CHALMERS
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Consequences of flooding in urban areas

The effects on society and people

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

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Department of Civil and Environmental Engineering
Division of GeoEngineering
Engineering Geology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Surface runoff on paved road surface in Gothenburg

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ABSTRACT

For the first time in human history, more people live in cities and urban areas than in rural areas. This has brought with it a reliance on technical systems in the city. Electric power, infrastructure, water distribution and telecom are essential for people to be able to live in the urban environment.

At the same time this happens, climate change is happening at a rate that human society has not been subjected to in recorded history. This brings with it a plethora of problems. The problem this report deals with is the consequences and effects that a severe cloudburst has on a city and its inhabitants.

To identify these effects, several steps were taken. The work consists of two parts; The first part deals with the "hard" aspects, concerning the damage costs and the physical infrastructure that is recruited to keep a city running. The second part deals with the "soft" aspects, namely the effects the first part has on the inhabitants of the city.

To amalgamate these parts into a result, a *Multi Criteria Analysis*, or MCA, was performed, investigating several parameters and categories. From this MCA, *energy* and *infrastructure & transportation* are the two parameters that will have the most severe impacts in people, should they fail during a cloudburst event, with the categories *work* and *communication* being where people will be affected the most. These results are supported by an analysis of how the trend in reliance of energy and transportation changes over time.

In conclusion, the energy distribution and production system will generally not suffer damage to the physical distribution infrastructure, but rather the subsystems, such as power junctions and control systems. The failure of these subsystems causes power outages. The outages in turn creates cascades of consequences when electricity dependent systems fail.

The effects can somewhat be mitigated by having plans that are made in advance of a cloudburst event. For these plans to be of any relevance, there must also exist an organization that has used and evaluated the plans in exercises. Such an organization must also be able to access resources that are needed in the event of an extreme cloudburst event.

Översvämningar i stadsmiljö
Effekter på bebyggelse och invånare

Examensarbete inom mastersprogrammet Infrastructure and Environmental Engineering

OSCAR ELIASSON
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SAMMANFATTNING

För första gången i mänsklighetens historia bor fler människor i städer än på landsbygden. Detta har medfört ett allt ökat beroende av tekniska system för att göra det möjligt att leva och bo i städer. Elektricitet, vattenförsörjning och telekom är absoluta nödvändigheter.

Samtidigt som detta skifte sker, så sker också stora förändringar av klimatet, i ett tempo som inte observerats tidigare. Detta för med sig en uppsjö av problem. Rapporten behandlar de konsekvenser och effekter som ett extremt skyfall över Göteborg skulle få för både staden och stadens invånare.

För att undersöka dessa effekter och konsekvenser gjordes ett antal undersökningar. Dessa ingår i två huvudsakliga delar. En ”hård” del som behandlar de rent ekonomiska och fysiska skadorna som kan uppstå i samband med ett extremt regnväder, samt en ”mjuk” del som behandlar effekter och konsekvenser som drabbar befolkningen, till följd av de effekter och konsekvenser som behandlas i första delen.

Dessa två delar sätts samman till ett resultat genom en MKA, innehållandes ett antal parametrar och kategorier. Resultatet från denna analys visar att det är *energi* samt *transporter och infrastruktur* som drabbas hårdast avseende fysiska skador på tekniska system. MKA visar också att följderna från dessa främst drabbar *arbete* och *kommunikation*. Resultatet förstärks också av en analys rörande förändringstrenden avseende beroendet av energianvändning och transport.

Sammantaget så klarar sig den fysiska infrastrukturen avseende energidistributionen relativt bra. Problemet uppstår när subsystemen inom denna kedja skadas av vattenmassor, vilket leder till omfattande strömavbrott. Strömavbrotten får följdeffekter på invånarna i det drabbade området.

Transportsystemen kommer i större utsträckning drabbas av skador på den fysiska infrastrukturen ovan jord jämfört med den nergrävda infrastrukturen, såsom el och vattenledningar. Därtill kommer transportsystemet också drabbas

av följdeffekter från exempelvis strömavbrott. Strömavbrott slår bland annat ut system för exempelvis trafikledning och säkerhetssystem i tunnlar.
För att kunna mildra effekterna krävs det att det redan på förhand finns uppgjorda handlingsplaner samt att dessa har övats i en organisation som besitter adekvata resurser för att hantera en sådan situation.

Table of content

Preface

This Master's Thesis work is aimed at studying the effects and consequences an extreme rainfall would have on a city and its inhabitants.
The project was carried out at the Department of Civil and Environmental Engineering, Chalmers University of Technology, as the final element of the Masters Programme of Infrastructure and Environmental Engineering.

I would like to extend special thanks to my supervisor, Lars Rosén, for support and guidance with this report. I also want to thank my opponent, Kristina Wetterhorn, for insightful discussion and ideas.

Notations

MSB	Swedish Civil Contingencies Agency	Myndigheten för Samhällsskydd och Beredskap
GGRS	Greater Gothenburg Rescue Services	Storgöteborgs Räddningstjänst
CAB	County Administrative Board	Länsstyrelsen
MCA	Multi Criteria Analysis	Multikriterieanalys
WWTP	Waste Water Treatment plant	Reningsverk
Cloudburst	A sudden and violent downpour of large amounts of rain	Skyfall

1 Introduction

1.1 Background

Flooding in urban areas is a common problem in many parts of the world. With changes in the climate, extreme rainfall events will become more and more common. As technical development progresses, inhabitants in cities are becoming more and more reliant on technical systems working without interruption of service.

The impact of flooding on society can be clearly seen in many parts of the world. In London, the Thames Barrier protects the city of London from tidal surges in the Thames River. The Maeslantkering Barrier in The Netherlands protects the port of Rotterdam from storm surges from the North Sea. The barrier is one of the largest moving structures ever built.

When hit by an extreme rainfall, the drainage systems in an urban area are unable to handle the water volumes, since they fall well beyond the design range that the drainage systems were designed to handle. Instead, the water will start to free flow on any kind of hardened surface. Indeed, water will also free flow on surfaces that normally are considered permeable, such as green surfaces, due to saturation of the ground.

The free flowing water will enter buildings and other areas in the city, causing damages to, for example, power grid substations. These are usually located in basements, making them vulnerable to water entering from ground level. Overall, technical infrastructure usually has important nodes and subsystems installed at or below ground level.
Other systems that are at risk of being damaged by large volumes of free flowing water is the transport infrastructure, where water can undermine the embankments for roads and railroads, cause damage to the road surface, flood tunnels and geographical low points with water.

A very recent example is the rain-induced flooding in Copenhagen in 2011. Large parts of the city were put out of commission due to extreme amounts of rain during a short period of time, causing severe damage to technical systems required to keep the city functioning.
Damaged and disrupted technical systems in an urban area will have consequences for people living in these areas. The last 50 years has seen a dramatic increase in the dependence on these systems. In particularly, electricity has become an indispensable part of everyday life.

Gothenburg, like many other large cities, is vulnerable to heavy rainfall events. In order to prepare for future rainfalls and to adapt to expected climate change conditions, there is a need for identifying and evaluating the risks and challenges posed by the threat of a heavy cloudburst striking Gothenburg. In order to manage and adapt to future rainfall events it is important to earn from past experiences.

1.2 Purpose

The overall purpose of this report is to provide a comprehensive study of the disruptions that occur due to heavy rainfall and how they affect the lives of people living in cities and other urban areas. It will try to quantify as to why a severe rainfall event disrupts the operations of an urban area and how it affects its inhabitants. It will also investigate the potential connection between dependence in technical systems and the consequences that follows this dependence, when a system is disrupted.

The report focuses on the following areas;

1. The effects in economic terms from damages to buildings and technical systems.
2. The effects on the individual inhabitant in relation to the damage on technical systems.
3. The potential of preventing and controlling damage incurred to buildings, infrastructure and individuals affected.

1.3 Specific aims

The specific aims of this report are;

- To evaluate the magnitude of the consequences, its impacts on the daily life of the inhabitants and the functionality of the city as an entity.
- To identify and value impacts of flooding in economic terms.
- To investigate measures that can be employed to reduce and prevent the extent of damage caused by rainfalls.
- To investigate the change of impacts over time.
- Evaluate how changes of the urban environment is related to changes in economic impact of heavy rainfall.

1.4 Limitations and assumptions

Since no simulations are carried out, factors that could have an effect on hydrology, such as season, terrain, surfaces and specific intensities, are omitted.

1.4.1 Years covered

The report aims to cover a time span beginning in 1950/60 and ending in 2010/15. This covers a very expansive period in the growth of the city.

1.4.2 Rainfall intensity

The report assumes a rainfall with an extreme intensity, corresponding to a rain with a return period of 1500 years.

1.4.3 Damage to systems, buildings and infrastructure

In relation to the rainfall intensity-assumption, it is also assumed that the damages are total damages, meaning that the affected structure has seized to work in its intended way.

1.4.4 Geographical area of focus

The studied areas in this report are located to central Gothenburg and the northern shore of Göta Älv, on the island of Hisingen. In central Gothenburg, an area in the district of Vasastaden is studied. For the areas on the island of Hisingen, a part of the Eriksberg-Sannegården district is studied.

2 Method

2.1 Evaluation of macro-effects on society and economic consequences

Criteria for selecting study areas

In the selection of areas that are to be studied, it was determined to select two areas with different characteristics. One area should have buildings and dwellings that are relatively old, ideally from the beginning of the time period covered by this study. The other area should have buildings that are much more recent, but built in an area that previously not had been intended for dwellings and housing.

Maps

Vital to the selection process was the use of maps. By comparing maps from different years, stretching approximately from 1900 to 2015, several areas of interest were located. Being from different years, the map comparison gives a view of how the city has expanded, how areas have been exploited and how the infrastructural systems has increased in area covered.

Maps were compared by editing them in Photoshop CC. The editing process involved editing each map in a separate layer. After loading each map into a layer, the layers were aligned with each other. To fine tune the alignment, fixed points on each map were used as geographical references in moving the map layers in relation to each other.

These findings were further evaluated by using interactive maps, provided by the Swedish Land Survey Agency. These digital maps incorporate the ability to make side-by-side comparisons of aerial photographs from the 1950/60 and aerial photographs from the present day.
Areas could roughly be estimated by using online map services.

Literature and statistics

The main usage of literature in the work of selecting study areas was to get an understanding of the history of the area. Furthermore, the literature was used in order to investigate if the areas had been rebuilt or renovated in any significant extent. For detailed information of each building, statistics were acquired from Göteborg Stad.

2.1.1.1 Geodata and computer software

An important tool in the process of this work has been GIS software. By using shape-files with information of the studied areas, much information could be extracted. Mainly, ArcMap 10 and ArcCatalouge 10 were used.
Once extracted, the data was imported into Excel for further analysis.
Some of the maps has also been edited and managed with Adobe Photoshop CC and Adobe Lightroom CC. The data used to analyse the underground infrastructure was edited and worked with in Autodesk AutoCAD and Autodesk Civil 3D. Statistical data has been analysed with Microsoft Excel and Matlab.

2.1.1.2 Economic evaluation

To evaluate economic consequences, standardised damage cost values, based on insurance data, were used. By making selections in the GIS software based on the type of buildings, and using the standardised value for the particular kind of building, a total cost of damage could be calculated. This was also done when determining costs for damage to infrastructure and technical systems.

2.2 Evaluation of effects on individual inhabitants

2.2.1 Literature review

In the literature used, a total of 8 events are included. The two most important events are the rainfall and subsequent flooding on Orust in 2002 and the cloudburst that hit Copenhagen in 2011. Other events that were studied are;

- Heavy rainfall in Örebro county, 5 – 9 September 2015.
- Heavy rainfall in Halland county, 17-19 August 2014.
- Heavy rainfall in Västra Götaland county, 19 – 22 August 2014.
- Cloudburst in Malmö, 31 August 2014.
- Cloudburst in Hammerö, 11 June 2009.
- Cloudburst in Hagfors, 4 August 2004.

Two cases that are to be studied closer are the flood events in Copenhagen in 2011 and on Orust in 2002. These are selected for closer study due to the immense impact the rain had, both in economic terms and in terms of discomfort for the inhabitants in the affected areas.
The aim of the literature review is to build up an understanding of how floods affect individuals and the consequences on their daily lives.

2.2.2 Multi Criteria Analysis, MCA

In order to evaluate the effect failure of critical technical systems has on an individual city inhabitant, a *Multi Criteria Analysis,* or *MCA,* was done.
A MCA is a method for systematically assessing and supporting decision making, based on an array of different factors and parameters (Department for Communities and Local Government, 2009). This approach is suitable when several factors and parameters must be used, since decisions made on a single factor or parameter will lack the necessary coverage of the problem at hand.

In generalized terms, a MCA awards different scores to different options or categories, in relation how well the options fulfil certain demands or parameters, specified by the users of the MCA. This is called a *performance matrix*. This matrix can look as exemplified in Table 1 (Department for Communities and Local Government, 2009).

Table 1 Example of a Performance Matrix, with three options/categories (A – C) and four parameters (A – D)

Categories	Parameter A	Parameter B	Parameter C	Parameter D	SUM
A	2	1	2	7	12
B	3	6	5	3	17
C	4	5	4	6	19
SUM	9	12	11	16	

The score awarded in each field is in turn the result of studying each parameter and category. These studies can include a wide range of methods, such as literature reviews, models or observations.

Commonly, the option with the highest score is considered the most appropriative option to choose. The score can also be reversed, with the lowest scoring option being deemed the most appropriate. It is also possible to determine what parameter is most important by summing up the scores in the columns.

Furthermore, parameters can also be weighted, to account for possible differences in impact on a final decision a parameter has. For example, an economical parameter is likely to have a greater impact on a decision than an aesthetical parameter. Thus, the score of the economic parameter is multiplied with the weight of that parameter.

2.2.2.1 Multi Criteria Analysis, MCA, of consequences of floodings caused by rainfall in Gothenburg

There has been other works that use MCA as a tool for analysis of rainfall and effects of rainfall in Gothenburg. One of these is a master's thesis work, written by Natalie Bergqvist in 2014[1]. Both this report and the report written by Natalie Bergqvist uses the same basic MCA method, the *linear additive method* (Department for Communities and Local Government, 2009). The linear additive method is a simpler method for adding together weighted scores of parameters and categories in a performance matrix. Ideally, the parameters can be separated from each other and not necessarily depending on each other either. (Department for Communities and Local Government, 2009)

[1] Environmental assessment and sustainable stormwater planning with regard to climate change through multi-criteria analysis (MCA) – Case study Guldheden by Nathalie Bergqvist. 2014. Master's Thesis 2014:156

In this report, the MCA evaluates four *categories* with respect to four *parameters*. The categories are; *Comfort*, *Work*, *Mobility* and *Communication*.
The parameters under which these are evaluated are; *Energy*, *Water*, *Infrastructure & Transportation* and *Telecom*.

The impact each parameter has on a category is rated 1 – 5, where 1 is least amount of impact and 5 is the greatest (worst) amount of impact.
With this, a minimum score of 4 and a maximum score of 20 is possible for each parameter. Scores are assigned based on the impact a total system failure for any of these systems these would have. The parameter with the highest total score is deemed to be the most critical for inhabitants of the city. This is also true for the categories.

The ***parameters*** are defined as;

Energy**:** This parameter involves electrical power and district heating.

Water**:** The water-parameter includes production and distribution of drinking water. It also includes the draining, removal and treatment of wastewater.

Infrastructure & Transportation**:** This parameter is in regards to infrastructure required for the movements of goods and people. This involves roads, tramlines and railroads. To some degree, it also involves bicycle and pedestrian-paths.

Telecom: The telecom parameter covers the means by which communication is done. Generally, this is in regard of electronic communications. Internet, IP-telephone, cellular telephony and radio are examples of components in this parameter.

The ***categories*** are defined as;

Comfort**:** Living in a current day society. The high standard of living in current day society is the result of development and operation of a multitude of conveniences, such as electricity, drinking water, safety and heating. Disruptions in any of these systems impacts the comfort level significantly.

Work**:** Workplaces require several systems to function. The production of goods and services are important sources of income for both the individual and the society. The ability of a workplace to function requires several technical systems to operate without interruption

Mobility**:** A current day society requires the ability of its inhabitants to move around. The reasons for this are several. Inhabitants need to travel to and from work, leisure and a multitude of other reasons.

Communication**:** Essential for the function of current day living is the ability to communicate with others. This can be other people, businesses, authorities and other entities that are present in a current day society.

The points are not weighted, since the impact of each parameter is evaluated separately, not taking into account the effect a particular parameter might have on the functionality of other parameters. The same is true for the categories. The potential impact of one category on another one is not taken into account. This is in line with the basis of the linear additive method.

Thus, the performance matrix for the report will look as follows;

Table 2 Performance matrix for evaluating consequences

Parameter / Category	Energy	Water	Infrastructure and transportation	Telecom	***Sum***
Comfort					
Work					
Mobility					
Communication					
Sum					

2.2.3 Statistics

Statistics were acquired from several sources. The primary sources have been Statistics Sweden and Göteborg Stad own statistic service.
To evaluate the impact over time of damages caused by extreme rainfall, a number of indicator factors are chosen. These factors are chosen based on results from the literature review. The indicator factors are;

- Population.
- Population growth.
- Usage of electric power.
- Internet usage.
- Car usage.
- Length of road network.
- Commuting.

By plotting these indicator values in relation to years in a series of line diagrams, trends in the development can be observed and analysed. Thus, the effect on the standard of living can be scored in a similar way as the analysis for the effects today.

3 Water and climate

Climate change is an ongoing process that is believed to be responsible for much of the changing weather patterns. In the 2010 – 2050 timespan, a 10% increase in occurrences of extreme rainfall is believed to be likely. The trend of increase is forecasted to continue with a 25% rise in extreme rainfall during the next half of the century, 2050 – 2100 (Jonas Olsson, 2013).

3.1 Rain

Rain is a climate phenomenon where vapor in the atmosphere of a planet precipitates and falls to the surface in liquid form. Depending on atmospheric conditions, the characteristics of rain can vary greatly.

The water cycle

The water cycle is a concept for describing how water flows in a system.
In the context of flooding and pluvial flooding, it is important to distinguish between the water cycle and the *urban* water cycle. While the two are similar, there are a number of key differences.

In urban environments, there is a much larger degree of hardened surfaces, limiting permeability of the ground. Also, whereas the water in the water cycle ends up in the ocean by itself, the water in the urban water cycle is usually first passed through different steps of treatment before it is released back into the sea. Urban surface runoff is also likely to be heavily polluted by particles and heavy metals that are generated in an urban environment by. These sources, being of a non-point type, are typically generated by motor vehicles, buildings, road top layers and spillages. (EPA, 2015)

Cloud formation

Clouds are formed when water on the earth surface evaporates and moves vertically into the air as water vapor. As the vapor rises, it is cooled and condensates into small droplets. These droplets range in size from 0.01 to 0.1 mm (SMHI, 2015) . If the vertical movement continues, the droplets are frozen and forms ice crystals (SMHI, 2014). The vertical movement of water vapor and cloud generation can be the result of several mechanisms. The three most common mechanisms are;

- *Orographic uplift*
- *Convection*
- *Frontal lifting*

- *Orographic uplift:* Warm, humid, air is forced upwards in the atmosphere by geological features, such as mountain ranges. (SMHI, 2014) The vapor will precipitate as rain or snow, depending on air temperature, when the air reaches its saturation point and precipitates as droplets.

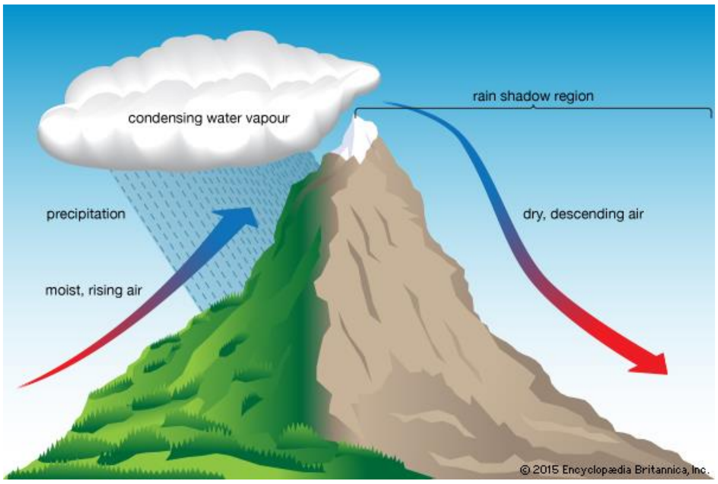

Figure 1 Orographic lift (Encyclopædia Britannica, 2014)

- *Convection:* Air is moved vertically when the earth surface is warmed by the sun. Clouds formed by convection are generally more local than other types of clouds, and as such, the precipitation is also more locally distributed. Thunderstorms usually are commonly originating from this type of cloud forming mechanism. (SMHI, 2014)

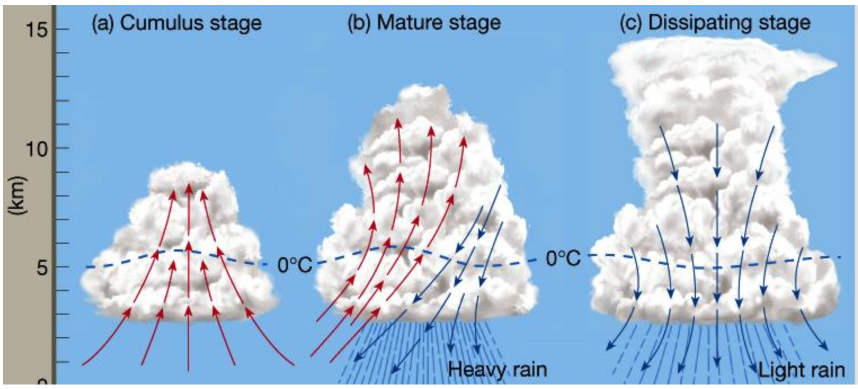

Figure 2 Convective lift (Stirling, 2015)

- *Frontal lifting:* Air is moved vertically when two air masses collides, forming *fronts*. With air masses having different temperatures, the collision results in one of two different types of fronts (SMHI, 2014). This is shown in Figure 3 and in Figure 4.

  A *warm front* is formed when warm air moves up on top of a colder mass of air. When this occur, the result is usually relatively long lasting rain. The opposite, a *cold front*, forms when a cold mass of air moves in under a warm mass of air due to the cold air being heavier than the warm air. Cold fronts are often the cause of storms and bad weather (SMHI, 2014).

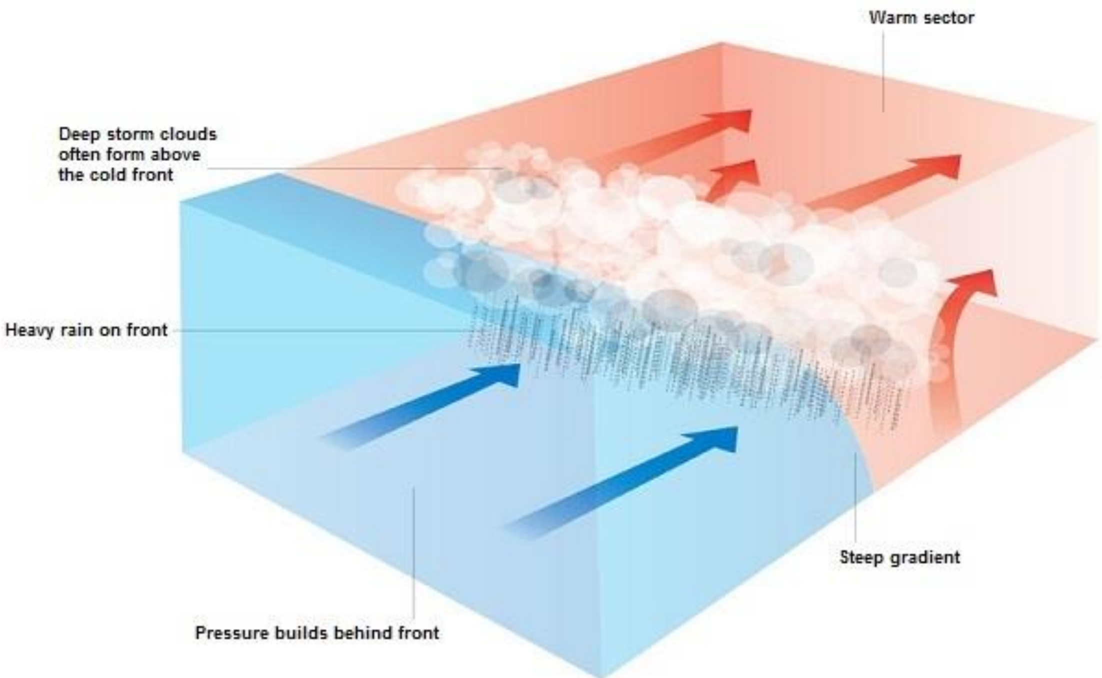

Figure 3 Cold front (Met Office, 2013)

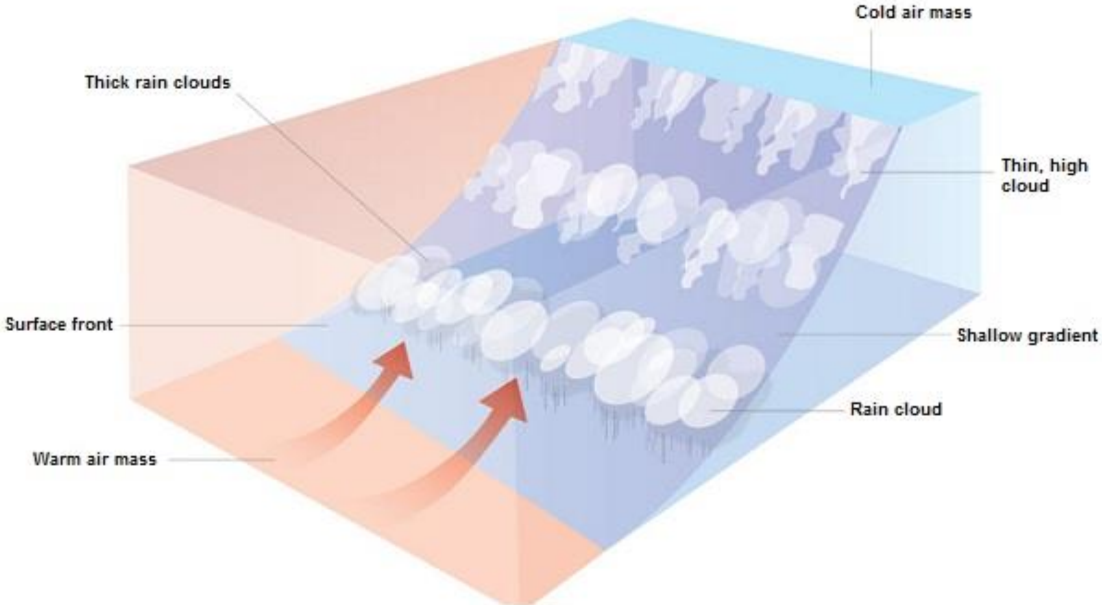

Figure 4 Warm front (Met Office, 2013)

Rain formation

Rain is precipitation from clouds in liquid form. The precipitation can also, under certain circumstances, also be solid in the form of snow or hail. Rain droplets are magnitudes larger than cloud droplets. A rain droplet will vary in size in a range from 0.1 to 5 mm. A drizzle-sized droplet is usually around 0,2 mm in diameter, while a representative raindrop can have a diameter as large as 2 mm (SMHI, 2015).

Rain is primarily generated from two different types of clouds;

Nimbostratus are clouds that forms in conjunction with front systems. Because of this, this cloud can cover large geographical areas. These clouds can form independently of the season. Because of this, they are often responsible for both rain and snow, depending on the season (SMHI, 2013).

Cumulonimbus are clouds that forms from convective lifting. Because of this formation mechanism, the Cumulonimbus cloud is more limited in its spatial extension. It is also this mechanism that causes this type of cloud to generate cloudbursts (SMHI, 2013).

Rain characteristics

Statistically, rain can be described with a duration-intensity function. The principle is that the more intense the rain is, the shorter its duration will be (Dahlström, 2006).
This is modelled as a so-called "block rain". A block rain is a theoretical rain that has an instantaneous start and an instantaneous end, with a uniform intensity between these (Jonsson, 2011). This is shown in Figure 5 Figure 5 Block rain diagram .

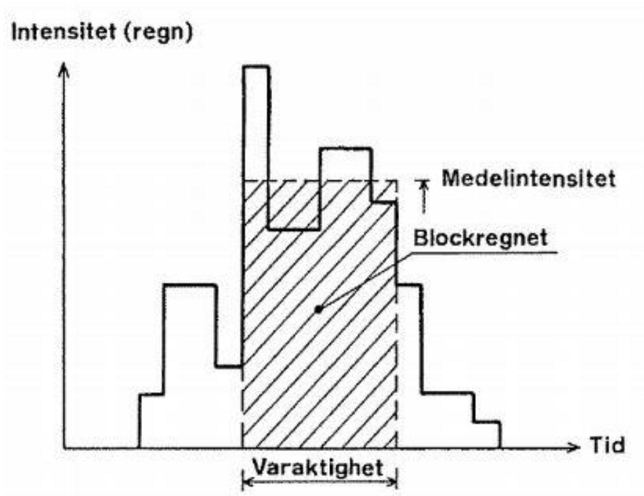

Figure 5 Block rain diagram (Jonsson, 2011)

Rain measurement

Measuring rain is done by collecting precipitation in measurement devices that are dispersed over a geographic area. The captured precipitation is measured in mm (SMHI, 2015).
To acquire accurate readings, it is vital to eliminate sources of error. The most important source of error to eliminate is wind. Rain that is moved by wind will not be captured by the measurement device. To mitigate the effects of wind, a variety of wind screens can be employed (SMHI, 2015). As a rule of thumb, the value of measured precipitation can differ up to 5% due to wind effects. (SMHI, 2015).

A problem of measuring precipitation is connected with how clouds are formed. Depending on the type of cloud, the precipitation can be spread over large areas or it can be extremely concentrated to a specific area. In the case of widespread precipitations, there is also the possibility of having a non-uniform intensity of the rainfall. (SMHI, 2015)

This is especially important when working with rain in the context of cloudbursts. Rain from cloudbursts tend to be heavily localized (MSB, 2013). Because of this, a normal dispersion of measurement devices will have difficult to capture the full dynamics of the rainfall in the affected area. A common distribution is to have 2 km between each measurement device (MSB, 2013). In the case of cloudbursts, there is indications that the precipitation from such events can vary over such small distances as 100 of meters (MSB, 2013).

3.2 Weather forecasting

In Sweden, the principal provider of weather forecasts is the Swedish Meteorological and Hydrological Institute (SMHI).
The making of a weather forecast involves three steps;

1. <u>Data gathering</u>

The first stage in any kind of forecasting is to gather the relevant data. In the case of meteorological applications, this data is in regards of current atmospherical conditions. Observational data is gathered from a large number of sensors that are spread across the country. Parameters monitored and observed are, for example, the speed and direction of the wind, air temperature, air humidity and air pressure. (SMHI, 2015) The measurement stations can be either automated or manual. Furthermore, observations are also gathered from other platforms such as weather balloons, aircraft, radar, satellites and ships.

2. <u>Data processing and analysis</u>

The basis of weather forecasting is numerical analysis of gathered atmospherical data. The atmosphere can be modelled as a fluid. This is due to the rules of fluid dynamics, which applies to both gases and liquids (SMHI, 2016). As such, models for fluid mechanics and thermodynamics can be applied when modelling the behaviour of the atmosphere and thus, the weather. Due to the huge amount of computational power required for this, the models are run on clusters of supercomputers (SMHI, 2015).

3. Data editing and refinement

Depending on the time frame covered by a forecast, errors will be present to a certain degree. The longer the time frame, the greater the errors will be. To counter this, a method called *ensemble forecasting* (SMHI, 2015) is used. The principle is that a large number of forecasts are compared during a set time frame. By having each prognosis using slightly different initial conditions. Based on the output from this comparison, analysis on the accuracy of the prognosis is made.

Depending on the time frame that a forecast is supposed to cover, more or less can be made from observations or from models. In very short time spans, it is usually more efficient to rely more on experience and knowledge of local weather patterns than models. (SMHI, 2015)
Models starts to become useful when the time frame supposed to be covered by a prognosis exceeds 12 hours. Beyond this, models are considered more useful. For extended time frames that covers up to 10 days, the previously mentioned method of *ensemble forecasting* is the predominant method of forecasting. (SMHI, 2015)

A weather forecast can also be updated in real time, so called "*nowcasting*" (MSB, 2013), using radar. With this, a potential storm system can be very closely monitored and tracked. This is extremely useful when issuing weather warnings. Depending on end-user, the forecast can also be adapted in certain ways. For example, marine traffic is likely to be more interested in detailed wind forecasts than land temperatures.

4 The urban environment and conditions

4.1 Studied areas

Three areas are studied in this report; Eriksberg, Sannegården and Vasastaden. An overview of the geographical locations of these areas is shown in Figure 6;

Figure 6 Geographical locations of studied areas[2]

Eriksberg - Sannegården

During most of the 20th century, the area was heavily industrialized, as it was the production facility of the Eriksberg Mekaniska Verkstad AB shipyard. The shipyard industry was in operation between the 1850s to the end of the 1970s. After the end of the shipbuilding industry, the area was developed into residential areas (Göteborg Stadsbyggnadskontor, Göteborgs Kulturförvaltning/Stadsmuseet, 1999).

Figure 7 View of Eriksberg. The gantry stands above the old dry dock, at its far end. [3]

[2] Map based on aerial photo retrieved from www.eniro.se

[3] Photo: The author

The next study area, Sannegårdshamnen, is located immediately to the northeast of Eriksberg. Works on the harbour was launched in 1908 and was finalized in 1914.
The harbour was mainly used for loading and unloading coal and cokes. With the diminished use of bulk cargo in favour of containerized cargo handling, operations were ultimately discontinued in 1982 (Göteborg Stadsbyggnadskontor, Göteborgs Kulturförvaltning/Stadsmuseet, 1999).

Figure 8 The former harbour area in Sannegården. [4]

For a while, the area was used as a storage location for cargo containers.
In the closing years of the 20th century, massive efforts to develop the area into a residential area, in a fashion similar to the close by area of Eriksberg, was undertaken. The area is also home to a number of commercial businesses and offices, besides residential buildings (See Table 5 and Table 6 in Appendix B).

Vasastaden

The Vasastaden district is situated just south of the Moat in central Gothenburg. Plans for the building expansion of the area was finalized in 1866, with construction starting a few years later. Construction work was finished in 1905. The buildings are typical for the age, being massive stone buildings with a courtyard encompassed by the buildings. Most of the buildings have retained their original appearance and gives a good idea of the building trends in the late 1800s and beginning of the 1900s. A distinguishing feature of the buildings themselves are the ornamented facades and artwork of the buildings (Göteborg Stadsbyggnadskontor, Göteborgs Kulturförvaltning/Stadsmuseet, 1999).

[4] Photo: The author

4.2 Technical systems of the city

For a city to function, a number of technical systems are required. These systems must be able to run continuously without service interruption and function reliably when used. Disruptions in service of these systems does not only affect the city as a whole, but also the individuals who live and work in the city.

4.2.1 Telecom

The telecom infrastructure of Gothenburg is operated by the municipal company GothNet. GothNet operates 1900 km (Göteborg Stad, 2002) of optical fiber network, supplying municipal authorities, private companies and individual citizens with telecommunications for telephone and internet access (Göteborg Stad, 2002).

4.2.2 Water (drinking and waste water)

4.2.2.1 Drinking water

Göta Älv is the main source of drinking water for Gothenburg. Water from the river is taken in at an intake facility, located at Lärjeholm. The water is also pumped up to Lake Rådasjön and Lake Lilla Delsjön. These lakes act as secondary water reserves and are used when the primary intake at Lärjeholm is closed. This is a rather common occurrence, since there are several issues with the water quality in Göta Älv (Rosén, 2016).

There are two water treatment plants that supplies the municipality of Gothenburg with drinking water, Alelyckan and Lackarebäck. Alelyckan is the main drinking water provider for the northern parts of Gothenburg, while Lackarebäck supplies the southern parts and the archipelago (Göteborg Stad, 2016). The water is distributed throughout Gothenburg via a total of 1760 km of water pipes (Göteborg Stad, 2016).

4.2.2.2 Waste water

All the water that has been used in some capacity by the inhabitants of a certain area is called wastewater (Göteborg Stad, 2016). This denotes water that has been used or produced in a multitude of applications and circumstances, such as toilets, kitchens, washing, urban storm water, water that is drained from ground surfaces in general and industrial waste, to mention a few.
In total, the waste water system is 2500 kilometres long (Göteborg Stad, 2016). The main facility for treating waste water is the Ryaverket waste water treatment plant.

4.2.2.3 Management of waste water

During normal conditions, the handling of urban storm water runoff is managed by the local sewer system. The idea is that runoff on hardened surfaces are moved into the sewer system and drained away to a water treatment plant. After treatment, the water is released back into a body of water, a *recipient*.

An urban drainage system is usually designed to handle normal amounts of rainfall. In most cases, a rain with a return-period of 10 years (MSB, 2013) is used as a design rain.

There are three common types of sewer systems (Petterson, 2012).

- *Combined system*: In this type of system, effluent water and storm water runoff is drained into one common pipe.

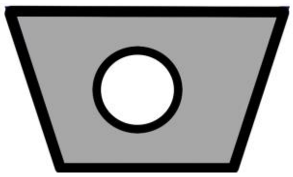

Figure 9 Combined system (Petterson, 2012)

- *Duplicate system*: The duplicate system is a more advanced variant on the combined system. Instead of draining both effluent and storm water runoff into a common pipe, the two are separated and drained into separate pipes.

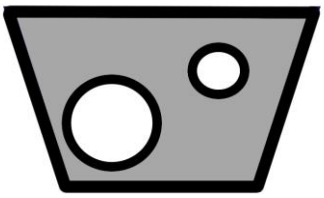

Figure 10 Duplicate system (Petterson, 2012)

- *Separate system*: Complete separation of wastewater and storm water. The wastewater is drained away in underground pipes, whereas the storm water is drained in surface ditches.

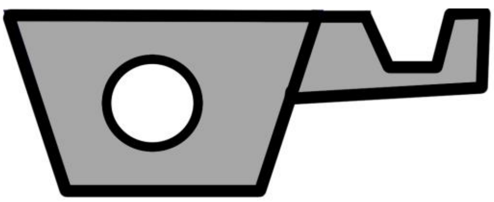

Figure 11 Separate system (Petterson, 2012)

Storm water is usually heavily polluted, since it draws with it all the particles and waste that has gathered on the ground surface. This can be a multitude of substances. For example, storm water is known to contain particles from motor vehicles, such as rubber particles from tires and oil spillages. It can also contain heavy metals from roofs and downpipes. Furthermore, it can also contain pathogens and other microorganisms.

To reduce the load on the urban drainage systems, there are several techniques used to reduce the flow rates of surface runoff. A common approach is to use green areas and permeable surfaces to slow down and infiltrate the surface runoff into the ground.

4.2.3 Infrastructure and transportation

The infrastructural network in the city of Gothenburg is mainly comprised of paved roads and tram lines. There is also a small presence of railroads, running to Gothenburg Central Station and Gothenburg Harbour.
The road network is owned and operated by two entities; the Swedish Transport Administration and the municipality of Gothenburg (Göteborg Stad, 2016).
In Gothenburg, all the major roads are owned by the state and operated by the Swedish Transport Administration (Trafikverket, 2016). These include three E-roads (E6/45/20). The state owned roads covers of approximately 150 km.[5] The layout of the network is displayed in Figure 12, with state owned roads in blue and municipality owned in red.

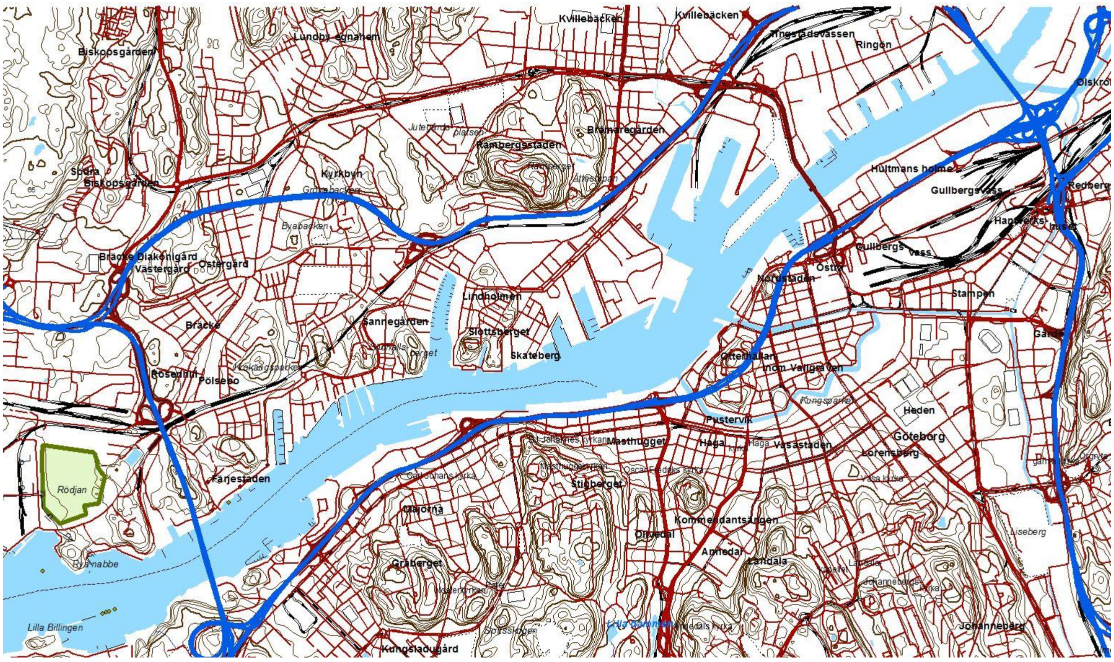

Figure 12 Road network in Gothenburg. Blue are state owned. The municipal road network consists of "all the other roads" that are not owned by the state.

Apart from the roads, the municipal infrastructure also includes paths for pedestrians and cyclists. These cover 530 km and 980 km, respectively [6]. The tram system is 161 km long (Göteborgs Stad, 2013).

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[5] Data extracted from Fastighetskartan, by Lantmäteriverket. Retrieved from maps.slu.se 2016-03-04

[6] Email correspondence with Trafikkontoret, Göteborg Stad. 2016-05-09

In Figure 13, the numbers of vehicles using the infrastructural systems are shown.

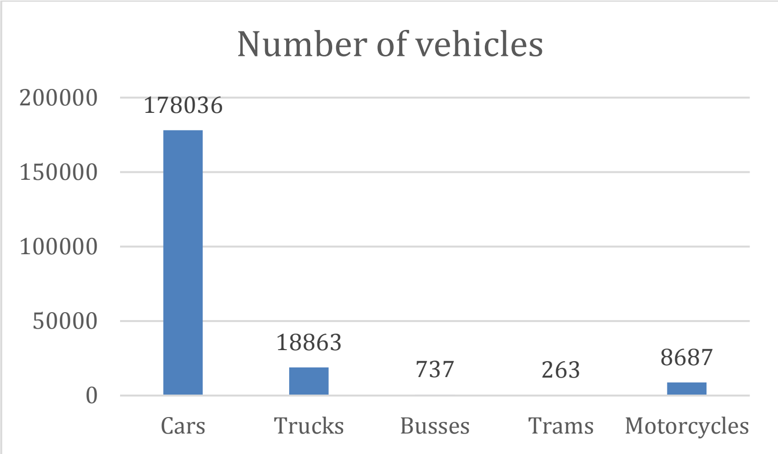

Figure 13 Numbers of road and rail vehicles in Gothenburg (Göteborg Stad, 2015; Göteborg Stad, 2013)

4.2.4 Energy

A key component in the functionality of any city is the ability to provide energy, electrical power and heating, to its inhabitants. Without these, it would not be possible to live and work in a city, since every other system in some extent is depending on electrical power to remain safe and operational.

4.2.4.1 Electric power

The most important system in any city is the electric power grid. As stated previously, this is the one key system that makes the operation of all other systems possible. The power grid encompasses approximately 6500 km of infrastructure (Göteborg Energi, 2016) and is mostly running in underground cables and utility tunnels. The majority of the power used by the city is produced by hydroelectric dams or nuclear power stations, while a minor portion is made up of wind, solar and district heating facilities (Göteborg Energi, 2016). The distribution between these are displayed in Figure 14 (Göteborg Energi, 2016).

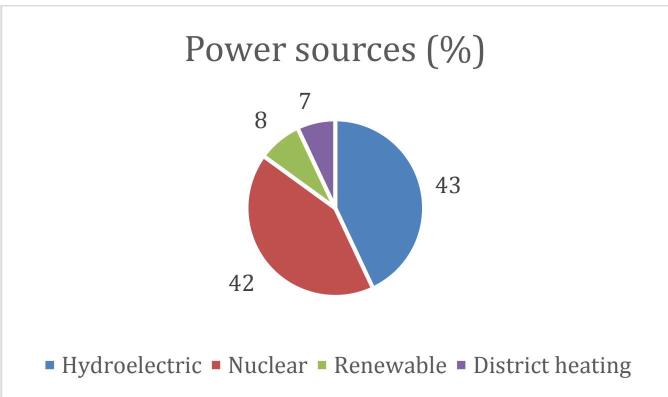

Figure 14 Distribution of power by type and percentage (Göteborg Energi, 2016)

4.2.4.2 District heating

In Gothenburg, a common way of heating and cooling buildings and dwelling is the use of district heating. District heating uses single sources to heat up water (Göteborg Energi, 2016), which is then pumped through an underground network of pipelines to the users. In total, the pipe network covers 1200 kilometers, supplying a vast majority of all apartment buildings with heating. (Göteborg Energi, 2016) Furthermore, a multitude (apart from apartment buildings) of other buildings are also supplied with heating by this system. (Göteborg Energi, 2016).

The working principle of the district heating system is shown in Figure 15**.**

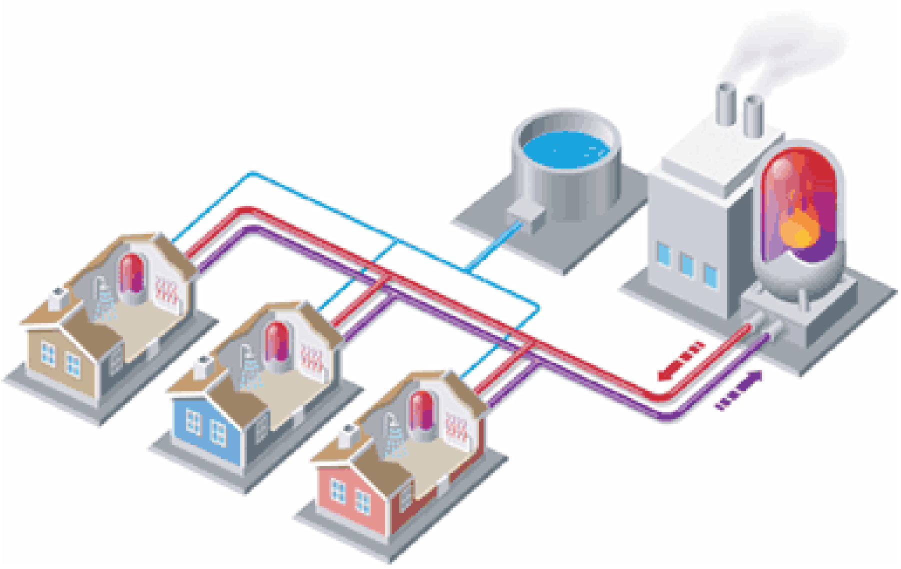

Figure 15 Working principle of district heating (Göteborg Energi, 2016)

5 Damage and damage prevention

5.1 Crisis management in Sweden

Crisis management in Sweden is organized in different levels, where the crisis is intended to be handled at as a low level as possible. It is also built on cooperation and coordination.

5.1.1 The problem posed by heavy rainfall and cloudbursts

Heavy and sudden rainfall, generating large volumes of surface runoff causes problems since the waste water system is not designed to handle such large volume in a short period. Normally, the runoff system is to handle a rain with a return period of 10 years (MSB, 2013). Furthermore, the magazine capacity of the ground in an urban environment is very limited, due to the large presence of impervious surfaces.

Without the ability either to drain the water away in pipes and sewers, or to infiltrate it into the ground, the surface runoff will reach unsustainable volumes, causing, potentially, massive damage to key technical systems in the cities.

5.1.2 Differences between normal rain and cloudburst

A cloudburst is more dangerous than “normal” rainfall due to its intensity and suddenness. Normally, the system for draining away storm water will be able to cope with the added runoff. However, when the runoff reaches a certain volume per unit of time, the drainage system will be filled to its maximum capacity, and no longer able to cope with the extra water (MSB, 2013). A similar phenomenon occurs in the ground, where it becomes saturated with water.

This characteristic is different from that of a normal, non-extreme, rainfall. In that case, the drainage system can cope with the runoff continuously for a long time. The ground also has more time to magazine the runoff, prolonging the time it takes for it to reach its saturation point.

Another difference is that rescue services has more time to react when the duration is longer, but the intensity is lower. In the case of a cloudburst, the time to react is generally very limited.

5.1.3 The individual citizen

The individual citizen is responsible for his or her own safety. It is recommended that every inhabitant in the city has a small storage of supplies to be able to survive for at least 72 hours in the case of an emergency (Göteborgs Stad, 2014).

5.1.4 The municipality of Gothenburg

In the event of an emergency, such as a natural disaster, it is the municipality affected by the event that has the main responsibility to handle the situation. Furthermore, it is also intended that the municipal functions should continue to operate as closely to normal operations as possible during a crisis. This includes responsibilities of municipal officials and locations from where municipal operations are directed (MSB, 2014).

5.1.5 The Västra Götaland Region

A middle ground between the municipal and the state level of crisis management is the regional level. If a limited number of municipalities are affected within the region, the County Administrative Board (CAB) can assist in coordinating efforts between municipalities, national authorities, county council and other entities that are involved in relief efforts (Länsstyrelsen Västra Götalands Län, u.d.).

The CAB can also, after a government decision, make decisions where to prioritize efforts and resources in the case of a crisis where resources are not enough. The CAB has a so called "geographic area of responsibility", meaning that it is responsible for coordination and collaboration between crisis management entities within this area (Länsstyrelsen Västra Götalands Län, u.d.).

5.1.6 The national authorities

On the national level, the Swedish Civil Contingencies Agency (Myndigheten för Samhällsskydd och Beredskap, MSB) is the principal authority in regards to crisis management (MSB, 2014). MSB can support the municipal crisis management in the events of a crisis that is too extensive for the individual municipality to manage (MSB, 2014).

Other authorities that can be involved in a crisis are, for example, elements of the Armed Forces and Police authority. In most cases, their assistance is primarily personnel to guard and monitor closed of roads of houses, map and assess damage extent from the air, provide additional equipment such as pumps and help in providing temporary housing to people who have been evacuated from their homes. This is regulated under the Administrative Proceedings Act, "*each authority shall render assistance to other authorities within the framework of its own operations*" (6§ Administrative Proceedings Act 1986:223) (MSB, 2011).

5.2 Fighting the flood?

Fighting a flood is an ardours task. Typically, the extent of the event causes damages and need for help on a scale that easily can overwhelm rescue services. To make this task possible, the work is segmented into several levels, from the individual inhabitants, up to national level.

5.2.1 Individual preparedness

An individual has a very limited set of options when a cloudburst is in effect. Prudent measures that can be taken is, for example;

- Having prepared to seal windows that lead to the basement with protective coverings, to prevent water intrusion from ground level.
- Remove valuable objects and items from the floor level and store them as high up as possible, to prevent damage to them in the case of water intrusion.
- Since there is a high risk of power failure in the event of a cloudburst event, individual inhabitants should have a plan on how to survive without basic services for up to 72 hours (Göteborgs Stad, 2014).

5.2.2 The municipal response; Greater Gothenburg Rescue Service

The municipality is the cornerstone of crisis management in Sweden. As stated previously, the municipality that is affected by a crisis also has the main responsibility for dealing with the crisis. It is obvious that no single municipality has the resources or capabilities for dealing with a Copenhagen-level event. The Greater Gothenburg Rescue Service (GGRS) is an association of six municipal rescue services. The involved municipalities are Göteborg, Mölndal, Härryda, Partille, Kungsbacka and Lerum (Räddningstjänsten Storgöteborg, 2015).

During the cloudburst event in itself, the GGRS will not be able to do much, aside from emergency work when there is an immediate danger to life.
Rather, the work starts when the rain subsides. (Gerring, 2016) The rescue efforts are concentrated according to priority. Saving and protecting vital installations and facilities, such as power grid nodes, hospitals, retirement homes and infrastructure are likely to have a high priority.

Property owners will most likely not be able to receive assistance within the first hours after the rain event. Depending on the amount of emergency calls received, it may take up to 10-12 hours before the GGRS has been able to visit and inspect all affected addresses. (Gerring, 2016) It should also be noted that far from all affected would be getting assistance to pump water out of basements or other actions. In the event of a Copenhagen-level event, the demand for pumps will be extremely high. Due to this, the pumps that are available must be deployed carefully to achieve optimal effect. In this regard, vital services will always have precedence.

A key factor in managing the aftermath of a cloudburst is cooperation and coordination. Two factors are to be accounted for in this;

Firstly, a cloudburst is generally not very extensive in the area covered and not likely to affect more than one municipality (MSB, 2013).

Secondly, because of the first factor, the rescue services in the unaffected municipalities can provide additional equipment and personnel during the clearing up of the aftermath (Räddningstjänsten Storgöteborg, 2015). The amount of effort that would go into that work is largely dependent on how severe the flooding was. The primary efforts would be to inspect critical infrastructure and facilities. For example, it would be important to establish the status of the waste water system, power grid and facilities, such as retirement homes and hospitals (Gerring, 2016).

In the event of a Copenhagen-level cloudburst, this will become even more important, since the available resources would be inadequate and assistance from other, unaffected, municipalities would be required. Relief efforts can be sped up significantly if comprehensive planning has been drawn up beforehand, outlining responsibilities and resource distribution. Furthermore, training exercises are a valuable component to test if the plans would hold up in a real situation.

5.2.3 Coordination between municipalities and the state

In the case of a Copenhagen-level event in Gothenburg, the GGRS in the Göteborg municipality would not be able to cope with the scope of the crisis. Assistance would have to be brought in from the other five municipal rescue services. Additionally, there is the County Board for Västra Götaland. The County Board works as the long arm of the government in the counties and can assist with coordination between municipalities and between the municipalities and the national authorities. Thus, the rescue services can focus on their work, while other entities manage coordination of relief efforts, communication and equipment handling.

5.3 Consequences of urban floods

Flooding in urban areas causes major damage and problems. As a result of this, it also brings with it large costs in the aftermath of a flood.
As an example, the Copenhagen flood event in 2011 caused damages at an estimated cost of 700 million Euro (€) (MSB, 2013). In a similar event in Sweden, on the island of Orust in 2002, the costs ran up to 150 million SEK (MSB, 2013).
As seen in Figure 16 the trend is a rising of costs for flood caused damages (MSB, 2013).

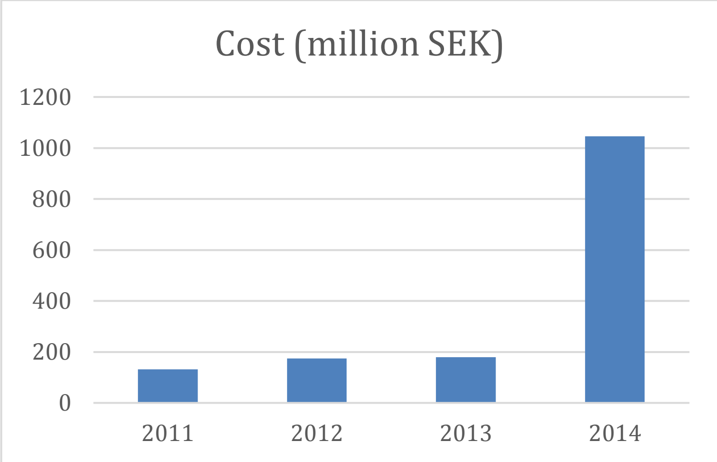

Figure 16 Increase of costs due to floods, by year 2011 – 2014 (MSB, 2013)

5.4 Past rainfall events

5.4.1 Orust 2002 and Copenhagen 2011

Two significant cloudburst events that are studied in this report are the series of heavy rain that hit Orust in 2002 and the extremely severe cloudburst that struck Copenhagen in the summer of 2011.

5.4.1.1 Orust 2002

The western parts of the island of Orust was struck by a series of massive cloudbursts between the 1st and 3rd of July in 2002. The area received over 240 mm of rainfall, with 200 mm between the 1st and 2nd of July. An additional 60 mm of rain fell on the area between the 2nd and 3rd of July (MSB, 2013).

The rain caused massive damage to power grid and roads. Also several basements were flooded, causing discomfort and problems for homeowners. 6 000 people were affected by disruptions in the power grid and 100 km of public roads were damaged and rendered unusable. This led to several people being isolated without ability to travel. This caused problems for municipal services to reach, for example, elderly people in need of assistance (MSB, 2013). It is estimated that the rainfall and the subsequent floodings caused damages in excess of 150 million SEK (MSB, 2013).

5.4.1.2 Copenhagen 2011

The cloudburst that hit Copenhagen on the 2nd of July 2011 has been called the worst weather related event in Europe during 2011 (Swiss Re, 2016). During 1.5 hours, Copenhagen received 150mm of rain, being equivalent of a rain with a return period of 1 500 years (MSB, 2013).

The cloudburst effectively brought the city to a stand-still. Electric power, infrastructure, telecom and wastewater were all severely affected by the water. Furthermore, the district heating system was also damaged, resulting in some 50 000 customers having disrupted service. 10 000 suffered power failures (Københavns Brandvæsen, 2014).

The failure of several systems critical for the functionality had widespread effects. For example: (Københavns Brandvæsen, 2014) (MSB, 2013).

- Damage to telecom infrastructure, resulting in service disruption of cell phone and landline telephone.
- A near-total stop of all train traffic in the Copenhagen area.
- Due to power failure, the continued operation of Rigshospitalet were at risk of shutting down and evacuation of patients.
- Damage to road and rail infrastructure.

5.4.2 Recent flood events in Sweden

- Heavy rainfall in Hallsberg. Örebro County. 5 – 9 September 2015 (Länsstyrelsen Örebro Län, 2016).

In the beginning of September 2015, the town of Hallsberg was struck by several days of heavy rainfall. At most, 112 mm of rain was measured.
The rainfall caused severe damage to infrastructure in the area, damaging highways and railways to such an extent that usability was severely limited och stopped entirely. Apart from damages to the infrastructure, the water caused difficulties for municipal services, such as home service and schools.

- Heavy rainfall in Halland county. 17-19 August 2014 (MSB, 2015).

Heavy rains hit several places in Halland County. The measurement station in Getinge recorded a total received rainfall of 150 mm. The damage hit power supply, roads, dwellings and municipal services. The power loss affected 700 residents and 50 houses had to be evacuated. Furthermore, the water supply was contaminated by bacteria from the wastewater system.

- Heavy rainfall in Västra Götaland county. 19 – 22 August 2014 (MSB, 2015).

A series of heavy cloudbursts struck several places in Västra Götaland county. In some places, more than a 100 mm was measured. Lidköping was worst affected by the rains. In several places, stations measured well over 100 mm of rain.
The municipality of Munkedal did also suffer floodings in the wake of the rains. Several houses were flooded. Amongst these were the city hall of Munkedal, causing a power outage that stopped several community services from working. Amongst the systems that were stopped was systems that handled reports for the home care services. Several other places were also faced with interrupted power supply services. The rain also caused disruptions in the operation of the railroad.

- Cloudbursts in Kristinehamn 20-21 August 2014 (MSB, 2015).

The city of Kristinehamn and the surrounding areas was struck by a series of heavy cloudbursts with precipitation peaking at 160 mm (MSB, 2015). Due to the intensity of the rainfalls, severe damage was suffered by several systems. The highway E18 was severely damaged with complete loss of structural integrity in several places. Similar damage also occurred to several other roads, resulting in people being cut-off from traveling.

- Cloudburst in Malmö. 31 August 2014 (MSB, 2015).

On the 31 August, heavy rains in Skåne County hit the city of Malmö, peaking at 100 mm of precipitation. 3 000 homes lost their power supply and the storm water drainage system was completely overwhelmed (MSB, 2015). This resulted in a series of floodings in the city, with the most serious being the flooding of Skåne University Hospital. The hospitals operation could continue unaffected to a large degree, despite having power sub stations flooded and disabled (MSB, 2015).

- Cloudburst in Hagfors. 4 August 2004 (MSB, 2010).

The area around the small town of Hagfors in Värmland County was hit by an extremely intensive cloudburst on the 4 August 2004. Peaks of precipitations were recorded as high as 210 mm of rain in 12 hours (MSB, 2010) .
The road network suffered the worst damage. In several places, the road was completely eroded away by surface runoff. The damage was aggravated by geological conditions (MSB, 2010). Apart from extensive damage to the road network, major damage on the telecom system and electric power grid was suffered (MSB, 2010). Inadequacy of the stormwater drainage system led to several basements being flooded

5.5 Damage types

The types of damages that arise from an extreme cloudburst event can be grouped into two categories; (MSB, 2013) (MSB, 2010)

- *Direct* and *indirect*
- *Tangible* and *intangible*
-

A *direct consequence* if, in this instance, is defined as a consequence that arises as a direct implication of water coming in physical contact with an object, such as short circuiting an electrical cabinet and causing a power failure.
Similarly, a *tangible* damage is a damage that can be connected to a direct consequence and thus can be measured in economic terms.

The other group are the *indirect consequences* and *intangible damages.*
The key difference is that this type of effects is difficult to measure in economic terms and are not necessarily a direct consequence of a cloudburst. These categories are defined in a matrix. An example of such a matrix is shown in Table 3;

Table 3 Damage matrix

	Tangible	*Intangible*
Direct	Damage to technical infrastructure, such as power grid, opto-cables etc.	Damaged personal property of sentimental value.
Indirect	Losses due to disruption of operations and infrastructure.	The distress from having property of great affectionate value damaged.

5.6 Flood protection measures

There are several ways in which flood caused damage can be reduced or prevented. There are two types of preventive measures that can be taken (MSB (Räddningsverket), 1997);

1. Measures that are aimed at *reducing the probability* of damage
2. Measures that are aimed at *reducing the impact* of consequences.

Measures in the first group are intended to reduce the probability that damages will occur in the event of extreme weather conditions.
The second group focuses on measures that are aimed at damage control and impact reduction. A common defensive measure is to build flood walls in areas that are under imminent threat of being flooded. This measure is most effective if the walls are constructed prior to the event. The idea is to channel excess water away from buildings and other infrastructure that are at risk of being damaged by excessive water flows. The walls can be built quickly using sandbags, pallets, tarpaulins or concrete segments. Areas that are flooded on a regular basis can also have flood walls permanently emplaced.

For an individual household, a simple and effective measure is to make sure that there are no possessions or items on the floor level in basements. By moving them upwards a meter will drastically reduce the property loss.
Another simple and effective measure is to secure basement windows that are close to ground level with waterproof materials, such as plastic or tightly installed wood boards. Although this might not completely prevent water from entering, it can reduce the rate at which water enters.

5.7 Costs of damages in studied areas

A flood event caused by an extreme cloudburst would have significant economic consequences in the studied areas. Viewed on a macro-scale, buildings and infrastructure will suffer the most damage in terms of costs.
Based on insurance data, the costs expected in the event of a severe flood event (Sweco, 2015) can be described as follows in Table 4.

Table 4 Costs for damages to different types of buildings and installations in case of flood events

Type of building/infrastructure by code	*Estimated damage cost (SEK)*
130, 131, 132 (Single-family property)	*40 608*
133, 135 (Apartment property)	*142 538*
Office building, property (499)	*142 538*
Commercial building (499)	*145 598*
Industrial building, industry and property (240)	*136 169*
Complement building (699)	*4 371*
Roads	*900 (SEK/m^2)*
Powerlines	*1,45 (SEK/m)*
Optical fibre cable	*1,45 (SEK/m)*
Water lines	*1 (SEK/m)*

Besides the buildings and infrastructure at ground level, there is a considerable amount of underground infrastructure that has to be taken into consideration. In the studied areas, there are three types of underground infrastructure[7];

- Electrical powerlines
- Optical fibers
- District heating

Between the areas studied, these systems are distributed as follows in Table 5 (Eriksberg), Table 6 (Sannegården) and Table 7 (Vasastaden);

- **Eriksberg**

Table 5 Length of underground infrastructure in Eriksberg

Type of infrastructure	*Amount (m)*
Electrical powerlines	67 055,00
Optical fibers	5 555,00
District heating	65 305,00

- **Sannegården[8]**

Table 6 Length of underground infrastructure in Sannegården

Type of infrastructure	*Amount (m)*
Electrical powerlines	21 723,00
Optical fibers	N/A[9]
District heating	12 733,00

- **Vasastaden[10]**

Table 7 Length of underground infrastructure in Vasastaden

Type of infrastructure	*Amount (m)*
Electrical powerlines	28 255,00
Optical fibers	2 100,00
District heating	16 927,00

[7] Water distribution not included, since this dada has not been possible to obtain.

[8] Data acquired from Göteborg Energi CAD-files. 2016-05-02.

[9] No data was provided for the optical network in Sannegården

[10] Data acquired from Göteborg Energi CAD-files. 2016-05-02.

Similarly, to buildings, these systems are also assigned an expected cost per damaged meter of system. These costs are presented Table 8.
It should be noted that the underground infrastructure in itself is not very likely to be damages in the case of a severe flood. Because of this, the cost for underground infrastructure is significantly lower than other systems and objects.

Table 8 Cost for damage to underground infrastructure (SEK/m) (Sweco, 2015)

System	*Cost (SEK/m)*
Electric powerlines	1,45
Optical fibers	1,45
District heating	1,44

6 The historical context

The main developments that has occurred during the timespan this report covers are mainly an improved standard of living and an increased reliance on technical systems, such as good roads, extensive electric power grid and broadband internet access.

Since the 1950s, the city of Gothenburg has grown substantially. The population has increased from 370 832 in 1950, to 549 839 in 2010.

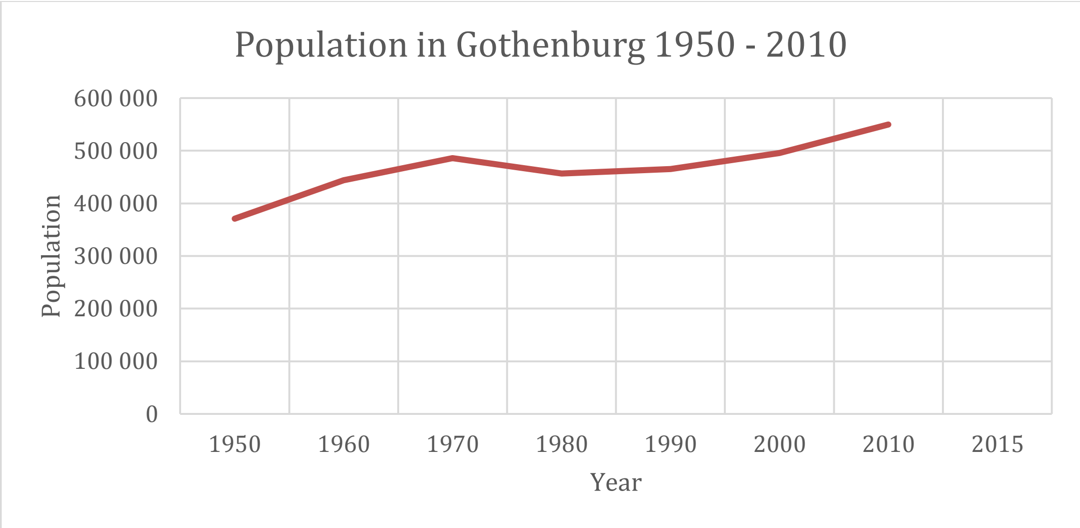

Figure 17 Population growth 1950 – 2010 (SCB, 2009)

During the period 1966 – 1984, the usage of electric energy in Sweden per capita followed a positive trend. This levels out and even starts to decline in the early 2000s, as seen in Figure 18.

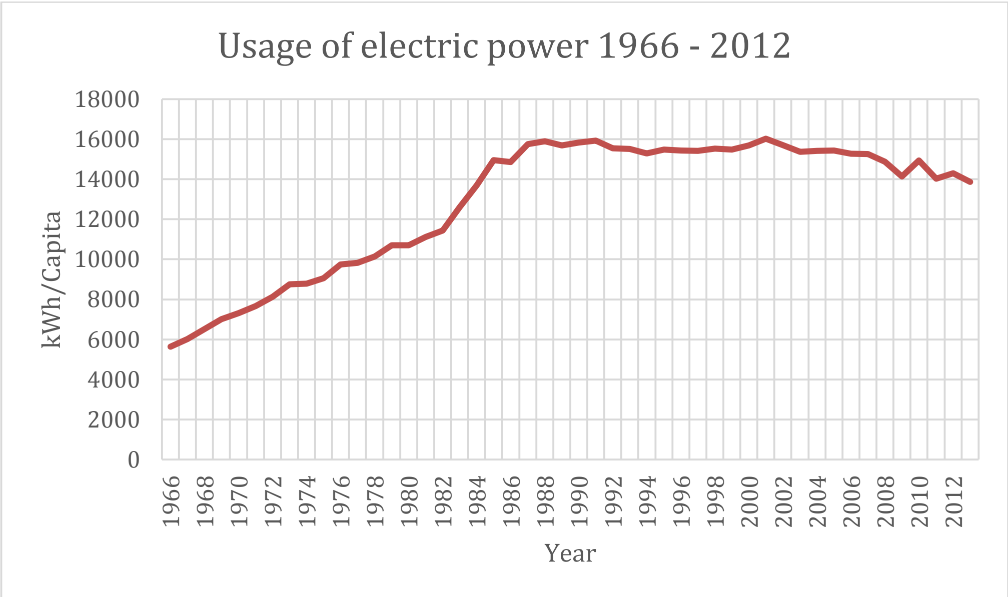

Figure 18 Energy usage 1966 – 2012 (The World Bank, 2016)

Furthermore, in conjunction with the electricity usage, there is also a steep increase in the number of internet users during the period 1989 – 2014, as shown in Figure 19.

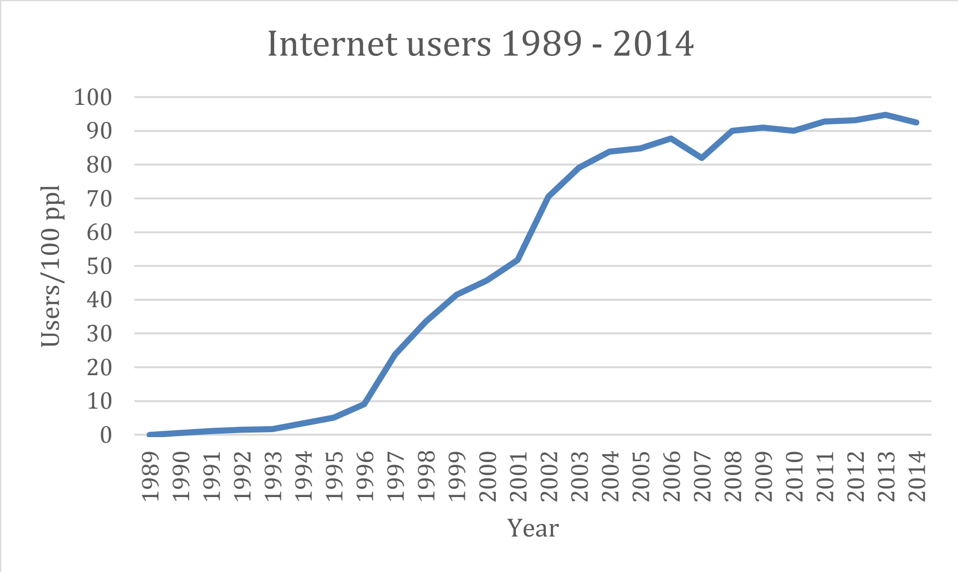

Figure 19 Number of internet users 1989 - 2014 (The World Bank, 2016)

Sweden is a sparsely populated country, forcing many of its inhabitants to rely on cars and roads. This is reflected in the numbers of cars in traffic, shown in Figure 20.

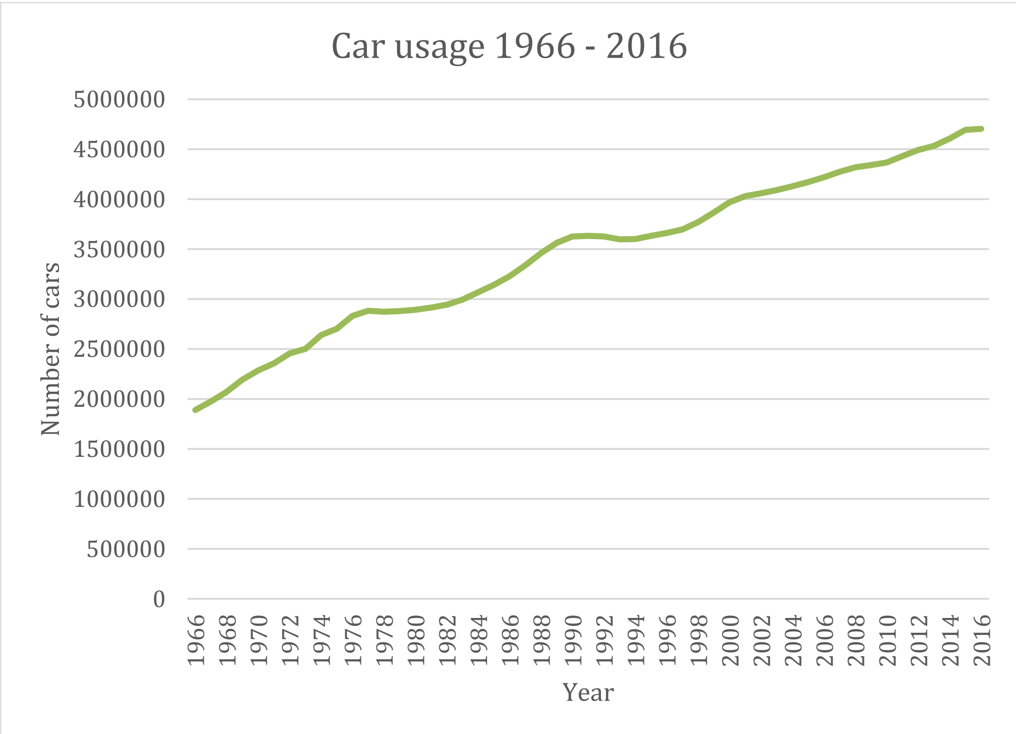

Figure 20 Number of cars 1966 – 2016 (SCB, 2016)[11]

[11] Data for 1966 – 1974 acquired from SCB Statistic Yearbook of corresponding years

Furthermore, the reliance on cars and roads is also seen in the length of the Swedish road network, shown in Figure 21.

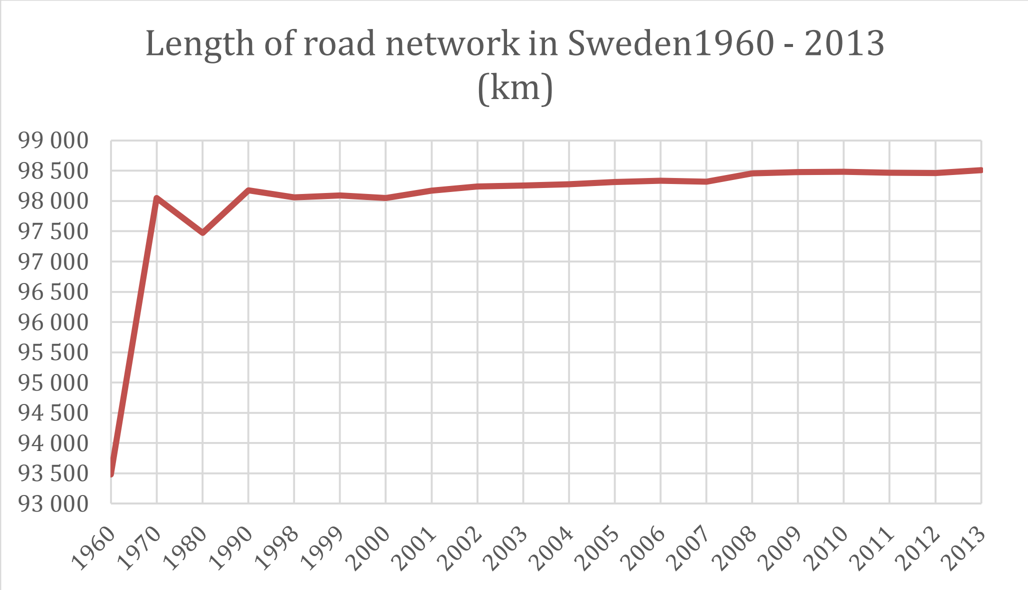

Figure 21 Length of the Swedish road network 1956 - 1970[12]

In the case of Gothenburg, a lot of people live outside the city and works in the city, making for a situation that is relying on commuting. The commuting is done by several kinds of traffic types, such as cars, trains, busses, bicycles etc.
This is closely connected with the extent of the road network.
The growth of commuting is shown in Figure 22.

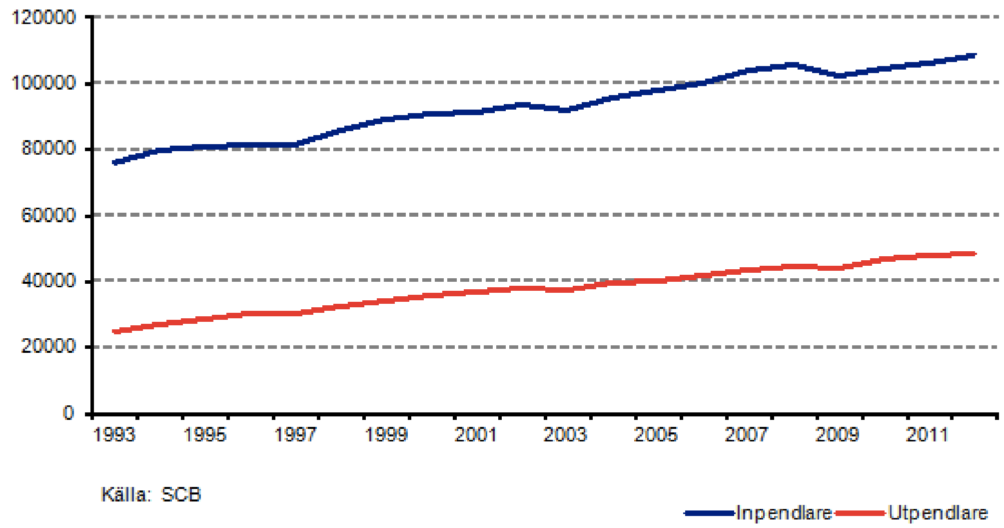

Figure 22 Commuting to and from Gothenburg 1993 - 2011 (Göteborgs Stad, 2015)

[12] Data acquired from SCB Statistic Yearbook 1965, 1970, 1975, 1985, 1990, 1996, 2001, 2014

7 Results

7.1 Evolution of the severity of consequences

As seen in the report, the increased amount of infrastructure and energy usage points to a correspondingly increased reliance on said structures (infrastructure and electric power) over the past decades. This would indicate that the society and the individual inhabitant is more vulnerable for the effects of urban flooding.

An effect of the increased dependency on electricity, and through that an increased vulnerability, would also imply a risk for greater economic loss in the case of a system failing in its operation. The losses would not primarily be in the destruction of infrastructure for electricity and telecom, but rather indirect losses from operation of services that requires these systems to be functional. Production industries and business would be severely impaired by the loss of these systems. Another factor to consider is the rise in population and the rise in average lifespan, indicating an increased standard of living.

7.2 Cities and floods

A flooding event usually denotes a situation in which a body of water is raised above normal, safe, levels and puts at risk to the health of people or damages property. A flood can be triggered by one or more of several factors. These can be rain, snow melting, onshore wind, dammed waterways, damaged or ruined hydroelectric dams etc.

A key difference between flooding in rural areas and urban areas is the scale of the consequences in both a human and an economic sense. In an urban area, the population density is significantly higher than in rural areas. Having more people in denser conditions also implies a higher concentration of property and other assets that are at risk of being damaged or destroyed in a flood situation. Furthermore, urban areas are also likely to house vital infrastructure and technical systems that are of great importance not just for the city, but also the surrounding rural areas.

7.3 Economic consequences in studied areas

7.3.1 Eriksberg – Sannegården

The area of Eriksberg covers 0.15 km^2 and is primarily a residential area, with few (if any) industrial buildings. Several buildings also house commercial activities. Eriksberg has significantly larger population than Sannegården, as seen in Table 15.

By type, the buildings are distributed as shown in Table 16 for Eriksberg and in Table 17 for Sannegården.
Sannegården covers an area of 0.27 km^2 and has a similar distribution of building types. The average year of construction for Eriksberg is 2009 and 1985 for Sannegården. Some of the buildings in Sannegården were renovated or rebuilt in the 1990s.

7.3.2 Vasastaden

The studied area in Vasastaden covers 0.17 km^2. The area shares several similarities with Eriksberg-Sannegården. For example, there is a complete absence of industrial buildings. There is also an emphasis on residential buildings with apartments, with no detached houses at all. The distribution of buildings is presented in Table 18.

Thus, in the event of large scale damage to the infrastructure above and below ground, the total costs for the studied areas would be as presented in Table 9. However, it should be noted that the infrastructure below ground in itself is very resilient to damage caused by flooding. Instead, the damages that are incurred concerning the underground infrastructure are of the indirect type, with damages coming from disrupted operations from pumping stations for the water and central heating and routing points and electrical supply for the optical fiber network. Thus, the cost for damaged underground infrastructure is not included in the total cost.

Table 9 Total damage costs for studied areas[13]

Area	*Buildings (SEK)*	*Infrastructure (above ground, SEK)*	*(Infrastructure (below ground, SEK))*	*Total (SEK)*
Eriksberg	11 130 000	6 964 000	50 000	***18 094 000***
Sannegården	18 898 000	33 499 000	200 000	***52 842 000***
Vasastaden	20 166 000	10 082 000	68 000	***30 248 000***

[13] Costs for the underground infrastructure are not included in the total cost.

7.4 Consequences for inhabitants due to system failures

The damages to the city not only affect the physical environments, such as buildings and infrastructure. An integral part of the city is its inhabitants. When technical systems fail during a cloudburst event, it ultimately hits the people living in the city. These systems are;

- Telecom
- Water distribution and waste water management
- Infrastructure and transportation
- Energy

7.4.1 Telecom

The telecom system is key for internet access and IT-systems. The core of the telecom system in Gothenburg is the optic fibre-network. The network is relatively robust, having its cables underground (Göteborg Stad, 2006). Furthermore, the network traffic can be rerouted trough other nodes in the event of damage to its infrastructure (Göteborg Stad, 2006). This makes for a robust system. The main treats against the network are high water levels and disruption of the supply of electrical power (Göteborg Stad, 2006).

7.4.2 Water

<u>Drinking water</u>

The system for providing the inhabitants in Gothenburg with drinking water is centred on the quality of the raw water at the intake points in Göta Älv and the Delsjön-area (Göteborg Stad, 2016). Circumstances that can degrade the quality are mainly extreme rainfall (Göteborg Stad, 2006). Other circumstances that poses difficulties with maintaining raw water quality are, for example, salinization and elevated water levels (Göteborg Stad, 2006).

When water levels rise in Göta Älv, the water tends to flood the nearby fields and wetlands. The problem this poses is the risk of pollutants that are bound in the soil and mud can be flushed out into the river. Furthermore, this also increases the turbidity of the water.

The infrastructure for treating and distribution of treated water can be viewed as two parts. One part is the water treatment plants. The other is the distribution network. The water treatment plants that supply drinking water to Gothenburg, Alelyckan WTP and Lackarebäck WTP, are themselves not likely to be much affected by extreme weather conditions. Instead, the risk lies in disruption of the power supply, which would bring the treatment processes to a standstill (Göteborg Stad, 2006).

A widespread power disruption would also have significant impact on the pumping stations that are located throughout the network. These are tasked with keeping adequate pressure in the pipe network. A failure of this component would lead to drops in the water pressure. Due to the age of the pipe network, cracks and leakages are commonplace. When the pressure inside the pipes is reduced, there is a risk of groundwater to seep into the pipes and contaminate the drinking water. As such, it is not the physical infrastructure in itself that is at risk of being damaged, but rather the *product* that is transported in the pipes.

<u>Waste water</u>
The waste water system is very sensitive to extreme weather, particularly extreme rainfall. It is designed to be able to handle a rainfall with a return period of 10 years. A more severe rainfall will disable the system by means of saturating the capacity to drain off the surface runoff. A common phenomenon when dealing with saturated wastewater systems is that wastewater is forced backwards and enters the basement in a building.

This also affects the infrastructure, causing roads and railways to become submerged in low areas where water is pooled. Under normal conditions, the runoff is drained away but when the wastewater system is disabled, the water will instead pool, causing damage to the road and support embankment, as well as hindering mobility on the road network. If the system is disabled for longer periods of time, there is also a risk of endangering the health of people in the affected areas. This is due to contaminated wastewater coming into contact with people, causing negative health effects.

Contrary to the drinking water system, the wastewater system is not all that reliant on electric power, since it mostly works by gravity flow of water. However, the system is designed to use pumping stations to regulate flowrates to the wastewater treatment plant. When the capacity of these is reduced, it may be necessary to divert untreated wastewater into the recipients.

7.4.3 Infrastructure and transportation

The transportation system is very sensitive to rainfall during extended periods of time and extremely intensive rainfall events. The problem is tripartite; The first part is that large amounts of water can cause damage to the roadbed due to soil saturation and erosion of the materials. The second is connected with the wastewater system. (Göteborg Stad, 2006)

When this system is filled to capacity, water will no longer be able to drain away from the road surface. This can cause problems with aquaplaning and longer braking distances. In a longer run, water pooling at low points in the road network can cause the road to be shut down and no longer usable, causing major traffic disruptions.

Third, if the electricity is disrupted, it will cause problems operating the traffic signals, traffic information systems and traffic management in general. A power failure would also stop the tram traffic completely, since they rely on electric power to run. They would also lose their traffic control systems.
Road lighting would also be disrupted, possibly leading to a higher rate of accidents involving both cars and pedestrians, due to degraded visibility, especially during low light conditions.

7.4.4 Energy

Electrical power
The most important system in the city is the electric power grid. Without it, every other system is severely impaired in its functionality or rendered completely inoperable. (Göteborg Stad, 2006)

The power grid itself, regarding the cabling, is very robust. Most of it is located underground and the cables that remain above ground is secured by other means. (Göteborg Stad, 2006)

The weakness lies in the systems substations, which are sensitive to elevated water levels. This is because they are usually located in basements or at ground level, exposing them to danger of being damaged in the event of a basement flooding. If a large number of substations are put out of operations, it will not be possible to reroute power past the damaged ones

District heating
The district heating system is responsible for most of the inhabitants need for heating homes, offices and commercial buildings. The main vulnerabilities for the system are long periods of severe cold and flooding. In the case of flooding, the main weak point is the heating plant at Rosenlund, situated close to Göta Älv. The risk is that water can enter the basement facilities and disrupt the pumping operations by damaging the plants electrical systems. This is especially critical during cold weather conditions. (Göteborg Stad, 2006)

The piping infrastructure as such is relatively robust against flooding. Most of the pipes are deep underground and in rock tunnels. If these underground facilities would be breached by flood water, the pipes themselves would likely remain undamaged. Instead, the damage would likely occur to operation support equipment and the insulation of the piping. (Göteborg Stad, 2006)

7.5 Effects of system failure on the individual inhabitant

Failure of each of the described systems would have different impact on the inhabitants in the city. This can be shown by using a performance matrix. In this case, the performance matrix used is scored in a range from 1 to 5.
The scale of 1 -5 represents very small impact to a catastrophic impact.
A high total score indicates that failure of that particular system will have a higher degree of negative impact on the daily life of an individual inhabitant.

In Table 10, the score-levels are presented in more detail and with a description of each score. In Table 11, the outcome from each parameter and each category is summarized and displayed, with the highest scores for parameters and categories underlined.

Table 10 Score table with descriptions

Score	Consequence	Comment
1	Small	Small impact. Some discomfort. Does not impede normal activity.
2	Minor	Some impact. Noticeable difficulties. Some disruptions in services.
3	Major	Major impact. Conditions impedes daily life. Disruptions in transportation and services
4	Severe	Severe impact. Heavy disruptions in services. Normal activities severely hindered.
5	Extreme	Extreme impact. Services out of operation. Normal activities close to impossible.

Table 11 Impact of system failure on the individual inhabitant. Underlined scores indicate maximum values.

Parameter / Category	Energy	Water	Infrastructure and transportation	Telecom	***Sum***
Comfort	4	4	3	2	***13***
Work	5	5	4	5	***<u>19</u>***
Mobility	3	1	5	2	***11***
Communication	5	1	3	5	***<u>14</u>***
Sum	***<u>17</u>***	***11***	***<u>15</u>***	***14***	

7.6 Consequences

When an extreme cloudburst hits an urban area, the damages are severe and widespread. As seen in the cases of Orust 2002 and Copenhagen 2011, as well as other events studied, the costs for damages to infrastructure, buildings and property are severe, ranging from 10s of millions to 100s of millions. However, the number of deaths and physical injuries are very limited.

From the MCA in Table 11, disruption to *power distribution* and the *transportation infrastructure* are the most influential on the daily lives of the inhabitants in the city. People are rendered immobile due to destroyed infrastructure and are also at a great discomfort when the power supply is disrupted. This is due to the immense reliance on stable power supply that is required to maintain the standard of living that people are used to.

Also seen in Table 11, failure of either the energy system or the infrastructure and transportation system is going to have the most significant impact on the categories *work* and *communication*.

7.7 Changes in consequences over time (1950 – 2013)

Over the years the standard of living has increased in conjunction with the development and evolution of technical systems. As such, the impacts arising from failure of these systems has changed over time. As in the MCA in Table 13, the four categories can also be analysed in a historical view, owning to the data provided in chapter 6, The historical context;

- Work.
- Communication.
- Mobility
- Comfort.

The literature review establishes the fact that disruptions of technical systems has significant impacts in the affected areas, due to the high degree of dependency on, for example, electrical systems. In chapter 6, the changes in several areas from 1950 to present day are displayed in terms of increased volumes/physical sizes/usage. The trend is an increase on a year to year-basis. Put together, this is used as an indication of to what extent the system is used, and thus, indicates to what degree of reliance is put on the system in question.

By amalgamating the diagram lines from figures 13 to 19 a general trend in development can be observed. The trend is positive, meaning that the level of development is increased by each year. This is also corresponding to how sensitive the societal system is in terms of being affected from damage on the critical systems and thus how severe the consequences would be.

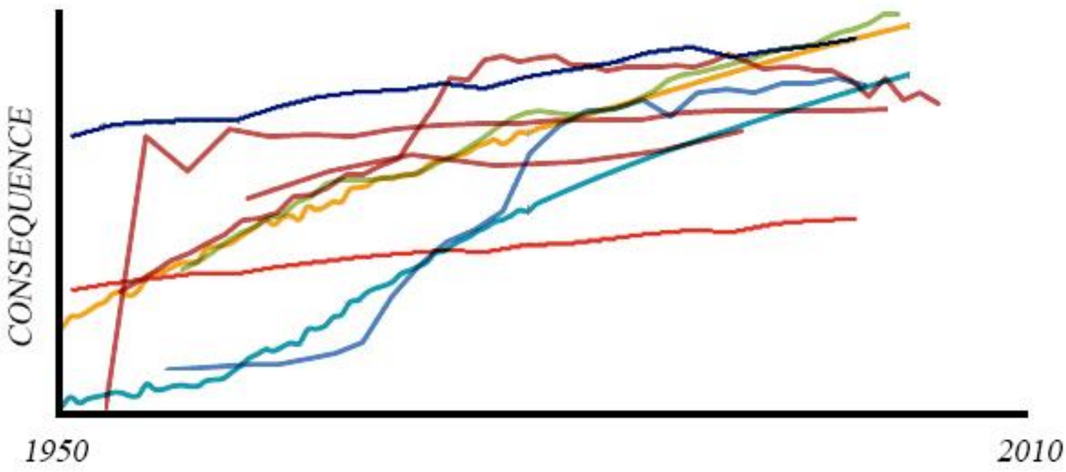

Figure 23 The effect of failure of city-critical systems over time (1950 - 2010)

From all figures, except Figure 22, a trend line can be extracted. There are a total of 5 trend lines extracted. Each of the lines is described by the following linear functions, displayed in Table 12. The data in Figure 22 is omitted from Table 12, since it is not possible to extract a trend line from it.[14]
Similarly, an r^2-value is extracted.

Table 12 Trend line functions and corresponding figures

Function of trend line	Corresponding graph
$y_1 = 22168x + 378225$	(Population in Gothenburg. Figure 17)
$y_2 = 196.57x - 8052.8$	(Energy usage per capita (kWh/Capita). Figure 18)
$y_3 = 4.8323x - 13.273$	(Internet users. Figure 19)
$y_4 = 52344x + 2 * 10^6$	(Number of cars. Figure 20)
$y_5 = 99{,}373x + 96964$	(Length of road network. Figure 21)

[14] All graphs are originally created in Excel by plotting individual data points. In Figure 22 however, the graph is from the report "In- och utpendling till/från Göteborg 1993-2012" by Göteborg Stad. See page 54, *Refrences.*

The graphs for each equation are shown in Figure 24 on an interval covering 1950 – 2013. For clarity, the trend lines are plotted in two separate graphs due to differences in scaling.

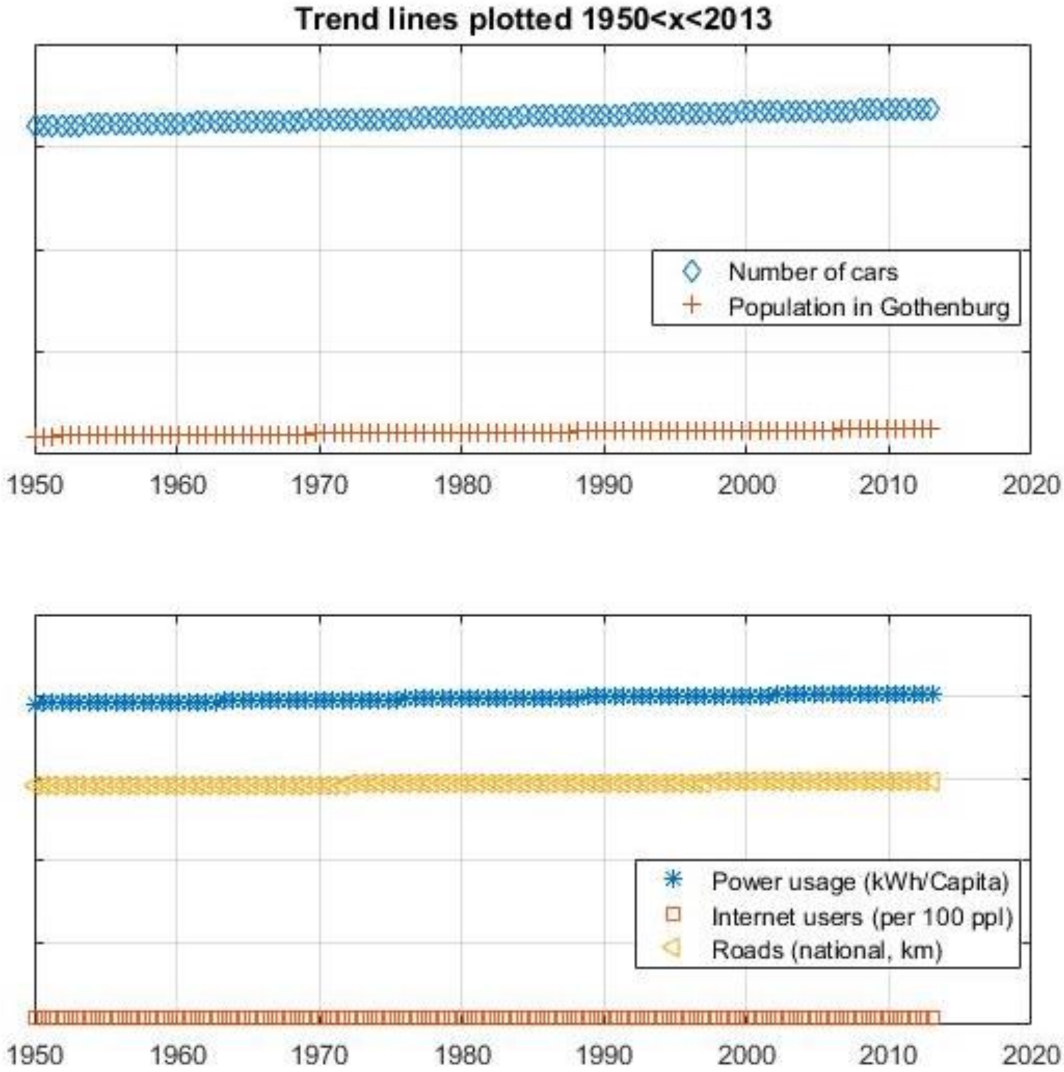

Figure 24 Plotting of trend line equations

In Figure 25, the trend lines are plotted individually on the 1950 – 2013 interval, with a step of 100 between each plotting point. By having each trend line in a separate subplot window, the inclination of each can be clearly seen. The r^2 value is displayed in the title of each graph.

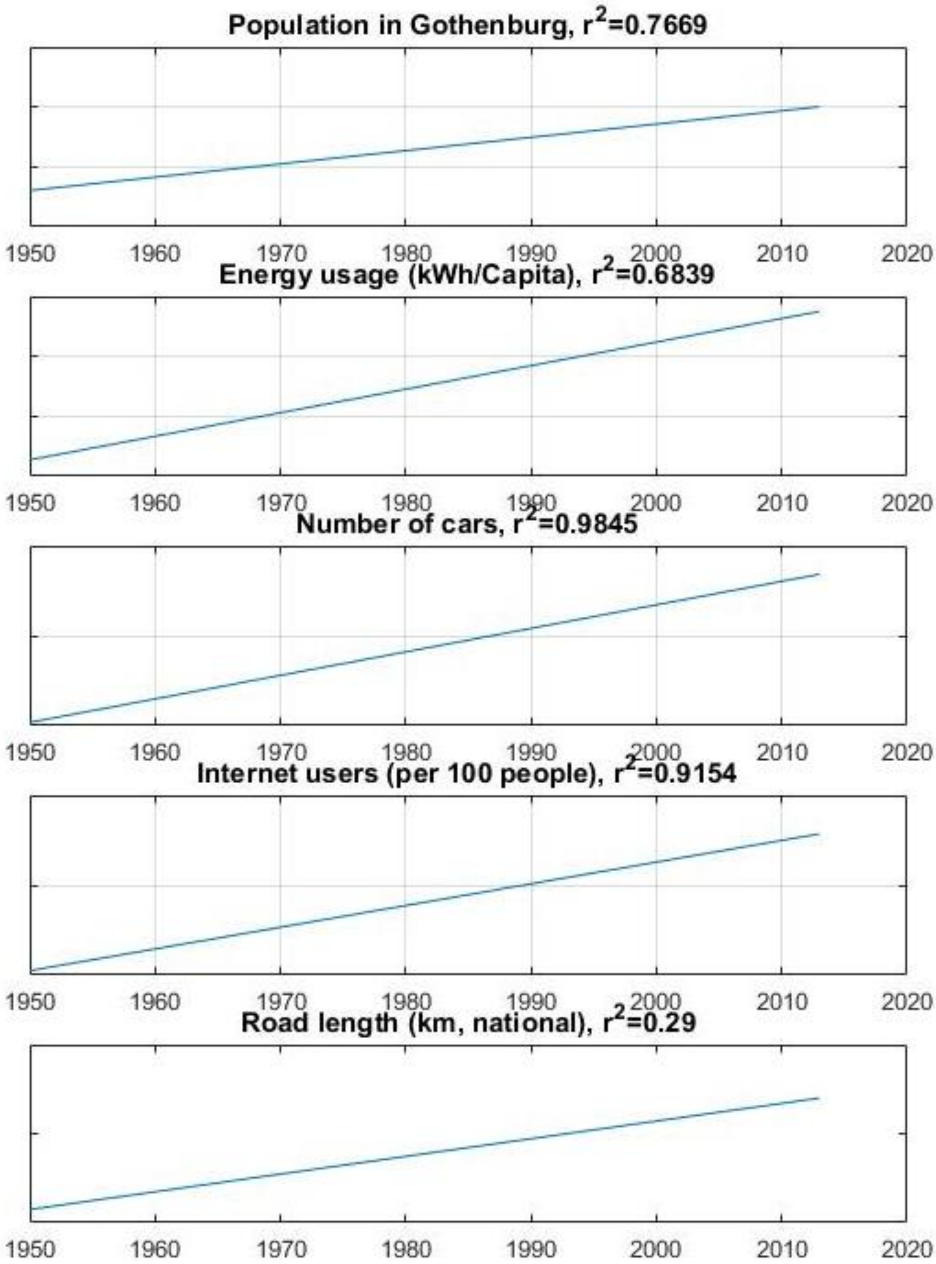

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Figure 25 Subplots of each trend line function, on interval 1950 – 2013

From these lines, the positive inclination following each function indicates an increase in consequence of failure from each system. The positive slope can be determined by deriving each of the trend line functions, resulting in the following derivatives;

[15] Graphs are arranged with graphs corresponding with equation y1 at the top to equation y5 at the bottom.

Table 13 Trend line function and derivative (with sign) and r²-value

Function of trend line	Derivative	Sign of derivative	r^2
$y_1 = 22168x + 378225$	$y'_1 = 22168$	+	0.7669
$y_2 = 196.57x - 8052.8$	$y'_2 = 196.57$	+	0.6839
$y_3 = 4.8323x - 13.273$	$y'_3 = 4.8323$	+	0.9845
$y_4 = 52344x + 2 * 10^6$	$y'_4 = 52344$	+	0.9154
$y_5 = 99{,}373x + 96964$	$y'_5 = 99{,}373$	+	0.29

Since each derivative is positive, given by its sign, the impact on the system in question will increase over time. The r^2-value indicates how close to the original graph the trend line is. The closer this value is to 1, the better the trend line is describing the original graph.
The low r^2-value regarding equation 5, the road network, can be explained by observing the sharp rise in the beginning of the diagram in Figure 21.

Since the length of the x-axis (Δx) is known, given that it corresponds with the time frame of 1950 – 2013, and the y-values for 1950 and 2013 can be calculated by inserting them into corresponding graphs, the Δy can be calculated.
With the length, Δx, and Δy known, the angle of inclination(A) is calculated through the trigonometric relation $A = \tan^{-1}\frac{\Delta x}{\Delta y}$ to obtain the angle A in degrees (°) for each graph in Figure 25.

The inclination of each graph would then correspond with the increase of dependency of each system during the time frame 1950 – 2013. The angles are presented in
Table 14.

Table 14 Angles and inclinations of slopes of graphs

Equation	Angle (°)	Inclination of slope (%)
$y_1 = 22168x + 378225$	$4.5110*10^{-5}$	$7{,}87319*10^{-5}$
$y_2 = 196.57x - 8052.8$	0.0051	0,008878843
$y_3 = 4.8323x - 13.273$	0.0066	0,011594688
$y_4 = 52344x + 2 * 10^6$	$5.8677*10^{-7}$	$1{,}0241*10^{-6}$
$y_5 = 99{,}373x + 96964$	$2.1230*10^{-4}$	0,000370536

When compared to the MCA summary in Table 11, it can be seen that there is a relation between the MCA summary and the trend line analysis.
The inclination of the trend lines for electric power usage and internet usage corresponds with the result from the MCA, that indicates that the categories *Work* and *Communication*, along with the parameters *Energy* and *Infrastructure and Transportation*. The most important factors of the everyday life of the inhabitants of a city is also those that are depending the most on the rapid growth of energy usage and internet access.

8 Discussion

8.1 Assumptions and predispositions

The assumptions made in the beginning of the study cut out some aspects that could be of interest to study. For example, it is assumed that the rainfall is uniform in its whole extent. As seen in the report, this is rarely the case. It is much more likely that there will be great variations in intensity and duration even in a small area covered by a rainfall. Furthermore, the study does not involve simulations of any sort. Most likely, this also limit the accuracy somewhat.

8.2 Data

Weather data is readily available from several sources, both private and official data from government agencies. However, the further back in time the data was recorded, the greater the possibility of errors are. There is also the case of how the data is gathered, i.e., how a parameter is counted.

This is especially evident when referring to the municipality of Gothenburg. This is because the municipality has expanded over the years by "annexing" other municipalities. Also, this is a problem that is present when referring to Västra Götaland county. The county of Västra Götaland is also that an amalgamation of previous administrative divisions.

8.3 Results

8.3.1 Economic effects

The results in the study are in line with what could be expected. When comparing with the other cases presented in the study, as well as calculations to small, well defined, areas in Gothenburg. The results that are acquired does seem to fall in between the extremes that has been seen in, for example, the literature study. It should be kept in mind that the calculated costs only are valid for the exact areas. In reality, the boundary is much more fluid and difficult to define. However, the results should be usable as an indicator of scale concerning the extent of economic damage in urbanized areas.

There is a possibility that the values calculated are valid for larger areas of similar type. If so, then the calculations for Eriksberg and Sannegården would be valid for much of the expansion of building on the northern shore of Göta Älv and the planned expansion in the Frihamnen area. Similarly, the results for Vasastaden would be valid for other areas in Gothenburg with older buildings of the same type. A limitation of the result of the economic damages are that it is very difficult to calculate the value of lost or damaged private property that is stored in basement cellars or if there are occurrences of damages to individual houses. The houses differ from each other. Therefore, where one house suffers a leak in its roof, the adjacent building might be completely unaffected in terms of leaking roofs.

8.3.2 Effects on the inhabitants

The basis for the evaluation of the effects on the inhabitants in the city is the MCA. A difficulty here is the fact that when dealing with the "human dimension", it is much harder to make "hard" conclusions, since it is a question of assessment. In these instances, an MCA is a very useful tool in working with quantifying assessments of "soft" issues. The resulting scores in the MCA should not be viewed primarily as absolute facts, but rather a way of observing and describing a trend in the changes.
The study of how people are affected by floods on an individual level should not be confined to an engineering perspective. It is likely that it would benefit greatly from perspectives from other disciplines in the social sciences.

One area that could be studied further is the division of categories and parameters. To achieve better resolution of the scoring in each of them, it would be possible to divide each into more specific categories. For example, the parameter "infrastructure and transportation" could be divided into "Road", "Rail", "Pedestrian" etc. This would also make it possible to discern and analyse smaller and subtler differences in the impact each parameter has.

The same could be done to the categories. For example, the "comfort" category could likely benefit from being divided into smaller, more specific, areas. However, this would require a more in depth review in the case studies, to find these differences.

Another approach to analyse these "soft" parameters would be to combine a more area specific study with a careful division of the demographics in the studied area. By doing so, it would be possible to gauge the effects on different population groups in relation to the conditions prevailing in a particular area.

8.4 Changes in consequences over time

The principal change that can be seen in this study is the increased reliance on technical systems, and I particular electricity and infrastructure. These are the foundations that a modern urbanised and technological society is built on. While the statistics can provide a sufficiently accurate idea of how a society may have worked, it does lack the "soft" input that is the personal experience. The study might have benefited from having interviewed people who were old enough at the specified years to have meaningful input on how, for example, a power failure, affected people.

The evaluation of consequences using the trend lines indicates that the effects on the inhabitants are indeed increasing. The trend lines are showing that the rate of change is slow, but persistent. The trend lines only show the vulnerability of the technical systems and the rate of change over time.

Although a very slight increase, the reliance on electric power is to be considered as great already at the start of the evaluated time span. This coincides with the of rapid economic growth and improvements in the standard of living in later half of the 20th century.

Two parameters are indicative of this increased standard of living; energy usage and car ownership. It points to an increased reliance on cars for transportation and electric power for satisfying everyday comforts, such as heating, lighting, communication and cooking. This added comfort of living quickly makes these systems an even more ubiquitous part of life for the individual inhabitant.

An offshoot from the reliance on electric power that has become more and more evident in the last 10-15 years is the rapid increase in internet usage. As seen in Table 14, these two parameters display the highest slope inclinations of their trend lines. This points to that in the current time, these two are the most prevailing factors regarding the consequences for the individual inhabitant. The internet reliance is of particular concern, given that in the last 10 years it has become a highly ubiquitous part of life for practically every single inhabitant in Gothenburg. This is a trend that is likely to continue, due to the demand for ever faster and accessible services based on mobile internet communication. Regarding car usage and road network length, a similar case is possible to make, with a key difference; namely that the increase in car ownership is far greater that the increase of the road network length. These two cases serve to further reinforce the overall case of an increased standard of living that is highly relying on these three "pillars".

As stated in chapter 7.7, there is a relation between the MCA shown in Table 11 and the trend lines in Figure 24 and Figure 25. The one parameter that does not fit completely is the *Infrastructure and Transportation*-parameter. However, it could be argued that this system would also be impacted a manner that still is in line with the overall relation between the MCA and the trend lines, due to the fact that infrastructure and transportation systems are heavily reliant on a continuous flow of a wide variety of information.

As stated previously, traffic control systems will not function properly without electric power, potentially causing disruptions in the flow of traffic. Subsurface road sections could be flooded and blocked if pumps are rendered inoperable due to power outage. With disabled communication systems, it would also be very difficult or impossible to manage and direct trucks and trains carrying goods and supplies. In this sense, the effects on infrastructure and transportation systems are a secondary, indirect, effect that still needs to be accounted for. Thus, it still fits in the relation between the MCA and the trend lines.

Normalization of the consequences and trend lines

It would be possible to make some sort of normalization of the combined graphs in Figure 23, accounting for the different factors that composes the graph. It stands to reason to have the maximum consequence at the end of the time axis, corresponding to 2010, and the minimum consequence at the beginning of the time axis, corresponding to 1950/60. This is further reinforced by studying the graphs in Figure 25.

For a more accurate indexing of the consequence axis between the origin and the end, it is likely that a more in-depth study would be required for each of the measured components; population growth, energy usage, number of cars, road network length and commuter volume.

Some caution is prudent when estimating future consequences from a linear function. In this report, the trend lines are used to determine whether or not the effects of the consequences have increased or decreased during a fixed interval. The trend lines should not be considered accurate enough for making definitive prognosis. Instead, they should be viewed as an indication of how the development has looked in previous years. Based on this previous experience and data, some conclusions about the immediate future could possibly be drawn.

Using linear approximations for establishing the trend lines will disregard certain aspects of the original graphs. The case of the road network showcases this, since it has a very large “jump” in the data, where the road length drastically increases over a short period of time at the 1950s, followed by a long period of unchanging data points regarding road length.

In cases where the investigated factor remains relatively stationary in terms of change for some time, such as the length of the road network or power usage, the trend line will indicate a very small change. However, if the initial volume of power usage or road length is already very high, the trend line will not take it into account. By that, the impact will still be severe, despite the trend line showing a small or almost negligible increase. If the system has a significant presence already at the beginning of the investigated time period, it can be assumed that it is heavily integrated in the everyday life of the inhabitants in a city and thus of great importance for living comforts.

9 Conclusions

If a weather event that disables and disrupts key technical systems in the city occurs, it will create significant problems for inhabitants and public services. First and foremost, the electrical power grid is the most important, since every other system to some degree is dependent on power supply. A disrupted power system is going to have cascading effects on practically every other technical system necessary to keep the city functioning.

9.1 Change in consequences

9.1.1 Economic consequences

The consequences of urban flooding have changed. Given the increased reliance on systems that are sensitive to being damaged by water. The economic impacts are due to damage to physical infrastructure and to personal property. With an increased population and a projected continued growth of said population, there is going to be a continued demand for building more houses and infrastructure.

9.1.2 Effects on the individual inhabitant

The magnitude of consequences for the individual inhabitant has increased since the 1950s. The effects stem from the fact that a current day society is much more dependent on undisrupted functionality of these systems. It can be ill afforded to have transportation of goods disrupted for more than a day. Likewise, the standard of living cannot be sustained at a current level without a constant and uninterrupted supply of electrical power.

9.2 Flood protection

9.2.1 Preparations

A flood can be defended from, given a reasonable amount of warning and thus time to prepare. Floodings of cities in close proximity to bodies of water, such as an estuary or a river, can expect raised water levels in conjunction with low-pressure weather, such as onshore winds. The problem with floodings caused by rainfall is that they appear suddenly, with little warning. This particular characteristic makes them very difficult to prepare for. Another key factor in preparing for a flood is exercises. Given how the Swedish crisis management system works, it is important that civil servants that can be expected to be involved in the management of a flooding event knows what to do.

Differing from the physical aspects of preparations, a “soft” parameter that is important is the *mental* preparedness of the individual inhabitant, as well as people in decision making positions of the authorities. The mental preparedness is based on the idea of accepting the fact that a flooding event can happen. This is to prevent a “shock”-experience and inability to act in the early moments of a flood event. Such a delay in acting will contribute to worsening the impact on people and property

9.2.2 Actions

When a weather event is ongoing, there is mostly a matter of dealing with the immediate situation. These efforts are aimed at damage control. This can be to reinforce barriers, move property to safety from basements that are about to be flooded, keep traffic away from flooded or damaged road sections and, most important, rescue people that are at risk of injury or death due to the water. Most of the work is done after the rain has stopped. The time that the recovery efforts takes to complete depends on the extent of damage caused by the rain.

9.2.3 System vulnerability and protection

The technical systems are not particularly vulnerable in terms of their physical infrastructure in terms of cables, pipes and pavement. Rather, it is the supporting infrastructure that is at risk. Examples of this are substations for the power grid, pumping stations for water distribution and embankments for roads and railways.

A multitude of services are depending on the systems working and begin operational. For example, damaged roads make it difficult for home care services to aid elderly people in their homes. Damaged power grids can make it impossible to use cellular phones or contacting authorities in an emergency. The water distribution requires pumps to run in order to keep adequate water pressure in the pipe network.

To point out "single points of failure" is there for difficult and sometimes not meaningful, since all systems to some degree depends in each other.
If the matter is to be drawn to its head, the electric power grid is the system that potentially has the greatest probability to be a single point of failure.
The vulnerability of the technical systems is increasing due to the increased reliance on these systems.

9.3 Recommendations

There is a lot to learn from past flood events. Evaluating and learning from mistakes made then makes for a good case when a similar event is about to happen again. Equally important is to recognise "good" efforts that did save property or life.

The key for this is that measures, actions and relief efforts are documented and evaluated to gather knowledge of the event. Then it is equally important that this acquired knowledge is used and implemented in planning and exercises of how to deal with a similar event in the future.

It is also a necessity that gathered knowledge is made available for entities that plan, build and maintains the technical systems and buildings. Much damage, and through that, consequences, can be alleviated if consideration to floodings has been taken already in the planning step of the building process.

As shown in chapter 7.7, there is also a continuing increase in usage of said technical systems and thus an increased reliance of them. Since a reversal of said trend is unlikely to occur, it is even more important that plans and contingency plans are kept up to date on how to keep the systems running to an as large extent as possible for as long as possible even under extremely severe straining of them. This will also require new thinking, methods and organization that mirror the increased reliance on electric power and internet access.

To ensure the integrity of the key systems mentioned in this report, several actions needs to be taken. Most importantly, it is necessary to combine the planning of actions and protecting vital parts of the physical infrastructure that concerns the operation of the electric power grid, communication systems and infrastructure vital for road and rail transportations.

In the preplanning of how to manage a severe flooding of a large urban area, it would be wise to pay some attention to the fact concerning the great reliance on "Just In Time"-deliveries of vital supplies, such as food, water and fuel, that are needed to keep the everyday life of the individual inhabitant liveable. Thus, it would be prudent to have a basic storage of said supplies close at hand for individual inhabitants, since it would reduce the individual sensitivity when access to such services are disrupted.

Regarding the physical infrastructure, the key is to take these considerations into account as early as possible in the city planning process. This is to ensure that the resilience of the infrastructure is an integral part that is built into the urban development and not a separate part built on the urban development.
As shown earlier, a major vulnerability is the sub nodes of the electric power grid. If the placement of these are made with regard to flood protection, it would be possible to lessen the extent of power outages. One approach to this could be to place these nodes in elevated positions, where the risk of flooding would be reduced. This would also reduce the risk of disruption in the telecom systems.

To reduce the risks of damage to the transportation infrastructure, similar approaches would be necessary. The integrity depends on two factors; the ability of road and rail to withstand flooding and the degree of which the management and control systems can continue to work uninterrupted.

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11 Figures and tables

12 Appendix

12.1 Appendix A - Buildings

Property and building definition codes; (Lantmäteriet, 2016)

130 - Residential. Small houses with one dwelling, not joined with another house. Small, detached, houses

131 - Residential. Detached houses, joined by garage or storage. One per property.

132 - Residential. Terrace houses and detached houses.

133 - Residential. Apartment building.

135 - Residential. Small apartment building.

240 – Industrial. Unspecified manufacturing industry

499 – Unspecified. Building used for unspecified purpose or activity.

699 – Complement building. Building used for unspecified purpose or activity

12.2 Appendix B – Distribution of building types

Table 15 Number of inhabitants in studied areas (Statistik Göteborg, 2016)

Studied area	Inhabitants
Eriksberg	8858
Lindholmen[16] (incorporates Sannegården)	3542

Table 16 Buildings in Eriksberg.

Type of building[17]	Number of buildings
130 (Residential house)	2
131(Residential house. Detached houses))	0
132 (Residential house. Terrace house)	41
133+135 (Residential house. Apartments)	70+6
499 (Business. Unspecified operation)	0
699 (Complement building. Unspecified operation)	14

Table 17 Buildings in Sannegården.

Type of building	Number of buildings
130 (Residential house)	1
131(Residential house. Detached houses))	0
132 (Residential house. Terrace house)	16
133+135 (Residential house. Apartment block)	117+117
240 (Industrial building)	1
499 (House. Unspecified operation)	8
699 (Complement building. Unspecified operation)	111

Table 18 Distribution of buildings in Vasastaden.

Type of building	Number of buildings
130 (Residential house)	0
131(Residential house. Detached houses))	0
132 (Residential house. Terrace house)	0
133+135 (Residential house. Apartment block)	97+0
499 (House. Unspecified operation)	21
699 (Complement building. Unspecified operation)	66

[16] There is no statistic for Sannegården in particular. Instead, the area is incorporated into the Lindholmen-area.

[17] For complete description of each number-category, see Appendix A.