event shows a different pattern when it comes to flood exposure in combined system areas compared to separate system areas. The combined system areas were only slightly more than twice (2.3 times) as severely affected by flooding during this event, compared to the areas with separate system. Almost the same result is found when the old pipe system is analysed instead (2.4 times). One reason why the 2007 event differs from the other events might be the difference in flood causality, where continuous rainfall during the preceding weeks saturated the ground with water. Flooding during this event was therefore less related to type of drainage system.

The number of flood claims per 100 hectares, as shown in Table 5, were calculated only for grid cells (50 × 50 m) where there is a building, as only claims from buildings are included in the two flood claim datasets. There are more people living in areas with combined system compared to areas with separate system (1.7 times more addresses), which makes the data biased. However, the number of reported claims to VA Syd in combined system compared to separate system areas are even higher. There are 8.3 times more claims to VA Syd from areas with combined system compared to areas with separate system. The bias in the LF Skåne dataset related to combined/separate system is probably similar as for the VA Syd dataset.

### 4.5. Three severe flood events

In this section, an overview of three severe flood events in Malmö is given (5 July 2007, 14 August 2010, and 31 August 2014). The overview is followed by descriptions of the consequences of the events.

During the rainfall event on the 5 July 2007, 89 mm rain fell between midnight and 19.45 in the evening (SMHI, station A). The ground was already almost saturated due to recurring rainfall during the weeks before. This led to flooding all around Malmö and 169 flood claims were registered at LF Skåne and 150 at VA Syd. Flooding was reported to have occurred in locations represented by 245 cells in the 50 × 50 m grid (from now on notated “x cells were flooded”). Several areas outside Malmö, like the neighbouring city of Lund (Fig. 1), were also flooded on the 5 July 2007, but the biggest rainfall volume was measured in Malmö.

On the 14 August 2010, 66 mm rain fell between 06.00 and 19.30 (SMHI, station A), out of which ~50 mm fell during the last 3 h. The number of flood claims sent to LF Skåne was 148 and to VA Syd 210. 270 cells were flooded. The rainfall event also led to flooding in northern Copenhagen and 99 mm rainfall was measured in Vedbæk (Fig. 1) (Olesen and Siewertsen, 2010).

The severe flooding on the 31 August 2014 is the biggest flooding event in Malmö so far, with 10 times more flooded cells compared to the 2007 and 2010 events. The flooding affected all parts of the city. A total volume of 101 mm fell between early morning (02.15) and late evening (21.30) (SMHI, station A). During the most intense hours (4.30–7.30), 71 mm fell. In total, 2649 flood claims were reported to LF Skåne and 2109 to VA Syd, spread over 2388 cells. Many properties within the same cells were flooded. The rainfall was even heavier south of Malmö compared to the city of Malmö. The maximum rainfall was measured in Höllviken (Fig. 1), Vellinge municipality (168 mm in total, 118 mm during 90 min). The rainfall covered a large area including Copenhagen, Denmark (Fig. 1). More details on the rainfall is found in a report by DHI (2014a).

The maximum sea level during the three biggest flood events (2007, 2010, and 2014) was less than 0.5 m and thus not high enough to affect the flooding.

Accumulated rainfall for the three flood events are shown in Fig. 7. During a period of 20 days before the 2007 event, about 145 mm had fallen, while about 90 mm had fallen before the 2010 event, and about 40 mm before the 2014 event. This is shown as the initial value on the left hand side. It can also be observed that the rainfall during the 2007 event was more evenly distributed in time, while the 2010 and 2014 events had more distinct peaks of rainfall. The 12 days before the 2014 event was almost dry (12 mm). Intensity-duration curves for the three flood events are shown in Fig. 4a together with IDF curves with return period of 10, 50 and 100 years from Hernebring et al. (2015). The 2014 event was the most intense for all durations less than 4 days (~1h), except for the 2 h duration, where the 2010 event was slightly more intense. For durations longer than 4 days, the 2007 event was the most intense. The 2010 event was more intense than the 2007 event for durations shorter than 8 h.
The locations of the rain gauges are found on the map in Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.5.1. Consequences of 2007 flood event
In Fig. 8a, cells where flooding was reported during the 5 July 2007 are marked with black. The flooded cells are spread all over Malmö, with higher density in areas with combined system. The rainfall was most intense in eastern Malmö, but the spatial variation was small. As can be seen in Fig. 8b, all durations under four hours represent less than a one in ten years event. During the most intense hour that day, ~10 mm rain fell. For durations longer than one day, the return periods were longer – from ten years up to fifty years for eight days duration. Since the soil was almost saturated after the long, rainy period, the infiltration capacity was reduced and the groundwater table was high. This led to worse flooding than would normally be expected from a 1-day rainfall with similar intensity as during the 2007 event. Many properties in upstream parts of the system were affected.

During the investigations after the 2007 flood event, it was found that approximately 50%4 of the basement flooding was due to groundwater intrusion through the foundation walls because of long-lasting rainfall. The number of reported flooded properties caused by overload of the pipe system was small in relation to the incident. Some areas, like Kronprinsen (Fig. 8a), a high-rise building in central Malmö, were affected by big amounts of extraneous water into the separate sewerage pipes. Although the high-rise building is connected to the separate system, it is situated close to the downstream part of the combined system, just 700 meter south of Turbinen pumping station. An investigation after the flood event showed huge amounts of extraneous water in the separate sewerage pipes at Kronprinsen as well as in other areas. The extraneous water probably came from intrusion of groundwater into the pipe due to high groundwater table.

In Toftanäs in eastern Malmö (Fig. 8a), the manual control of a floodgate was covered with water during the long-lasting rainfall and the open detention basin could therefore not be drained, as it was impossible to open the gate. Because of this, many buildings in the surrounding area were flooded. After that, the control gate was redesigned and reconstructed.

Table 6
Consequences of the severe flood events in Malmö in 2007, 2010, and 2014. Effect on areas with combined system, compared to areas with separate system, spatial distribution of flooding, and effects on the pipe system, pumping stations, and detention basins and recipients.

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Flood magnitude within combined sewer area, compared to separate sewer area</th>
<th>Spatial distribution of flooding</th>
<th>Effects on pipe system</th>
<th>Effects on pumping stations</th>
<th>Effects on detention basins and recipients</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-07-05</td>
<td>2.3 times more</td>
<td>Evenly spread over the city</td>
<td>A lot of extraneous water from intrusion of groundwater table due to high groundwater table</td>
<td>Spillepeneg pst overloaded. Led to flooding of properties at Segevång and Valdemarsro</td>
<td>Problems with manual flood gate control at Toftanäs basin led to flooding of surrounding buildings</td>
</tr>
<tr>
<td>2010-08-14</td>
<td>3.8 times more</td>
<td>More severe along main pipe network</td>
<td>Several main pipes in the separate sewerage system were filled with extraneous water</td>
<td>Spillepeneg pst overloaded</td>
<td>No reports</td>
</tr>
<tr>
<td>2014-08-31</td>
<td>4.2 times more</td>
<td>Almost the entire city. More severe along main pipe network</td>
<td>Overland flooding in several parts of the city. Inundated water entered separate sewerage pipes through basements</td>
<td>Turbinen pst was partly flooded and CSO could not function as intended. This probably exacerbated flooding in upstream areas</td>
<td>Most basins were overloaded, which led to inundation above/around them. High water levels in Sege Brook led to decreased CSO capacity and thereby flooding upstream</td>
</tr>
</tbody>
</table>

* Source: Unpublished reports written by VA Syd after the flood events.

In Table 6, an overview of the consequences of the three severe flood events are given. These consequences are presented in detail in the following Section 4.5.1–4.5.3.

A couple of buildings in Segevång were severely flooded with big damage (Fig. 8a). The area is connected to a separate system and located 1000 m upstream of Spillepeneg pumping station.
The pumping station was overloaded during the rainfall event due to reduced capacity of the pumps in combination with heavy load from the combined sewerage system. One of the pumps was not working and another pump was stopped during the critical phase of the rainfall due to an error in the control system. This led to flooding of properties at Segevång, and consequent claims for around 1.5 MSEK (~160 k€).

The failure of Spillepengen pumping station also led to flooding of at least 30 houses in Valdemarsro (Fig. 8a), an area from the 1920s, with combined sewerage system, located northeast of the city centre.

4.5.2. Consequences of 2010 flood event

The flooding on 14 August 2010 was spread over all of Malmö, but some areas were more severely flooded than others (Fig. 9a). One highly affected area was Södervårn, an area where there used to be a small watercourse. Along a similar watercourse in another part of Malmö, Limhamn, 25–30 properties were reported flooded (Fig. 9a). Heavy rainfall in combination with wet soils after a rainy August led to high amounts of extraneous water in the separate sewerage system. Still, the flooded areas were more concentrated along flow paths of the major system, compared to the 2007 event.

There was no clear relationship between local rainfall measured at the different rain gauges and the number of flooded properties nearby. For instance, the rainfall volume was small at Bellevue (Fig. 9a, third station from the left), compared to other stations, while areas close to this rain gauge were still severely flooded. Rainfall for all stations is presented in Fig. 9b.

From the reported basement floods, some areas can be distinguished. Along the Södervårn pipeline, which has a separate system, large volumes of extraneous water caused flooding in the area of Regementsgatan and Roskildevägen (Fig. 9a) along the eastern branch of the main sewerage pipe toward Turbinen pumping station. This main pipe ran full all the way from Söderkulla to the Turbinen pumping station (~4500 m).

In western Malmö, the main separate sewerage pipes (diameter: 500 & 600 mm) ran full all the way from Annortpsvägen to Turbinen pumping station (~4500 m), probably due to disconnection or leaking pipes. This caused flooding of 30 basements along the pipeline. The combined system in the area also got flooded. Around 30 houses, which were connected to the combined pipe between Södöverborgsgatan and Erikslust, were flooded (Fig. 9a), since some parts along the main pipeline in Vittskövlegatan–Gylleborgatan are undersized.

The Spillepengen pumping station was overloaded due to a problem with the inlet pipe just like during the 2007 event. This problem was resolved after the 2010 event.

4.5.3. Consequences of 2014 flood event

Almost the entire city was severely affected by the flood event in 2014. The rainfall was heavy all over Malmö and most intense in the central areas (Fig. 10a and b). Like both the 2007 and the 2010 events, the flooding in 2014 affected more or less all areas of the city. The spatial pattern of flooding during the 2014 event was more similar to the 2010 event than the 2007 event, as some areas were clearly more affected than others. The flood claims came from property owners in more or less the same areas as during the 2010 event, although many more properties were affected. The severely flooded area in western Malmö (Limhamn) follows the former open watercourse, like in the 2010 event, indicating that stormwater rapidly flows towards the former open watercourse during intense rainfall. This was also true for the flooded areas around Södervårn (in the centre of Fig. 10a).

A large part of the basement flood reports (67%) came from the combined system, which is not designed to handle such a heavy rainfall during a short time. Compared to the 2007 and 2010 event, several parts of Malmö were flooded not only in basements, but also affected by overflow flooding, which was the situation at Rönneholm, Holma, Söderkulla, Heleneholm, Lindängen and Sofielund (Fig. 10a). Most detention basins, both open and underground, were overloaded which led to local inundation above and around several of them.

At some places, inundated water entered separate sewerage pipes through basement floor drains in areas with separate system as well as through small holes in manhole covers. From Söderkulla to Turbinen pumping station (Pildammsdiket), and from Rosenväg to Turbinen pumping station (Hylliediket), the assessments showed that the water level in the manholes of the separate sewerage system had reached the ground, or near the ground. This led to basement flooding mainly in Djupedal, Ribersborg, Sofielund, Fägelbacken and Slottstaden (Fig. 10a). Kronprinsen and the main hospital were also flooded from the separate sewerage system.

The main pumping station, Turbinen (Fig. 10a), was partly flooded during the heavy rainfall. Problems with an inlet gate caused a huge pressure on the station and problems with a gate for combined sewerage overflow (CSO) led to flooding of the pumping hall. The reduced pumping capacity probably had a minor effect on the flooding situation in the upstream system, as the pumping station is designed for 2.5 m³/s and the inflow was extremely high. The inflow is unknown, but if half of the upstream area

Fig. 9. Flood event 2010, Malmö. a) Cells where flooding was reported are marked with black dots. Rainfall volume for 1 h (light blue circles), rainfall volume for 6 h (mid-blue circles) and rainfall volume for 1d (dark blue circles). Areas of special interest like Södervårn (SV), Limhamn (Lim), Regementsgatan (Reg), Roskildevägen (Ros), Turbinen pumping station (Tu pst), Söderkulla (SK), Annortpsvägen (Ann), Södöverborgsgatan (Sov); Erikslust (Erl), Vittskövlegatan (Vit) and Gylleborgatan (Cyl) are marked on the map. b) Rainfall volumes during and before the 2010 event in Malmö measured at eight rain gauges. The locations of the rain gauges are found on the map in Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
contributes to the flow, it was \( 150 \text{ m}^3/\text{s} \) during the six hours with most intense rainfall. The problems with reduced CSO capacity was probably a bigger problem, as it serves as a security during heavy inflow. Moreover, the inflow to the pumping station was obviously limited by pipe and inlet capacity upstream in the system. It took two days for the water level to decrease, and another two days before the pumping system operated at normal capacity. No problems were reported from any of the other pumping stations during the 2014 event.

Some areas in Rosendal catchment got flooded due to high water level in Sege Brook (north-eastern Malmö), which decreased the CSO capacity. The high water level might even have caused backflow from the brook into the sewerage system.

In summary, most flood claims came from areas with combined sewer system in central Malmö. The flooding was most severe along the main pipelines following former open watercourses and in some areas the flooding was aggravated by local, technical problems.

4.6. Flood hazard modelling

The City of Malmö made a thematic supplement to the comprehensive master plan, “Plan for water in Malmö”. During this work, a flood hazard model was prepared to investigate the consequences of extreme rainfall in central Malmö. This two-dimensional, hydrodynamic model includes overland flow and infiltration, but not pipe flow. Instead, the simulated rainfall (a 100-year event according to statistics on local data) is reduced with the 10-year rainfall intensity, corresponding to the drainage capacity of the piped system. The model is developed in Mike 21 (software by DHI) with a \( 4 \times 4 \text{ m} \) rectangular grid based on City of Malmö’s lidar data. (DHI, 2014b) In this study, the model is compared with flood claim data to discuss how modelling results and historical data can be used separately or together.

Fig. 11 shows maximum inundation depth from an overland flow simulation for a 100-year rainfall event (a). On top of the model simulation, the minor (main sewers) and major system (overland flow paths) are shown, as well as flood claims from VA Syd and LF Skåne for the 2007 (b), 2010 (c), and 2014 (d) events. In the northwestern corner, the overland flow model indicates high flood risk. The minor and major systems pass this area. The overland flow model gives a good indication of where intense rainfall events lead to severe flooding (Fig. 11c and d). However, the model cannot predict the spatial extension of flooding during longer rainfall events, like the 2007 event (Fig. 11b), probably because of limitation in interaction between runoff, infiltration and subsurface flow dynamics. The model points out many, small areas where
overland flooding might happen. Most of these areas are not indicated as problematic by the flood claim data, which might have one of two causes. Either information is missing, as no insured properties are located in the area, or the model incorrectly indicates higher flood risk than expected. It is difficult to point out continuous areas with especially high risk from the flood hazard model solely. These areas, with higher exposure to flooding, are more clearly visible from the flood claim data. It must be kept in mind that the flood claim data show affected properties, often flooded from the sewerage system, while the flood hazard model shows flooding from overland flow. The model can show streets, railroads, etc. with flood risk, which are not included in the flood claim data, while the model does not show basements that might get flooded as they are connected to overloaded parts of the pipe system.

The present datasets contribute with valuable information to flood hazard mapping. For cities that have been saved from severe floods, and therefore have little data, flood hazard mapping can be made e.g. through two-dimensional flood inundation modelling of overland flow (Fewtrell et al., 2008) or through coupled modelling of major and minor system (Maksimović et al., 2009). However, modelling should be carried out with caution if data are unavailable for validation (Mark et al., 2004; Mignot et al., 2006). In general, hydraulic modelling can give a rough estimate of the effects of extreme events. Beven (2008) divides model construction into three parts: 1) a perceptual model, which is how we understand the physical system, including the full complexity of the system, 2) a formal model, which is the mathematical description of the system, and 3) a procedural model, which is the model that will be run on the computer using numerical solution techniques. All three parts of model construction are associated with problems when the model is used to simulate extreme events. Extreme events are uncommon, and therefore the modeller’s understanding of how the system behaves during extreme situations is limited. Inundation models are still often used to predict pluvial flooding in cities (Lekuthai and Vongvissomjai, 2001; Mark et al., 2004; Zerger and Wealands, 2004; Mignot et al., 2006; Fewtrell et al., 2008; Maksimović et al., 2009; Schmitt and Thomas, 2009). Measured data to calibrate models for spatial distribution of inundation is often missing (Hunter et al., 2007), especially data from extreme events. Only a few studies have used insurance data for calibration and validation. Chen et al. (2009) validated a GIS-based, urban flood inundation model for a small area in Memphis, Tennessee, US, with inundation depths in flooded rooms in the Law School Library. Zhou et al. (2013) validated an inundation model for Aarhus, Denmark, with spatial distribution of flood claims. Both studies conclude that flood claims are valuable for calibration of inundation models with respect to frequency and location of flooding, especially as other kinds of data for calibration are rare. Yu et al. (2016) used crowd-sourced data from a single, extreme storm event in a similar validation process and found good agreement between the model results and reported flooding.

This study has shown that an overland flow model can give a good approximation of flood extent from intense rainfall. However, it does not capture the spatial distribution of flooding after a long period of wet weather, where the pluvial flooding is less related to the minor and major systems. The slower dynamics of such an event requires a different kind of model, where groundwater dynamics is better taken into account. It also underestimates the severity of flooding along major flow paths during intense rainfall. The studies on dual-drainage modelling of urban flooding that Schmitt et al. (2004) carried out, point out that flow simulations require a highly detailed, physical representation of surface area to be accurate. This kind of data is usually not available, and therefore restricts the use of model results for practical application. In the present study, historical data has been available and used directly to describe mechanisms and characteristics related to pluvial flooding, without support of modelling. However, it is not possible to test future scenarios, e.g. related to climate change (Paludan et al., 2010), or interaction with other systems, e.g. accessibility for emergency service (Coles et al., 2017), without a model. For such studies, a model calibrated and validated with measured inundation data, like flood claims including one or several extreme events, are preferably used.

4.7. Mechanisms and characteristics of flooding in Malmö

4.7.1. Rainfall

Flooding in Malmö is mainly pluvial. The rainfall during the three biggest flood events (2007, 2010, and 2014) was heavy all over the city. Other, minor floods were caused by highly localised rainfall, where only a certain part of the city was affected. A few of these events were however severe in the affected area. The extent of flooding is related to both rainfall intensity and total volumes. This was made clear by the flooding on 31 August 2014, which was bigger than all other events in flood severity, as well as, in rainfall intensity and rainfall volume. However, the correlation between flood severity and rainfall is not linear. This has been shown in other studies as well (Spekkers et al., 2013a; Zhou et al., 2013; Zhang et al., 2014; Berghuis et al., 2016), ten Veldhuis et al. (2009) showed that the most important contribution to flooding in Haarlem, the Netherlands, was gully pot blockage (79% of reported
complaints), while the contribution of heavy storm events was much lower (5%). The present study shows that the situation in Malmö is different, with rainfall as the dominating driver for flooding. Ten Veldhuis et al. do not explain why gully pot blockage is such a big problem in Haarlem. The results from Torgersen et al. (2015) showed a correlation between extreme rainfall and extent of urban flooding in terms of insurance claims. The most costly events occur during the long intensive rainfall rather than shorter rain, which is different from Malmö. Zhou et al. (2013) discussed possibilities to pursue the relation between precipitation and pluvial flooding in depth. Such possibilities were noted during this study as well. As pluvial flooding is caused by short, very intense downpours or convective storms, the spatial distribution of the precipitation is highly uncertain and might represent a major challenge for such analyses (Niemi et al., 2017). Spekkers et al. (2013a) show that rainfall alone cannot explain flood severity. Therefore, other mechanisms and characteristics are important to understand flood extent. This study contributes to a better understanding of such factors.

Bengtsson and Milotti (2010) have made a detailed description of extreme precipitation in Gustafsson et al. (2010) have identified the atmospheric patterns behind extreme summer precipitation in southern Sweden. Climate change will lead to more urban, pluvial floods in Sweden in the future, as examined by Semadeni-Davies et al. (2008a,b) and Berggren et al. (2012).

4.7.2. Topography

The severity and the location of flooding within Malmö are, apart from the rainfall, governed by the topography: the flat ground and the flow paths towards and along old watercourses. The most severe flood events were caused by rainfall evenly distributed over the whole city. From this study, it is clear that former watercourses that have been integrated in the underground pipe system, will act as underground watercourses during severe flood events. Therefore, it is not recommended to develop new urban areas above such watercourses. The spatial pattern of flood claims correlates well with the main pipelines. Overland flow follows flow paths towards the old watercourses and thus towards the main pipelines. During some large rainfalls, like the 2014 event, many parts of Malmö are unaffected by flooding. Areas close to the main sewers and the major overland flow paths (<100 m) are more than twice as affected by flooding as upstream areas. For rainfall events like the 2007 event, when consistent rainfall during a long period made the soil wet and the groundwater level increased, and for smaller events, the flooding is more evenly spread over the city. In this case, also upstream areas are affected and the concentration of flood claims from property owners along the main sewers is less noticeable.

4.7.3. Drainage system type

Another decisive factor behind flooding is the type of sewer system. In general, for all flood events, areas with combined sewerage system are more severely flooded and more vulnerable to basement floods than areas with separate sewerage system. On average, the combined system was five times more flooded. The reason for this is the direct connection between sewer and installations in basements in the combined system. In most places, the system is not designed for more than a 10-year event. As many house owners do not have a backwater valve to protect their basements, the risk of getting flooded in areas with combined system are much higher than in areas with separate system, where surface runoff or groundwater intrusion in principle is a prerequisite for flooding. Combined and separate systems are equally threatened by overland flooding, and during extreme events, even the separate sewerage pipes can get flooded due to inflow from inundated areas. On top of the higher flood risk in areas with combined system, the wastewater in the combined system makes the health risk higher compared to flooding from separate stormwater pipes. As an example, an infection from rats during clean-up of a flooded basement lead to a man’s death in Copenhagen after a severe flood in 2011. It is well known among sewage engineers that combined sewers are more vulnerable to extreme rainfall. However, this has not been confirmed in a comprehensive scientific study prior to the present study due to lack of detailed, spatial data of good quality. Semadeni-Davies et al. (2008b) showed that both urbanisation and climate change would exacerbate current problems with combined sewers. By disconnection of stormwater from the sewers, these effects can be diminished. SUDS and stormwater connections can e.g. reduce CSO to very low levels, both for the present and future climate (ibid.).

4.7.4. Technical breakdowns

Locally, some flooding is caused by breakdown of the system, e.g. when a sewer pump stops pumping due to system error. On the one hand, the phenomenon with local breakdowns could be seen as unique incidents that are not likely to happen during future flood events. On the other hand, and in reality, it seems inevitable that a few of these unique incidents happen during every flood event. They should therefore be expected and seen as an indirect cause of flooding also on city scale.

4.8. Potential strategies for Malmö

The city of Malmö is most exposed to flooding along the major flow paths from the outer areas into the city centre. These areas are aligned with former watercourses, where the main paths of both the minor (pipe system) and the major (overland) system are found. If some particularly vulnerable buildings could be removed from parts of these low-lying stripes of land associated with high risk, and the pipes could be reconstructed with open canals for separate stormwater, then the flood risk could be substantially lowered (Jha et al., 2012). Proper overland flow paths are one important factor to reduce flooding (Torgersen et al., 2015). The flood risk would also become more visible for citizens and city planners with an open canal system. Such open canals are expensive to establish. Nevertheless, they might have multiple functions since they contribute to a dynamic and beautiful urban landscape, even though these effects are difficult to "prove", according to Wild et al. (2011), due to lack of peer-reviewed publications. It might also be fruitful to increase downstream capacity by strategic maintenance before late summer when flood risk increases, as they do before monsoon season in Mumbai, India (Sörensen and Rana, 2013) and as suggested for Fredrikstad, Norway (Torgersen et al., 2015).

To lower the flood risk along the major sewers more extensively, the velocity of the stormwater must be slowed down. This can be achieved through partial separation of the centralised stormwater system in combination with construction of big and small structures for detention in upstream areas. Separation of major pipes and/or restoration of natural drainage channels, “daylighting”, are very expensive, as already mentioned. Therefore, it is preferable to separate locally in upstream areas instead, rather than close to the main sewers. The city of Malmö has good experience from separation of combined sewer systems. An example is the 31 hectares area of Augustenborg, where stormwater was disconnected from the combined system and instead handled by open storm drains, a so-called Sustainable Urban Drainage System (SUDS). This area was less affected by flooding during the 2014 event, compared to similar areas with conventional drainage (Sörensen and Emilsson, 2017). Still, a few basements in the area were flooded, as overland flow along the streets could make its way directly into those basements. Sörensen and Emilsson (2017)
showed that local, often small elevation differences can play an important role in directing the overland flow away from buildings. Besides aesthetic, ecological and health benefits with SUDS, it has been shown that flood risk reduction by SUDS retrofitting can be feasible from an economic point of view (Ossa-Moreno et al., 2017). The work to decrease pluvial flood risk can be used as a catalyst to improve green infrastructure and urban spaces (Malmö stad, 2016).

Another way forward is to introduce insurance policies with strong incentives for house owners to install a backwater valve, as suggested by Ladson and Tilleard (2013). If all buildings with basements have a backwater valve, the risk of basement flooding would be considerably lower. This solution is rather cheap and easy to implement, compared to separation of combined sewers. However, separation of stormwater from the combined system has valuable side effects, like decreased combined sewer overflow (CSO) and physical and environmental improvements by improved blue-green infrastructures. Implementation of one solution should not hinder implementation of others.

Besides concrete measures, organisational changes are needed. The City of Malmö and VA Syd work together on a strategy, an action plan, and an emergency plan to manage pluvial flooding. They suggest organisational changes for municipal departments to cooperate better and to incorporate flood risk in all physical planning (Malmö stad, 2016). As a part of this work, it is important to assess if groups that are more vulnerable need better protection, information and other measures. Such a study has been conducted for Greater Manchester, UK, where areas associated with poverty and cultural diversity correlates with areas susceptible to flooding (Kazmierczak and Cavan, 2011). In Malmö, the socio-economical segregation and social polarisation has increased between 1992 and 2006, leading to bigger differences between richer and poorer areas (Wallin, 2010). It is therefore relevant to make a similar study in Malmö, as Kazmierczak & Cavan did in Greater Manchester. The new plans also incorporate measures to increase the public awareness of urban flooding, which is an important success factor in any flood management scheme.

4.9. Data reliability

Flood claim data are found to be a useful source of information to evaluate flood risk in urban areas. In this study, data from both the utility company (VA Syd) and an insurance company (LF Skåne) were used. The two datasets are slightly different, as the insurance company collects data for each insured household that was flooded, while VA Syd has approximately one customer per connection to the water and waste water systems. It was found that the spatial distribution of flood claims in the dataset from the utility company VA Syd does not differ significantly from the dataset from the insurance company LF Skåne. As LF Skåne, being an insurance company, can make claims to VA Syd, some claims might be identical. However, some citizens might not have a proper insurance, probably due to low income, and it is probable that citizens without insurance are more common in some areas. There are also other insurance companies beside LF Skåne not included in the study. Precaution must therefore be taken if decisions are made based on the dataset. Both datasets give information on flooded buildings. No information is available on flooded roads, parks, etc. Despite this lack in the data, it is plausible that the datasets give a good representation of flood severity and spatial distribution.

Like other datasets (e.g. Spekkers et al., 2012), damage causes are poorly defined in the two databases. Therefore, thorough examination of the records were required and done before further analyses. There might however, still be misinterpretations regarding the causality behind some of the flood events, especially for highly localised flood events for which precipitation data might be lacking in spatial resolution.

Douglas et al. (2010) emphasise that historic flood data must be collected by a single body and made available to flood risk management agencies. Such data are available in Sweden through the water utility companies or the municipal sewer department, but it is not clear whether the data can be made available for other agencies outside the water utility company or municipality. Information on flooding of individual properties are available due to the Swedish principle of public access to official records.

Rainfall data from both VA Syd and SMHI as well as sea level data from SMHI are considered reliable. The same applies for data on topography, which is from a national, good quality dataset, and data on sewerage system types, urban areas, streets, watercourses, etc.

4.10. Conclusions

Flooding in Malmö, Sweden is mainly pluvial, although a few flood claims related to high sea level have been reported after storms. Densification of urban areas and climate change are expected to aggravate the problem. The spatial pattern of flooding in Malmö, a typical Scandinavian city, differs between flooding caused by short (1–10 h), intense rainfall events, and flooding caused by consistent rainfall during several days. For the more intense rainfall events, most flood claims are reported from areas close to the main sewers. Both the minor system (pipe system) and the major system (overland flow paths) rapidly lead water to these areas. For floods caused by long-term rainfall, the flood claims are more evenly spread and not as strongly related to the topography. Another factor governing the spatial distribution of flooding is the drainage system type. In general, areas with combined system are more affected by flooding, compared to areas with separate system. Even if only 31% of the urban land in Malmö is connected to the combined system, 70% of the flood claims are reported from these areas. Finally, the spatial pattern of the precipitation affects the spatial pattern of flooding. For the three biggest rainfall events in Malmö, however, heavy rainfall was measured at more or less all nine stations.

In conclusion, the main mechanisms and characteristics of floods extent and its spatial distribution in Malmö are intensity and spatial distribution of rainfall, distance to the main sewer system as well as overland flow paths, and type of sewer system. The sea level has little influence on flooding.

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Flood Risk Reduction by Urban Blue Green Infrastructure – an Evaluation using Insurance Data

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Abstract
One of many important features of blue green infrastructure, is the ability to lower flood risks by detention of stormwater. As extreme events are rare, few assessments have been made to evaluate the risk reduction.

In 2014, Malmö (Sweden) was hit with by extreme precipitation corresponding to a return period of 50–200 years which led to severe, pluvial flooding. This event, as well as a number of other large events, gave the opportunity to evaluate the efficiency of the 15 year old stormwater system retrofit in the Augustenborg area (30 hectares) through analyses of flood claim data. Augustenborg and its stormwater control measures was compared with five similar neighborhoods that have conventional sewer systems (combined or separate). The long-term trends of insurance claims showed less flood damage in Augustenborg compared to the nearby areas which indicates a direct effect of the retrofit with stormwater control measures. Even though a few properties were flooded in Augustenborg, it was shown that the retrofitted stormwater system performed successfully during the extreme event in 2014.

KEYWORDS: extreme precipitation; pluvial flooding; best management practices (BMP); green infrastructure (GI); low impact development (LID); sustainable urban drainage systems (SUDS)

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1. Introduction

The societal consequences of flooding are severe. In the developed world, flooding primarily causes financial loss, but there are also reports of direct mortality and indirect health effects from contamination of drinking water and failing sanitation systems (Kunkel et al. 1999; Schmitt et al. 2016). In Europe, flooding is expected to increase due to climate changes (Jongman et al. 2014). More intense rainfall and more flood events are expected in several regions worldwide (IPCC 2014). In combination with current land use changes due to urbanization, this will increase the problems with urban, pluvial flooding (Semadeni-Davies et al. 2008).

There is a need for proactive planning, design, and implementation of a range of solutions to mitigate future problems with urban pluvial flooding (Sörensen et al. 2016). Blue green stormwater control measures (also known under e.g., Best Management Practices (BMP), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), and Low Impact Development (LID) (see Fletcher et al. 2014)) are designed and installed to decrease urban runoff and reduce peak flows, but have during the last years also been put forward as a component of larger concepts, including Green Infrastructure or Blue Green Infrastructure (Lerer et al. 2015) and Nature Based Solutions as defined by the European union (European Commission 2013, European Commission Directorate-General for Research and Innovation 2015). These concepts focus on multifunctionality, connectivity, innovation, social factors, co-creation, and involvement as key success factors for implementation of solutions for improved quality of urban spaces and for combating urban flooding, which have very much been at the heart of the development of the city of Malmö and especially the Augustenborg neighborhood.

Urban flooding can be categorized in many ways: pluvial flooding, fluvial flooding, sewer system failure, flash floods, groundwater flooding, ice melt flooding, and coastal flooding are often mentioned in the literature (Douglas et al. 2007; Zevenbergen et al. 2010 (p. 42–45); Saul et al. 2011). This study focuses on pluvial flooding, which is caused by extreme local storms when the drainage capacity is exceeded (Maksimović et al. 2009). Urban drainage systems often have a limited hydraulic capacity that is designed to cope with precipitation with, for example, a 10 year return period (Svenskt Vatten 2016). This means that even when design standards are followed, minor and moderate flood events will occur on average every 10 years.

There are numerous investigations on the performance of blue green infrastructure under moderate rain events (Villarreal et al. 2004; Shukri 2010; Qin et al. 2013; Liu et al. 2014; Sebti et al. 2014; Liu et al. 2015) but, to our knowledge, no systems installed with stormwater control measures have been evaluated during extreme events, as these events are rare. Earlier research on flood reduction with stormwater control measures has focused on model simulations, including three studies made in Augustenborg (Villarreal et al. 2004; Shukri 2010; Haghighatashar et al. 2018).

Hydraulic modeling can give a rough estimate of the effects of extreme events, but there are some problems related to such modeling. Beven (2008) divides model construction into three parts: firstly a perceptual model, which is how we understand the physical system, including the full complexity of the system; secondly a formal model, which is the mathematical description of the system; and finally a procedural model, which is the model that will run on the computer. Where necessary, approximate numerical solutions are implemented. In all these parts, extreme event modeling is problematic. As extreme events are uncommon, modelers’ understanding of how the system behaves during extreme situations is limited. As little data is available, calibration and validation of extreme events is difficult. Despite this, modeling is a powerful tool to evaluate the hydraulic function of different measures; however, other methods must be used to evaluate flood control effects achieved by blue green infrastructure during extreme events.

In this study, we have chosen to go straight to the measured effects of extreme rainfall, and to use insurance claims to evaluate the performance of integrated blue green infrastructure on urban flood reduction. Flood insurance data from a long series of flood events, including one severe event, are used for this evaluation. In Sweden, property losses from overland flooding, flooding of drainage systems, and
flooding from groundwater intrusion are typically covered by a person’s or a company’s insurance company. The property owner can make a claim both to the insurance company and to the water utility company. The water utility will cover the deductible from the insurance company. In addition, the water utility company collects flood reports from other property owners and covers claims from insurance companies. Due to this system, spatial data on flooded properties are available. Similar data sets have previously been used in several studies, for example to analyze the distribution of large claims (Smith & Goodman 2000), for validation of urban flood inundation and damage models (Chen et al. 2009; Zhou et al. 2013), to study correlations and links between extreme rainfall, their characteristics, and flood damage (Spekkers et al. 2013 a&b; Torgersen et al. 2015; Sörensen & Mobini 2017), and to analyze buildings’ exposure and the influence of spatial placement variables for vulnerability to lake floods and extreme rainfall (Grahn and Nyberg 2014; Torgersen et al. 2015). However, no such studies on the performance of stormwater control measures during extreme events were found.

The extreme rain event that hit Malmö on August 31, 2014 is central to this study. Almost the entire city was affected, and about 3000 properties were reported flooded (SMHI 2014; Lindher 2015; Hernebring et al. 2015; Sörensen & Mobini 2017). Streets, houses, underground garages, and even the hospital were flooded. Several families could not move back to their homes for more than a year. The return period was estimated at 50–200 years. The intense rainfall and the severe flooding following it make this event suitable for evaluation of flood reduction by the blue green infrastructure in Augustenborg. The evaluation is also needed given the current interest in installation of stormwater control measures and nature-based solutions for the mitigation of problems related to urbanization and climate change. Few places have been retrofitted with blue green infrastructure as extensively as this area. It is hard to find any similar evaluation of flood reduction with historical data in the scientific literature.

Thus, the present study is an in-depth analysis of flood claims from property owners that were affected by the severe storm in August 2014 as well as by other events during a 20-year period. The function of the blue green infrastructure is evaluated by a combination of insurance data and flood reports in relation to flood events during the 20-year period, including the severe single storm event that hit Malmö in 2014. Flood risk is evaluated by studying the damage during these historical events, which are assumed to be representative for urban pluvial flood events in the dense urban fabric of mid-size cities in temperate climates.

Our investigation compares a 30 hectares area retrofitted according to typical principles for design of blue green infrastructure with stormwater control measures (Stahre 2008), to adjacent conventional neighborhoods where no or very few stormwater control measures have been installed. The study uses insurance claims to investigate: 1) the long term trends of these claims in the selected neighborhoods; 2) the direct effect of the retrofit looking at pre- and post-installation data; and in particular 3) the performance of a completely retrofitted neighborhood during an extreme rainfall event.

2. Methodology

2.1. Study area

This investigation is set in the southern parts of Malmö, Sweden (Figure 1a) where a large-scale retrofit of an existing neighborhood, Augustenborg, took place in a project called Eco-City Augustenborg in the late 1990s (55°34’45”N 13°01’30”E). Eco-City Augustenborg is used in this investigation of flood risk reduction by blue green infrastructure, as the retrofit of the combined drainage system was completed with stormwater control measures as an alternative to an installation of a conventional separated pipe system. To be able to discuss what effects blue green infrastructure has on flooding, Augustenborg was compared to the nearby neighborhoods of Persborg, Löngården, Lindgatan, Södra Sofielund, and Norra Sofielund (Figure 1b). These areas are similar to Augustenborg in several ways, with the exception that stormwater control measures have not been implemented there.
About 3000 people live in the Augustenborg area in 3–6 story apartment blocks built in 1948–1952. Lawns, bushes, and trees were planted around the buildings from the start, but with no direct function for stormwater drainage. The objectives to renew Augustenborg in the late 1990s were to achieve sustainable urban development, to make the buildings energy efficient, to improve solid waste management, to stop basement flooding, to provide renewable energy, to involve residents in the development of their neighborhood, and to make the environment greener. This study mainly focuses on flood reduction by the blue green infrastructure that was implemented during the retrofit of Augustenborg. The multifunctional systems have been investigated elsewhere in relation to many aspects during these 15 years as in, for example, citizen involvement (Krantz & Hjerpe 2002), environmental assessment (Ludzia 2014), green roof maintenance (Emilsson et al. 2007), water quality (Berndtsson et al. 2006; Ahmed 2010), water runoff quantity (Bengtsson et al. 2004b), blue green infrastructure design and maintenance (Söderblom 2004), and biodiversity (Ohlsson 2001; Ohlsson 2002). The area continues to be developed, and in 2016, a 14-story eco-friendly building named Greenhouse was finished.

The Augustenborg stormwater system

The Augustenborg blue green infrastructure contains flow detention in ponds and areas for temporary flooding, infiltration on green roofs, lawns, and parking, as well as slow transport in swales, ditches and channels (Stahre 2008). The blue green infrastructure was constructed by the end of the 1990s by Malmö Service Administration and Malmö Water (today VA Syd, utility company) and MKB (housing company) as a part of the Eco-City Augustenborg project (Stahre 2008). An existing combined sewerage system was upgraded and separated with soft, vegetated and hard, constructed features for detention and transportation of stormwater. Green areas were lowered to make space for excess water. The capacity of the blue green infrastructure is unknown and it was not designed according to a certain standard. The old combined sewers are still used for wastewater and backwater valves are not installed in basements. Two pictures from the area of the first redevelopment phase are shown in Figure 2.

The piped drainage system of Augustenborg is dominated by a combined system (225–750 mm). However, as the blue green infrastructure manages most of the stormwater, the combined system acts almost as a separate system for sewerage only. Through the central part of the area, a stormwater pipe (300–600 mm) constructed in 2002–2003 complements the blue green infrastructure by draining the main street.

The southern part of Augustenborg’s blue green infrastructure consists of an upstream, industrial area with 2000 m² of impermeable paving and 9500 m² of green roofs. The water is gathered in two small ponds, interconnected with a channel. From the downstream pond, the water is pumped to a small wetland, where a further 3000 m² of paved surfaces and 1000 m² of roofs are connected. The discharge is detained in two dry detention ponds. From the ponds, the main channel leads the stormwater toward two wet ponds. The channel is 170 m long and slopes approximately 1%. The full capacity of the channel is 200 l/s. Additional stormwater from 1500 m² of permeable paving, 3000 m² of roofs, and 1300 m² of semi-permeable surfaces discharge into the channel. A mini-wetland of 100 m² is placed along the channel, to which the channel can overflow. (Bengtsson et al. 2004b) The original blue green infrastructure was constructed with a large (750 m²) pond at the end of the channel. This pond was later divided into two ponds with a grassy area in-between and a small brook interlinking the ponds, for aesthetic and maintenance reasons (Söderblom 2004; Stahre 2008). After this double pond, the flow continues via an overflow to a “cube channel.” This is a 100 m long channel with concrete cubes of different heights on the bottom. The channel ends in a public park where the grass area has been lowered to make space for the water in a bioswale type of installation. Through the park, a meandering swale leads the water toward a pond, from where there is an overflow to the municipal stormwater pipe system (Stahre 2008). For further description of the southern part of the blue green infrastructure in Augustenborg, see Villarreal et al. (2004).

The northern part of Augustenborg’s blue green infrastructure is constructed more naturistically than the southern part. It consists of a long swale that has partly been designed as a rain garden. Stormwater is
collected from buildings through small concrete channels and led to the swale. The uppermost part of the swale is about 200 meters. It leads to an open pond, and from there the flow goes under a street through a siphon pipe. Another 300 meters of naturistic swale leads the water from the siphon pipe to a 60 meter long concrete channel, ending in a small pond. (Stahre 2008)

Due to lack of reports on actual usage during the flood event on August 31, 2014, the full capacity of the stormwater control measures in Augustenborg is unknown. However, the size of the most important detention basins was measured and the total storage capacity of ponds and swales in Augustenborg was estimated as up to 1000 m³ during extreme rainfall. In addition, the grass area that has been lowered in the central, public park can probably store up to 3000 or 4000 m³ during extreme rainfall.

2.2. Description of nearby areas

The five nearby areas that are used for comparison can, similarly to Augustenborg, be described as urbanized with mostly medium density to dense urban fabric (Figure 1b). Norra Sofielund has more continuous urban fabric compared to the other areas. Land use is predominant residential with some industrial and commercial areas. Only a few areas are green urban areas or areas for sport and leisure activities. The building coverage is 20% in Augustenborg, compared to 19–30% in the five nearby areas that are used as comparison areas (Table 1). Roads and parking cover between 31% and 42% of the areas, with the least roads and parking in Lönnvärd and Persborg and the most in Lindgatan. The total approximate imperviousness is 57% in Augustenborg and between 50% and 70% in the nearby areas. Some buildings in Lindgatan and Södra Sofielund were constructed in the 1910s and 1920s, but most of the land was agricultural land until the 1930s when this part of Malmö was urbanized. Augustenborg and later Persborg were not urbanized until late 1940s and early 1950s. All of the areas were constructed with a combined sewer system, which was the dominating system in Sweden until at least the 1950s (Cettner et al. 2012). Later, the sewer systems in some areas were reconstructed with separate stormwater and sanitary sewers. Below follows a description of each of the five nearby areas. Information on buildings come from the city of Malmö cultural and environment department and the County administrative board of Skåne (2001, 2002 & 2004), and information on the pipe system were received from VA Syd.

Lindgatan is a part of Augustenborg but was not part of the Eco-City development and is regarded as a separate area in this study. The oldest stormwater pipes in the area are from 1927, while most of the stormwater pipes (600 mm) and the sewerage pipes (200 mm) are from 2001. The system has separate stormwater and sewerage pipes.

Lönnvärd has combined sewers from 1935–1936. The privately owned 4-story buildings are placed perpendicular to the main roads to the north and the south of the area with green yards in-between. Under each of the roads is a 450 mm pipeline, interconnected by 300 mm pipes between the buildings.

Norra Sofielund. The northern half of the area consists of 4-story apartment buildings with closed inner yards. The combined sewers (225–450 mm) in this area are from 1935–1936. In the south, the buildings are generally lower and smaller, typically with two stories. This part of the area has a separate sewer system where most pipes were constructed in 1975–1980. The separate sewerage pipes are 225–400 mm and the separate stormwater pipes are mainly 300–600 mm.

Södra Sofielund. The first pipes in the drainage system were constructed in 1910, while most of the system is from the 1930s and the 1940s (225–750 mm, combined system). Between 1965 and 1985, the western part of Södra Sofielund, which consists mainly of small, privately owned houses, was separated with a new sewerage pipe (225–1000 mm). The old combined pipes were turned into stormwater pipes. One of the main interceptor sewer pipes, which is a 2000 mm concrete pipe that drains a large area with the combined system, runs through the area. This sewer was constructed in 2000 as a combined stormwater and wastewater pipe. The area used to consist of mainly industrial buildings and open land until the 1930s and 1950s when residential buildings were erected. There are still industrial buildings in the area. The apartment blocks in the area have both closed and half-public courtyards.
Persborg was built upon in the mid-1950s by MKB. The meandering placement of the buildings ensures spacious, green yards between the redbrick buildings. The drainage system consists of a combined sewer system constructed in 1954, reaching from south (300 mm concrete pipe) to north (600 mm concrete pipe).

2.3. Flood claim data from insurance companies and water utility company

The flood claim data used in this study mainly consist of two data sets: one from the insurance company Länsförsäkringar Skåne (LF Skåne) (received 03-24-2015), and one from the water utility company, VA Syd (received 03-14-2016). The data set from LF Skåne, the dominating insurance company in the region, contains 9704 reported flooded properties in the Scania Region, Southern Sweden, during a period of 28 years (1987–2015), and the data set from VA Syd contains 5868 claims and reports from Malmö and neighboring municipalities for the period between June 1990 and March 2016 (26 years). In general, there is consistency between the data from LF Skåne and from VA Syd, and the material gives a good measure of flood extent from both small and severe flood events. Data from LF Skåne are not considered as reliable before 2007 compared to after 2007, and these data were therefore not used in the study. The data set from the water utility company covers mostly flooding events where water has entered the building from the sewerage system. In addition to the long-term data sets from LF Skåne and VA Syd, data representing the severe flood event on August 31, 2014 were received from Malmö municipal housing company (MKB, 25 claims), the insurance companies Lifra (33 claims), IF Skadeförsäkring (list of number of flooded properties for each postal code), and Moderna Försäkring (132 claims), and the municipal property manager Stadsfastigheter (165 claims). The insurance database covers property loss from overland flooding, groundwater intrusion through basement walls, and flooding from the drainage system, and is used as a proxy for flood severity for different events.

2.4. Rainfall data

Rainfall data were collected from SMHI (Swedish Meteorological and Hydrological Institute), which has one station in Malmö (Station A), and VA Syd, which has eight stationary stations. Station MA03 Augustenborg Ystadvägen, located in the botanical roof garden in Augustenborg, is the closest station for all study areas (<2 km distance). Data from a mobile station in Söderkulla was also used in the data analysis of the 2014 event.

SMHI measures the volume of precipitation each 15 minutes, while all VA Syd stations are tipping buckets with 0.2 mm bucket volume. Data from VA Syd were converted to 5 min precipitation volume before further analysis. For comparison, the updated precipitation statistics from Hernebring et al. (2015) based on precipitation measured in Malmö 1980–2013 are used.

2.5. Topography data

Data on topography in a 2x2 m grid were retrieved from the Swedish official digital elevation model (Ny Nationell Höjdmodell, NNH). The vertical error of the elevation model is 5 cm and the horizontal error is 25 cm on average for open, hard surfaces (Swedish national mapping, cadastral, land registration authority 2015).

2.6. Data analysis and statistics

Flood magnitude is defined as the number of flooded properties per hectares (NFP/ha). For comparison, the number of flooded properties per number of addresses (NFP/address) is used, as the number of addresses in an area is (loosely) connected to the number of sewer connections. Each entrance typically has its own address (e.g., Augustenborgsgatan 3A, 3B, 3C, etc.). The number of flooded properties per total number of properties was also considered as a measure for flood magnitude. However, it turns out that the size of the properties in the different areas is inhomogeneous, and the other measures (NFP/ha and NFP/address) therefore give a better picture of the flood magnitude.
Thorough quality control was made for all data points in the LF Skåne data set. This data set contains the Swedish unique identifying numbers for parcels (in Swedish: fastighetsbeteckning). All parcel numbers were verified against cadastral data as street addresses were needed to georeference the data points. The online tool Batchgeo was used for georeferencing of the LF Skåne data set, and a random set of the georeferenced data points (~10%) were then manually verified. For the VA Syd data set, this procedure was not needed, as both the flooded addresses and georeferences were given.

To study the flood reduction in Augustenborg after the blue green infrastructure was implemented in the district, the flood magnitude during 2007–2015 was compared with the nearby areas Lindgatan, Lönngården, Norra and Södra Sofielund, and Persborg. Insurance claims and reports from both VA Syd and LF Skåne were used in this analysis.

A bootstrap resampling technique was used to statistically evaluate long-term differences between flood magnitudes in the retrofitted area Augustenborg in comparison to the five nearby areas. Flood magnitudes were listed for each event in each area, and 1000 random samples were taken from the Augustenborg list and the list of one other area. This procedure was repeated 10 000 times. The comparisons with Augustenborg were done independently for all five nearby areas. As the 2014 event dominates the flood statistics in Malmö, the bootstrap analysis was done both including and excluding this event. Data from both VA Syd and LF Skåne were used for these analyses.

Data from VA Syd were used to compare flood claims during one period before blue green infrastructure was implemented in Augustenborg with flood claims after the implementation. The comparison was done for Augustenborg as well as the other, nearby areas to assess similarities and differences in detected changes.

Detailed information about the 2014 event is presented in this study to evaluate the function of the blue green infrastructure during an extreme flood event. This event is of particular interest, as such extreme events are uncommon, and no similar event has been reported in the literature on flood reduction by blue green infrastructure before.

3. Results

In this section, we first present the long-term trends of reported insurance claims in the selected neighborhoods, secondly the direct effect of the retrofit on flood frequency based on pre- and post-installation data, and finally the performance of a complete retrofitted neighborhood during an extreme rainfall event.

3.1. Long term trends of reported insurance claims in the selected neighborhoods

Flood reduction after stormwater retrofit in Augustenborg was evaluated by comparison with the five nearby areas. The flood event on August 31, 2014 dominates the flood claims in the evaluated period; during 2007–2015, more than 80% of the flood claims in Augustenborg, Lindgatan, Lönngården, Norra and Södra Sofielund, and Persborg were reported during this single event. Therefore, the 2014 event is considered as an extreme flood event and studied separately from the other, less severe, flood events. As can be seen from Table 2, the flood magnitude (number of flooded properties per hectare) was more than 10 times smaller in Augustenborg compared to the other areas both during the 2014 event and during the other events in 2007–2015.

All flood events in the period, in total 36 events, were evaluated with bootstrap statistics. It was found that the flood magnitude is significantly lower, that is, zero differences are outside the 99% bootstrap confidence interval, in Augustenborg compared to all the nearby areas individually. The test was also performed without the 2014 event, giving the same result.
3.2. Direct effect of the retrofit on flood frequency based on pre- and post-installation data

Augustenborg was more affected by flooding before blue green infrastructure was implemented, with five flood claims reported to VA Syd before and none after (Table 3). However, the number of flood claims reported was also low before implementation. In addition, Lindgatan was less affected by flooding after, which could be explained either by the fact that the area is connected to the same sewer as Augustenborg downstream, or that the combined sewer in the Lindgatan areas was separated in 2001. For the other four areas, either as many or more flood claims were reported during the after period as compared to before. One reason for the increase in two of the areas (Norra and Södra Sofielund) might be heavier rainfall in the after period. It should be noted that the rainfall during the two periods are not necessarily comparable. Another reason for the increase might be degradation of the sewer system. Both these areas have a mix of combined and separate sewers.

Reporting to VA Syd is slightly different than claims to an insurance company, as mainly property owners will report to VA Syd and consequently there is at most one report per sewer connection per event. This limits the number of reports to VA Syd from Augustenborg, as the area consist of rental apartments owned by Malmö municipal housing company (MKB). Persborg, an area with similar owner structure, is thus especially useful for comparison. Flooding was not reduced in Persborg between the period before and after the retrofit of Augustenborg. This strengthens the indication of flood reduction by blue green infrastructure in Augustenborg after the retrofit.

It is difficult to draw definitive conclusions based on a comparison of flood claims before and after stormwater control measures were constructed as there might have been a change in several other variables such as the tendency to report flooding to VA Syd, rainfall pattern, etc. Unfortunately, no flow measurements were made in Augustenborg before the new system was built.

3.3. Performance of a completely retrofitted neighborhood during an extreme rainfall event

The extreme rainfall event on August 31, 2014 makes it possible to evaluate flood reduction of the blue green infrastructure in Augustenborg. In the following subsections, details on the rainfall event and its consequences in Augustenborg and nearby areas are given.

3.3.1. Rainfall on August 31, 2014

The rainfall over Malmö on August 31, 2014 corresponded to a rainfall with return period of 50 to ~200 years and had a total volume of 60–120 mm (spatial variation). This was the biggest rainfall event since measurements started in the late 1800s and led to severe flooding in most of Malmö as well as in neighboring villages and in some parts of Copenhagen, Denmark. In Augustenborg, 116 mm was measured, and most of the rainfall (100 mm) fell within 3.5 hours (Figure 3). The rainfall was severe, causing damage spread over all Malmö, with slightly more damage in areas with a combined system (Sörensen & Mobini 2017). The maximum rainfall measured at Augustenborg during one hour was 41.6 mm. It can be assumed that the intensity was similar in neighboring areas, looking at a mobile station nearby. Bengtsson & Milotti (2010) earlier reported the maximum rainfall during one hour to be 28.6 mm (data from 1996–2007, station M03 Augustenborg) and for a nearby station (Turbinen) they found that 41.0 mm could be expected during one hour with a 100 year return period. As can be seen in Figure 3, the return period according to Hernebring et al. (2015) is shorter. Only for durations longer than two hours does the rain event exceed the 100 year rainfall threshold.

3.3.2. Flood reduction in retrofitted area on August 31, 2014

The flood magnitude, that is, the number of flooded properties per hectare, for August 31, 2014 is shown in Figure 4 as reported by five sources (LF Skåne, VA Syd, Lifra, Stadsfast, and Moderna). It can be seen that the level is lower in Augustenborg compared to the five nearby areas. The highest flood magnitude is found in Södra Sofielund, where one of Malmö’s main sewerage pipes passes through. Table 4 shows that compared to the five nearby areas without blue green infrastructure, in the same part of Malmö,
approximately 10 times less properties were flooded in Augustenborg during the event. Lindgatan, which
was the least flooded apart from Augustenborg, was 6.4 times more flooded than Augustenborg, while
the most heavily flooded area, Södra Sofielund, was 18.4 times more flooded than Augustenborg. Flood
magnitude was also calculated as the number of flooded properties per address (Table 4). The same
pattern appears, however with smaller differences. It should be noted that the number of reported flood
claims was also low in Augustenborg before the blue green infrastructure was implemented (Table 3).
However, it seems that the number of reported flood claims has increased in general, while this is not the
case for Augustenborg.

The flood reports from IF Skadeförsäkringar cannot be interpreted in the same way as the data from LF
Skåne, VA Syd, Lifra, Stadsfast, and Moderna, as these reports were received as a list of flooded properties
per postal area. In Figure 5, the number of flooded properties for each postal area is shown. It can be seen
that there was no reported flooding in the postal area that is fully within Augustenborg. From one area
partly within Augustenborg, partly within Södra Sofielund, and partly within Lindvägen, eight flood
claims were reported to IF Skadeförsäkringar. Apart from the fact that many flood claims were reported
from Södra Sofielund compared to all the other areas, and none from the postal area within Augustenborg,
which is consistent with the reports from the five other sources, there is no clear pattern of flood claims
from IF Skadeförsäkringar.

3.3.3. Flood reports from MKB housing company on August 31, 2014

Additional information regarding the effects of the flooding was derived from descriptive, internal reports
from the local offices of Malmö’s biggest housing company, MKB, after the flood event on August 31, 2014.
Not all flooded properties are listed in these reports, and therefore no quantitative comparison is
possible, but interesting information can still be derived from the reports.

The MKB flood report from Augustenborg reports that several basements were flooded, however none of
them severely. One garage was severely flooded on Lantmannagatan. An elevator was out of order on
Norra Grängesbergsgatan and the pavement was undermined at Grängesbergsgatan 44. It is worth noting
that Lönngården, which was not retrofitted with stormwater control measures, is included in this report,
and that the elevator that was flooded is located there. MKB has 33 properties in Augustenborg and 4 in
Lönngården.

The MKB flood report from Möllan includes MKB properties in the Möllevången (outside the study areas)
and Norra Sofielund neighborhoods, where MKB has 51 properties in total. It reports that all basements
were flooded with up to 10 cm of black sewage except for six properties. MKB has five properties in Norra
Sofielund and two of these were reported as not flooded, meaning that three properties likely were
flooded here. Apart from the flooded basements, there were few problems in the MKB properties in Norra
Sofielund.

The MKB flood report from Persborg reports that almost all of the properties owned by MKB in Persborg
were flooded. The basements in 18 properties were flooded. Some garages were also flooded. In total MKB
has 25 properties in Persborg.

The MKB flood report from Seved reports that there was 3–25 cm of black sewage in all basements of MKB
owned properties. In three of them, it was much worse, with 6 meters of water in the most severely flooded
basement. In addition, basement apartments were flooded in Seved as well as garages, however not
severely. Seved is an area within Södra Sofielund, where MKB has 38 properties in total of which 37 are
in Seved.

These reports from MKB also describe that some buildings lost electrical power, hot water, and TV
connection, that pavements were damaged, and that elevators were broken. No human injuries were
reported, but one person was stuck in an elevator in Södra Sofielund and luckily managed to escape by
herself as the water reached her chest (Sydsvenskan 2014). In conclusion, most damage in Augustenborg
reported internally by MKB regards pavement and other damage outside, while several buildings in the other areas were severely flooded on August 31, 2014.

4. Discussion

4.1. Flood risk reduction

Blue green infrastructure, as constructed in Augustenborg, Malmö has been proven efficient in flood risk reduction by the analysis of flood damage during historical flood events registered as insurance claims. Similar results were found through hydraulic simulation of the severe flood event in 2014 (Haghighatafshar et al. 2018). Altogether, the land use and stormwater systems are similar in all study areas, except for the blue green infrastructure in Augustenborg, excluding other determinants of flood risks in neighboring areas. What is interesting to note is that Augustenborg was rather green already before the blue green infrastructure was constructed. During extreme rainfall, the green/pervious areas contribute to runoff (Berggren et al. 2013) if they are not constructed for stormwater detention, as they were in Augustenborg after retrofit. From the long-term trends, it can be concluded that it is not only green areas that lower flood risk. The small-scale topography is also of importance for flood risk reduction.

Based on findings in previous studies (Villarreal et al. 2004; Shukri 2010), a reasonable explanation for reduced flood damage is a reduction in peak flows and total runoff volumes from blue green structures for stormwater management. For example, in a modeling study of Augustenborg for up to a 10-year design storm, Villarreal et al. (2004) found that the detention and retention capacity of the ponds, in combination with the regulation of the outflows, plays a major role in reducing the flood risk in the area. In addition, it was shown by hydrograph simulations that the system is able to detain all runoff from a 10-year event, both under dry and wet initial conditions. Villarreal et al. concluded that the 10-year event could have been handled without risk of flooding with a pipe-bound system instead of the blue green infrastructure, through separation of the combined system. This would, however, have led to major earthworks in the area during construction and increased flow downstream of Augustenborg after reconstruction. The downstream areas would thus have suffered increased flood risk, and the receiving waters would have suffered from erosion or water quality degradation (Villarreal et al. 2004). The results from Lindgatan indicate some proof for this theory, but the data are too weak as the area is small (3.4 ha). Another study compared the blue green infrastructure in Augustenborg with the former (combined sewer) system by modeling, and found a 50% decrease in discharge rate for a heavy rainfall in June 2007 (Shukri 2010). The peak runoff was delayed by 5–10 minutes with blue green infrastructure, compared to the combined sewer. For high-intensity rainfall, the piped system reacted with more flooding, compared to the blue green infrastructure. Villarreal et al. (2004) emphasize that storage capacity is of major importance for flood risk reduction in such systems, especially for high intensity events like 10-year events, and Shukri (2010) points to the larger available volume in the system as the main reason why the blue green infrastructure gave a lower discharge rate compared to the piped system. These explanations are reasonable also for flood reduction during extreme events, as shown in this study.

Using model simulation, Qin et al. (2013) found that stormwater control measures could reduce flood risk in Guang-Ming New District in Shenzhen, China. Swales, which are a space-efficient technology, have a positive impact on flood risk reduction as they can store big water volumes. Despite this, they recommend green roofs and permeable paving for flood reduction, as these had the biggest effect according to their study. The three mentioned technologies, swales, green roofs, and permeable paving, have different effects on early, mid, and late runoff peaks. Qin et al. therefore recommend a combination of the three solutions to achieve maximal effects for different kinds of rainfall events. Liu et al. (2014) claimed that runoff with 1–2 years return period can be eliminated with blue green infrastructure, while runoff with 5–10 years return period can be reduced by 93–97% in an urban community in Beijing. These results come from a model, where no calibration or validation was done. They showed that an integrated solution, where several technologies are used together, is more useful to reduce flood risk in urban areas, compared to single technology facilities. Torgersen (2015) has shown that precipitation events prior to the extreme events have a significant impact on insurance claims after urban flooding. The ability for Augustenborg’s
blue green infrastructure to handle large storms during wet initial conditions as modeled by Villarreal et al. (2004) is in line with this previous research.

Green roofs were one of the main components during retrofit of Augustenborg, frequently used in branding of the project as green and sustainable. Runoff from a 30 mm sedum-moss roof in Augustenborg was measured during one year by Bengtsson (2004a). Approximately 9–10 mm rainfall was needed to initiate runoff, corresponding to storage at field capacity. It can thus be assumed that the green roofs in Augustenborg had a minor effect on flood reduction during the extreme event in 2014. If the roof is wet when the rainfall starts, runoff during one hour equals the precipitation during that hour. Compared to runoff from black roofs, the runoff from the studied green roofs in Augustenborg is delayed with a time of concentration of up to 20 minutes (Bengtsson 2005). Villarreal (2007) modeled the runoff from Augustenborg’s green roofs with the downstream pond complex. To achieve the same detention for the 10 years event, without green roofs, the pond complex needed to be at least 29% bigger than its present size. The thickness of the green roof substrate layer as well as vegetation composition will influence the effective storage depth, but this will have most influence on small and moderate storms (Qin et al. 2013, Stovin et al. 2017). In Augustenborg, close to 14 000 m² (24%) of the roofs are green roofs which is similar to the green roof scenario (20%) in the Guang-Ming New District model (Qin et al. 2013). However, the green roofs in Augustenborg could only capture ~140 m³ of the 35 000 m³ stormwater that fell over the area during the extreme rainfall in August 2014, if the results from Bengtsson (2004a) are valid also for this event. This can be explained by the thickness of the roof, where the roofs in Guang-Ming New District consists of a vegetated layer, a soil layer (150 mm), and a storage layer (75 mm) with an underlying drain, while the total height of the Augustenborg roofs are 30 mm. It is worth noting that storage capacity of the Guang-Ming roofs was calculated with a simple formula, while it was measured in Augustenborg.

Zahmatkesh et al. (2014) modeled the potential effect of blue green infrastructure in Bronx River in New York City. They found the greatest effect from permeable pavement. In Augustenborg, the effect of permeable pavement on flood reduction is probably small. Only limited parts of the pavements are permeable, and as the underlying soil is clayey till (County administrative board of Skåne 2016), deeper percolation is probably very slow. Limited infiltration is only possible in the upper soil layer.

Malmö is situated in a flat landscape where the highest elevation is 37 m above sea level. In Augustenborg, the elevation is on average 14.7 meters above sea level. This is slightly higher compared to the other areas (Persborg 14.3 m; Lönngården 12.6 m; Lindgatan 11.1 m; Södra Sofielund 11.1 m; Norra Sofielund 10.2 m). The difference is small and cannot explain the great difference in flood magnitude. Two areas next to Augustenborg on higher elevation, Hindby in the west and Almhög in the south, were heavily affected by flooding on August 31, 2014. These areas are not used for comparison in this study, but they show that small differences in altitude do not influence flood magnitude. For Södra Sofielund, however, the elevation might play a role, as a small stream used to run through this area. This watercourse is now tunneled and constitutes one of the main pipelines in the sewer system of Malmö. Södra Sofielund is situated along the major flow path through this part of Malmö and is thereby at higher risk of flooding (Sörensen & Mobini 2017). Norra Sofielund, the lowest area in this study, was flooded only to half the magnitude of the flooding in Södra Sofielund, indicating that the main sewers have a greater influence on flood magnitude than topography. Topography mainly governs where the main sewers are placed, but not exclusively.

Flood risk reduction through stormwater management is not enough to fully protect an area from flooding. The Augustenborg case shows that excess water still can flow into basements and garages straight from the streets down ramps to underground parking garages and down stairs to basement entrances. Water from upstream areas can enter basements in Augustenborg through the combined system, as no backwater valves are installed (Haghighatafshar et al. 2018). To avoid all basement flooding during extreme rainfall, when new flow paths appear on the surface as on August 31, 2014, such constructions must be reconstructed with a barrier that keeps the excess water away from buildings, and backwater valves must be installed.
4.2. Insurance data as a measure for flood extent

Insurance claims and flood reports from housing companies, as used in this study, have some limitations. Firstly, not everyone is covered by insurance according to the data provider at Länsförsäkringar Skåne. People in different housing districts are probably covered differently by insurances, as the coverage might be related to the socioeconomic situation for a family. Even though Sweden is regarded as a country with a high degree of income equality, residential segregation exists in Malmö (the National Board of Housing, Building and Planning 2010). Differences in insurance coverage between the areas compared in this study, however, probably small, as the socioeconomic status in the areas are even: the six areas all belong to the lower quartile of socioeconomic status (Wallin 2010). Secondly, property owners who only get minor losses might not report these to the insurance company, as the deductible is high for some insurances. Therefore important information, especially on smaller events, might be missing in the data sets. Thirdly, the data sets only represent information from buildings. There is no data from other societally important constructions and functions, like roads and railways, power stations, the harbor, water utilities, and telecommunication installations. As mentioned before, the areas compared in this study are, however, similar in many aspects, and the main objective of this study – to analyze what influences blue green infrastructure has on flooding – is probably not affected by this limitation in the data sets.

5. Conclusions

Flood risk reduction in Augustenborg was achieved through implementation of an extensive blue green infrastructure. Five areas with similar age, land use, and imperviousness around Augustenborg were selected for comparison of flood magnitude. All five areas have combined sewer systems, corresponding to what Augustenborg had before the blue green stormwater retrofit. Direct effect of the retrofit looking at pre- and post-installation data indicates that Augustenborg was more affected by flooding before stormwater control measures were constructed. We also showed that most of the unretrofitted neighboring areas have been more affected by flooding in recent years as compared to Augustenborg. In the long term, reported insurance claims show that the flood magnitude was more than 10 times smaller in Augustenborg compared to the other areas both during the extreme event on August 31, 2014 and during other reported events in 2007–2015. Our data also show that the system is not perfect, as excess water can reach basements directly from the streets during extreme events.

Flood insurance data are found to be a useful source of information to evaluate flood risk in urban areas. The study can also conclude that risk levels for the insurance companies are lower in areas with stormwater control measures, which might increase insurance companies’ interest in such retrofit projects.

Acknowledgments

The authors thank Helén Nilsson from the insurance company Länsförsäkringar Skåne and Stefan Milotti from the utility company VA Syd for flood claim data. Susanne Steen Kronborg and Tomas Wolf from VA Syd are thanked for valuable data about the Malmö drainage system, rainfall data, etc. Cooperation with Länsförsäkringar Skåne was originally established by Joanna Theland during her master’s thesis and she collected data from several companies and organizations, which were used in this study together with complementary flood claim data received later. Thanks also to Malmö municipal housing company (MKB), Lifra (property manager), IF Skadeförsäkring (insurance company), Moderna Försäkring (insurance company), and Stadsfastigheter (property manager for Malmö City) for data. Lars Bengtsson and Rolf Larsson are thanked for their valuable comments to the manuscript and Cintia Uvo are thanked for help with the statistical analysis.

GIS data on urban areas, streets, etc., were distributed by the Swedish national mapping, cadastral, land registration authority: © Lantmäteriet, Dnr: I2014/00579.

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Table 1. Calculated building and road coverage as well as details on drainage system in Augustenborg and the five nearby areas used for comparison in this study.

<table>
<thead>
<tr>
<th>Name of area</th>
<th>Area [hectares]</th>
<th>Building coverage [%]</th>
<th>Road coverage [%]</th>
<th>Total approximate imperviousness [%]</th>
<th>Period of construction</th>
<th>Dominating drainage system type</th>
<th>Maximum pipe dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augustenborg</td>
<td>30</td>
<td>20</td>
<td>37</td>
<td>57</td>
<td>1948–1952</td>
<td>Blue green infrastructure</td>
<td>750 mm (pipe in combined system)</td>
</tr>
<tr>
<td>Lindgatan</td>
<td>3.4</td>
<td>20</td>
<td>42</td>
<td>62</td>
<td>1910s–1960</td>
<td>Separate</td>
<td>600 mm</td>
</tr>
<tr>
<td>Lönngården</td>
<td>9.2</td>
<td>19</td>
<td>31</td>
<td>50</td>
<td>1935–1936</td>
<td>Combined</td>
<td>450 mm</td>
</tr>
<tr>
<td>Norra Sofielund</td>
<td>25</td>
<td>29</td>
<td>41</td>
<td>70</td>
<td>(1910s)</td>
<td>North: combined</td>
<td>750 mm (North: 450 mm South: 600 mm)</td>
</tr>
<tr>
<td>Södra Sofielund</td>
<td>33</td>
<td>30</td>
<td>38</td>
<td>68</td>
<td>1910s–1950s</td>
<td>Combined West: separate</td>
<td>1000 mm* (West: 750 mm)</td>
</tr>
<tr>
<td>Persborg</td>
<td>11</td>
<td>19</td>
<td>31</td>
<td>50</td>
<td>mid-1950s</td>
<td>Combined</td>
<td>600 mm</td>
</tr>
</tbody>
</table>

*One of the main interceptor sewer pipes lies in this area, a 2000 mm combined stormwater and waste water pipe.

Table 2. Flood magnitude (NFP/ha) reported by LF Skåne and VA Syd in Augustenborg and five similar areas for 2007–2015 (both years included) with the severe flood event in 2014 shown separately.

<table>
<thead>
<tr>
<th>Name of area</th>
<th>Flood magnitude (NFP/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007–2015 (except 08-31-2014)</td>
</tr>
<tr>
<td>Augustenborg</td>
<td>0.03</td>
</tr>
<tr>
<td>Lindgatan</td>
<td>0.29</td>
</tr>
<tr>
<td>Lönngården</td>
<td>0.87</td>
</tr>
<tr>
<td>N Sofielund</td>
<td>0.67</td>
</tr>
<tr>
<td>S Sofielund</td>
<td>2.02</td>
</tr>
<tr>
<td>Persborg</td>
<td>0.54</td>
</tr>
</tbody>
</table>
Table 3. Flood claims reported in each area before and after stormwater control measures were constructed in Augustenborg. Before is represented by the period 1994–1999 (six years), while after is represented by 2009–2014 (six years). Data from VA Syd was used.

<table>
<thead>
<tr>
<th>Period</th>
<th>Augustenborg</th>
<th>Lindg.</th>
<th>Lönn.</th>
<th>N. Sof.</th>
<th>S. Sof.</th>
<th>Persborg</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (1994–1999)</td>
<td>5</td>
<td>25</td>
<td>12</td>
<td>23</td>
<td>44</td>
<td>4</td>
<td>113</td>
</tr>
<tr>
<td>After (2009–2014)</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>39</td>
<td>162</td>
<td>3</td>
<td>225</td>
</tr>
</tbody>
</table>

Table 4. Number of flooded properties, and flood magnitude for Augustenborg and the five nearby areas on August 31, 2014.

<table>
<thead>
<tr>
<th>Name of area</th>
<th>Area [hectares]</th>
<th>Number of flooded properties [NFP]</th>
<th>Flood magnitude [NFP/ha]</th>
<th>[NFP/address]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augustenborg</td>
<td>30</td>
<td>11 0 15</td>
<td>0.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Lindgatan</td>
<td>3.4</td>
<td>8 3 11</td>
<td>3.2</td>
<td>0.24</td>
</tr>
<tr>
<td>Lönngården</td>
<td>9.2</td>
<td>50 7 59</td>
<td>6.4</td>
<td>0.55</td>
</tr>
<tr>
<td>Norra Sofielund</td>
<td>25</td>
<td>46 30 85</td>
<td>3.4</td>
<td>0.19</td>
</tr>
<tr>
<td>Södra Sofielund</td>
<td>33</td>
<td>163 129 300</td>
<td>9.2</td>
<td>0.67</td>
</tr>
<tr>
<td>Persborg</td>
<td>11</td>
<td>37 3 41</td>
<td>3.7</td>
<td>0.43</td>
</tr>
</tbody>
</table>

*Note that the numbers in this table are slightly higher than in Table 2, as Table 2 only includes data from LF Skåne and VA Syd, while this table also includes data from Lifra Stadsfast and Moderna.

Fig. 1. a) Top corner: Europe (part of) with Malmö marked. Main map: Malmö with study areas marked (black), main sewers (dark, thick lines), and system type (combined sewers in dark gray and separate waste and stormwater in light gray with hatch).

b) Study areas, i.e. Norra Sofielund, Södra Sofielund, Lönngården, Persborg, Lindgatan, and Augustenborg. Land use types from Urban Atlas (European Commission 2012) with degree of sealing for urban fabric within the brackets.
Fig. 2. Channel and pond in Augustenborg in the southern area, which was redeveloped during the first phase of retrofit. The area in the right hand side picture was reconstructed from a wetland to a double pond with a small brook between for aesthetic and maintenance reasons. Photographer: Johanna Sörensen.

Fig. 3. Maximum precipitation volumes in Augustenborg (M03_Augu) and average precipitation measured in Malmö (Augustenborg, Turbinen, Djupadal, Bellevue, Limhamn, Bulltofta, Hammars Park, Höja, Söderkulla (mobile station), and SMHI station A) on August 31, 2014 for durations between 15 minutes and 12 days rainfall. For comparison, intensity-duration-frequency (IDF) curves from Hernebring et al. (2015) are given. For the average rainfall, a 95% confidence interval is given, assuming normal distribution of the precipitation for each duration.
Fig. 4. Flood magnitude (NFP/ha) for Augustenborg and five similar areas on August 31, 2014. High flood magnitude is shown in dark gray and low flood magnitude in light gray.

Fig. 5. Number of flooded properties reported to the insurance company IF Skadeförsäkring. The reports only give the total number of flooded properties for each postal area. Therefore, the extents of each postal area are marked.
Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities

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Abstract

Amidst the on-going trend of urbanisation, and the notable effect of climate change, there have been calls for a more sustainable management of stormwater. As part of this movement, blue-green measures, with their multifunctional benefits, have been recognised as a sustainable solution and a necessary complement to pipe-bound solutions. The aim of this study is to identify barriers and drivers of the implementation of blue-green measures in a Swedish context in order to increase the understanding of how they could be implemented in a more successful manner. The used methodology is qualitative and based on semi-structured interviews. Through the lens of transition theory and a multi-level perspective, was used to locate the main barriers and drivers as well as to provide an understanding of the interaction or lack of interaction between levels. Today there are many factors that encourage municipal actors to implement blue-green measures, such as increased need for recreation, protection of biodiversity and protection from climate change. The majority of the problems related to the implementation of blue-green solutions however exist within the municipal stormwater management itself but are also related to other inter-organizational barriers, such as lack of knowledge among politicians, officials, exploiters and civilians, fragmented roles and responsibilities, as well as uncertainty within the long term, economic management of stormwater. Another important barrier for municipal actors is related to the legal structure around stormwater management which, tie the hands of involved actors. Legislation therefore needs to be clarified. Also, new norms as well as organisational models related to how to manage urban stormwater must be established, as this can change the perception of the problem and facilitate a broader insight into the benefits of blue-green measures.

Keywords: blue-green solutions, sustainable urban drainage systems (SUDS), urban planning, transition theory, multi-level perspective

1. Introduction

More and more people choose to live in cities, which leads to an increasing urban growth (Jha et al. 2011). This leads to major land use changes in and around urban areas, which has a complex set of economic, social as well as environmental impact on urban space. It is difficult to predict the complete consequences of this growth, as it is a process influenced by both the type as well as the speed of growth. Simultaneously, climate change leads to increased torrential rains, flood risk, heat waves, drought, and sea level rise (Maksimović et al. 2015). A large part of its effects will be concentrated to urban areas (IPCC 2014), which will increase the demand on stormwater management and drinking water provision (Wong & Brown
Due to a history of relatively sparse residential construction in Sweden, compared to other countries, housing shortages in attractive urban areas and political ambitions to reduce emission of greenhouse gases and spare agricultural land drive the development of a denser urban space rather than urban sprawl, which put an even higher pressure on urban space management.

Due to these challenges it is argued new approaches to urban stormwater management is urgently needed (SOU 2014: 212). Stormwater management must be able to maintain its functionality during sudden local extreme events and at the same time provide benefits for people and nature in denser urban contexts (Ashley et al. 2011). This necessitates a holistic planning that minimize environmental impact, utilize land in a more multifunctional way taking social as well as well-being aspects into consideration and simultaneously is efficient with economic resources (Stahre 2004; Cettner et al. 2013). The ambition of holistic planning has been met with the idea that technical urban stormwater solutions should be combined with solutions using nature’s diversity as inspiration. The urban green infrastructure should in this perspective be seen as a part of the urban water management structure including features such as green roofs, rain gardens and rainwater ponds (Voskamp et al. 2015; Maksimović et al. 2015:3). The dynamic between water and vegetation can create an environment that can buffer and balance extreme weather events such as torrential rain and flooding (Dreiseitl 2015). It is also argued that such solutions can mimic natural systems and make them more resilience to climate change as well as cost-efficient and could therefore have the potential to increase and accelerate the desired transformation of urban water management (Mguni et al. 2015).

Blue-green solutions are frequently promoted as umbrella terms for such sustainable multifunctional measures able to reduce negative effects of urbanisation and adapt to a changing climate such as heat- and water regulation, air and water purification, increased biodiversity and recreation (National Housing Board 2010a; Cettner et al. 2014; Voskamp et al. 2015; Lerer et al. 2015; European Commission 2015). Other terms that are used are nature based solutions (NBS), sustainable urban drainage systems (SUDS), water sensitive urban design (WSUD), low impact development (LID), and sponge city (see Fletcher et al. 2014; Jia et al. 2016). These concepts have slightly different flavours from more green to more blue and usually have a stronger affiliation to one scientific discipline than another. Implemented in the urban context their aim is typically stormwater detention, infiltration and purification in a decentralised manner.

In Sweden, blue-green solutions are, in the area of stormwater management, known since the 1970s, primarily under the name lokal omhändertagande av dagvatten (LOD, local treatment of stormwater) in the last decade there is an emerging trend where many municipalities support open stormwater management and blue-green solutions to create a more robust and multifunctional management that is able to handle both social challenges as well as effects of climate change (Ashley et al. 2011; Cettner et al. 2014). However, the dominating solution to stormwater management is still pipe-bound solutions (Cettner et al. 2012), which is the current norm among both municipalities, developers and contractors (Ashley et al. 2011).

The dominating regime to stormwater management in Sweden is pipe-bound solutions (Cettner et al. 2012). Municipalities, are key players in the stormwater management as they are legally responsible for stormwater management, this responsibility is frequently delegated to public water services. There are three main laws regulating the management of stormwater; the Planning and Building Act (PBL), the Environmental Code, and the Act on Public Water Services (SFS 2010: 900, SFS 1998: 808, SFS 2006: 412). PBL provides conditions for how to use the land. The Environmental Code and the Act on public water services govern the
handling of stormwater at the municipal level (National Housing Board 2010b). A municipality can direct a certain stormwater management approach on private land as a part of the permission process, but have little influence on already built areas.

In addition, there is EU legislation implemented in Sweden, which may influence the regime of stormwater management: the EU Water Framework Directive (WFD) (Directive 2000/60/EC) and the Floods Directive (FD) (Directive 2007/60/EC). The WFD aims to ensure access to water of good quality in river basins and the FD handles flood risk management. The two EU directives has introduced a new way of organising water management. Water issues have gained an increasingly larger place in the physical planning (National Housing Board 2010a). However, within the current stormwater management regime, it is not allowed for water utility companies to spend money collected for urban drainage on solutions that cannot directly be motivated to be a part of a structure for urban drainage in accordance with municipal responsibility (Svenskt Vatten 2016). This means that reconstruction of a park to handle stormwater during extreme precipitation events can be difficult to motivate legally, as stormwater control during extreme events are not a legal responsibility for the municipalities in Sweden. Nevertheless there is an emerging trend where many municipalities support open stormwater management to create a more robust and multifunctional stormwater management system to handle both urban social challenges as well as effects of climate change (Ashley et al. 2011). In the two recent decades, numerous pilot projects and experiments with different types of blue-green solutions have been implemented, both in Malmö and Helsingborg, the case municipalities in this article. These projects have been financed by external money in the form of various EU projects and are seen as an important step to develop and gain practical knowledge in relation to alternatives measures for stormwater management suitable for local conditions (Farrelly and Brown 2011). A question that can be asked is: Why are these solutions not being implemented at a faster rate and not spread beyond the externally financed projects? Several studies have noted that the uptake of blue-green solutions is progressing slowly (van de Meene et al. 2011; Brown et al. 2009c; ref). Cettner et al. (2012) describe this slow transformation of stormwater management in Sweden as caused by the “pipe bound culture”.

The aim of this paper is twofold. The first aim is to identify barriers and drivers hindering or encouraging the transition from a pipe-bound stormwater management to a widespread implementation of blue-green solutions to handle urban stormwater, and to analyse these barriers and drivers from a multi-level perspective. The second aim is to discuss potential ways to overcome the barriers and to encourage transition to a more sustainable and multifunctional urban stormwater management system.

2. Transition theory- an analytical tool to assess socio-technical change

In this paper, transition theory is used as an analytical tool to explore barriers and drivers that may exist in relation to an altered management of stormwater in Sweden. Transition theory sees socio-technical systems, in this case the stormwater management system, as composed of three constellations: regime, niche and niche-regime. Surrounding these is the landscape that forms the pre-requisites for the system (de Haan & Rotmans 2011). The three constellations and their surrounding landscape is shown in Figure 1. While Rotmans et al. (2001) relate the levels to bureaucratic levels (macro, meso, and micro level) or nested hierarchies (2011), we perceive the levels as including organisational, technical as well as social systems as suggested by Geels (2011). In the following section we briefly explain the features of the different levels and thereafter we discuss how transition theory perceives change in a system.
The regime dominates the system and is the way that societal needs are met (de Haan & Rotmans 2011). A regime includes institutions, technologies, practical applications and social relationships (Geels 2002, Smith et al. 2005). The regime is the most powerful constellation of the system (de Haan & Rotmans, 2011). In Sweden, the current regime of urban drainage management consists of a pipe-bound system with a centralised management. Several actors are involved in developing and maintaining it (Cettner et al. 2012). A new regime is more than just an evolutionary transformation of a previous regime it has to be significantly different. For instance, to change from combined to separate sewers is an evolutionary transformation, while the change from pre-sewered cities to sewered cities can be considered as a transition to a new regime. (Ashley et al. 2011).

A niche is a system that only meets certain, specific societal needs (de Haan & Rotmans 2011). The niche level is mainly referred to where emerging innovations are developed that are fundamentally different from solutions at the regime level (Geels 2011).

A niche-regimes is a regime that is not currently dominating, while it has significant power to compete with the regime for the functioning of the system (de Haan & Rotmans 2011). Thus, a niche-regime is somewhere between niches and the regime in strength.

The landscape level represents the wider context (legal systems, demography, economy and the natural environment) that in a long term perspective is able to influence and affect the development of the practices at regime, niche-regime and niche levels (Geels 2002; Geels 2011; Koppenjan et al. 2012).

A central idea of the transition theory is that change emerges from niche through alternative solutions to niche-regime to displaced or replaced regime but a regime can also be influenced by actions and ideas emerging from landscape level (Koppenjan et al. 2012, Geels 2011 Smith et al. 2005). The challenge of the regime emerge from the dispersal of new social norms concerning how to solve a problem, know-how and motivation that alternative solutions bring with them when developed and implemented at the niche level (Koppenjan et al. 2004; Van de Bruges et al. 2005; de Haan & Rotmans 2011; Ashley et al. 2011 Farrelly & Brown 2011).

Drivers for this type of socio-technical transition has been divided into three categories stress, pressure and tensions (de Haan & Rotmans 2011). Pressure comes from alternative technologies that become viable competitors to the regime. Stress emerges when the regime is inade-
quate or internally inconsistent in meeting the needs of the system. Tension is when the system compromises in its relation to its natural or social environment. The tensions can either be structural, related to physical aspects of the regime, legal or cultural, related to cognitive or discursive aspects of the regime (de Haan & Rotmans 2011). Structural tensions are more frequently related the landscape level where as the cultural tensions can emerge from both niche and landscape level (Ashley et al. 2011).

Due to entrenched technological path dependency and cognitive lock-in, actors may be unable or hindered to implement new solutions (Brown & Farrelly 2009a; Werbeloff et al. 2011). Such implementation barriers, have different origins and be technological, legal organisation, financial social, educational or related to political will (Holtz et al. 2008; Brown & Farrelly 2009a; Brown & Farrelly 2009b; van de Meene et al. 2011; Cettner et al. 2013; Cettner et al. 2014; Winz et al. 2014; Mguni et al. 2015). As a consequence a transformation of a regime must consist of both physical, administrative and structural changes in the regime (Bettini et al. 2015) and change usually has to occurs at multiple levels for a regime to alter (Geels 2002). Barrier and drivers can originate from one level in the multi-level perspective, but affect the outcome at another level.

3. Method

The empirical material to this study was collected through interviews with 20 municipal and water utility company bureaucrats in two municipalities and two water utility companies in the south west of Sweden. The two municipalities (Malmö and Helsingborg) focused on in this study, use two different water utility companies, VA-syd (Malmö) and NSVA (Helsingborg), to provide stormwater management and water treatment services to a total of 730,000 persons (Figure 2). Malmö (330,000 inhabitants) and Helsingborg (140,000 inhabitants), are the two largest in the region and have a long experience of working with blue-green solutions.

Fig 2. Municipalities covered by the water utility companies in the study, NSVA (dark grey) and VA Syd (light grey).

Interviewees were chosen by contacting a key actors in each of the municipalities, and thereafter new interviewees were chosen by snowball sampling aiming to cover an as broad range as possible of the municipal expertise related to the management of stormwater and blue-green solutions (Flowerdew et al. 2005). The interviewed persons work at different departments, as environmental administration and planning office, and have a varied academic
background. A majority though have a background in natural and technical science (Table 1). In total, 20 persons were interviewed. Interviews were recorded, transcribed and written down in text format.

Table 1. Interviewees and their professional background.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Municipality</th>
<th>Department</th>
<th>Professional title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Helsingborg</td>
<td>Green</td>
<td>Environmental strategist</td>
</tr>
<tr>
<td>2</td>
<td>Helsingborg</td>
<td>Green</td>
<td>Head of department, environmental strategy</td>
</tr>
<tr>
<td>3</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Water planner</td>
</tr>
<tr>
<td>4</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Landscape architect</td>
</tr>
<tr>
<td>5</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Physical planner (zooning planning)</td>
</tr>
<tr>
<td>6</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Plan co-ordinator (zooning planning)</td>
</tr>
<tr>
<td>7</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Landscape engineer</td>
</tr>
<tr>
<td>8</td>
<td>Helsingborg</td>
<td>Planning</td>
<td>Head of department, building permit</td>
</tr>
<tr>
<td>9</td>
<td>Malmö</td>
<td>Planning</td>
<td>Community planner</td>
</tr>
<tr>
<td>10</td>
<td>Malmö</td>
<td>Planning</td>
<td>Landscape architect</td>
</tr>
<tr>
<td>11</td>
<td>Malmö</td>
<td>Green</td>
<td>Project leader (leads projects and development)</td>
</tr>
<tr>
<td>12</td>
<td>Malmö</td>
<td>Green</td>
<td>Project leader (leads projects and respond to referrals)</td>
</tr>
<tr>
<td>13</td>
<td>Malmö</td>
<td>Planning</td>
<td>Building permits, architect</td>
</tr>
<tr>
<td>14</td>
<td>Malmö</td>
<td>Planning</td>
<td>Head of department, planning</td>
</tr>
<tr>
<td>15</td>
<td>Malmö</td>
<td>Planning</td>
<td>Physical planner</td>
</tr>
<tr>
<td>16</td>
<td>Malmö</td>
<td>Planning</td>
<td>Environmental strategist</td>
</tr>
<tr>
<td>17</td>
<td>Malmö</td>
<td>Planning</td>
<td>Environmental administrator</td>
</tr>
<tr>
<td>18</td>
<td>NSVA</td>
<td>Blue</td>
<td>Civil engineer</td>
</tr>
<tr>
<td>19</td>
<td>NSVA</td>
<td>Blue</td>
<td>Civil engineer</td>
</tr>
<tr>
<td>20</td>
<td>VA SYD</td>
<td>Blue</td>
<td>Head of department, new construction and exportation</td>
</tr>
</tbody>
</table>

The purpose of the interviews was to collect information about barriers and drivers related to the implementation of alternative solutions to urban stormwater management. The interviews were semi-structured (Flowerdew et al. 2005) and based on an interview guide with three themes: 1) barriers respective 2) drivers related to implementation of blue-green solutions and 3) what would be needed to overcome barriers and start a transition towards a more holistic stormwater management.
The material was analysed by the hermeneutic process – a circular analysis process where new insights are integrated from the understanding and interpretation of the studied material through a constant exchange between the parts and the whole (Kvale & Brinkmann 2009).

Based on this analysis, topics were identified in relation to the themes in the interview guide. Based on the themes and the topics a data table was compiled to categorize the informants’ quotes and expressions. This approach to categorizes the empirical material gives a clear structure and stability of how and which actor that express the drives and barriers. From this categorization, patterns could be distinguished among the answers from the interviewees.

Analysing and categorising of the empirical material was made in two steps. One part was to count how many of the interviewees mention a specific driver or barrier. This is reported in table 2 and 3 in the result section of the article. After this categorization, the next step was to understand how the barriers and drivers are framed in the context of transition theory and the multi-level perspective. The identified barriers and drivers were therefore first categorized by their origin in the multi-level perspective, for example is climate change a landscape factor..

4. Results and analysis

In this section, the result from the interviews and an analysis of identified barriers and drivers for the implementation of alternative stormwater structured is made.

4.1. Drivers for blue-green solutions

From the interviews, three types of drivers were identified: ecosystem services, climate change, and economy. In table 2, the identified drivers are presented in relation to how many of the informants that mentioned each driver.

Table 2. Drivers for increased implementation of blue-green solutions identified among the informants. The categories is a categorisation where blue is bureaucrats working mainly with water, green is bureaucrats working mainly with ecology and vegetation and planning is bureaucrats working mainly with urban planning.

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Number of informant that mention it</th>
<th>Green</th>
<th>Blue</th>
<th>Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecosystem services</td>
<td>20/20</td>
<td>4/4</td>
<td>3/3</td>
<td>13/13</td>
</tr>
<tr>
<td>Climate change</td>
<td>17/20</td>
<td>4/4</td>
<td>2/3</td>
<td>10/13</td>
</tr>
<tr>
<td>Economy</td>
<td>6/20</td>
<td>0/4</td>
<td>1/3</td>
<td>5/13</td>
</tr>
<tr>
<td>Politics of urban densification</td>
<td>7/20</td>
<td>2/4</td>
<td>0/3</td>
<td>5/13</td>
</tr>
</tbody>
</table>

4.1.1. Ecosystem services

All informants (20) mentioned ecosystem services such as recreation, biodiversity, delay and clean water as driving factors to work with blue-green solutions. Green and open solution provides values and qualities to the urban space (Informant 11, 2016). Environmental protection of for instance watercourses is a driver for blue-green solutions (Widarsson 2016, Ashley
et al. 2011), but also cultural ecosystem services, like aesthetics, are mentioned both by the interviewees and in the literature (Widarsson 2016). The interviewees mention different services as the most important for example;

*The need for recreation areas are the primary drivers behind the implementation.* (Informant 10 2016)

*The important thing is delay and treatment of stormwater.* (Informant 7, 2016)

*Another incentive could be to create more biodiversity and the desire to create a different environment, not just a lawn but something else. That can be an important driver.* (Informant 20, 2016)

*Water gives a beautiful aspect to a city, combining park and water facilities* (Informant 18, 2016).

At the same time some of the respondents mentioned, that if there is a choice between biodiversity and construction of houses, nature comes second. The following quote shows this argument in an illustrative manner.

*There are few who experience a visible damage when dragonflies decline in a river.* (Informant 1 2016)

4.1.2. Climate change

Almost all respondents (18) mentioned climate change as a driver to implement blue-green solutions. The interviews show that there are awareness and knowledge about that the climate is changing and that the actors need to adapt urban areas to be able to handle the increased precipitation.

*Climate change is almost a positive thing and the fear of flooding. It has opened up for discussion with an entirely different width than earlier.* (Informant 1 2016)

Climate change pushes society to adapt the existing infrastructure, to make it more flexible and robust (Ashley et al. 2011). Awareness among officials can stimulate a process of change and facilitate increased cooperation between administrations in a municipality, but also inspire other actors to act, as developers or consultants. Climate change as a driver can lead to a greater consensus and dialogue between administrations, and between different disciplines in a city. To succeed with an implementation of blue-green solutions involvement of different actors, with different backgrounds, is needed for a successful change (Van de Bruges et al. 2005; van de Meene & Brown 2009; Mguni et al. 2015). Climate change is a driving factor for local authorities to work with multifunctional stormwater solutions.

4.1.3. Economy

Many of the respondents (14) mentioned that the financial aspect is a driver to implement blue-green solutions. There is an awareness of the economic impacts of downpours that may affect the municipality. One respondent argued that;
There is a fear of the economic impact of downpours, such as basement flooding, damages, compensation for poor planning (Informant 1 2016).

Several respondents mentioned that it is expensive to increase the number and dimensions of existing sewage pipes in the existing built environment. It was also argued that many pipes are getting old and will need to be replaced. From that perspective, blue-green solutions can be more cost effective (Ashley et al. 2011) and municipalities claim that they use the solutions to reduce costs (Widarsson 2007).

*It is not economically viable to lay pipes in the existing built environment (Informant 10, 19 2016).*

*If one is to follow up on the grid with larger pipes it will be expensive (Informant 3 2016).*

There is a difficulty working with nature, that it doesn’t have a defined cost, and natural values are therefore complex to include in city planning. Utility companies in England have to some extent started to see commercial advantages of blue-green solutions (Ashley et al. 2011) and more research focus on the cost-benefit of ecosystem services (Read et al. 2016, Ossa-Moreno et al. 2017). Interestingly, no bureaucrats with ‘green’ background mentioned economy as a driver (see table 2).

4.1.4. Politics of urban densification

Urban densification was mention both as a potential driver and a barrier in the interviews. There was 7 informants that mention urban densification as a potential driver to implement blue-green solutions. Most of them is working with planning (5). See the quote below.

*We know that we make more and more impervious surfaces, and then we have more water to take care of. It is the main driving force. (Informant 7 2016)*

*I believe that the awareness grow continously, especially in the work with urban densification. We need to address these questions. (Informant 6 2016)*

This shows that there is a awareness about how a larger densification affects the urban climate, with more water runoff, in a city. Urban densification is two folded which can create a awareness among actors, and obstruct green and blue structures in the urban matrix.

Existing drainage system often lack capacity when new areas are developed or densified (Widarsson 2007) as runoff are higher from denser urban areas (Sjöman & Gill 2014). This puts a stress on the regime, as it cannot any longer meet the main needs. In Västerås, such a stress within the current regime led to cooperation over organisational borders and a new surface water strategy was written with the goal to eliminate the combined system, reduce extraenous water to the waste water treatment plant and to reduce pollution of Lake Mälaren (Widarsson 2007).

4.2. Barriers for blue-green solutions

Eight types of barriers to the include new stormwater solutions were identified in the interviews. In table 3, these barriers are presented in relation to how many of the informants that mentioned each barrier.
Table 3. Barriers against increased implementation of blue-green solutions identified among the informants. The categories is a categorisation where blue is bureaucrats working mainly with water, green is bureaucrats working mainly with ecology and vegetation and planning is bureaucrats working mainly with urban planning.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Number of informants mentioning it</th>
<th>Green</th>
<th>Blue</th>
<th>Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>18</td>
<td>4/4</td>
<td>3/3</td>
<td>11/13</td>
</tr>
<tr>
<td>Roles and responsibilities</td>
<td>17</td>
<td>4/4</td>
<td>2/3</td>
<td>10/13</td>
</tr>
<tr>
<td>Lack of knowledge</td>
<td>17</td>
<td>4/4</td>
<td>2/3</td>
<td>11/13</td>
</tr>
<tr>
<td>Legislation</td>
<td>14</td>
<td>4/4</td>
<td>3/3</td>
<td>9/13</td>
</tr>
<tr>
<td>Municipal organisation</td>
<td>13</td>
<td>4/4</td>
<td>1/3</td>
<td>8/13</td>
</tr>
<tr>
<td>Urban densification and housing shortage</td>
<td>10</td>
<td>2/3</td>
<td>1/3</td>
<td>7/13</td>
</tr>
<tr>
<td>Political interests</td>
<td>9</td>
<td>3/4</td>
<td>1/3</td>
<td>5/13</td>
</tr>
<tr>
<td>Time and workload</td>
<td>9</td>
<td>1/4</td>
<td>2/3</td>
<td>5/13</td>
</tr>
</tbody>
</table>

4.2.1. Economy

The interviews conceived economy both as a barrier and as a driver, depending on which economical aspect the informants referred to. While 14 informants mentioned economy as a driver, almost all (18) mentioned economy as a barrier against implementation of blue-green solutions. Several informants mentioned the uncertainty of the costs for maintenance of the solutions. Economic reasons counteract an increased implementation of blue-green solutions (Cettner et al. 2014) and some developers perceive non-piped solutions as more costly (Ashley et al. 2011).

A majority of the respondents argued that economy is an important factor that define the outcome of the activities of the planning process. The different municipal department has their own budgets. Several informants argued that there is a difference between planning for a solution and a different story to implement them.

*Many times these solutions exist at the planning stage. Space is allocated in the first sketches that the landscape engineers develop. The more time that passes, the more space the developer wants to exploit. The land is precious today and these solutions are excluded. (Informant 18, 2016)*

Furthermore, according to the interviewees there is an uncertainty about which actor will finance solutions, with creating a resistance to implement blue-green solutions. The business model of water utilities can also inhibit implementation, like in Wales (Ashley et al. 2011).

There is a difficulty working with nature, that it doesn’t have a defined cost, and natural values are therefore complex to include in city planning, but it do act as a driver that puts a tension on existing stormwater regime.
4.2.2. Roles and responsibilities

In the studied municipalities, there are several players with different skills, knowledge and training involved in the stormwater management chain, from the strategic and overall planning to detail planning for building permits and to private individuals. In the interviews the lack of clarity of roles and responsibilities emerged as an issue.

*It may also be that there is an unclear division of responsibilities or that we are not enough involved in each other’s projects.* (Informant 3 2016)

Van de Bruges et al. 2005 have argued that water management in an urban environment is a "persistent" problem. Mguni et al. (2015) and van Herk et al (2011b) describes this as a "wicked problem". Hordijk et al. (2014) suggest that the reason is that different stakeholders value water differently.

The interviews revealed a mixed picture regarding who has the overall responsibility for the implementation and management of blue-green solutions. Several interviews mentioned that the Department of Housing and Urban Development has the overall responsibility for establish blue-green solutions, while the Water utility companies have an important role. But several informants also argued that there should be a shared responsibility to implement blue-green solutions involving not only the municipality but also consultants, property owners and developers. But it was argued that these actors do not realize their role in the big picture which increase the unclarity of responsibilities.

*The responsibility for the stormwater lies with everyone actually, right down to the homeowner, but we are far from there.* (Informant 16, 2016)

4.2.3. Lack of knowledge

In Sweden there is a widespread awareness about blue-green solutions (Ashley et al. 2011). Still, a majority of the respondents (14) mentioned that there is a lack of knowledge among officials regarding blue-green solutions. The comments shows that lack of knowledge creates an inertia to understand the importance of blue-green solutions in the urban landscape. As a consequence actors slow down or even block a change.

*There is need to work wider and to include the ecological expertise in a different way than we did before. Even more intersectoral and more ecological knowledge, either through the recruitment of new people or through educating those already working* (Informant 11, 2016)

This has also been confirmed in other studies where it is forwarded that an increased knowledge among stakeholders can encourage the transformation and integration of different skills and approaches as well as open new ways of thinking as well as drive the uptake of new technologies in the urban context (McCormick et al. 2013).

The lack of knowledge does not only concern implementation of new solutions but also how solutions should be maintained. In several interviews lack of knowledge also concern maintenance as even if knowledge of construction costs are known the maintenance costs are not. There is a lack of knowledge regarding cost-efficiency and lack of experience from established solutions (Widarsson 2007, Ashley et al. 2011).
Research on organisational learning and climate adaptation shows that it is a challenge to spread learning outcomes (Storbjörk 2010). So far, much of the work in Sweden has been done by enthusiastic individuals that drives workings groups within the organisation (Widarsson 2007, Storbjörk 2010, Cettner).

It is also argued that the lack of knowledge also concerns other actors, like private property owners.

> There is a very difficult actor and that is the property owner who has a rather big responsibility too. All villa carpets that are hard paved. There is no awareness, or at least very few are aware. (Informant 12, 2016)

Private actors affect land use in urban areas through investments and the urban infrastructure is largely influenced by their economic and social interests. Lack of knowledge and focus on private exploiters desire to maximize profits is a factor that can both block and allow for a change (Olazabal & Pascual 2012).

Another factor that potentially can drive and push an for a increased implementation of blue-green solutions is forwarded in one of the interviews which is;

> It feels like there is a new generation of officials on their way, so it feels like a lot has happened and blue-green solutions is a part of the work. If you think climate proof buildings. There is an increased awareness. It is clear that some senior officials continue as they have always done and then it is difficult to change later. (Informant 18, 2016)

An increased knowledge of officials, developers and the public are probably important in order to achieve a holistic stormwater management.

### 4.2.4. Legislation

The legal structure related to the management of stormwater is complex and to a certain extent unclear, which make it difficult to apply the different legislation that affect stormwater, which increase uncertainty for involved stakeholders; both municipalities and private actors (Persson et al. 2012; Dir 2015: 115). Legislation is crucial for how municipalities will be able to implement blue-green solutions in the future. It was highlighted in interviews, that the current legislation leads to a complex planning process of implementing blue-green solutions. Municipalities cannot demand special technical requirements for different landowners. This means that municipalities cannot require more than stated in the PBL or Building Regulations BBR (Building and Planning 2016).

> In the legislation it’s possible to indicate a request but it is not possible to demand technical requirements. Land allocation is given through an exploitation agreement. The environmental Code and PBL are in coalition with each other. There is a conflict between environment and permission to build. The motivation is there, but you are restrained. (Informant 17 2016)

The lack of special, technical requirements can therefore operate as a blocking barrier for experimentation and innovation to be established in stormwater regime. The municipality cannot make stronger demands on developers, which could have been a stimulating act for a
change to occur. According to the interviews, the problem is that the detailed planning is mainly focused on exploitation. The focus on development slows down the transition, since the focus is to exploit and not to evaluate the potential positive effects of blue-green solutions.

Several of the informants mentioned that it is a problem that blue-green solutions do not have a quantitative value in the planning process. There are clear standards about the number of parking spaces, the size of a turning zone or the number of schools, but there are no clear standards related to the size and number of blue-green space. This means that after demands for parking lots and schools are met, there is a risk that there is no physical space left for implementing blue-green solutions (Informant 15, 10 2016). Another respondent argues in a similar manner;

*If you let all functions add on top of each other, the distance between houses and people become even bigger. Then we do not talk about the dense city, but the sparse, and then transport need are increased. We need to dare to prioritize. It is not possible to add functions on top of each other. Let’s say that you must have six meters roadway, four-meter trees, and then you add on three-meter bike road and two-meter pavement. If you add all these measures on top of each other, the street canyons become very broad. (Informant 14 2016)*

It has been recognised at a national level that uncertainty about roles and responsibilities among actors is affected by unclear legislation which resulted in a government investigation in Sweden (SOU 2017:42). Brown & Keath (2008) have argued that drivers at the landscape level are required to stimulate a change in the regime, despite the innovations and new technical solutions at niche level which is confirmed by the interviews in this study. Also Widarsson (2007) argues that top-down requirements from authorities are needed. In Sweden, regulations in the Act of public water services inhibit implementation of blue-green solutions in practice (Ashley et al. 2011).

Despite implementation of the UK Flood and Water Management Act 2010, which was developed mainly in response to the 2007 flooding, piped solutions are still the default solution (Ashley et al. 2011).

4.2.5. Municipal organisation

In several of the interviews it has been argued that there is a lack of structure that can promote the cooperation needed to implement blue-green solutions.

*The structure, how the organization is structured. It is this pipe thinking. You sit on your budget, your own resources, interests, responsibilities... Everyone talks about communication and collaboration. Everyone talks about it and then we use all the old tools and it’s not working. (Informant 15, 2016)*

Holtz et al. (2008) argues that innovation needs to be integrated into existing cultural networks and structures. Based on the interviews involved authorities have their roles. There are various processes as well as projects "owned" by the Town Planning and the Environment Department. But these innovative experiments and pilot projects have had difficulties to establish themselves as a mainstream solution.

The interviews also showed that there is a willingness to cooperate, but there are barriers linked to how the municipality is organised.
The structure of the municipality leads to a “narrow-thinking”, because each department has their own budget, interest and responsibilities when it comes to community planning (Informant 16, 2016).

Several studies have found that widespread implementation of climate adaptation measures and new solutions are highly dependent on single, engaged persons within the municipal organisation (Storbjörk 2010, Widarsson 2007, Cettner). This make the knowledge base vulnerable and the work lacks continuity (Storbjörk 2010).

4.2.6. Urban densification and housing shortage

Several informants (7) mentioned densification and housing shortage as a barrier. Some informants said that there is a ‘housing shortage panic’ in the municipalities (Informant 9, 12, 15, 17, 2016) and that there is therefore a risk that officials don’t have time to take blue-green solutions into consideration (Informant 12, 2016). There is a general shortage of housing in Sweden that put pressure on the use of surface especially in urban areas and decrease the possibility to introduce blue-green solutions. Van de Meene et al. (2015) draws attention to the problem of a dense city, when a large part of a city is built up with impervious surfaces, there are limitations when it comes implement blue-green solution in the city environment. Other places, other development land use and roads are prioritised over blue-green solutions (Ashley et al. 2011).

It seems however as if the there is an awareness of the potential conflict between dense and blue-green solutions;

It was great that we recognized that there was a conflict between dense and green (Informant 15, 2016)

4.2.7. Political interest

Several informants mentioned the that the urgent housing need is a priority for the politicians. Other places urban flooding is so high on the agenda that the multiple benefits of blue-green solutions are forgotten (Ashley et al. 2011). If the need of blue-green solutions could be clarified, it could become a way to make it easier for officials to prioritize the implementation of more blue-green solutions. There is a tension between interests, values and prioritise (Storbjörk 2010).

Visions are hard to say no to. It is clear that we want multi-functional solutions and purify water, of course we want to save biodiversity. It's not hard. But it is when the individual decisions come in, not to make the connection between real estates and environmental goals. There is a will, but then it is the same politicians who approve urban densification and the constructions. (Informant 1 2016)

The lack of housing and need for densification influence the political agenda of stormwater management. This can have negative effects on an increased implementation of blue-green solutions. Politicians can obstruct and partially block an increased implementation of blue-green solutions as the politicians have the last word when it comes to what can be built and not.
4.2.8. Time and workload

Several of the informants (9) mentioned time and workload as a barrier that hinders the implementation of blue-green solutions which is an important barrier and block implementation of new solutions.

All municipal administrations are committed to an open stormwater solution, then how hard the issue is driven depends on how many other demands there are. (Informant 10 2016)

In those cases where more has not been done to integrate multifunctionality, is due to lack of time in the projects and that the workload is high for many (Informant 7 2016)

There is little resources to work proactively with alternative solutions (Ashley et al. 2011), especially in many small municipalities (Widarsson 2007). Widarsson argues that the water utility often is weak in comparison with the municipal office for the built environment.

5. Discussion

5.1. Drivers

In this study, four drivers of change were identified: ecosystem services, climate change, economy, and politics of urban densification. The two first are external to the stormwater regime and has their origin in two different fields of international and national politics that has gained momentum under the last years. The debates about climate change and ecosystem services seem to have created awareness among involved actors and climate change work as a driver both from a general political level and at an individual level. Where the latter driver, climate change, is related to the concrete torrential rains and downpours that hit Malmö in 2014, resulting in major economic consequences for many actors, municipalities, private individuals, property owners and insurance companies. Previous research has shown that it often takes a crisis for a transition to take place (Loorbach 2007: 18; Brown & Keath 2008). The effects, both social and economic, of the downpurs act directly on the regime and created an internal stress and fear of more extreme events, which could open up for a shift towards an increased implementation of blue-green solutions in a city environment.

The national politics of densification of urban areas also emerged as a driver for the implementation of blue-green solutions, in particular in combination with the economic driver, where the inclusion of blue-green solutions is seen as more feasible than re-piping a whole city. Something which also has been identified in other studies (ref).

In the literature, other drivers are mentioned that were not identified in this study, this concerns for example technical problems with the piped system, stressing the regime such as reoccurring problems with flooding often initiate use of blue-green solutions (Widarsson 2007, Ashley et al. 2011, Sörensen & Emilsson under review). Another factor driving for change raised by the literature is that in some cities it is critical to reduce the amount of extraneous water to waste water treatment plants (Widarsson 2007).

5.2. Barriers

The barriers that were identified include economic factors, roles and responsibilities, lack of knowledge, legislation, municipal organisation, urban densification and housing shortage,
political interest, and time and workload. Several of these barriers are closely related, like economy and political interest, and lack of knowledge and municipal organisation.

The legal barriers mainly concerns the water management. Regulation of water is a complex matter, mainly due to the liquid character of the substance, which influence the possibility to divide the responsibility of it, in a meat manner. This has been recognised and increasingly dealt with at a watershed scale level in rural areas, but in cities the watershed management idea has not been implemented (ref). One reason is the additional legal structures regulating urban stormwater management for which municipalities are responsible, a responsibility often delegated to water service organisations in Sweden. The responsibility of private land owners in connection to downpours is not clearly defined (SOU 2017:42). According to the interviews, one barrier is the lack of possibilities to pose special technical requirements on urban developers and property owners.

The barrier related to unclear roles and responsibilities is intimately linked to the legal barriers but also to the physical problems of managing water in the compartmentalised organisation of the municipality, where different disciplines to a large extent are separated, and in an organisation that lack cooperative structures. According to Cettner et al. (2013), the urban planner has a key role in creating links between the planning process and the actors involved in stormwater management. However, according to Ashley et al. (2011) other actors such as constructors, possesses a great power, as they often get municipalities to opt for traditional stormwater management by the desire to maximally exploit the land.

Another barrier that appeared as important was the political pressure for urban densification as there would be little space for blue-green solutions in a dense urban matrix. In such a context, the problem is not only a potential lack of capacity in the stormwater pipes, but also the potential effects of the lack of green space for the urban dwellers (Tratalos et al. 2007). In the interviews it was clear that is a conflict between different aspects of building a city. There is a lot of different interest that need to be taken inte account. The lack of housing in Sweden has a large political focus, which make it difficult for official to argue for different values as blue-green solutions. In Scania, 28 of 33 municipalities has a housing shortage, and in on national level only one municipality has an excess of housing (Länsstyrelsen 2017).

Lack of knowledge and know-how emerged as another barrier to why multi-functional blue-green solutions has not gained momentum as a general way of thinking. Several of the existing nature-based solutions have been implemented through pilot projects funded by external project money, and knowledge about and processes for implementation has not been mainstreamed into relevant part of the municipality. Due to the lack of knowledge of how to construct and maintain these solutions, as well as lack of funding in the everyday stormwater management, public officials and project leaders choose the easy and known way out, pipe-based solutions. Other interviewees argued that it is rather due to lack of time and an already heavy workload and yet other argued that the problem is lack of willingness among public officials. What is lacking is a culture where public officials are permitted to test and fail as a part of a learning process, otherwise it will be difficult to increase the implementation of blue-green solutions. Some interviewees also related the lack of implemented blue-green solutions to the lack of political interest.

5.3. Suggestions

Time is short when aiming to manage adverse effects of both urbanization and climate change. Blue-green solutions may handle some of these challenges through an increase or improvement of the green spaces for the benefit of both humans and wildlife (ref). Under this time pressure and in the midst of a densification boom of Swedish urban areas, there is
an increased need to identify the factors causing the lack of transition and find counter-measures to speed it up (Liu & Jensen 2017). Based on the identified set of driving forces and barriers, this study is not surprisingly indicating that societal change is a complex process. There are multiple instances, connections, links, and levels that affect the outcome of a barrier or momentum for change. A sustainability transition has to includes the improvement of several aspects of inter-institutional and public-private collaboration.

In a transition context it is often pointed out that innovation of conventional ways of designing and managing urban spaces and structures, and practical experiences of this approach through testing and improvement are essential for inducing change. It is argued that through such a development, new social norms are developed concerning how to solve a problem (Koppenjan et al. 2004, Van de Bruges et al. 2005, de Haan & Rotmans 2011, Ashley et al. 2011, Farrelly & Brown 2011). One reason for the strong attention given to the role of niche innovation is, according to Cettner et al. (2014), that a bottom-up transition is more visual to media, and that it leads to an increased public awareness and hence political ears. According to the approach, interpretation of change potential, a strong focus has been put on promoting different types of technical innovation at niche level. Based on the findings in this article, this view of change, provides a rather simplified view on change and the interaction or possible interaction between societal actors and legal structure. In the transition literature, there are also voices raising the importance of factors at the landscape level (Koppenjan et al. 2012, Geels 2011 Smith et al. 2005, Mguni et al. 2015). Brown & Keath (2008). Yet others have argued that to achieve a transition, changes must occur and be integrated between levels (Geels and Schot 2007). We argue for the latter understanding of the potentials of change, where change is promoted by a combination of alternation at different scales of the system. Transition also requires a mutually-reinforcing shift in each of the cognitive, normative, and regulative pillars of a regime. A specific barrier experienced by a city often reflects the lag in the transition of one of the two other regime pillars, even though conditions in the other pillars may be ready. The existing implementation of blue-green solutions (normative) does not seem to be transformed into a mainstream solution until regulations are implemented (regulative pillar) and municipal organization (normative) are updated to support the application. So what can this study teach us about the potential ways to overcome the barriers, strengthen the drivers and to encourage transition to a more sustainable and multifunctional urban stormwater management system in a southern Swedish perspective?

**Legal**

One way could be reduce the legal barrier linked to the removal of the possibility to define technical requirements. Early 2018, the Swedish government present a national climate change strategy. The strategy is giving different measure to adapt the society to climate change. One measure concerns changes in the legislation, i.e. the PBL, and either reintroduce the possibilities to pose specific technical requirement concerning the water management capacity at each plot. Another possibility that actually is on the decision table is to demand private actors to submit site improvement permit when changing the infiltration capacity of their land (Government officials of Sweden 2018). The political debate anticipating the removal of the technical requirement mainly targeted construction technical requirement and issues concerning water management rather concerned issues relating to the management of public goods. If such changes are implemented it may provide a very important basis for change. According to Lui & Jensen (2017), green technology and innovations, such as blue-green solutions, cannot become mainstream until relegations exist to support their inclusion, which many of the informants in this study mentioned as a problematic area. Other research has shown that demands from authorities and legislation that puts a pressure on the current
regime are important for transition towards widespread implementation of alternative solutions (Widarsson 2007, Ashley et al. 2011).

A more radical way to induce change through legal means could be to demand that each parcel of land to handle a certain percentage of the rain water landing on it, for example by implementation in a detail plan. It is clear that to use such an approach would be easier when building on new land, and in the already build space it is much more difficult, and with more conflicts of aims (include something about sponge city). In line with these suggestions, Widarsson (2007) suggests using a model from Franklin, US, in Sweden. In Franklin authorities demand a permit to outlet stormwater. The permit must be renewed every five years and can only be given if there is a stormwater programme with clear objectives, including routines for maintenance.

**Economy**

One way to strengthen the economic driver, might be to differentiate the water fee payed to the municipalities/water utility companies so that property owners with less impervious surfaces pay less (Widarsson 2007). Similar incentives have been tested for decades, for instance you can get 2500 SEK per disconnected downpipe in Malmö (VA Syd 2018), but such a possibility needs to be developed also in relation to what such a water fee actually can include. Hence a redefinition of what a water fee could include as services should be developed.

Money to increase the number of upstream wetlands and ponds could be introduced and in 2018 the Swedish government decided to distribute xx miljon to such wetlands (ref).

**Knowledge and learning processes**

In the interviews a need to learn and test solutions at the niche level is raised. Pahl-Wolst argued already 2008 that to test new solutions the municipalities can create a solution-oriented document base so a project manager can more easily find solutions which can lead to increased adaptive capacity at the regime level. From this study it is clear that if such testing is just performed by using external project money such as in Augustenborg (Stahre 2008), a stronger structure for organisational learning and knowledge transfer to the ordinary planning and development processes is needed. However, as noted by Geels (2011), if sufficient time is given to gain experience, develop knowledge and innovation, and update regulations, blue-green solutions could mature as an alternative approach to pipe bound solutions to urban stormwater management. In accordance to this reasoning, Mguni et al. (2015) argues that niche innovations have begun to mature and it has a much broader use than before, which is also the case in Sweden.

It is clear that there is a need to increase the knowledge about blue-green solutions, but this is rather related to knowledge exchange and sharing between sectors, than lack of understanding of what a blue-green solutions are. In this context, the perceived change in new generation employees more holistic understanding of the importance of blue-green solutions also could positively influence the future implementation. A complementary solution could be to develop a catalogue of solutions (including general ideas of their benefits, implementation and maintainance cost) that different actors can use. Such a list could also include information about other benefits of blue-green solutions than water management, and in that sense strengthening the knowledge of the multiple benefits of blue-green solutions.

Widarsson (2007) suggests that house owners should be informed about flood risk when they buy the house. Such information is for example available in Denmark (Danish EPA, 2018). In one of the interviews, it was mentioned that an important part for a change to occur
would be to integrate property owners and the general public, in order to blur the boundaries between the blocks of private owned and public owned land. It could lead to a more efficient establishment of blue-green solutions in the urban environment. VA SYD has also recently started to work more directly with private property owners, through the project “Together we make space for water” (VA SYD, 2018).

**Organisation of spatial planning**

One solution to overcome the sectoral divide and increase the speed of organisational learning could be to develop an organisational structure in the municipality that ensure the cross sectoral learning process in relation to both the implementation and management of blue-green solutions. Municipalities could for example employ a person in the planning system that ties together the tasks, facilitates dialogues between involved actors and ensures a joint understanding of the problem at stake. Also important would be to increase the interaction between green space development and stormwater management. In Wales, the surface water management strategies is linked to the green space strategy, which is probably a fruitful way to make the planning more holistic (Ashley et al. 2011). Widarsson (2007) suggest that groups are formed with representatives from all involved departments to increase cooperation within the municipal organisation. Another aspect in this is that the planning process include various municipal officials, which require trans-disciplinary of trans-professional approaches and skills (van Herk et al. 2011a). Storbjörk (2010) investigated barriers for organisational learning in two Swedish municipalities. In one of the municipality the city councils waits for national regulation of climate change adaptation, in this case flooding risk reduction, before they act. The other municipality engage neighbouring municipalities, arrange conferences, etc. While this is a more proactive approach, much of the work is done by a single servant and therefore vulnerable. It is therefore also important that every city has a surface water management strategy with clear goals (Widarsson 2007), like the climate adaptation plans in Denmark (Københavns Kommune 2012) or the surface water management strategy from Welsh Water (Ashley et al. 2011).

Another measure that supports the organisational capacity could be to increase dialogues and to strengthen capacity building among public and private landowners about the potential benefits of introducing blue-green solutions. A capacity building that could increase the understanding and develop the benefits (for example recreation lower, temperature, noise reduction, health benefits) of blue-green solutions the cities in a similar ways as integrated water management does in rural areas (ref). In Copenhagen, public dialogues have been initiated to locally verify and legitimise stormwater solutions for flood control. This type of initiative can create a consensus among actors in the regime and find common approaches to be able to mainstream the implementation of blue-green solutions at a broader scale than just particular project. It is also important that public and private landowners, officials, consultants and politicians find common approaches to achieve an integrated flood-proof stormwater management.

Lui and Jensen (2017) argues that a transition is two folded, innovative and experience is creating a deeper knowledge among actors, but more structural changes is also needed such as change inregulations so new solutions could mature. There is a need to combine o top-down, legal change, and bottom-up-down strategies, niche projects that promote learning processes, to accelerate a transformation process from pipe-based solutions to nature-based solutions. This is also clear from this study there need for top-down and bottom up changes or a transition to accrue. Niche project is more difficult to establish itself as a part of the planning culture in the municipality. Many of the innovative pilot-projects in Malmo or in Helsingborg, indicates that municipal actors are able operate at niche level, as they support,
invest in and seek funding to start up pilot projects. However, there seems to have been a lack of link between this niche level project and the main planning culture as the ideas and knowledge have not been mainstreamed into the municipalities more daily development. Clear responsibilities among regime institutions, favorable conditions provided for developing accountability and collective responsibility, and improved incentives as well as clear procurement rules, and municipal decision-making processes for public-private collaboration, may help overcome this (Cettner, Ashley, Hedström, & Viklander, 2014; Cettner, Ashley, Viklander, & Nilsson, 2013; Kennedy, 2011; Lund & Vaaben, 2014).

List of ideas to include or not include in the discussion:

- **Clear responsibilities among regime institutions, favorable conditions provided for developing accountability and collective responsibility, and improved incentives as well as clear procurement rules, and municipal decision-making processes for public-private collaboration, may help overcome this** (Cettner, Ashley, Hedström, & Viklander, 2014; Cettner, Ashley, Viklander, & Nilsson, 2013; Kennedy, 2011; Lund & Vaaben, 2014).

- **Bottom up transition:** Brown and Keath (2008) argue that a key factor to implement sustainable transformations is to improve the link between actors at the regime and niche level. The actors at the niche level can respond to barriers in the regime such as lack of knowledge and awareness and could lead, for example, to larger financial support and legitimacy at the regime level in the longer run (Brown & Keath 2008). But there is a problematic side to the bottom-up, niche project. Its more difficult for such a project to establish itself as a part of the planning culture in the municipality. Many of the innovative pilot-projects in Malmo or in Helsingborg, indicates that municipal actors are able operate at niche level, as they support, invest in and seek funding to start up pilot projects. However, there seems to have been a lack of link between this niche level project and the main planning culture as the ideas and knowledge have not been mainstreamed into the municipalities more daily development. urban environment (ref Cettner? Farrelly?).

- The barriers and uncertainties related to the roles and responsibilities make it difficult to change the regime. Links between different groups within the regime needs to be clarified in order to raise awareness. This barrier hinders the link between the level niche and regime level as it leads to imbalance between different players and that no one wants to take responsibility for increasing implementation. Learning and cognitive changes of the system could lead to legislative and regulatory changes within the regime (Geels 2006).

- In the end handling water need to take space in the urban matrix. More space efficient and multi functional solution could be introduced especially if planners learn more about the different qualities a blue-green solution could have. But there is a limit to how little space they can take in use. There is a huge focus on building houses due to a large house shortage, which complicates the implementation of blue-green solutions. In extension there are conflicts of aims for blue-green solutions possibility to outweigh the number of parking spaces or the turning radius of a turning zone, which there are establish standards for in the community planning.
Det finns nya tänkandet som blivit regiem för ex in Malmö nya detaljplaner får man in mina lösningar (Ashley 2011) men Ashley har ju fattat fel….

The municipality has, due to the planning monopoly, a large potential to change the management of stormwater and creating a more holistic approach to policy development and planning through dialog.

Every city must have a surface water management strategy with clear goals (Widarsson 2007), like the climate adaptation plans in Denmark (Københavns Kommune 2012) or the surface water management strategy from Welsh Water (Ashley et al. 2011).

Efficient routines for blue-green solutions are needed in the planning process (Widarsson 2007).

Blue-green solution is left to a question of negotiation between byggherre and kommun...

Annika Kruuse: Vi har gjort oss kända över pilotprojekt här i stan med Bo01 och Augustenborg och på så vis har vi ju faktiskt gått från ord till handling rätt så snabbt men att få in det som ett arbetsätt och generellt tänkande där är vi inte än och det har gått betydligt trögare. Det beror på att stadsplanering är så bred och komplex fråga och många frågor som ska hanteras parallellt.

References


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A framework for strategic urban development using blue-green infrastructure and nature-based solutions (NBS)

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Abstract
A common strategy to lower the demand for intensive land use and energy consumption is the densification of urban areas. While this might be a fruitful strategy for its main objectives, one concern is the concomitant decrease in space for urban green areas and surface water. Therefore, urban densification increases the need of strategies to implement, develop and manage multifunctional blue-green infrastructure with nature-based solutions (NBS) in urban areas. Smarter spatial planning strategies are needed, both for maintenance of existing NBS and for implementation of NBS in new developments. Spatial planning should ideally be based on well-evaluated context specific solutions. Such evaluation must in turn be based on appropriate data material for each city. Today there are several types of difficulties related to adequate provisioning of data to ensure appropriate implementation and maintenance of NBS.

This study focuses on exploring the gap between data availability and implementation of NBS that persists in many city-planning authorities today. By identifying information barriers, this study aims to develop a framework to serve as a basis for a discussion on strategic urban development and help urban planners overcome these gaps and facilitate the inclusion of context relevant and multifunctional high quality NBS in the larger blue-green infrastructure.

Selected interviews with urban planners and experts in the area of NBS and GIS were performed to develop the framework based on the idea that well-structured and user-friendly data, supporting city-planning strategies, are essential to facilitate the implementation of NBS.

The identified challenges arise from issues such as lack of data and patchy data sets, lack of access to data and data rights issues, lack of knowledge both concerning other sectors and scientific disciplines, data storage not adapted to users’ needs, organisation of data storage and the difficulties concerning how to use the existing data strategically.

The conclusion that can be drawn is that there is need for an improvement of the organisation of data management including better trans-disciplinary skills to understand and interpret different types of data in the municipality.

What can be understood as well-structured and user-friendly data depends on the goals and needs expressed in strategic plans, which mean that there is a need for a close interaction between the collection of data and the development of strategic political goals expressed in spatial planning documents.

KEY WORDS: nature-based solutions, blue-green infrastructure, spatial planning, strategic planning, stormwater management, climate change adaptation, data, GIS

1. Introduction
A common strategy to lower the demand for intensive land use and energy consumption is the densification of urban areas (Grimm et al. 2008). While this might be a fruitful strategy for its main objectives, e.g. to decrease urban sprawl on agricultural land and increase the population density for an efficient public transport, one concern is that space for green areas and surface water will decrease (Haaland and van den Bosch 2015). E.g. the urban green space of
Swedish cities and towns decreased by 0.6–1.5% between 2000 and 2005 (SCB 2005). Other challenges may be a lack of freshwater at certain times and in certain places, pollution of different kinds, lack of areas for recreation, increased noise, increased urban temperatures and loss of biodiversity (Grimm et al. 2008, Stott et al. 2015). Therefore, densification increases the need for strategies to preserve, build, develop and ideally simultaneously increase the quantity (area) and quality of green and blue spaces (vegetation and surface water) in urban areas in a multifunctional manner (Hansen 2014; Pauleit 20011), to ensure that these areas provide the necessary functions to counteract a broad array of challenges caused by urbanisation. This approach is also supported by goal 11 of the UN’s 17 Sustainable Development Goals aims to “make cities inclusive, safe, resilient and sustainable” which includes providing access to green and public spaces for all strata of society (UN 2015).

On top of an increased densification of urban space, climate change puts a pressure on the urban environment. In the future, more intense rainfall events and thereby more flood events are expected in several regions worldwide (IPCC 2014). In combination with current land use changes due to urbanization and increased industrialization of agriculture and forestry, problems with urban flooding will increase further (Semadeni-Davies et al. 2008; Voskamp and Van der Ven 2015). At the same time, droughts are expected to become more frequent (IPCC 2014). Again, both quantity and quality of blue green spaces in urban areas will be important to counteract effects of climate change.

Many cities have ambitious strategic plans for green urban spaces (Turner 1995, Sandström 2002). When such spaces are designed to align with the natural water cycle, we hereafter call them blue-green infrastructure. These blue green areas are seen as important for recreation, urban biodiversity as well as climate adaptation and handling of cloud bursts. Recently the European Commission has introduced the concept of nature-based solutions (NBS) and states that NBS are “actions inspired by, supported by or copied from nature” (EC 2015). According to the Commission’s definition these should both address specific demands or challenges and seek to maximise other environmental, social and economic co-benefits, including habitat for biodiversity creating a multifunctional green space. In this article, we have chosen to use the concept blue-green infrastructure for the overall strategic planning, while we use NBS for individual solutions (e.g. a green roof or a water-retention pond). We assume that municipal authorities have an overarching goal to strategically coordinate the implementation of blue-green infrastructure into the built environment and improvement of existing to provide good environmental living conditions for inhabitants in a changing climate, while simultaneously providing ecologically sustainable cities and habitat for biodiversity. Working towards such a goal requires strategies that combine maintenance of existing blue-green space with strategic placement and good quality of NBS, both in existing and new urban developments. The aim should be to optimise the delivery of benefits over the whole city, rather than in any one individual NBS. The type of solution that will be introduced depend on the main purpose of the blue-green infrastructure, water retention, biological diversity or recreation. This is a challenge for many reasons, one being that administrative borders often do not coincide with the spatial or temporal scales necessary for adequate maintenance and governance of ecosystems and ecosystem services (Borgström et al. 2006, Faehnle et al. 2015). In Sweden for example, the National Board of Housing, Building and Planning (Boverket) has the responsibility for guidelines regarding green infrastructure in urban areas. Municipalities have a monopoly on spatial planning, and municipalities or separate water utility companies are responsible for urban drainage, but neither can in detail govern what is built on private land. Furthermore, the Swedish Environment Protection Agency through the County Administrative Boards is responsible for the green infrastructure in general both rural and urban areas. Thus, there is potentially a weak link at the regional scale between green and
blue structures in, and between rural and urban areas. Water is often managed within municipal borders, which do not follow hydrological catchments.

As there will be less available space when urban areas grow denser, we therefore argue that an urban development introducing one or several NBS must be founded on well-evaluated solutions and based on relevant (spatial or other) data for each city, to make optimal use of the limited space. Today there are several types of difficulties related to gathering and accessing adequate data for appropriate implementation of blue-green infrastructure as well as NBS. These difficulties are related to both economic, social and environmental factors and span from lack of information about the extent of the existing blue-green infrastructure, cost of maintenance and citizens’ perceptions and preferred use of NBS, to difficulties of a more technical character such as data base structure, the data format of available GIS information and patchy data provision based on lack of data, including lack of coordination between different data collecting authorities at different scales (Hansen and Pauleit 2014; Ahern et al. 2013).

The aim of this study is to address the information gaps in data availability for adequate planning of blue-green infrastructure and NBS that persists in many municipalities today. We do so by identifying information barriers between expressed data need, data collection and use, and use this information to develop a framework to help strategic spatial planners overcome information gaps to facilitate the inclusion of high quality and context relevant blue green infrastructure and NBS in urban planning.

2. Definition of Green Infrastructure, Sustainable Urban Drainage Systems and Nature-based Solutions

Several concepts have been launched by researchers and authorities at different administrative levels to describe and aid planning and implementation of green and blue structures in both urban and rural areas. While NBS is a relatively new concept, proposed by the European Commission (EC, 2015), Sustainable Urban Drainage Systems (SUDS) and Green Infrastructure (GI) have been used in urban planning since the 1990s. In this section, we will define the differences between these concepts and how they relate to each other by focussing on different scales and aspects of blue green structures.

Green Infrastructure (GI) or ‘green structure’ has been perceived as a way to upgrade green space as a coherent planning entity and incorporate aspects of both ecological sustainability (including biodiversity conservation) and the well-being of urban dwellers (Sandström 2002, Tzoulas et al. 2007, Ahern 2013, Hansen and Pauleit 2014). The concept of Green Infrastructure is used as an urban planning tool emphasizing the quality as well as quantity of urban and peri-urban green spaces (Turner, 1996; Rudlin and Falk, 1999), their multifunctional role (Sandström, 2002), and the importance of interconnections between habitats (van der Ryn and Cowan, 1996). Green infrastructure should be a coherent planning entity where individual urban green spaces are multifunctional systems (Sandström 2002). GI builds on landscape ecological theory, with ecological or functional connectivity as an important tool to manage e.g. meta-populations and biodiversity conservation in human modified landscapes (Ahern 2013, Snall et al. 2016). In the urban landscape GI is currently seen as a way to reduce the negative effects of urbanisation and to adapt to an anticipated changing climate, including an increased need for surface water and stormwater management, and to create multifunctional areas with both environmental and social functions (Hansen and Pauleit 2014). In 2013 the GI concept was launched by the EC as a way to preserve and enhance healthy green infrastructure to help stop the loss of biodiversity and enable ecosystems to deliver their many services to people and nature. GI was described as a
strategically planned and multifunctional network of natural and semi-natural habitats, as well as other environmental features, in rural and urban areas (EC 2013). The Commission is arguing that because GI is partly defined by its geographical extent it is a suitable tool to bridge the urban-rural interface and to use in planning at several spatial scales (EC 2013). SUDS are drainage systems constructed to handle stormwater in a decentralised manner, typically through stormwater detention, infiltration and purification in e.g. open channels, ponds, wetlands, and via green roofs (Stahre 2008, Cettner et al. 2014, Hoang and Fenner 2015). SUDS aim to copy the natural hydrological cycle, to prevent harmful effects of urbanisation on streams, groundwater and marine environments.

To some extent SUDS are interchangeable with other water management related concepts, such as Sponge City in China, Water Sensitive Urban Design (WSUD) in Australia, Best Management Practice (BMP) and Low Impact Development (LID) in the US, and local control and use of stormwater (LOD) in Sweden (Jia et al. 2016, Brown et al. 2009, Fletcher et al. 2014). The term used in non-urban contexts is Sustainable Drainage Systems (SuDS). More recent concepts, like the Sponge City and WSUD have incorporated the idea of resilience. The city is viewed as a “sponge”, soaking up water during rainfall and releasing it when needed (Jia et al. 2016). The idea of the above mentioned, concepts is to mimic functions from nature that are valuable in urban areas, such as purification of water, flood control, water storage, and temperature regulation.

NBS is one of the newest ‘green’ concepts and was launched as a way to adapt to climate change by the International Union for Conservation of Nature (IUCN) in 2009 in its position paper on the United Nations Framework conventions on climate change (UNFCCC) COP 15 (IUCN, 2009). In 2015, the European Commission (EC) launched the concept in relation to the Horizon 2020 call. In recent years, NBS has been put forward within the European Commission, as a measure to increase innovation and development of multifunctional solutions inspired, supported by or copied from nature (European Commission, 2015). The introduction of nature-based solutions is expected to support economic development and deliver multifunctional benefits for the health of people, society, economy and the environment. Key focus areas are sustainable urbanisation, restoring ecosystems, climate change mitigation, improved risk management, and resilience (European Commission 2015).

The three concepts have a slightly different focus, mainly related to their uptake and use in different disciplines and their related sectors. SUDS consist of techniques (e.g. swales, green roofs, canals) and concepts (e.g. multifunctionality, decentralisation), while the GI concept is a broader principle including the need to improve the quality of green urban space (Fletcher et al. 2014) and when the European Commission launched it as a tool in 2013 it also incorporated a strong rural component. Whereas GI has a strong link to large scale green planning and water is a secondary feature, SUDS is a concept that has emerged from practice and disciplines of urban storm water management with emphasise on the use of ‘green’ solutions for storm water management. It has been argued that for SUDS, other benefits are considered added value, but not targeted per se (Stahre 2008, Voskamp and Van de Ven 2015). The GI concept on the other hand, does not explicitly include water. NBS on the other hand include both blue and green features and solutions. NBS is focused on solving specific challenges, but concept is also used when discussing larger scale green structures both outside as well as inside urban areas (Keesstra, 2018). What the concepts have in common is that they all require work beyond administrative ‘silos’ and engaging across disciplines and sectors, as well as systemically involving stakeholders, including citizens (e.g. Hansen and Pauleit 2014; Ahern et al. 2013).
Our brief assessment of these concepts, shows that these green planning tools has a history and they have different relations to; urban/rural, green structures/water, and large scale/small scale, which make the recycling of ideas complex and to some extent even confusing. In this study we focus on spatial urban planning and, we use ‘blue-green infrastructure’ when we talk about large-scale structures in, while NBS or ‘blue-green solutions’ are used for one or several connected elements of the blue-green infrastructure. Thus, blue-green infrastructure defines the spatial extent and distribution of mainly green structures that are in line with the hydrological cycle, while different NBS define the content and quality of separate elements. There are two important reasons for this “redefinition”, the first is that different actors are involved in planning large scale structures and smaller elements, the second concerns the addition blue to green infra structure which highlights the importance of water in strategic planning.

3. Method

The framework was developed in three steps:

Step one, brainstorming within the author group, with the aim to identify barriers influencing the flow of information. The authors represent different disciplinary background and approaches to blue green infrastructure and NBS (more blue to more green) and their implementation. In step 1 some NBS elements (Table 2) were selected to illustrate a variety of suitable placements (street, roof, park, garden, square, etc.), functions (hydrological, biological, aesthetic, social, pedagogical, etc.), needs for maintenance, ownership and scale of implementation. In step one a draft framework was developed.

Step two, interviews with selected municipal officials and practitioners working with development and implementation of NBS from different parts of the implementation chain, with the aim to complement the initial list of potential barriers through the experience from practice. The main focus of the interviews was to identify what data or information was missing to meet urban challenges and plan for an optimal distribution and placement of NBS. The drafted framework was used as a basis for the questions. Six practitioners were interviewed. Interviews were semi structured (Bryman 2015) taking the point of departure in the experience of each interviewee.

Step three, analysis of findings using triangulation and development of the final framework. In triangulation results from several methods are used to grasp a complex set of relations (Mathison 1988). In this case we combined our three disciplinary backgrounds with a “reality check” based on practical experiences of bureaucrats working at different levels in the NBS implementation chain, and additional information from scientific articles.

Table 1. Interviewed practitioners

<table>
<thead>
<tr>
<th>Interview</th>
<th>Name</th>
<th>Position</th>
<th>Educational background</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Annika Arvidsson</td>
<td>Malmö city planning office, planning department</td>
<td>Landscape Architect</td>
</tr>
<tr>
<td>1</td>
<td>Jonna Nilssdotter</td>
<td>Malmö city planning office, strategy department</td>
<td>Ecologist</td>
</tr>
<tr>
<td>2</td>
<td>Kristina Hall</td>
<td>Planning engineer at water utility company (VA Syd)</td>
<td>Civil Engineering</td>
</tr>
</tbody>
</table>
Table 2. Elements selected for comparison and discussion

<table>
<thead>
<tr>
<th>Element</th>
<th>Geographical extent</th>
<th>Typical property owner</th>
<th>Placement</th>
<th>Main function</th>
<th>Maintenance need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees in streetscape</td>
<td>Point</td>
<td>City council, private</td>
<td>Along streets and on parking</td>
<td>Aesthetic, Climatic</td>
<td>Yearly</td>
</tr>
<tr>
<td>Raingardens</td>
<td>Point</td>
<td>City council, private</td>
<td>Along streets</td>
<td>Hydrological, Aesthetic</td>
<td>Continuously</td>
</tr>
<tr>
<td>Extensive green roofs</td>
<td>Point/area</td>
<td>Private, city council</td>
<td>Roof</td>
<td>Aesthetic, Biological</td>
<td>Seldom</td>
</tr>
<tr>
<td>Daylighting of urban streams</td>
<td>Linear element</td>
<td>City council</td>
<td>Larger dedicated areas</td>
<td>Hydrological, Biological</td>
<td>Continuously</td>
</tr>
<tr>
<td>Permeable pavement</td>
<td>Point/area</td>
<td>City council, private</td>
<td>Parking, school yards</td>
<td>Hydrological</td>
<td>Seldom</td>
</tr>
<tr>
<td>Retention pond</td>
<td>Point</td>
<td>City council</td>
<td>Park</td>
<td>Biological</td>
<td>Continuously</td>
</tr>
<tr>
<td>Park or urban forest</td>
<td>Area</td>
<td>City council</td>
<td>Bigger, dedicated areas</td>
<td>Recreational, Biological</td>
<td>Continuously</td>
</tr>
</tbody>
</table>

4. Results

4.1. Results step 1: Brainstorming

A set of brainstorming sessions with the authors were conducted in autumn 2016 and spring 2017. During these sessions, different perspectives on data availability and data management in the urban spatial planning of blue-green infrastructure and nature-based solutions were discussed.
Several gaps as well as question were identified already in the first brainstorming sessions, such as lack of information about the extent of existing NBS, costs of maintenance, citizens’ perceptions and preferred use of NBS, difficulties of a more technical character such as data base structure, the data format of available GIS information, and patchy data provisioning based on lack of certain data, including mismatches in the coordination between data collecting authorities working at different scales. Three main areas of problems were identified: the multiple need of data, lack of GIS data, and problems related to data management.

4.1.1. Multiple needs of data
Several kind of data is demanded, e.g. information that can aid actions to reduce noise, control pollution, limit lack of green areas, reduce heat islands, reduce stormwater runoff and increase infiltration and evapotranspiration. There is a need for data that can be developed into maps that show the availability, lack of and need for, as well as provide information on what functions and services the NBS blue-green infrastructure can deliver.

4.1.2. Lack of data and GIS data
Some data are missing due to difficulties related to data collection. It is for example difficult to investigate underground infrastructure and to keep track of maintenance needs for less visible systems. In some cases, it is costly to maintain often updated datasets, for instance on the spatial distribution of species in different urban habitats.

Data collection is affected by ownership structures. For example, green roofs built by city council or a water utility company are more likely to be registered in a database compared to those constructed by private house owners.

Inventories of existing biological and ecological values are often made based on available knowledge rather than actual need of information. The Swedish Species Information Centre uses crowdsourcing as one of their data collection methods through the Swedish Species Observation System. This will lead to a more reports on rare species close to where interested biologists live, and a lack of information in other areas. A SIS standard for biodiversity surveys exist since 2014, and is starting to be implemented at the municipal level to inform in planning processes (SIS/TK 555 Naturvärdesinventering).

4.1.3. Problems related to data management
Several problems related to data management were identified, from technical issues such as incompatibility between database structures, to problems related to human resources. The latter includes low priority among assignments, scant knowledge about available data in other departments and organisations, competition, prestige and difficulties to cooperate between departments as well as leadership related issues.

Collection and processing of data to assess the development and function of NBS are divided between different national, regional and local authorities. Data is collected in relation to the legal responsibility of authorities, e.g. the responsibility to assess future rainfall and the capacity of current stormwater system, to handle precipitation based on climate modelling, to assess spatial distribution and quality (through different types of surveys) of green areas, or to assess nutrient or pollution run-off to surface and ground water, etc. Because the purpose of collecting and assessing data differ between authorities, the collected data seldom comprise a comprehensive ground for planning blue-green infrastructure and its elements. Neither is it comprehensive in spatial cover, content or quality.
4.1.4. Raised questions

Several questions were raised during one of the first brainstorm sessions which together with the initially developed framework were used to guide the framing of questions during the interviews:

- Which data exist at which scale?
- What kind of data is lacking?
- Is the data format convenient or not when to cooperating with other professions in the planning process?
- Are authorities working at different spatial scales aware of the need to pool the data to understand NBS at the local scale?
- What are the costs of maintenance of future and existing NBS? Maintenance is closely linked to quality and functions of green spaces and SUDS.
- What are citizens’ perceptions and preferred use of NBS? Are their perceptions obtained and used in the planning process?

4.1.5. Present situation

A list of available data and data in current use (Table 3) was collected during the brainstorming and later supplemented by the authors. The list includes data on different planning scales, provided by various authorities and organisations. From the list, the following categories of data needed in the planning process of blue-green infrastructure evolved.

- Cadastral
- Technical
- Geological
- Biological
- Environmental
- Risks
- Social
- Administrative
- Meteorological

Table 3. Datasets available for planning.

<table>
<thead>
<tr>
<th>Geographical scale</th>
<th>Planning scale</th>
<th>Authority/organisation</th>
<th>Kind of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>Comprehensive planning</td>
<td>The Swedish Species Information Centre, SLU</td>
<td>Artportalen (Swedish Species Observation System) -- citizen science, observations, new findings</td>
</tr>
<tr>
<td>River basins</td>
<td>Comprehensive planning</td>
<td>Competent Authorities of the Swedish Water Districts, the County Administrative Boards and the Swedish</td>
<td>VISS (Water Information System Sweden) – Status classification, environmental quality standards, environmental monitoring, protected areas</td>
</tr>
<tr>
<td>Agency for Marine and Water Management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>Properties</strong></td>
<td>Comprehensive planning</td>
<td>Insurance companies</td>
<td>Flood claim data</td>
</tr>
<tr>
<td><strong>All of Sweden</strong></td>
<td>All</td>
<td>Lantmäteriet – The Swedish mapping, cadastral and land registration authority</td>
<td>Cadastral maps</td>
</tr>
<tr>
<td><strong>All of Sweden</strong></td>
<td>All</td>
<td>Lantmäteriet – The Swedish mapping, cadastral and land registration authority</td>
<td>Orthophotos (also historic orthophotos)</td>
</tr>
<tr>
<td><strong>All of Sweden</strong></td>
<td>All</td>
<td>Lantmäteriet – The Swedish mapping, cadastral and land registration authority</td>
<td>Digital elevation model (Nationella höjdmodellen)</td>
</tr>
<tr>
<td><strong>-</strong></td>
<td>Livsmedelsverket – National food agency</td>
<td>Quality standards for drinking water</td>
<td></td>
</tr>
<tr>
<td><strong>Regional</strong></td>
<td>Comprehensive planning</td>
<td>Länsstyrelsen – County administrative board</td>
<td>Pluvial flood risk assessment (doubtful quality in urban areas)</td>
</tr>
<tr>
<td><strong>Local</strong></td>
<td>Comprehensive planning, zoning</td>
<td>Länsstyrelsen – County administrative board</td>
<td>Environmentally hazardous business</td>
</tr>
<tr>
<td><strong>City, regional</strong></td>
<td>Comprehensive planning</td>
<td>Länsstyrelsen – County administrative board</td>
<td>Targeted inventories</td>
</tr>
<tr>
<td><strong>Local, regional</strong></td>
<td>Comprehensive planning</td>
<td>Länsstyrelsen – County administrative board</td>
<td>Ad hoc inventories</td>
</tr>
<tr>
<td><strong>Local</strong></td>
<td>Comprehensive planning</td>
<td>Länsstyrelsen – County administrative board – SGI coordinates research and training</td>
<td>Polluted soil and groundwater</td>
</tr>
<tr>
<td><strong>National</strong></td>
<td>Comprehensive planning</td>
<td>Metria, Lantmäteriet, Länstyrelserna i Östergötland och Stockholm, etc.</td>
<td>National land cover map – CadasterENV</td>
</tr>
<tr>
<td><strong>River basins</strong></td>
<td>Comprehensive planning, zoning, building permit</td>
<td>MSB – Swedish civil contingencies agency</td>
<td>Flood risk assessment along watercourses (prioritise rivers)</td>
</tr>
<tr>
<td><strong>-</strong></td>
<td>Municipal emergency service</td>
<td>???</td>
<td></td>
</tr>
<tr>
<td><strong>Local</strong></td>
<td>Comprehensive planning, zoning</td>
<td>Municipalities</td>
<td>Reports related to environmental control programme: air, water (EU</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning, zoning, building permit</td>
<td>Municipalities</td>
<td>Municipal maps for planning (plankartor)</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------</td>
<td>----------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Local</td>
<td>Comprehensive planning</td>
<td>Municipalities</td>
<td>Ad hoc inventories of species</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning</td>
<td>Municipalities</td>
<td>Groundwater</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning</td>
<td>Municipalities – some of them</td>
<td>Pluvial flood risk assessment</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning</td>
<td>SCB – Statistics Sweden</td>
<td>Urban green areas, extent</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning</td>
<td>SCB – Statistics Sweden</td>
<td>Public access to urban green areas</td>
</tr>
<tr>
<td>River basins – few</td>
<td>Comprehensive planning</td>
<td>SGI – Swedish geotechnical institute</td>
<td>Landslide risk assessment</td>
</tr>
<tr>
<td>River basins</td>
<td>Comprehensive planning</td>
<td>SGI – Swedish geotechnical institute</td>
<td>Observed landslides and other ground movements (Swedish Landslide Database)</td>
</tr>
<tr>
<td>Coastline, river basins, lakes</td>
<td>Not good enough for detailed studies</td>
<td>SGI – Swedish geotechnical institute</td>
<td>Coastal vulnerability index (erosion)</td>
</tr>
<tr>
<td>Local</td>
<td>Building permit</td>
<td>SGI – Swedish geotechnical institute</td>
<td>Stability – hållfasthet (myndighetsansvar?)</td>
</tr>
<tr>
<td>-</td>
<td>Zoning, building permit</td>
<td>SGI – Swedish geotechnical institute</td>
<td>Costs calculation for management of masses and for foundation</td>
</tr>
<tr>
<td>-</td>
<td>Zoning, building permit</td>
<td>SGI – Swedish geotechnical institute</td>
<td>GeoEkoKalkyl (GIS-baserat verktyg) för att identifiera, dokumentera och visualisera betydelsen av ekosystemtjänster (EST) och byggkostnader vid exploatering av mark</td>
</tr>
<tr>
<td>Coastline</td>
<td>Comprehensive planning, zoning, building permit</td>
<td>SGU</td>
<td>Sea level rise</td>
</tr>
<tr>
<td>Coastline</td>
<td>Comprehensive planning</td>
<td>SGU</td>
<td>Ongoing erosion</td>
</tr>
<tr>
<td>Local</td>
<td>Comprehensive planning, zoning, building permit</td>
<td>SGU</td>
<td>Well and borehole archive</td>
</tr>
<tr>
<td>Local</td>
<td>Comprehensive planning, zoning</td>
<td>SGU</td>
<td>Rock and soil properties</td>
</tr>
<tr>
<td>--------------</td>
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<td>------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Local</td>
<td>Comprehensive planning</td>
<td>SGU</td>
<td>Exploitation of soil, gravel, and stone</td>
</tr>
<tr>
<td>Regional</td>
<td>Comprehensive planning</td>
<td>SGU</td>
<td>Groundwater</td>
</tr>
<tr>
<td>Regional</td>
<td>SMHI</td>
<td></td>
<td>Climate data (temperature, wind, precipitation, etc.)</td>
</tr>
<tr>
<td>River basins</td>
<td>SMHI</td>
<td></td>
<td>Flow</td>
</tr>
<tr>
<td>Regional, city</td>
<td>Comprehensive planning, zoning, building permit</td>
<td>SMHI</td>
<td>Risk assessments (water level, drought, floods, etc.)</td>
</tr>
<tr>
<td>National</td>
<td>SMHI</td>
<td></td>
<td>Climate models</td>
</tr>
<tr>
<td>City</td>
<td>Comprehensive planning, zoning</td>
<td>Stadsfastigheter</td>
<td>Properties owned by municipals</td>
</tr>
<tr>
<td>River basins</td>
<td>Comprehensive planning</td>
<td>Vattenmyndigheterna – Competent Authorities of the Swedish Water Districts</td>
<td></td>
</tr>
</tbody>
</table>

4.2. Results step 2: Interviews with municipal officials and practitioners

From the interviews, six themes could be distinguished: lack of data, data access and rights, lack of knowledge, data storage tools not adapted to users’ needs, strategic data use, and organisation of data storage.

4.2.1. Lack of data

In two of the interviews, lack of GIS data related to ecosystem services such as pollinators/pollination, tree shade, the marine environment, and mapping of biotopes (Interview 1, 3) were mentioned. Another area mentioned was the lack of ‘green’ data for private land (which related to lack of inventories of green cover and biodiversity). One of the interviewees mentioned that there is a tree plan for public land in Malmö but no such plan for private land, whereas the downpour plan (a plan to handle rainstorm and flood events) concerns the whole city. As a consequence, it becomes difficult to assess the real lack of green space (1).

In interview 1 it was argued that the Swedish Species Information Centre has uneven data and to interpret available data correctly it is important to have the proper meta knowledge of the structure and purpose of the data collection (1).

In relation to storm water information it was mentioned that maps do not follow the development of the city. Deep holes at construction sites can accept a lot of water during downpours, but what happens with the water when the site has been built on? Even if the data quality is improving, the resolution is still low and data update processes are slow (2).
4.2.2. Data access and rights

In interview 1 and 2, the lack of access to inundation data from insurance companies was mentioned as a problem. However, in interview 2 it was mentioned that insurance companies are working on facilitating access to these data and the possibility to combine insurance data and data from their own flood claims to enable calculation of expected flooding costs in the future (2). It is also argued that meta data related to different flood hazard modelling scenarios as well the model outcome is not stored systematically which mean that other persons than the one running the models have difficult to access data as well as the underlying scenario (2).

It was mentioned that municipal maps of the blue structures cannot easily be used for strategic planning at the municipal level, because the Department for Strategic Development does not have access to certain GIS layers from the Streets and Parks department within the same municipality (1, 3). In interview 2 it was also argued that the strategic service providers (e.g. energy suppliers, fire and rescue services) claim that they have control over their infrastructure and environmental risks related to them, but the municipality doesn’t know on what they base their assessments (2).

Another problem related to data access is that data is physically scattered. For example, data about pipes and property owners covers the whole municipality but is spread between different databases and formats, such as digital maps, but also as scanned documents as well as paper (1). In relation to the downpour plan it was argued that one simulation result, namely the flood hazard risk map for a so called hundred-year-rain, is available in ArcGIS, while other simulation results only exist in the computers of the consultants that performed the downpour modelling (2). It was also mentioned that an evaluation of green values such as ecosystem services were made for the downpour plan but did not enter the final report (2).

One of the interviewees had experiences from data management in different municipalities and argued that it is especially difficult in some municipalities, as they are afraid of making mistakes which result in a very restrictive access (3).

4.2.3. Lack of knowledge

Many municipality staff members use either GIS or CAD based planning platforms, but very rarely both (3). Planners most often use CAD and do not know GIS very well (2). Small municipalities are generally not using any of these platforms, but if using GIS it enters at the end of the planning process and the production of maps. This situation is mainly due to lack of local GIS knowledge, as a lot of data is available to the municipalities through the Swedish geodata collaboration (3). Using GIS is a matter of practice: if you do not work in a GIS environment every day there is a threshold to open these type of programs (2). Even staff members that use ArcGIS on regular basis are not aware of all possibilities related to the software. In interview 3 it was argued that there is a need for basic GIS education, at least one day for middle management positions, to make them aware of the importance of GIS competence among the staff members.

The City of Malmö is working to improve the so called Malmö City Atlas, where the goal is that employees should have their own GIS layer. In the future, the atlas will be linked to the Swedish Species Information Centre to show reported species occurrences (interview 1).

4.2.4. Data storage tools not adapted to users’ needs

A problem identified is that ArcGIS costs 30,000-50,000 SEK (3,500-6,000 USD) for a licence plus some 1000 SEK for maintenance per year. This system is not perceived to be adapted to municipal needs. There is a sort of oligopoly of ArcGIS in Sweden where three
companies deliver services and municipalities are bound to the structure they choose to buy from the start (3).

Another problem related to tools is that persons working in the field of maintaining stormwater systems lack access or the routine to add new data when they find that existing data is wrong or missing (1,2).

In interview 2 several wishes for tool developments were expressed. It was for example mentioned that it would be great with a system where different rainfall scenarios could be tested in real time. Today it takes two weeks to run a model for a scenario and a consultant is needed to make the simulations. In the detailed planning stage, it would be valuable to be able to assess how much water an area undergoing planning receives and how much it drains to other areas (2). It is however difficult to develop tools that are able handle all needs (3). An initial step is to provide open access data (3). A dream would be to have lists of open data including meta data, with different security levels depending on the type of data (3)

4.2.5. Organisation of data storage

In interview 2 it was mentioned that there are too many different plans and programs to relate to when developing GI and NBS. The fact that these plans are often only available in different PDF documents makes it difficult to handle and compile the information during the planning process (2).

The GIS infrastructure is organised very differently in different municipalities. In interview 3 it was argued that in Malmö, there is one staff member responsible for GIS at each department, but the departments do not work together. In another municipality, Helsingborg, there is instead one GIS unit serving the other departments. Moreover, GIS competence is often sorted under the City survey department situated under the planning unit. However, the budget work is done far from this unit and data collection and data infrastructure may therefore become of low priority. Information Technology issues are on the other hand often organised under the leading functions of a municipality and therefore higher prioritised. As data availability is of strategic importance, data storage infrastructure and collection strategies should be organised from a more strategic position to increase its status and priority (3).

It was further argued that the only solution to the lack of GIS data is to sit together in the municipality and focus on getting the existing data into a system. It is a one-time-only job, but it is very important to do it in a proper way. Lack of progress is in several municipalities probably due to a combination of lack of knowledge and economic resources (3).

To create a structure for data flow, it is important to handle the three pillars of information handling: storage of data, analysis and visualisation, and data maintenance. These three pillars can use different software but they should preferably be based on open source code (3).

Data follow different standards which has lately been harmonised in Sweden. Most municipalities follow SWEREF as geographic coordinate system. Before the standardisation it was more confusing and e.g. Malmö sometimes still uses a different coordinate system (3).

Several ongoing initiatives to improve data organisation to ensure that it is more available, for example are SKL and Vinnova currently cooperating to make planning more digital. More and more data become open, for example the data from the cadastral and land registration authority is now open access for municipalities (3). Another example mentioned was the current cooperation around “ekogeokalkyl”, led by the Swedish Geotechnical Institute, which will include green space and ecosystem services in urban spaces. This tool will be open for anyone that work in ArcGIS/ArcScene and (2).
4.2.6 Strategic data use

An issue regarding strategic use of data that was brought up in two of the interviews is that there is too much information. This leads to a risk to “get lost in the data”. Both in interview 1 and 2 it was argued that there is a need of more data, but not too much data. There is also a need to know which data to focus on. In the neighbourhood Söderkulla in Malmö in total 14 models have been run to simulate the effects of downpours. A multitude of simulations make the information difficult to handle (2).

Another issue brought forward is that politicians want to be good at everything and consider everything. As a municipal staff member you have to be clear about what you have prioritised and know that not everything can be prioritised (2).

In interview 1 it was argued that strategic data is available in the Malmö City Atlas, databases about areas of national interest and the Swedish Species Information Centre. This data can be used to prioritise what to protect and what action to take, and it is possible to be strategic if you are prepared early on in the planning process. The interviewee gave an example of a park and a dam in two newly developed areas where this information had been used (1).

4.3. Proposed framework

Through the three steps we have identified issues relevant for a strategic use of data to aid the development of NBS. It includes now eight main issues (Figure 1). Three boxes lie outside the main flow in the figure: citizen’s needs, the fact that values change over time and scientific evaluations and support. Appropriate data to develop new NBS, or maintain current ones, is essential to ensure a strategic development to benefit both people and nature (biodiversity) itself. Hence the step evaluation and data collection, is essential and can be seen as both the starting and end point of the framework. It is here essential that the evaluation and data collection step includes links to broader municipal goals to ensure a relevant collection of data. It is also essential to keep track of time related changes in data needs. A structured and continued evaluation of implemented structures is essential to assess their success. However, if the collected data is not stored in a proper way, access to it may in reality be limited. Moreover, as urban areas change quickly, data maintenance is essential to ensure its relevance and quality. This step has to include both data maintenance in a more technical meaning as well as information on how collected data has been collected.

As the main purpose of the data discussed here is to be used in further analysis, there is a need for both tools and structures for proper use once data is collected. If different types of models are used it may be important to save and store analyses of different scenarios in a structured way. The collected data and performed analysis thereafter has to serve as a basis for planning which need some type of visualisation of the data at a scale that is useful for spatial planning but also form smaller project.
5. Discussion

In recent years a set of semi-scientific/semi-policy concepts have entered the field of spatial planning and management and development of green space. In this paper we have discussed GI, NBS and SUDS. These concepts focus on different issues, mainly related to their uptake and use in different scientific disciplines and sectors. The GI concept is frequently related to larger scale green structures whereas NBS mainly focuses on smaller and more separate blue green elements. SUDS on the other hand has a stronger focus on urban storm water management and is scale wise situated between the other two concepts. Depending on which concept that is in focus in the particular planning situation, different sets of data will be needed. All concepts incorporate ambitions which to be fulfilled require work beyond administrative and disciplinary ‘silos’, including a more systematic involvement of relevant stakeholders, including citizens. Based on this understanding this article has aimed to better understand the information gaps and develop a framework that can support adequate planning of blue-green infrastructure.

The interviews indicate that to ensure work beyond administrative (disciplinary) silos especially five were brought forward. Three of the issues brought up were new and was used to improve the drawn-up framework form the brainstorming set; data storage technology, data maintenance and visualization of analysis and data. In the following sections, we will discuss these issues in relation to relevant scientific literature and suggest how the framework could be used in the future strategic work to implement long term sustainable NBS in urban areas.

One of the major obstacles related to a strategic development of NBS in urban areas turned out to be lack of data related to the quality of green areas and the marine environment, patchiness of existing data and the continuous change of the urban matrix. If aiming for the development of multifunctional green infrastructure and nature-based solutions this is a challenge that has to be tackled. The collection of people’s perception of green space nor data related to human wellbeing was mentioned in the interviews neither the economic benefits of a solution or the cost of development and maintenance. This may reflect the selected interviewees but of relating to the identified list of data in step 1 this data does not exist on a more national level. Similar results have been identified in an article, mapping research priorities for green and public urban space in the UK (Bell 2007) where health and well-being
were identified as areas with weak support and where research had been undertaken on physical aspects, and on biodiversity. In relation to lack of data it was also mentioned that there was an unsystematic use of data and a similar observation was made by Eliasson (2000) in relation to the use of knowledge about climate in urban planning especially when conflicting interest appears in the end of the planning process.

In the interviews, it was also argued that different actors produce and have access to different sets of data. Lack of access was both related to security (sensitive societal activities such as electricity and transport infrastructure and hospitals) and privacy issues (i.e. information collected by insurance companies on events in specific households). The ethical aspects of data access, is increasingly brought forward in the literature (see for example Yeh 2005; Newman 2010; Schweitzer 2017) raising questions concerning access and not access between municipal departments, municipality and private actors as well as between these actors and citizens. One major concern is that the increased use of informatics may increase the gaps in power and political voice between experts and non-experts (Viitanen, 2014; Grindrod 2016). With the development of smart green cities where information systems are out-sourced ethical assessments and consideration of consequences of data collecting systems will consequently grow in important and it will probably therefore be essential for municipalities to consider how to store model results as well as scenario structures in a transparent way as an increasingly amount of especially water related data to support urban planning is produced by models frequently run external consultancy firms. For public decision-makers especially in small municipalities with only a few employees it may be difficult to keep up with the development of a specific model and to interpret what the produced data actually mean and at what scale it mean something. And at a more general level it may even be difficult to discern what type of model or consultancy advice that is procured for, which can be illustrated by a review a of decision support tools for informed decisions on urban water management made by Lerer et al. made in 2015. The reviewed tools were categorized in three groups, i.e. "How Much"-tools, "Where"-tools, and "Which"-tools. None of the reviewed tools addresses all aspects of water and they are influenced by the local context of where they were developed.

Another challenge brought forward in the interviews was the lack of knowledge related to or shortage of human resources knowledgeable in GIS. This lack is related to knowledge about other sectors and disciplines problems and perspectives as well as how to use and organize data storage and data management. The difficulty for different disciplines to understand and the negative consequences related to practical and scientific development is not a new discussion (Brogren 1998). When it comes to the use and organization of data storage and data management, Yeh (2005) has concluded that the main constraints concerning the use of GIS in urban planning are not technical, but linked to the availability of data, staffing and need of organizational change, which confirm the findings in this paper. One example of the lack of knowledge of perspectives and techniques used by different expert groups in the urban planning process can be illustrated by the identified mismatch between non-GIS supported data, GIS data and visualization of urban visions and designs. For architects, visualizations are an important tool to convey his or her ideas but these ideas need to be connected to plans at more general levels as well as data supporting the understanding of context specific parameters relevant for a continued provision of high quality green space and vice-verse. Consequently, some kind of translation structure is needed from data to visualizations and from visualizations to data, to ensure communication across disciplines and between actors. In this structure there is also a need to move between a larger more strategic scale and a more concrete level where a specific NBS are implemented. The interviews showed that the GIS skills is weak to support such a “translation”. Häggquist and Nilsson (2016) examined officials’ use of geological information in Swedish municipalities and found that the perceived
usefulness, educational efforts, work tasks and gender affected the rate of usage which may be something to consider when aiming to increase digitalization.

Different municipalities have chosen to organize its data storage in different ways, a fact also indicated by Hansen (2017). Some municipalities have a central unit for data storage and management whereas others have a more decentralized organization. To ensure a more holistic approach a more centralized system where data storage and management for strategic urban development purposes is part of a centrally organized municipal service such as Malmö StatsAtlas may be the way forward. But then they probably would need to be connected to for example the IT unit of the municipality. When developing such systems, it is essential to develop good and solid data categorization systems to ensure that data is found when needed as well as maintained.

Moreover, it was argued by several of the interviewees that there is too much data or that the politicians want to do everything which makes strategic use of the data difficult. This finding can be interpreted in several ways the data handling systems are not good enough or the goal of the NBS are not clear enough. The first issue has been discussed above, as for the second issue it seems therefore essential to more clearly define or decide for what or who, a NBS is developed which clearly indicate a need to include data related to green structures as an integral part of general planning documents. Several municipalities have initiated the develop of such assessment they should be used as inspiration for how to organize the work in Swedish municipalities.

This article has focused on Swedish municipalities, which due to the Swedish municipal plan monopoly, are relatively independent in their role in promoting urban development. The Swedish decentralized organization of urban development may influence the result as each municipality are free to organize their work in different ways creating different structures for promoting the development of blue green solutions. Despite the possible different situation for Swedish municipalities compared to municipalities, we believe that there are more similarities than dissimilarities due to similar challenges in urban areas and the similarities related to challenges and possibilities of the use of information systems.

The findings indicate that if a municipal ambition is to ensure a development of green infrastructure and NBS in urban areas that are both cost efficient and contributes to the general well-being of both nature and people it is essential to develop a data collection and data management system that is a pan-municipal, bridging sectors and disciplines and is able to involve citizens as a data source, especially at the super local scale thorough different types of crowd sourcing structures. The digitalization of information is developing fast on Sweden which opens the way for integrated decision platforms. Through for example the Geodata Cooperation, Swedish municipalities are able to using a more similar set of GIS data. But as noted in the interviews there is still a lack of knowledge of how to use it and there are several datasets are missing. The constructing sector is increasingly using collaborative IT systems such as BIM where expert areas are integrated into one IT structure (Dossick, 2011). Recent research has showed their ability to work as digital boundary objects (Alin 2013) but the potential of these structures is strongly interlinked with how a user perceive the organization of the form and content of the use if such a tool (Poirier 2017) which ties back to the findings in this article that organization seems to play a central role in the success of the integration of new IT technology to support decision making. Spatial planning could be supported by similar tools where experts on different aspects of planning as well as citizens could create a collaborative space and learn from each other. In Hopkins et al. (2005) has developed an initial version of a planning data model (PDM), will enable urban development decision makers to conceive of planning as involving many actors whose many plans can provide
useful and usable information. There are also other potential data sources that could be explored as a part of the development of spatial planning and mainly the inclusion of citizens such as mobile phone data (Reades et al. 2007)

The developed framework accompanied by the list of existing data set could serve as a basis for an identification of gaps in data availability, acknowledging the need of different kinds of data to ensure holistic, strategic planning of blue-green structures and features in urban areas. The dilemmas that have been brought up can be used as basis to identify the more specific challenges in municipalities to strengthen and develop a clearer structure for how the different sectoral practices and their interrelated disciplines can collaborate.

We believe that such a gap analysis could provide local politicians with more useful information concerning the value and cost of blue green solutions better as if including knowledge about various urban values at early stages of the spatial planning process, it will be easier to assess the impact of the direction of the urban development to defined environmental and sustainable development goals and unnecessary high costs later in the planning process could be avoided. This suggestion goes in line with the idea that multi-functionality should be promoted through planning objectives or an agreed set of functions or standards that need to be considered in green space planning (Ahern 2014; Haaland 2015) and where a sound knowledge of the green space potential is needed to exploit its opportunities (Lennon 2015). This could support a governance approach where data collection management and use to sustainable cities as an infrastructure comparable to other urban infrastructures such as roads, electricity net and sewage and storm water systems. In the long run this could facilitate a systematic assessment of the urban space, improved links to defined guidelines and goals for sustainable development, the provision of a variety of functions throughout the urban space, a basis for assessments of synergies trade-offs between different functions and a basis for collaboration between departments as well as with citizens as well as between municipal authorities and science.

As a step for further research we suggest that the framework is used in a set of real contexts which in addition to assessing the framework in itself and identifying more specific challenges to provide input on how to organize the data collection, management and use, one important area to further explore is the need of data at different scales, supporting the understanding of how to enhance multifunctionality at all spatial levels and indicating how this multifunctionality is distributed in space and time to help identify priorities in conserving and enhancing certain functions and ecosystem services.

References


