CHALMERS

Cost-benefit analysis

A tool for decision-making in pluvial flood risk management

Master of Science Thesis in the Master Degree Programme Infrastructure and Environmental Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Several municipalities in Sweden have suffered from severe flooding due to heavy rainfalls. A major problem in urban areas is that the capacity of the drainage systems is limited and damages due to flooding result in substantial costs to the society. In order to have a comprehensive basis for prioritization of available economic resources there is a need to evaluate the efficiency of flood protection measures with respect to their benefits and costs. Sweco Environment AB has developed a Microsoft Excel-based CBA model that has been applied in several projects in Sweden. The damage costs estimations of the model are primarily based on statistics from insurance companies. The model does not consider externalities such as effects on ecosystem services, health, or cultural heritage. Further, it does not take social considerations into account, such as local environmental quality and amenities, anxiety, or equality. The main objectives of the thesis have been to: (1) improve the damage assessment of the model, primarily based on literature studies, with respect to integration of social and sustainability aspects, and (2) adapt the model to better integrate flooding situations due to heavy rainfalls and insufficient drainage water systems. Two case studies have been performed in order to evaluate the model updates. Two of the conclusions from the case studies are that the value of ecosystem services can decide the outcome of the CBA, and that small-scale solutions to pluvial flooding seem to be the most profitable. The main conclusion of the thesis is that even though many modifications have been suggested, the CBA model is still in need of continued development in terms of both improvements of damage estimations and adding of more parameters. This in order to reduce the amount of uncertainties associated to this otherwise proven useful and extensive tool for decision making.

Key words: Cost-benefit analysis, pluvial flooding, flood risk management, decision-making

Kostnads-nyttoanalys (KNA)
Ett verktyg för beslutsfattande inom pluvial översvämningshantering

Examensarbete inom Infrastructure and Environmental Engineering och Design for Sustainable Development
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SAMMANFATTNING

Flertalet svenska kommuner upplever problem med översvämningar till följd av intensiva regn. I urbana områden är ledningssystemens kapacitet ofta undermålig, vilket leder till översvämningsskador som resulterar i dyra kostnader för samhället. För att kunna ta väl grundade beslut om hur ekonomiska tillgångar skall användas för översvämningsåtgärder är det nödvändigt att väga åtgärdernas fördelar och nyttor mot varandra. Sweco Environment AB har utvecklat en Microsoft Excel-baserad kostnads-nyttoanalysmodell som har använts i flera projekt runt om i Sverige. Skadekostnaderna i modellen är främst baserade på statistik från försäkringsbolag. Modellen tar inte hänsyn till yttre omständigheter såsom inverkan på ekosystemtjänster, hälsa eller kulturvärden, eller sociala aspekter såsom jämlikhet och rekreationsvärden. Huvudsyftet med examensarbetet har varit att: (1) genom litteraturstudier förbättra skadekostnadsuppskattningar i modellen, med fokus på sociala och hållbarhetsaspekter, samt (2) anpassa modellen för att på ett bättre sätt kunna integrera regnöversvämningsscenarion och otillräckliga VA-system. För att illustrera förbättringar i modellen har två fallstudier genomförts. Två slutsatser som dragits av resultaten är att värdet av ekosystemtjänster kan avgöra resultatet i en kostnads-nyttoanalys samt att småskaliga lösningar verkar vara mest lönsamma mot regnöversvämningar. Det huvudsakliga resultatet från examensarbetet är att det, trots uppdateringar, behövs förbättringar och vidareutveckling av kostnads-nyttoanalysmodellen, speciellt med hänsyn till skadekostnads-uppskattningar och även inkluderande av fler parametrar. Detta för att minska osäkerheterna som kan uppstå vid användning av denna annars användbara och utförliga metod för beslutsfattande.

Nyckelord: Kostnads-nyttoanalys, pluvial översvämning, skyfall, översvämningshantering, beslutsfattande

PREFACE

This report concludes our studies at the Master of Science programmes Infrastructural and Environmental Engineering and Design for Sustainable Development at Chalmers University of Technology. This cross-disciplinary work with our different backgrounds has resulted in a report with a holistic approach of pluvial flood management and cost-benefit analysis. We hope we have been able to embrace various societal perspectives and enable a more including decision-making process.

We would like to thank the staff at Sweco that has contributed in our project with professional assistance and input. A special thanks to Johan Nimmermark, Lars Rosén, Mats Andréasson for support and guidance, Lisa Ekström and Johanna Hulthén for help with pluvial measures, Sepideh Jourabchi Makhsoos, Jonas Persson and Andreas Karlsson for hydraulic modelling and Håkan Alexandersson for input on rescue services. Further, we would also like to thank Brittmarie Ohlsson and Johnny Kristiansson in Staffanstorp and Rickard Kalm and Kristofer Dahlberg in Norrköping for providing material and guidance to our case studies.

Gothenburg, May 2014

Sara Karlsson　　　　Marie Larsson

CONTENTS

LIST OF ABBREVIATIONS

BMP	Best management practices: a term used for drainage systems in the US.
CBA	Cost-benefit analysis.
CE	Choice experiment.
COI	Cost-of-illness.
CV	Contingent valuation.
ISWM	Integrated storm water management.
LID	Low impact development: a term used for alternative urban drainage systems.
LUDS	Local Urban Drainage Systems.
NPV	Net present value.
OUDS	Open urban drainage systems.
RP	Revealed preference.
SP	Stated preference.
SuDS	Sustainable Urban Drainage Systems.
TCM	Travel Cost Method.
VOSL	Value of a statistical life.
VOLY	Value of a life year.
WTA	Measure of peoples willingness to accept a change.
WTP	Measure of peoples willingness to pay to avoid or achieve a change.
WWTP	Wastewater treatment plant.

1. INTRODUCTION

The number of extreme weather events has increased significantly in Sweden the past 40 years (MSB, 2011). Intense rainfall occurs annually in many areas and may be one of many possible repercussions of climate change (MSB, 2010). These events have resulted in severe flooding in several municipalities (MSB, 2011). In urban environments, they generate surface flows and pooling as a result of overloaded drainage systems (Spekkers et al., 2011a). These kinds of floods are commonly referred to as pluvial floods. The implications of pluvial floods encompass consequences on human health, the environment, cultural heritage and economic activity. The magnitude of these partly depends on where the rain hits and the existing runoff conditions (Sweco, 2013). As it is difficult to predict where and when a rain will strike, many municipalities experience difficulties to prepare for severe rain events even in areas that repeatedly have suffered from flooding. Flooding generates immense costs for several sectors and in a socio-economic perspective, it is more beneficial to use these expenditures for preventive measures rather than for reparations and other reactive measures connected to floods. Cost-benefit analysis (CBA) facilitates the evaluation and prioritization of flood mitigating measures and can act as an asset in decision-making in flood risk management. The analysis results in economic figures; a language that all concerned stakeholders understands.

The purpose of this master thesis is to further develop an existing model for cost-benefit analysis developed by Sweco (Rosén et al., 2011), in order to better manage pluvial flooding. The existing CBA-model has previously been used for fluvial flooding, i.e. flooding associated with rising surface water levels, and has limitations regarding estimation of risk cost. The research will address ways to estimate benefits in terms of avoided damage costs due to implementation of preventative measures. Furthermore, optimal time for implementation of measures will be studied. Special attention will also be given to improved integration of soft values in the model, in order to attain sustainable development and decision-making.

1.1. Background

The following section will describe the concept of cost-benefit analysis and how it can be used in the context of pluvial flooding in urban environments. It will also describe the terminology of different types of damages.

1.1.1. Cost-benefit analysis and flood risk management

Cost-benefit analysis (CBA) is a method to evaluate costs and benefits in monetary terms imposed on society from a certain decision or measure, during a certain time span. This means that an economic value has to be put on goods and services as well as other aspects such as the environment and human health. CBA can be used to calculate and compare flood mitigating actions within flood risk management, in order to decide whether an action is economically feasible or not. This is achieved by weighting cost of each action (i.e. cost for implementation and execution) against the total expected benefits in terms of reduced risk and possible additional benefits.

The conceptual idea of cost-benefit analysis is to measure gains and losses that occur as a consequence of a decision compared to status quo (Hanley & Barbier, 2009). Ideally, the gains and losses would be measured in terms of *utility*, which economists use to describe factors that create or explains effects on human welfare. Utility is difficult to translate into cardinal measures, such as kilometres per hour, and money is therefore often used as a unit in the assessments. For example; it is not possible to measure the change in utility that one person gets from listening to REM rather than Radiohead. The utility change can however be measured by money metrics using peoples preferences, for example by studying the willingness to pay (the demand for compensation) to increase (reduce) the welfare (Kågebro & Vredin Johansson, 2008). The key principle underlying CBA is the Hicks-Kaldor[1]

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[1] By John Hicks and Nicholas Kaldor.

compensation test, which examines whether or not a decision brings about a *Potential Pareto Improvement* (PPI) (Hanley & Barbier, 2009). PPI shows that those who gain benefits from a decision are willing to pay more for the decision to be realized than those considered entitled to compensation requires for allowing it to happen. The basic concept of the Hicks-Kaldor idea is that the winners, who gain benefits, can compensate the losers if the total societal welfare is maximized (Kågebro & Vredin Johansson, 2008). The general objection against this theory is the fact that distribution effects are neglected. Instead, something called Little's criterion is often used for prioritization, which in addition to the Hicks-Kaldor criterion also demands 'acceptable' distribution effects, though the definition of acceptable effects is a political matter.

The cost of a flood protection measure encompasses the actual cost of construction, maintenance as well as other negative impacts that the measure inflicts on society (Rosén et al., 2011). The benefit of a measure is the sum of the flood risk or damage cost avoided by means of implementing the measure and any additional benefits that can be gained. Flood risk is defined as a function of *hazard*, *vulnerability* and *exposure* (Haynes et al., 2008). Hazard describes the return period of a flood event, i.e. the probability of occurrence. Vulnerability is the degree of which assets and people can be affected by the hazard. Exposure is the related impact of the hazard, e.g. damage to property, ecosystems, human health, cultural heritage and stress (Meyer & Messner, 2005). Many of these effects can easily be translated into monetary terms whereas others, the so-called intangible effects, are more difficult to monetize and may instead be expressed in other units such as lost lives or area of lost ecosystem.

When performing a flood risk analysis, not only one specific extreme flood event is considered; the frequencies of different possible flood events are combined in order to estimate the total flood risk (Messner et al., 2007). This can be illustrated with a damage-probability curve as in Figure 1.1. The curve shows the relationship between: 1) probability and 2) damage (and the related vulnerability) where the area under the graph is the total flood risk over a given time. As shown in the figure, the higher probability the lower damage and vice versa. In other words, the risk of a very severe event occurring can be low due to its low probability. This may also be true for the risk of an event with high probability if the consequences (damage, or exposure and vulnerability) are small. It should be noted that the risk can never be completely eliminated no matter how many or costly measures are implemented, see Figure 1.2. Instead, the risk will be reduced as shown in Figure 1.3. Furthermore, this relationship suggests that two completely different measures; one lowering probability and one lowering the damage can achieve the same decrease in risk level. In order to support decisions regarding which measure that is the most feasible, a CBA can then be used to compare the benefit of the eliminated risk with the cost of the measure. However, no economic analysis can comprise every single cost and benefit accurately and precisely (Messner et al., 2007). Instead, the CBA should seek to include the most important benefits and costs in order to provide the best possible decision support.

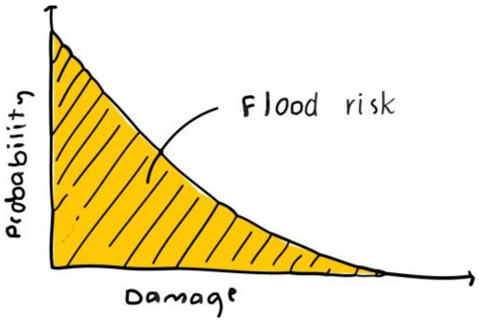

Figure 1.1 Damage-probability curve illustrates the flood risk (the area of the curve)

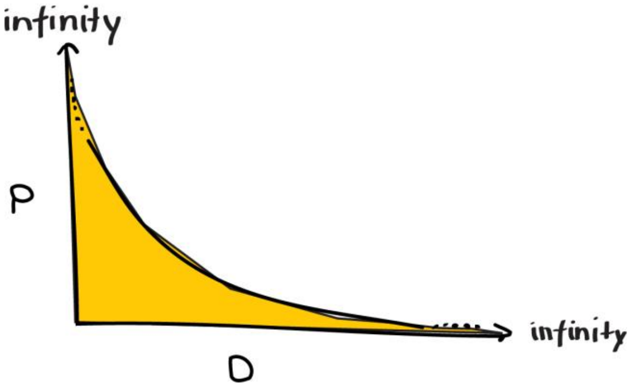

Figure 1.2 Risk can never be completely eliminated

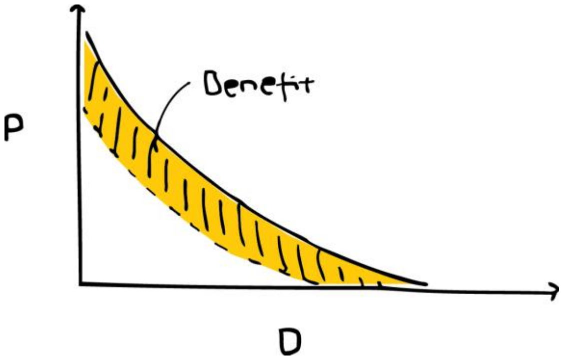

Figure 1.3 Benefit equals reduced flood risk

There is a variety of examples where CBA-methods have been used in flood risk management. However, since climate change adaptation is mostly focused on storm surges and rising water levels in lakes, flood damage is typically assessed by stage-damage functions with flood depth, duration and land use as variables (ten Velhuis & Clemens, 2010). The literature is limited regarding CBA-assessments on pluvial floods (Zhou et al., 2012). Furthermore, existing CBA-methods mostly focus on tangible costs and benefits and little attention has been given to intangible values (Lekuthai & Vongvisessomjai, 2001).

1.1.2. Tangible and intangible damages

Damage cost estimations can be divided into *tangible* and *intangible damages* (Lekuthai & Vongvisessomjai, 2001). Tangible damages refer to damages that can be measured in monetary terms, whereas intangible damages are not possible to express in the same manner since they do not have a related market value[2]. Both the tangible and intangible damages can be further divided into *direct* and *indirect* damages. Direct damages are connected to the direct physical impact, for example of a flood (Messner et al., 2007). Indirect damages, on the other hand, are not a result of actual contact with flood water but rather the damage on a separate, associated activity or item on which a flooding event has secondary impact. The *tangible direct damages* can thus be exemplified as those caused to certain objects, such as buildings (Lekuthai & Vongvisessomjai, 2001). The *tangible indirect damages*, on the other hand, are caused by a disruption to physical and economic linkages, for example interruption of traffic flows, loss of personal income and business profit. *Intangible direct damages* can be exemplified as loss of life, health effects or loss of ecological goods that are hard to monetize but never the less are caused by physical contact with flood water (Messner et al., 2007). *Intangible*

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[2] Market value is defined by the International Valuation Standards Council as "*The estimated amount for which an asset or liability should exchange on the valuation date between a willing buyer and a willing seller in an arm's length transaction, after proper marketing and where the parties had each acted knowledgeably, prudently and without compulsion*" (IVSC, n.d.).

indirect damages include for example traumas on survivors; an effect that is a secondary result of a flooding event for which it is difficult to estimate the economic cost. Table 1.1 presents the typology of flood damages in terms of tangible/intangible and direct/indirect costs with examples.

Table 1.1 Typology of flood damages with examples (Messner et al., 2007)

		Measurement	
		Tangible	*Intangible*
Type of damage	*Direct*	Physical damage to assets: – Buildings – Contents – Infrastructure	– Loss of life – Health effects – Loss of ecological goods
	Indirect	– Loss of industrial production – Traffic disruption – Emergency costs	– Inconvenience of post-flood recovery – Increased vulnerability of survivors

1.1.3. Pluvial inundation in urban environments

Heavy rainfall leading to flooding is a common issue in Sweden that is expected to increase with climate change (SMHI, 2013). There were 200 events of intense precipitation in Sweden between 2009-2011, of which about a hundred led to damages or interruptions of different kinds (MSB, 2013). Flooding can be the result of prolonged rain or short, intense raining (SMHI, 2013). The latter is characterized by a large volume of rain water that fails to infiltrate or drain in time. This leads to an accumulation of rain on the ground surface. Pluvial flooding is common during summertime, and often in urban areas where impervious surfaces obstructs the water from infiltrating. Urban areas can be described to consist of physical elements (roads, buildings and people) and functions (housing, transport, recreation and economic and industrial activity) that constitute the urban system (Stone et al., 2013). . The majority of the economic losses due to flood damage in urban areas are assumed to arise as a result of damages to either of these, e.g. impairment of structures, cost of business shut-down and failure of infrastructure (Jongman et al., 2012). The result is a disturbance in the urban system in terms of physical damages and interruptions in daily life (Stone el al., 2013). Large volumes of water may for example cause problems in drainage systems, leading to sewer overflows and basement floods.

Urban water is divided into storm water, drainage water and wastewater, see Figure 1.4. Storm water is the precipitation that falls on the ground, while drainage water is discharged from the ground. Wastewater is a generic notation for black water and grey water, where black water is from toilets and grey water is from bathing, dishes or laundry. There are two types of sewer systems to take care of urban wastewater: *combined* and *separated* sewer systems. The combined sewer was common in Sweden until the beginning of the 1950's (MSB, 2013). In this system, storm water, drainage water and wastewater is conveyed in the same pipe and there is thus a higher risk of basement flooding in areas with combined sewerage. To relieve the pressure from the system it is common to disconnect large surfaces that produce storm water and instead use basins or sustainable urban design systems. In the separated system, which has been used since the 1950's, the storm water and wastewater is transported in different pipes. Drainage water is normally connected to the wastewater pipes due to levelling.

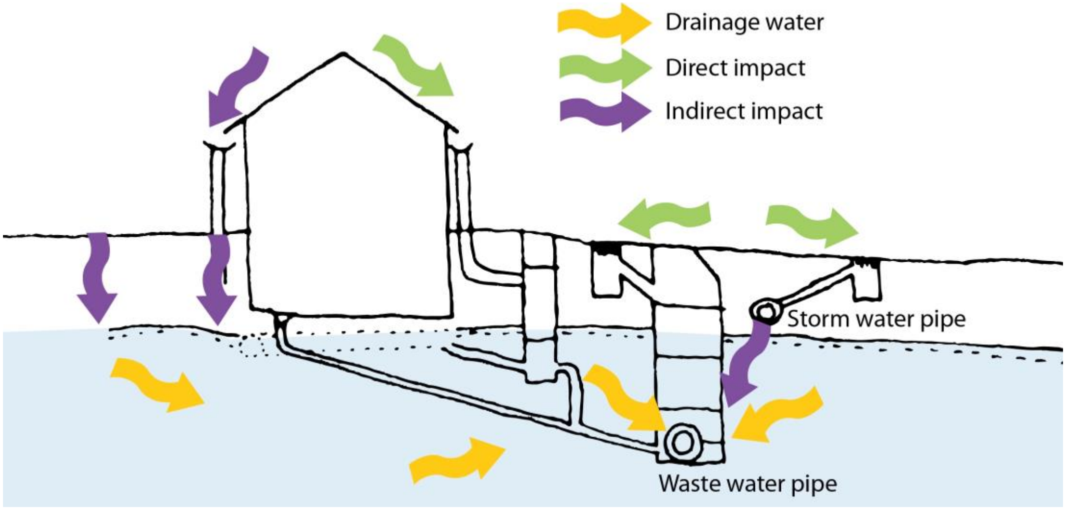

Figure 1.4 Separated sewer system

Pluvial flooding in urban environments occur when rain reaches surfaces with low infiltration capacity; materials such as asphalt, concrete or stone (Ivarsson et al., 2011). Along with urban development, the possibility for the water to naturally infiltrate has gradually been reduced. Instead, water is conveyed through the sewer system. The issues arise when maximum capacity of the system is reached, which has been the result of many rain events during the past decade. Basement flooding and wastewater back flush is one unpleasant, but yet common, example of the consequences of the system limitations. It is important to identify the elements and functions of the urban system in order to make an assessment of the effects of a flooding. However, it is impossible to include all cost aspects in an assessment and therefore it is necessary to make prioritizations of the major cost categories. Furthermore, it should not be forgotten that it is not only the big events, i.e. with low probability, that generate big costs; the sum of many smaller rain events with a higher probability could reach high figures unless the sewer system is able to handle it.

1.2. Aims and objectives

The overall aim of this thesis is to further develop an existing model for cost-benefit analysis (CBA) to be able to assess measures to reduce pluvial flood risks in a Swedish context. The specific objectives of the master thesis include:

- Provide concrete guidance for the estimation of damages of pluvial flooding
- Include soft (intangible) values to achieve a sustainable and accurate decision-making process
- Investigate optimal timing for implementation of measures
- Discuss measures for pluvial flood adaptation and identify additional related societal benefits
- Discuss benefits and disadvantages of using CBA in the context of pluvial flooding
- Provide a basis for continued work on the development of the Sweco model
- Perform two case studies to test and illustrate the updated Sweco model

1.3. Method and thesis outline

This master thesis is carried out in cooperation with a Swedish consultancy company: Sweco Environment AB. The CBA model, which is going to be further developed in this thesis, was developed by the very same company. The thesis is also part of an ongoing research project at Sweco financed by SWWA (Swedish Water & Wastewater Association), where Swedish municipalities and Sweco participate. In this project, one of the aims of which this thesis is a part of, will be to study measures for adaptation and mitigation of pluvial flooding by using cost-benefit analysis.

The current CBA model used by Sweco is described in chapter 2. Through literature studies of both national and international research, methods of damage cost estimations are explored in chapter 3. In order to estimate the benefits of measures studied in a CBA, the damage estimation methods found in the literature review are adapted to be included in the new CBA model, which is presented in chapter 4. Since one of the focuses in this thesis is to highlight intangible values, a number of adaptation measures have been studied in order to demonstrate how to identify and estimate such values. These are presented in chapter 5. Chapter 6 studies the timing of implementation of measures. The final suggestions for updates of the Sweco model are summarized in appendix 2 and finally, two case studies are performed in chapter 7 in order to test and evaluate the developed CBA-model. Discussion and conclusions of the master thesis are presented in chapter 9.

1.4. Delimitations

This project will focus on estimation of effects of measures for pluvial flooding and their related benefits. In order to do so, information on hydraulic and hydrodynamic conditions is necessary, i.e. where the flooding will occur and its characteristics. The means of extracting this information varies depending on the case study site and thus the focus of this thesis is not to produce such material. For the case studies performed this data is provided.

There is no intention to list all available measures to reduce risk of pluvial flooding, as this is highly dependent on local conditions. Some measures will be investigated through case studies in order to exemplify their corresponding benefits.

Two case studies in the municipalities of Staffanstorp and Norrköping are performed in order to test the updates of the CBA model and to give examples of how it is used practically. To be able to perform these case studies within the time limits of the master thesis, their design has been simplified and is based on a number of assumptions (see system boundaries in chapter 7). Since relevant in-data has been provided by involved stakeholders, the quality of the results from the case studies fluctuates accordingly.

The discount rate used for CBA calculations can largely affect the results. There are many recommendations for which rate to use, but this has not been a matter to develop further in this thesis. In the case studies a discount rate of 3.5 % has been used, which is recommended by the Swedish Traffic Administration.

2. THE SWECO CBA MODEL

The ‘*Sweco model’* for cost-benefit analysis consists of a methodology description and a calculation tool developed in Microsoft Excel. In order to make a CBA, some preparatory steps need to be carried out. The method of cost-benefit analysis developed by Sweco (Rosén et al, 2011) follows an eight-step procedure:

1. Hydraulic and/or hydrodynamic modelling
2. Economic evaluation of damage costs
3. Cost-estimation of risks
4. Identification of measures
5. Cost-estimation of measure implementation
6. Reduced risk costs as a result of measure implementation
7. Cost-benefit analysis
8. Prioritization of measures

2.1. Step 1: Hydraulic and hydrodynamic modelling

The first step consists of hydraulic modelling to determine the propagation of a certain flood event. A ‘*flood scenario’* is defined by a specific water level, the associated return period, the level of propagation and the duration. Water levels are calculated based on different water flows and terrain models. Each combination of a flow and water level has a specific return period. An analysis of the water propagation for each water level is carried out in GIS, where flood risk areas and objects can be identified. It is recommended to perform at least three flood scenarios in order to obtain a reasonable approximation of the risk cost.

2.2. Step 2: Economic evaluation of damage costs

In the Sweco model, the damage costs have been divided into three main categories: *direct*, *recovery treatment* (post flood) and *long-term* costs. Direct costs are those generated by maintenance of societal functions and emergency actions. Post flood treatment cost consists of reparation costs or costs to replace and restore damaged buildings, infrastructure, nature etc. to the same function as prior to the flood. Long-term costs are the costs of unrepairable or long-term damages, e.g. to the environment, water supplies, obstructed development or fatalities. A set of indicators to estimate damage costs have been aggregated, see Table 2.1.

Table 2.1 Damage cost indicators (Rosén et al., 2011)

Direct costs	Post-flood treatment costs	Long-term costs
Acute measures	*Residential buildings*	Restrictions in land-use
Revenue costs	Single family houses	Fatalities and physical injuries
Interruption in production	Multi-family houses	Psychological damages
Interruption in sale	*Office-, commercial – and industrial buildings*	*Other*
Loss of income	Offices	
Traffic delays	Commercial buildings	
Road traffic – per person	Industrial buildings	
Railway – per person	*Public buildings*	
Road traffic – per goods	Critical services such as fire station, police station, hospitals and health care	
Railway – per goods	Schools, library, day care, etc.	
Interruption in technical supply/infrastructure	*Other buildings*	
Treatment plant	Garages or storehouses	
Water plant	Cultural heritage	
Compensation interruption water supply	Event buildings	
Compensation interruption electricity supply	*Damage to infrastructure*	
Damage environment/ agriculture	Road (m^2)	
Leaking of contaminated substances	Railway (m)	
Damage to forest	Storm water pipes (m)	
Damage to farmland	District heating pipes (m)	
Water supply	Substation	
Other	Electrical lines (m)	
	Other	

Damage costs are estimated by using a so-called object-based approach, where the number of affected objects is multiplied with the corresponding standard values of the object category (i.e. estimated cost for the specific object category). The standard values in the current Sweco model have been calculated where damage data has been available, e.g. provided by insurance companies or previous experiences within Sweco. The number of objects is obtained from the analysis in Step 1. If a standard value is missing, it has to be estimated specifically for that object, or be omitted from the cost estimation. The total damage cost of a flooding is calculated by summing all objects and their costs. There is often a level of uncertainty regarding both in the calculation of affected objects and the of the damage costs. Therefore, damage costs are represented by an uncertainty distribution, providing the possibility to make a sensitivity analysis.

2.3. Step 3: Cost-estimations of risk

The risk cost is calculated by the following equation:

$$R = P_f C_f \tag{1}$$

where:
P_f = probability of flooding;
C_f = damage cost (SEK).

A total risk can be illustrated as in Figure 2.1, where three flood scenarios have been mapped out. The total risk cost is the sum of all probable flood scenarios and their related damage costs. As mentioned in Step 1, it is recommended that at least three flood scenarios are used.

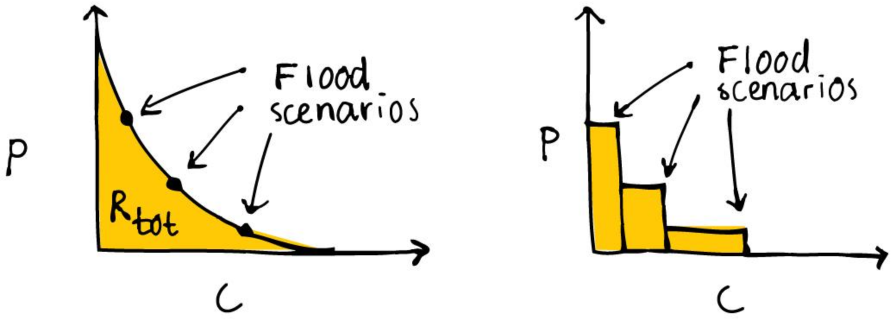

Figure 2.1 Risk as a function of cost and probability (Rosén et al, 2011)

The more flood scenarios that are used, the better the approximation of risk costs. However, calculation of each flood scenario requires an extensive amount of work. The general equation to calculate an approximation of the total risk is:

$$\boldsymbol{R_{tot} = P_{f1}C_{f1} + \sum_{i=2}^{n} P_{fi}(C_{fi} - C_{f(i-1)})} \tag{2}$$

where:
n = number of calculated flood scenarios;
i = 1, 2, 3, …, n.

2.4. Step 4: Identification of measures

The appropriate measure(s) depend on the specific situation. Flood risk can be reduced by both damage preventing and damage reducing measures, which can be permanent, temporary or semi-permanent.

2.5. Step 5: Cost-estimation of measures

Measure costs can be divided into various categories, for example: investment costs, maintenance costs, re-investment costs and additional costs. It is necessary to know the time when each cost is supposed to appear, in order to make an accurate calculation of its present value (see Step 7).

2.6. Step 6: Reduced risk costs

The impacts of chosen measures are analysed through hydraulic and/or hydrodynamic modelling. A new estimation of damaged objects is then used to calculate a new risk cost. The cost is presented in a diagram which shows the risk cost if no action is being taken, and the reduction in risk cost due to implementation of measures, i.e. the benefits.

2.7. Step 7: Cost-benefit analysis

Cost-benefit analysis is used to compare the reduced risk due to measure implementation with the costs of implementing the measures. The probability of a weather event occurring does not change by implementing measures, however, the propagation and related damage cost do. The valuation of impact and related costs is done for each measure alternative $i = 1, 2, 3, \ldots, n$. A new total risk cost ($R_{tot,i}$) is then calculated for each measure. The following equation is used to calculate a ‘target function’:

$$\boldsymbol{NPV_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left[\left(R_{tot,0}(t) - R_{tot,i}(t)\right) - K_i(t)\right]} \qquad \textbf{(3)}$$

where:
r = discount rate;
T = time horizon;
K = cost for implementation and maintenance of measure;
t = year.

A positive result of the target function indicates that the measure is beneficial to the society. ASEK 5 recommends that a discount rate of 3.5 % is used for socio-economic calculations (Trafikverket, 2012), whereas the Stern review recommends a discount rate of 1.4 % for climate change damages (Stern, 2006).

2.8. Step 8: Prioritization of measures

It is possible to calculate which of the studied measures that is the most beneficial. Further, it is possible to study the probability that a specific measure will result in a positive net present value.

2.9. Uncertainty and sensitivity analysis

There are many uncertainties associated with a cost-benefit analysis of flood protection measures. Without reliable in-data, it is impossible to get a full and valid understanding of the actual costs and benefits. The uncertainties associated with each risk or cost variable used in the calculation can be described with statistical uncertainty distributions based on data or expert judgement. The uncertainty distribution in the results (target functions) are then calculated using Monte Carlo[3] simulation, see Figure 2.2.

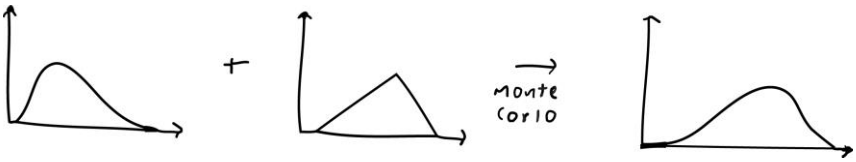

Figure 2.2 Concept of Monte Carlo simulation

To give an example; the following information can be read from an uncertainty distribution of the present value: expected value (the average distribution value), most probable value, mean value (50 percentile), most improbable value (e.g. 5 percentile and 95 percentile), see Figure 2.3.

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[3] Monte Carlo is calculated in the Sweco model (developed in Excel format) with an add-in program called Crystal Ball by Oracle.

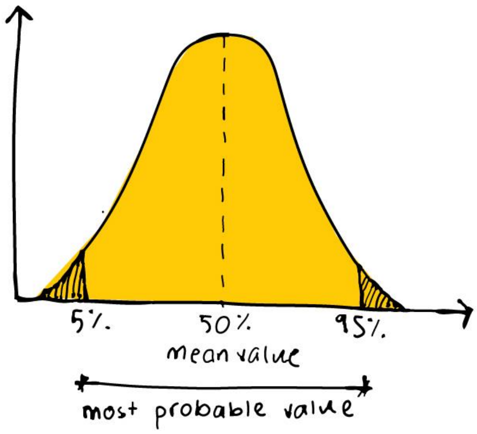

Figure 2.3 Normal distribution with 5 and 95 percentiles

Some variables used in the CBA can be more or less uncertain than others. A sensitivity analysis is used to identify the variables with most impact on the level of uncertainty and provides a possibility to assess which information that could be of interest to evaluate further in order to reach a more accurate result.

3. METHODS OF BENEFIT QUANTIFICATION

The practice of CBA addresses what Hanley & Barbier (2009) call "*the fundamental economic problem: how to allocate scarce resources in the face of unlimited wants*". Other than allowing a comparison of the benefits and costs of a particular action, CBA also allows for ordinary people's preferences to be included in government decision-making. In the following section, a number of methods and approaches to measure benefits (e.g. the reduction in risk cost due to pluvial flood protection) are studied. Experience and knowledge can be gained from international research, even though CBA assessments in the field of pluvial flooding are scarce, conclusions from other studies can also be useful.

3.1. Flood damage evaluation

The reduction in risk cost is calculated from the damages caused by flooding, together with the probability of the event. The nature of the hazard and the vulnerability of the affected part of society decide the severity of the damage.

3.1.1. Area of investigation: macro, meso and micro scale

When choosing the appropriate method for evaluating damages in relation to flood risk, the size of the area investigated should be kept in mind (Messner et al., 2007). Usually three types of spatial scales are identified: *macro*, *meso* and *micro* scale. Macro scale methods are applied to national or international levels and could for example constitute comprehensive flood mitigation policies. Meso scale methods are applied to regional levels and could include large scale flood mitigation strategies. Micro scale methods consider local levels where single protection measures usually are investigated. The smaller the scale the more detailed the precision needs to be. In case of national or regional level damage evaluation, the aim is often to justify allocation of public funding or similar, in which rough estimations of the total amount of damages is often acceptable. However, on micro scale level, such as individual houses, the demand on precision is higher; wrong results might lead to adverse outcomes such as a false sense of security.

3.1.2. Land use data

In order to collect information about the characteristics of assets at risk (e.g. number, location and type of element), land use data is necessary (Messner et al., 2007). This can be obtained by either considering object-oriented data (single properties are identified) or aggregated data (areas of fairly homogenous land use are considered as one entity). When it comes to damage evaluation aiming at a high level of precision, such as micro scale methods, object-oriented data is recommended in order to reach detailed results. An example of categorizing object-oriented data would be to separate buildings between residential and non-residential, and then further divide these two categories into subcategories. However, approximations are surely needed, such as assuming an average size of residential buildings when estimating damage costs.

3.1.3. Flood damage data

After having identified the location, number of objects and type of element at risk, the next step is to quantify their value in order to calculate damages in monetary terms and insert them into a cost-benefit analysis (Messner et al., 2007). First, the value of the elements at risk needs to be identified. There are two types of flood damage data: *empirical* (real flood damage data) and *synthetic* data. When estimating empirical data, the impacts of actual floods are quantified after the floods have occurred. This data is then used as input in models to estimate potential flood damage in another area. One example of empirical data is insurance claims related to flood events. The problem with using this type of data is that it is often biased and estimations of effects are often under or overestimated. Depending on when and how the cost assessment is done; it is likely that the conditions on the historical flood site are different to those of the investigation area. Synthetic data on the other hand, is created by estimating standardized property types. The difficulty in this approach is to ensure that the estimated value correctly represents actual properties as well as all components. To exemplify synthetic data, the value of residential buildings could be estimated by using market prices (as done in the Netherlands) or by using actual sale prices (as done in Germany).

When information about land use, inundation depths and the value of assets at risks have been identified, it is possible to estimate an economical cost for the assets at risk in case of flooding, i.e. how much of its value will each object loose (Messner et al., 2007). One widely used way of estimating this is to assess the objects' susceptibility to different flood levels using depth-damage functions. Several research conclusions show that there is an immense uncertainty connected with the use of depth-damage functions. In Germany, the absolute depth-damage function used derives from a database using 4,000 damage records (Merz et al., 2004). The data is highly inconsistent and the variation cannot be explained by means of the used functions, although the usage of subcategories for assets at risk somewhat improves the estimations. Furthermore, de Moel & Aerts (2011) conclude that the values of elements at risk and depth-damage curves are the main sources of uncertainty in flood damage estimates rather than hydraulic conditions and other parameters.

3.1.4. Social impacts and vulnerability

Yet another way to look at impacts from flooding is from the social point of view (Messner et al., 2007). Social impacts can be the result of both direct and indirect flood effects, such as loss of items with a sentimental value (direct) or stress induced by the flood (indirect). In some cases, social impacts can be more severe and important to victims than the economic loss. The impact of a flood can also be related to the vulnerability of the population in the area. Vulnerability is defined as the degree to which people are more sensitive to suffer harm from hazards than other people. Examples of population groups that are regarded as extra vulnerable could include for example children, those aged 75 years or older, single parents, long term sick and people who do not own a car.

3.2. Methods to assess tangible costs

Depending on the type of asset, different approaches can be used for estimation of tangible values and costs (Messner et al., 2007). The most common approaches are: 1) *market prices*, 2) *construction/reparation costs* or 3) *insurance values*, see Figure 3.1. The former can for example be used for estimation of damage costs to cars, such as the market value of a new car with a linear depreciation[4] added. Construction costs are often used to determine the value of infrastructure, such as streets and railways, which is expressed in cost per metre or square metre. Insurance values are common when determining the value of household goods. As insurance values are used in the Sweco model for assessing buildings, these will be described in more detail below.

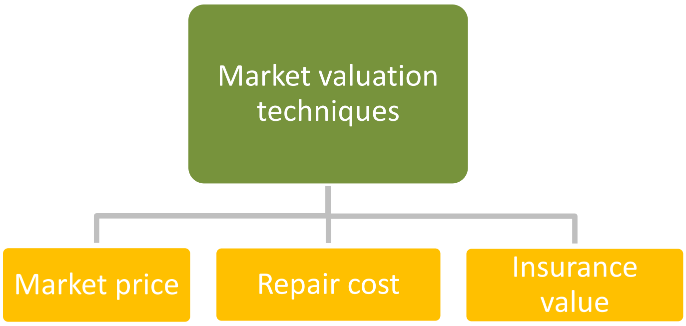

Figure 3.1 Example of approaches to assess asset values

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[4] In terms of a socio-economic perspective, it is appropriate to use depreciated values and not the values of new goods to determine damage costs (Messner et al., 2007).

3.2.1. Insurance values

Insurance values are one way of measuring the cost of damage to buildings and inventory (Zhou et al., 2013a). This method is used in the Sweco model, as mentioned earlier in chapter 2. Insurance companies often hold data on heavy rain events covering several years. This enables a possibility to establish a relationship between flood damage costs and mapping of rainfall extremes, where several parameters are included such as spatial and temporal factors. A study by Zhou et al. (2013a) investigates around 1,000 insurance claims related to direct tangible damages as a result of extreme rainfall events. The purpose of the study was to reflect the flood damage in relation to rainfall characteristics such as damage cost level depending on depth and intensity. Besides from claimed costs, the data used shows geographical location of the properties. The damage claims were divided into cost per claim and daily damage cost, where the latter was obtained by aggregating cost per claim on a daily basis. The data on insurance claims and location were then compared with hydraulic models showing pluvial inundation depth and spatial distribution. For assessment of the hydraulic models, three return periods were used: below 10 years (often), 10-100 years (sometimes) and above 100 years (very unlikely). The result of the comparison showed a clear relationship between the number of insurance claims and probability of flooding in different property locations; in the category *often* 56% had insurance claims, *sometimes* 29% and very *unlikely* 1%. However, when assessing the cost of the claims the correlation was less clear; there seem to be no relation between frequency in flooding and cost per incident. However, the variation in claimed cost per day seems to be more explainable by means of rainfall statistics.

Some problems of using insurance data can be identified. It lacks information about flood depth, details on damage type and house category (Spekkers et al., 2013). Furthermore, Spekkers et al. (2011b) conclude that due to for example privacy, insurance companies are often reluctant to contribute with relevant data.

3.3. Methods to assess intangible costs

Intangible damages due to flooding, such as effects to the environment, human health or cultural heritage, are not possible to valuate using market prices. Instead, there are alternative methods called non-market valuation techniques (Figure 3.2).

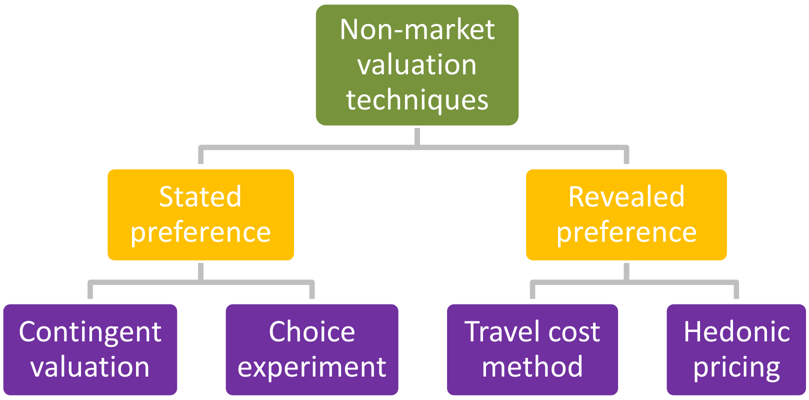

Figure 3.2 Example of methods to assess intangible costs (Armbrecht, 2012)

3.3.1. Stated and revealed preferences

There are two categories of methods to study intangible costs: *stated preferences* (SP) and *revealed preferences* (RP) (Armbrecht, 2012). Stated preferences are expressed by an individual's *willingness to pay* (WTP) or *willingness to accept* (WTA) to achieve or avoid a certain situation (Hanley & Barbier, 2009). Individuals are asked for their preferences by means of open-ended or closed-ended questions (Armbrecht, 2012). Open-ended questions provide an opportunity to freely express thoughts of a subject, while close-ended questions offer options of predefined answers. Revealed preferences are methods that are based on observations of people's behaviour on existing markets (Armbrecht, 2012; Vredin Johansson & Forslund, 2009). Examples of SP methods are contingent valuation (see chapter 3.3.2) and choice experiments (see chapter 3.3.3). Examples of RP methods are travel cost method (see chapter 3.3.5) and hedonic price method (see chapter 3.3.6).

3.3.2. Contingent valuation

The focus of contingent valuation (CV) is to value the 'whole' picture (Hanley & Barbier, 2009). Using this method, it is possible to identify the willingness to pay for a non-market priced product or service (Vredin Johansson & Forslund, 2009). The concept is to construct a hypothetical market where an individual is supposed to share their preferences for a product or service (Armbrecht, 2012). The method has three criteria of implementation: 1) a clear description of the circumstances, 2) questions that reveal the individual's WTP and 3) questions of the socio-economic background of the respondent. The main criticism against the CV method is that respondents either overestimates or underestimates their WTP of the hypothetical scenario compared to a real situation.

3.3.3. Choice experiments

Choice experiments (CE) focuses on the value of the 'parts' (Hanley & Barbier, 2009). In this method, the respondent is asked to prioritize or choose amongst different options. The data is then statistically assessed in order to evaluate the product or service (Vredin Johansson & Forslund, 2009).

3.3.4. Conjoint analysis

Another method that is less used, but nevertheless has potential, is the conjoint analysis. It gives the respondent alternatives of scenarios to choose from (Messner et al., 2007). Table 3.1 illustrates option A and option B where the respondent's answer illustrates the WTP for increased flood protection and proximity to green areas. The technique has the advantage that it does not address the issue of who pays, as the CV method does.

Table 3.1 A hypothetic choice of conjoint analysis (Messner et al., 2007)

	A	B
Risk of flooding	1 in 10	1 in 200
Monthly housing cost	600 euros	1,000 euros
Number of bedrooms	3	2
Proximity to park	1 kilometre	100 metres

3.3.5. Travel cost method

The travel cost method (TCM) has mostly been used to assess outdoor recreational values, such as bathing, fishing or kayaking (Hanley & Barbier, 2009). The method is based on using travel costs as a measure of the price for recreation, which is obtained through calculation of both monetary expenses (also called 'out-of-pocket' costs such as fuel costs) as well as the time costs of travelling. There are two basic types of TCM's: one is focusing on developing a relationship between the number of visitors to a particular site and the travel costs they have in making the visits. The second type of TCM, which has much in common with the CE method, focuses on how recreationalists choose which place to visit from a number of options. Basically, the first approach aims to answer the question 'how many trips?', while the second approach seeks answer to 'where to go?'. The latter site choice model depends on the characteristics of a recreational site.

3.3.6. Hedonic price valuation

The hedonic valuation method is used to monetize intangible parameters such as natural amenity values (Gibbons et al., 2014), the effect of cultural heritage (Lazrak et al., 2014) or green areas (Morancho, 2003) by observing their effect on the market value of for example housings. The aim of hedonic valuation is to identify relationships between intangible qualities and marketed goods in order to measure benefits of changes in the environment (Hanley & Barbier, 2009). Examples of this kind of relationships are property price decline by every given percent of increase in decibel levels (noise) or decrease in nearby woodland cover.

One of the problems faced using hedonic price valuation includes market segmentation: it can be difficult to assess the spatial size of the market that is investigated, e.g. if an entire city can be considered to apply to the identified relationships or only the close proximity (Hanley & Barbier, 2009). Furthermore, the method assumes that buyers and sellers are well informed about the characteristics related to all housing locations in the area considered. Also, the method excludes non-use values; for example the amenity value of a green park will only be seen as a benefit due to the direct user through price increase of a house in the neighbourhood. It will not estimate for example altruistic values such as the appreciation of knowing that one’s child is attending school close to a park. One advantage compared to other methods is that it is based on data on actual behaviour, unlike for example WTP.

3.3.7. Value transfer

The aim of value transfer is to transfer results from one ‘survey’ context to a new ‘policy’ context and thereby avoiding the need for new valuation surveys each time a new policy question appears. There are two common approaches of benefit transfer: simple transfer of mean values and transferral of value functions (Brouwer & Bateman, 2004). Value function transfer is used in England when evaluating the economic values of ecosystem services. The variables in the functions include for example distance and availability of substitutes (Brander et al., 2008).

3.3.8. Value of a statistical life and value of a life year

There are two main concepts of valuating risk to human health according to Hanley & Barbier (2009): the value of a statistical life (VOSL) and the value of a life year (VOLY). A statistical life shows people’s WTP for taking a risk reducing measure to save a life (Vredin Johansson & Forslund, 2009). A statistical life is not equal to the value of a life or a certain individual. For example: a population of 10,000 inhabitants knows that one person dies each year due to a certain risk that can be eliminated. If each one of the inhabitants is willing to pay 100 SEK to eliminate the risk, then the willingness to pay to save a life is 1 million SEK. The recommended VOSL in Sweden stated by the traffic administration is 31 MSEK (Trafikverket, 2012), see chapter 4.8 for more information.

3.3.9. Quality Adjusted Life Year and Disability Adjusted Life Year

The quality adjusted life year (QALY) method considers, as opposed to VOLY, the quality of a saved life (Vredin Johansson & Forslund, 2009). This means that it is possible to differentiate between a healthy life year and a sick life year. One reason of using QALY is that WTP to save a life may differ depending on the quality of the saved life. Disability adjusted life year (DALY) is focusing on the level of disability an individual has. Both methods are, however, hard to estimate. It can for example be difficult in term of ethics to valuate a perfectly healthy life compared to a disabled life.

4. DAMAGE COST ESTIMATION

The following chapter describes how to assess damage costs in order to quantify the reduced risk a measure provides and thus benefits to the society. Cost categories (see bullet list below) have been selected in accordance with the focus of this thesis: inundation in an urban context. The categories are based on the eleven types of *critical societal functions* described by the Swedish Civil Contingencies Agency (MSB, 2014).

- Housing
- Vehicles
- Technical infrastructure (wastewater and drinking water)
- Transport (passenger and freight)
- Energy supply
- Industry and commercial
- Health care, education and emergency services
- Human health
- Cultural heritage

Urban environments are vulnerable to pluvial flooding. As mentioned in chapter 1.1.3, hard surfaces prevent storm water to naturally infiltrate; it accumulates in local depressions such as viaducts, which for example may lead to large traffic jams. The complexity of the urban system is likely to result in various damages and interruptions that are difficult to predict. The selected cost categories are believed to stand for the largest damages of flooding in urban context, but it is likely that important aspects may not have been considered. Environmental assets are not classified as an individual cost category; instead the secondary effect is included in the total cost of the estimation of each category. For example, the cost of sewer overflow on ecosystems is included in technical infrastructure. In this chapter, the cost categories are described with methods and standard values summarized from a number of studies estimating damage costs of each category. These are compared, assessed and adapted in order to be implemented into the updated Sweco model. In some categories, due to unacceptable degree of uncertainty or lack of data, it might not be possible to incorporate each cost category in an ideal way and some methods will therefore be omitted.

4.1. Housing

As mentioned in chapter 3, the most significant tangible cost category is regarded to be housings and the inventories. Depth-damage functions can be used to estimate the magnitude of the cost of each flooded building where input values could be market or sales prices. However, as stated in chapter 3, depth-damage functions often show a wide range of results and are frequently deemed as unreliable. Stone et al. (2013) also supports this theory and has therefore suggested a different and simpler approach. In the function below, the average values for damage of building structure and content are multiplied with the number of affected buildings and then summed to obtain the total damage cost. The assessment is thereby made on an object-based basis.

$$COST_{building} = CV_i \times NUM_{build,i} + BV_i \times NUM_{build,i} \qquad \textbf{(4)}$$

where:

$COST_{building}$ = Total damage to building of type i including content damage (€);
CV_i = Average content damage for building type i (€);
BV_i = Average damage for building type i (€).
$NUM_{build,i}$ = Number of flooded buildings of type i;

As input values for average damage, Stone et al. (2013) mentions two types of values: estimated data and empirical data from insurance claims. Values have been obtained from studies regarding housing in the Netherlands and are listed in Table 4.1.

Table 4.1 Average values for housing (Stone et al., 2013)

	Estimated average value (€, 2012)	Average insurance claim per client (€, 2012) [Standard deviation]
Apartment	121,000	-
Family home	202,000	-
Content	-	935 [476]
Property	-	1406 [663]

The current Sweco model is using the same method as Stone et al. (2013); the input values for cost of structures and contents are combined and derived from insurance claim statistics, see Table 4.2. Housing is divided into single family and multi-family housing and the estimation of flooded properties is done by means of flood maps derived from hydraulic modelling.

Table 4.2 Standard values used in the Sweco model (Sweco, 2011a)

Damage category	Standard value
Single-family housing	32,495 SEK
Content assets	17,843 SEK
Multi-family housing	122,859 SEK
Content assets	17,843 SEK/ household

As a comparison to the Sweco insurance data, the Swedish climate and vulnerability assessment presented following average cost figures: 50,000 SEK/property in Göteborg and 5,000-15,000 SEK/property in combined sewer areas in Malmö (SOU, 2007). Furthermore, a study from the Netherlands (Messner et al., 2007) approximates the full value of household goods per flat to 70,000 EUR (year 2000) with aggregated insurance data as source. In other countries the approach is very different, for example in German studies an average value per square metre of living area is estimated to be either 700 EUR (full replacement value) or 350 EUR (depreciated value). The Dutch and German values could be used in cost estimations where damage functions are applied in order to identify the ratio of inventory that is damaged in case of flooding. However, as previously mentioned, depth-damage functions are not recommended to use in a CBA.

Conclusion

Standard values vary significantly, but it is considered that the insurance values from Sweden are most appropriate to use in this study since they display local conditions and are results of actual events. In the new Sweco model, cost for structure and contents will however be separated since some measures, such as warning systems, may lead to reduced damages to building contents and therefore benefits will be easier to estimate.

4.1.1. Basement floods

Floods in basements can occur when wastewater sewers are loaded with storm water (MSB, 2013). The issue often occurs when water finds its way into the basement through floor drains at a low elevation. Other places of entry for the water can also be through garage doors where the pavement is connected to the street. If water would enter a basement the only way to remove it is through floor drains or by pumps. This in turn causes problems for the downstream neighbour and can result in flooding for several houses in the same area.

Conclusion

In the insurance values used in the current Sweco model, it is not possible to identify which claims that are a result of basement flooding, although it is likely that these are a large part of the damage costs.

Therefore the same standard values will be used for houses regardless if they suffer from basement or surface flooding.

4.2. Vehicles

Damage to vehicles often makes up a significant portion of the total value of assets susceptible to risk (Messner et al., 2007). There is a distinction between commercial and private vehicles and as the former are normally included in the businesses fixed assets. Private cars must therefore be evaluated separately. It is common to use market values for estimations of damage costs of cars, as was mentioned in chapter 3. One method is to recalculate the market value of new cars with an assumed linear depreciation of the car value. Messner et al. (2007) presents an approximate value of 9,700 EUR (2000 year price level). It is also possible to use the market price of used cars, but it must be considered that second hand prices are diverted away from perfect market prices and will lead to a very approximate estimation of the car's real value. According to the Swedish statistical bureau, the average car in Sweden is worth 50,000 SEK (Jansson, 2000). In another report from 2007, the most common car in Sweden is a Volvo V70 from 2000 (SCB, 2007). The same model, but from 2002, is worth approximately 37,000 SEK[5] (2014 year price level). In the HAZUS model used in the United States, the direct damage to vehicles is estimated using relationships between water depth and damage (see Table 4.3).

Table 4.3 Depth-damage relationships of vehicles (FEMA, n.d.)

Flood level	Car	Light truck	Heavy truck	% of damage
Below carpet	< 0.5 m	< 0.8 m	< 1.5 m	15%
Between carpet & dashboard	0.5 – 0.7 m	0.8 – 1.1 m	1.5 – 2.3 m	60%
Above dashboard	> 0.7 m	> 1.1 m	> 2.3 m	100%

Conclusion

Vehicles will be included as a new parameter in the updated Sweco model. In order to estimate the number of vehicles that will be damaged it is assumed that each Swedish household owns 1.07 cars, based on 4,492,604[6] cars in use divided by 4,176,313[7] households. The number of affected cars will thus be identified by the number of flooded properties. Furthermore, the depth-damage relationships provided by the Federal Emergency Management Agency (FEMA, n.d.) will be used to determine the level of damage to the car. These figures will then be multiplied with an average car value of 50,000 SEK (Jansson, 2000). No account will be taken to when the flood occurs; night and day is not separated. Neither will large parking lots, e.g. in industrial areas or outside supermarket, be assessed; the standard value is only valid for residential areas.

4.3. Technical infrastructure

Technical infrastructure refers to water management including both wastewater and drinking water. These are important functions in a society; an eventual disruption may cause severe consequences. See chapter 1.1.3 for further information about water management.

4.3.1. Wastewater

Intense precipitation may, as earlier mentioned, increase the risk of flooding (SOU, 2007). It stresses main systems for water and sewage that eventually may result in discharges and overflows. This

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[5] Value of cars can be derived from http://www.bilsvar.se/

[6] Number of cars in use February 2014 (http://www.trafa.se/statistik)

[7] Number of households in Sweden 2012 (http://www.scb.se)

section deals with damages related to this type of events. Damages to pipes and sewer overflow in properties are treated in chapter 4.1. This separation is used as damages to pipe systems in the property are included in the insurance figures.

4.3.1.1. Sewer overflow

In Sweden, the general requirement is that urban drainage systems should be designed to cope with rainfall events with return period of 10 years (SWWA, 2004). As mentioned in chapter 1.1.3, flooding in urban environments often results in overload in the sewer system leading to overflows. There is a difference between *hydraulic overflow* and *emergency overflow* (Bengtsson Sjörs, 2014). Sewer overflow commonly refers to overflow caused by high pressure in the pipe system, so-called hydraulic overload. Overflow due to disruption, rebuilding or maintenance work in the pipe system or pump station is called emergency overflow. The main issue with overflows is that the release of contaminated water poses a risk to both human health and the environment since it allows contaminants in sewer water to be released into the recipient without any treatment. Health risks related to sewer overflow will be assessed in chapter 4.8.3.

Environmental damages

Sewage overflow is an important matter from an environmental perspective; it can for example lead to serious consequences if wastewater is released in proximity to a raw water source or central parts of urban development (Miljösamverkan, 2013). Further, it contributes to eutrophication. The European Water Framework Directive, implemented in Sweden by the regulation of quality on water environments (SFS 2004:660), aims to provide a common approach to achieve and protect *good ecological status* or *good chemical status* of the water bodies in European Member States (EC, 2014).

The quality of the water that is released during overflow depend on how diluted the wastewater is and what kind of water that is connected to the pipe system (Bengtsson Sjörs, 2014). Common contents associated with wastewater are bacteria, biochemical oxygen demand (BOD), suspended substances, phosphorus (P) and nitrogen (N). In order to assess the effects of overflow it is necessary to determine its volume and level of contaminants. Standard values of contamination levels can be calculated based on recorded levels in wastewater or recorded levels in the overflow water in the wastewater treatment plant (WWTP), see Table 4.4 and Table 4.5.

Table 4.4 Calculating levels of contamination in overflow water (Bengtsson Sjörs, 2014)

Calculating level of contamination in emergency overflow	
Option 1: Level of contamination = 100 % of recorded contamination level in receiving wastewater to WWTP	Option 2: Level of contamination = theoretical mean wastewater flow/ flow in the hydraulic system in the beginning of the overflow. The theoretical mean wastewater flow is calculated from charged water consumption.
Calculating level of contamination in hydraulic overflow	
Option 1: Level of contamination in the overflow at the WWTP (annual average)	Option 2: (Same as Option 2 above)

Table 4.5 Example of calculation of theoretical standard mean value of P in wastewater (Bengtsson Sjörs, 2014)

An area of 500 inhabitants living in 170 single-family houses is charged 25,000 m^3/ year for drinking water. This corresponds to approximately 68.5 m^3/day or 0.8 l/s. The specific standard value level (P_{tot}) is 2.1 g/person and day (Naturvårdsverket, 1995). The mean wastewater flow is assumed to be equal to the charged water. Overflow is assumed to begin at a flow rate of 20 l/s.

$$P_{tot}\ in\ mean\ waste\ water\ flow = \frac{2.1 \cdot 500 \cdot 365}{25\ 000} = 15\ mg/l$$

$$Dilution\ factor = \frac{Flow\ when\ overflow\ begins}{Mean\ waste\ water\ flow} = \frac{20}{0.8} = 25$$

$$P_{tot}\ in\ overflow\ water\ flow\ (annual\ mean) = \frac{15}{25} = 0.6\ mg/l$$

Table 4.6 Summary of approaches for assessment of contamination levels in overflow water (Bengtsson Sjörs, 2014)

	Proportion of wastewater in the overflow water	Recorded standard mean value of contaminants	Theoretical standard mean value	Increased amount of contamination (particle-bound) during first flush[d]
Hydraulic overflow	7-15%[a]	Level in overflow water at WWTP[d]	See Table 4.5	100-200%
Emergency overflow	100%	100% of receiving levels to WWTP	P_{tot}= 2.1 g/pd[b] N_{tot}=13.5 g/pd[b]	-

[a] Results from several modelled scenarios. First flush is not included.

[b] Specific amounts of contamination expressed in gram per person and day (Naturvårdsverket, 1995).

[c] First flush refers to the first 30 min during the overflow.

[d] Some municipalities assume that overflow water contains 20-25% of contamination levels of incoming wastewater to WWTP.

Eutrophication

Overflow water mainly affects the recipient by: oxygen consumption, toxic substances, bacteria and nutrients (Bengtsson Sjörs, 2014). Nitrogen and phosphorus are the primary contributors to eutrophication. The nutrient load can be calculated for each point/source of overflow. Data on volume of overflow at each point (m^3/year), as well as calculated or assumed level of contamination in the water, are needed for the assessment. In order to assess the economic impact of nutrient load from overflow, the cost per load of compound discharged into a receiving water body can be used. One Swedish study concludes values for both nitrogen and phosphorus emissions in SEK per kilograms (Ahlroth, 2007). The study is performed using travel cost method and contingent valuation in order to estimate the willingness to pay (see chapter 3.3) for a non-eutrophicated Baltic Sea. Using this information, monetary data of the cost of emitting phosphorus and nitrogen separately could be obtained since the degree of contribution to eutrophication differs between the two substances. In the study the values are also applied to freshwater. A eutrophicated lake or river is in general not very appealing to people since it renders fish death, algae bloom, high turbidity and overgrowth. However, Swedish lakes and rivers are phosphorus limited and therefore nitrogen does not contribute to eutrophication. The estimate of WTP per kilo of phosphorus emitted to a freshwater body is 2,400 SEK. It should be observed that this value depends on the type of recipient and several other factors such as available substitutes. Considering an example of an area with several polluted lakes, the community around it is more likely to value the clean-up of the first lake higher than the clean-up of the second one (Brander et al.,2008). This is because the first lake becomes a substitute for the second, and since the economic limits of the user might have been reached after cleaning the first lake.

Table 4.7 Cost of reducing eutrophication (Ahlroth, 2007)

Category	Compound	Cost SEK/kg (2005)
Eutrophication of freshwater	Phosphorus	2,400
Eutrophication of sea	Phosphorus	470
Eutrophication of sea	Nitrogen	60

Contamination in storm water

Storm water contains various contaminants harmful to health and environment (Alm et al., 2010). It also contains phosphorus and nitrogen. The average standard values vary depending on literature but one study in Lund in southern Sweden uses average values of total nitrogen 3.15 mg/l and total phosphorus 0.25 mg/l (Czemiel Berndtsson & Bengtsson, 2006).

Conclusion

It is of interest to account for the environmental damages, since it affects a resource for the society and thus complies with the aim of a CBA (to value the impact on societal welfare). It is also a matter of sustainable development as environmental damages is an issue regarding future perspectives. In the updated Sweco model hydraulic overflow will be the issue of most interest. In cases where overflow contaminant levels are measured such values should be used. Otherwise, if there are records of contaminant levels in the overflow water at the WWTP those values can be used as contamination level for any overflow spot on the study site. Else, a theoretical standard mean value can be calculated as in Table 4.5. However, this requires information about drinking water consumption and flow just before the overflow starts. If this data is not available, the assumption that overflow water contains 20-25 % of the contaminant level at the incoming water at the WWTP should be applied. The current Sweco model does not include sewer overflow or flooding of wastewater treatment plants. In the updated model, the values presented in Table 4.7 together with the methods for estimating amounts of contaminants emitted when overflow occurs will be used in cases where feasible, i.e. such as when water bodies considered of interest to the public concerned. No studies monetizing the emission of substances other than nitrogen and phosphorus have been found.

4.3.1.2. Water treatment cost

When storm water from intense precipitation enters the wastewater system other results than flooding and overflow are to be expected. One that can be implemented into the CBA is the additional associated costs related to an increase in water volume that needs to be treated. The price of treating wastewater varies throughout Sweden; in the Gothenburg region, the price for treating wastewater is 5.17 SEK/m^3 (Gryyab, n.d.) whereas Käppala WWTP in Stockholm treats the water for 2-3 SEK/m^3 (Käppala, n.d.).

Conclusion

Whenever rain water is diverted into the wastewater system a cost will arise due to the additional treatment volume in the WWTP. In this study 5 SEK will be used as a standard value for each additional cubic metre that needs to be treated due to precipitation.

4.3.2. Drinking water supply

Drinking water is extracted from raw water sources and pumped to water purification plants for treatment. If a water purification plant is damaged, contaminated or of some reason closed down, additional cost such as of loss of income, potential cleaning costs or reparation costs might appear. The identification of affected water purification plants can be carried out through hydraulic modelling. The water from the purification plant is approximately used as follows (SWWA, n.d.): 10 % for industry, 10 % public use such as schools and hospitals, 20 % within the purification plant and leakages and 60 % in households. The average price for water is 0.025 SEK/litre. In a study by Tyréns (2009), drinking water shortage was simulated in two Swedish hypothetical municipalities, named A and B. The characteristics are presented in Table 4.8.

Table 4.8 Characteristics of typical municipalities (Tyréns, 2009)

	Municipality A	Municipality B
Number of inhabitants	20,000	60,000
Housing	5,000 in multi-family housing 15,000 in single-family housing	20,000 in multi-family housing 40,000 in single-family housing
Water supply	18,000 connected to municipal water and sewage systems	55,000 connected to municipal water and sewage systems
Heating	10,000 connected to district heating	30,000 connected to district heating
Health care	2 care centres 1 public dentist 6 private dentists 4 elderly care homes	1 emergency hospital 4 care centres 2 public dentist 30 private dentists 10 elderly care homes
Education	25 pre-schools 25 elementary schools	75 pre-schools 40 elementary schools High schools
Commercial	15 grocery stores 1 smaller suburb centre 20 restaurants	25 grocery stores 2 bigger suburb centres 40 restaurants
Industry	2 smaller industries dependent on water	2 process industries 4 smaller industries dependent on water 1 combined power and heating plant

Three scenarios were simulated in total: 1) a total interruption in water supply, 2) contaminated water and 3) water containing water borne disease. The costs generated by each scenario are presented in Table 4.9.

Table 4.9 Scenario simulations of water supply shortage (Tyréns, 2009)

	Costs without water cooking recommendations	Costs with water cooking recommendations
Scenario 1: Municipality A	7 MSEK	37 MSEK
Scenario 2: Municipality B	80 MSEK	160 MSEK
	Cost in municipality A	**Cost in municipality B**
Scenario 2 + 3:	136 MSEK	415 MSEK

There is an example from the Swedish municipality of Tjörn where the quality of the drinking water was insufficient for more than three months (Tjörns kommun, 2012). The inhabitants were compensated with 1,000 SEK/household by the municipality. Distributed over a period of approximately 100 days, this corresponds to a value of 10 SEK/household and day. For the municipality, the total cost for the event reached 3 MSEK. This cost included 1 MSEK for distribution of bottled water, 1 MSEK for water and sewage works including pipes, fire hydrants, rent of machines, 0.4 MSEK for labour, 0.4 MSEK in compensations and 0.2 MSEK for analyses of the water.

Conclusion

Drinking water has not been considered in the current Sweco model, but it is a parameter that is relevant in cade of flooding, e.g. in terms of flooded purification plant or impact on water quality through seepage in pipes. If there is a reason to expect that a water purification plant needs to close down, the loss in production for the plant could be estimated as follows, where 0.6 is the volume of municipal water that goes to households (SWWA, n.d.) and 0.025 is the cost per litre water produced (SWWA, n.d.):

$$Loss\ of\ income = 0.6 \cdot 0.025\ \cdot total\ production\ volume \cdot duration \quad \textbf{(5)}$$

Additional damage or cleaning costs of the purification plant in case the plant is contaminated has not been assessed; there are no indications that pluvial flooding could cause such damages. Potential flood to a raw water source will not be treated in the updated Sweco model; it is assumed to be of low probability that contamination occurs as a result of pluvial flooding. If such a scenario would occur, it is generally possible to obtain water from either a backup water source or a backup purification plant (SWWA, n.d.). Compensations for insufficient water supply should be included in the calculations as an attempt to measure people's discomfort (equation 6). Here, the value of 10 SEK/day and household that was given at Tjörn is seen as an appropriate value.

$$Compensation = 10 \cdot duration \cdot number\ of\ affected\ households \quad \textbf{(6)}$$

Other possible costs such as distribution of bottled water and necessary work to restore the drinking water supply have not been assessed. The values from Tyréns (2009) could be used as standard values if the studied area has similar characteristics as the hypothetical municipalities. It should however be noted that these values are associated with substantial uncertainties. Further, the standard values of scenario 2+3 should not be used in the Sweco model since these values include health aspects, which are assessed separately and therefore would result in double-counting of costs.

4.4. Transport

Flooding of streets and railways can cause physical damages and interruptions in both passenger and freight traffic.

4.4.1. Physical damage costs of roads and railways

Physical damages to roads and railways can generate significant costs. Studies have been made of possible costs of a landslide to parts of road E45 (SGI, 2011a). Restoration costs used in the study are 12 MSEK/100 metre E-route road and 1 MSEK/100 metre municipal road (2010 price level). The former Swedish Road Administration (Vägverket) used 800-1,000 SEK/m^2 to estimate restoration costs of flooded state roads (SOU, 2006). The average restoration cost for railway was estimated to 20,000 SEK/metre. This figure was determined by the Swedish Rail Administration, which used damage costs from the flooding in Arvika in 2000-2001 as a basis of evaluation for damage costs. According to their study, the restoration costs were estimated to range between 10-200 MSEK depending on the water depth and duration. However, some sources argue that infrastructure is not sensitive to flooding (Messner et al., 2007). On the other hand, a study of climate effects on Swedish railways conducted by Lindgren et al. (2009) states that flooding is considered a major threat to the railway system and that high water levels caused by intensive precipitation can cause severe damages. Increased precipitation can affect the ground stability as well as cause failures in drainage system.

In a flood risk analysis of the municipality of Karlstad conducted by Sweco VIAK in 2006, a standard value of 500 SEK/m^2 was used for quick calculations of the cost to construct new roads (Sweco VIAK, 2006). This figure was seen as a lower indication of the actual cost, since damaged roads may also consist of additional structures such as road ducts or bridges. Therefore, a few assumptions were added to the standard value in the assessment of Karlstad, including:

- The road width had a mean value of 6,1 m
- The road was flushed away or undermined at 20 locations; each damaged location being 30 m in distance
- 20% of the total road construction at these locations, or 6 m per damage, needs to be rebuilt to a cost double the standard value (2*500 SEK/m^2)
- Remaining 80% of the locations, or 24 m per damage, needs to be renovated to a cost half of the standard value (250 SEK/m^2)

The corresponding standard value for railways was set to 15,000 SEK/m for new construction of railway. Rail embankments are believed to be more robust than road structures, thereby causing fewer damages. Following assumptions was made in the calculations for Karlstad:

- Railway is flushed away or undermined at 5 locations, each location being 30 m in distance
- 20% of the total rail structure, or 6 m, needs to be reconstructed with a doubled cost of the standard value (2*15,000 SEK/m)
- The remaining 80%, or 24 m, needs to be renovated to a cost half the standard value (7,500 SEK/m)

In the Sweco model, the standard values of damages have been set to 1,000 SEK/m^2 and 12,000 SEK/m for roads and railways respectively (Sweco, 2011a). These standard values have never been used in any risk assessments by Sweco due to the difficulties to determine potential damages.

Conclusion

It is difficult to attain reliable standard values for flooded roads and railways since the structures vary in design (e.g. the road ducts that is assumed to have the highest cost). Further, there is little knowledge of the structures resistance to flooding. Current values for damages to roads and railways stated in the Sweco model (1,000 SEK/m^2 and 12,000 SEK/m) will be maintained, with a notion to use it cautiously.

4.4.2. Interruption in passenger traffic

Flooded roads and railways cause interruption in passenger traffic. Interruptions is estimated in terms of extended travel time, which can be monetized by loss of production and peoples WTP to avoid being late. A national study of traffic delay values has been conducted by WSP (2010). This study has been the basis for ASEK 5[8]'s recommendations for calculating the value of travel time. The study builds upon stated preference surveys (see chapter 3.3.1) amongst travellers, where the travel time value has been interpreted as the value of a shortened travel time (Trafikverket, 2012). This value has, in terms of passenger travels, been divided into private regional travels (less than 100 km) and private long travels (more than 100 km). ASEK 5 recommends that the following criteria should be used to estimate travel cost:

- Travel time uncertainty (standard deviation) = 0.9 x the travel time value
- Average delay value = 3.5 x the travel time value
- Value of congestions = 1.5 x the travel time value

Table 4.10 and Table 4.11 presents recommended time values for private traffic for short-term and long-term socio-economic calculations respectively. Table 4.12 presents the time values for work travels.

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[8] A group working with socio-economic calculations and analyses within the transport sector at the Swedish Transport Administration

Table 4.10 Time values for traffic delay: private travels for short-term socio-economic calculations (2010 years price level) (Trafikverket, 2012)

	Car and air (SEK/h)	**Bus (SEK/h)**	**Train (SEK/h)**
Long travels			
Travel time	*108*	*39*	*73*
Travel time uncertainty	**0.9** * 108 = 97	-	-
Average delay time	**3.5** * 108 = 378	**3.5** * 39 = 137	**3.5** * 73 = 256
Time of traffic congestions	**1.5** * 108 = 162	-	-
Regional travels			
Travel time	Work: *87* Other: *59*	Work: *53* Other: *33*	Work: *69* Other: *53*
Travel time uncertainty	**0.9** * 87 = 78 **0.9** * 59 = 53	-	-
Average delay time	**3.5** * 87 = 305 **3.5** * 59 = 207	**3.5** * 53 = 186 **3.5** * 39 = 137	**3.5** * 69 = 242 **3.5** * 53 = 186
Time of traffic congestions	**1.5** * 87 = 131 **1.5** * 59 = 86	-	-

Table 4.11 Time values for traffic delay: private travels for long-term socio-economic calculations (2010 years price level) (Trafikverket, 2012)

	Car and air (SEK/km)	**Bus (SEK/km)**	**Train (SEK/km)**
Long travels			
Travel time	*145*	*52*	*98*
Travel time uncertainty	**0.9** * 145 = 131	-	-
Average delay time	**3.5** * 145 = 508	**3.5** * 52 = 182	**3.5** * 98 = 343
Time of traffic congestions	**1.5** * 145 = 218	-	-
Regional travels			
Travel time	Work: *117* Other: *78*	Work: *71* Other: *44*	Work: *92* Other: *71*
Travel time uncertainty	**0.9** * 117 = 105 **0.9** * 78 = 70	-	-
Average delay time	**3.5** * 117 = 410 **3.5** * 78 = 273	**3.5** * 71 = 249 **3.4** * 44 = 150	**3.5** * 92 = 322 **3.5** * 71 = 249
Time of traffic congestions	**1.5** * 117 = 176 **1.5** * 78 = 117	-	-

Table 4.12 Time values for traffic delays: work travels (2010 years price level) (Trafikverket, 2012)

	Car and air (SEK/km)	Train (SEK/km)	Bus (SEK/km)
Values for short-term socio-economic calculations			
Normal travel time	*291*	*247*	*291*
Travel time uncertainty	**0.9** * 291 = 262	-	-
Average delay time	**3.5** * 291 = 1,019	**3.5** * 247 = 865	**3.5** * 291 = 1,019
Time of traffic congestions	**1.5** * 291 = 437	-	-
Values for long-term socio-economic calculations			
Normal travel time	*390*	*331*	*390*
Travel time uncertainty	**0.9** * 390 = 351	-	-
Average delay time	**3.5** * 390 = 1,365	**3.5** * 331 = 1,159	**3.5** * 390 = 1,365
Time of traffic congestions	**1.5** * 390 = 585	-	-

There are also recommendations of time travel values for bicycles, see Table 4.13. Average bicycle speed of 15 km/h is used as a standard value on all types of bicycle paths.

Table 4.13 Time values for bicycle travels (2010 years price level) (Trafikverket, 2012)

	Time values (SEK/h)
Short-term planning	
Mixed traffic	150
Bicycle path in road	135
Bicycle path on the side of a road	125
Bicycle path	120
Long-term planning	
Mixed traffic	201
Bicycle path in road	181
Bicycle path on the side of a road	168
Bicycle path	161

Other costs related to interruption in passenger traffic besides from those deriving from stated preferences could also be relevant. For example, when an industry or a house is completely cut off due to a flooded road, various serious consequences could arise such as rescue personnel being unable to reach people in need and complete stagnation in production. No methods for estimating such costs have been identified.

Conclusion

Identification of flooded roads is carried out through hydraulic modelling. In order to estimate the total cost of traffic delays due to flooded roads, it is necessary to determine the additional time needed for taking an alternative route. This requires information on both traffic flows and alternative routes, which can only be obtain through detailed studies for each flooded road. Regarding ASEK 5's recommended time value factors to add to the time values, a suggestion is to use the travel time uncertainty (standard deviation) and average delay factors but not the factor for traffic congestions, since it is uncertain to assume whether or not there will be any congestion. The time delay values differ significantly between private travels and work travels. It could be assumed that travels in peak hour in the morning are mainly represented by travellers on their way to work. This aspect will not be considered in the CBA model since the time a flood event occurs will not be assessed. Bicycle traffic will not be included in the model; this aspect is assumed to be more relevant in for example traffic analysis and planning rather than occasional flooding.

4.4.3. Interruption in freight transport

This sections deals with freight transport by road and rail.

4.4.3.1. Freight transport by road

Freight time values, expressed in SEK per tonne hour, can be used to calculate interruptions in freight transport on roads (Trafikverket, 2012). The values are based on product values (SEK/tonne) multiplied with the factors for: a) cost of capital 20 %, b) the logistic system that is assumed to be available 3,600 h/year and c) the logistic factor 2 as an indicator of logistical benefits due to shorter transport times. Total freight time values for all product categories of SAMGODS[9] and STAN[10] are presented in Table 4.14. Specific freight time values to each product category are referred to Trafikverket (2012). According to ASEK 5, the recommendation for calculating the delay values (SEK/ hour) of freight transport is to multiply freight time values by a factor 2.

Table 4.14 Freight time values (Trafikverket, 2012)

Product groups	Freight time values 2010 (SEK/tonne hour)	Delay values 2010 (SEK/tonne hour)
SAMGODS	1.62	3.24
STAN	1.62	3.24

The freight time values are separated between truck transports with or without a trailer and private car in duty, see Table 4.15.

Table 4.15 Freight time value per transport (Trafikverket, 2012)

Transport	Freight time value 2010 (SEK/vehicle hour)	Delay values 2010 (SEK/vehicle hour)
Truck with trailer	45	90
Truck without trailer	10	20
Private car in duty	4	8

4.4.3.2. Freight transport by rail

Costs for interruption in freight transport by rail are calculated on the same basis as transport by road using freight time values (Trafikverket, 2012).

Conclusion

The recommended values recommended by ASEK 5 should be used to calculate interruptions in freight transport. Transport by rail is unfortunately dependent on information about the average cargo weight, information that today is difficult to find (VTI, 2012). According to a study of freight transports in Sweden, there is no data of cargo weights on neither regional nor municipal level.

4.5. Energy supply

In Sweden, the electricity distribution has three levels: the high tension network distribution of approximately 400 kV, the regional network of 130-20 kV, and the local networks of 230 V (Svensk Energi, n.d.a). The electricity is transformed in substations between each level. It is unlikely to obtain damages in the electricity network due to pluvial flooding (Stone et al., 2013). Substations, on the

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[9] Swedish national model for freight transport

[10] Software for strategic planning of national and regional freight transportation, http://www.inro.ca/en/products/stan/index.php

other hand, are normally located on street level and are at risk of flooding. The damages to substations can be estimated by calculating the total cost to replace it (Stone et al., 2013). SGI (2011a) estimated following damages costs to energy supply, see Table 4.16.

Table 4.16 Damage costs on energy supply (SGI, 2011a)

Power lines/ voltage	**Estimated cost per 100 m new installations**
12 kV (high voltage)	70,000 SEK
400 V (low voltage supply pipe)	70,000 SEK
400 V (low voltage transmission lines)	50,000 SEK
Substation/ voltage	**Estimated price for new construction**
Small substation for distribution (a neighbourhood block or residential area)	500,000-1,000,000 SEK
Substation 40/10 kV (supply for a smaller community)	15,000,000-20,000,000 SEK
Substation 130 kV (supply for a larger community or industry)	50,000,000 SEK
District heating	**Prices for new installations**
Pipes[a]	2,500 SEK/m
Culvert	5,000 SEK/m
Excavation	10,000 SEK/m

[a] (SOU,2007)

In the Sweco model, standard values have been given for a substation: 10,000-500,000 SEK in material for the substation and 7,500-300,000 SEK in labour costs (Sweco, 2011a). Further, a damaged substation will also cause energy outage for households and industries connected to the specific substation.

4.5.1. Compensations to loss of electricity

According to the electricity regulation (SFS 1997:857), the consumer has the right to acquire compensation for electricity outage if the outage exceeds 24 hours (Svensk Energi, n.d.b). This is normally 12.5 % of the yearly cost, but at least 900 SEK. Then, the compensation will increase based on duration of the outage. However, if the reason for electricity shortage is beyond the control of the network owner, e.g. due to a natural hazard, this requirement is no longer valid. Nevertheless, even if the consumer cannot achieve any compensation, an electricity outage may still generate additional indirect costs. Industries may need to shut down their production, perishable goods may be destroyed or people might need to leave their homes in the middle of the winter (Stone et al., 2013). An electricity outage may therefore cause production losses, material damages and disruption of daily life and leisure time. In the Netherlands, a household is entitled to compensation during electricity outages. After the first four hour, the compensation is 35 EUR, which include damages to content of freezer and refrigerator. For each additional periods of four hour, the households acquire an additional 20 EUR for experienced inconvenience. Even if these values are requirements for the electricity producers in the Netherlands, they could be interpreted as the average value of loss for households during outages; 35 EUR for contents in refrigerators and freezers, and that 20 EUR worth of discomfort for every additional period of four hours.

Conclusion

Loss of production specifically due to energy outage will not be treated as there is a risk of double-counting. Even though there is no requirement for the electricity producers in Sweden to compensate for electricity outages due to flooding. Considering that the CBA model is used for Swedish conditions, the compensation values that the consumer is entitled to in Sweden could be the most appropriate. But, the values that are used in the Netherlands are also a measurement of the socio-economic loss and more importantly, they consider an earlier stage of the outage. Therefore, the values from the Netherlands are found to be better for estimation of damaged perishable goods and discomfort. The standard values for physical damage on substation in the current Sweco model will remain in use.

4.6. Industry and commercial

In this section, the damage loss to industries and commercial business has been divided into physical damages and loss of production.

4.6.1. Physical damage to property and assets

Industries and commercial businesses contain many kinds of assets such as: property, inventory, machinery, equipment, products and goods. The asset values vary extensively with the type of economic activity. Therefore, it is reasonable to estimate damage costs based on types of activity at risk (Seifert et al., 2010). Damage to industry and commercial buildings are identified by hydraulic modelling. In the current Sweco model, standard values for industrial and commercial buildings have been calculated based on insurance values. The standard values are presented in Table 4.17.

Table 4.17 Standard values in the Sweco model, based on insurance values (Sweco, 2011a)

Damage category	Cost
Office building (property)	122,857 SEK
Commercial building (businesses + property)	224,310 SEK
Industry (industry + property)	278,287 SEK

As mentioned before, there is an argument to assess the different types of assets separately; not only does the cost vary between different types of assets but also the susceptibility (Seifert et al., 2010). Some fixed assets may not be possible to move during a flood, while other assets such as products are possible to secure. Through literature study, Seifert et al. (2010) have distinguished five different approaches to quantify damage costs to industry and commerce:

1. A method for determining the building asset value for a chosen building occupancy is to multiply the total floor size of a building occupancy with the building replacement costs per square foot. This has been done for 16 types of building occupancies in the industrial and commercial sector in the US (Seifert et al., 2010). In order to assess damage costs, depreciated values are used instead of full replacement costs. The inventory assets are estimated as a fixed percentage of the building asset value (see Table 4.18).

Table 4.18 Contents value as percentage of structure value (FEMA, n.d.)

Building occupancy		Contents value (%)
Commercial	Retail trade	100
	Wholesale trade	100
	Personal and repair services	100
	Professional/ technical/ business services	100
	Banks	100
	Hospital	150
	Medical office/ clinic	150
	Entertainment & recreation	100
	Theatres	100
	Parking	50
Industrial	Heavy	150
	Light	150
	Food/ drugs/ chemicals	150
	Metal/Minerals processing	150
	High technology	150
	Construction	100

2. In Japan, unit economic values were calculated for different elements at risk (Seifert et al., 2010). Eight types of non-residential objects were distinguished. In order to monetize properties and inventories, the number of workers per type was multiplied by unit prices per worker and type.

Table 4.19 Economic values for industrial properties and inventories in Japan (Dutta et al., 2003)

Type of industry	Property value/employee (MYEN 2003)	Stock value/employee (MYEN 2003)
Mining	8.16	1.91
Construction	1.98	6.61
Production	5.18	3.69
Electricity/ gas/ water	129.87	1.87
Whole sale & retail sale	2.41	2.9
Finance & insurance	5.72	0.64
Real estate	26.05	34.54
Service	5.72	0.64
Government	5.72	0.64

3. In Australia, the damage to industrials was determined by their relation to a medium-sized family house using replacement ratios calculated by Seifert et al. (2010):

$$Relation\ ratio = \frac{Cost\ ratio \cdot Floor\ area}{Floor\ area\ of\ a\ medium\text{–}sized\ family\ house} \qquad \textbf{(7)}$$

Relation ratios are then used to calculate damage as house equivalents by multiplying the relation ratio with a central damage value. The latter is a factor ranging between 0 and 1 and is used to distinguish the level of damage (Blong, n.d.). The house equivalents are multiplied with the asset value of a medium-sized family house, which is AUD\$800/m^2. This method only treats buildings and not any content such as machinery or inventory.

4. One German example is where a fixed ratio of 8 % of the gross stock of fixed assets is used to estimate the inventory of four types of economic activities (Seifert et al., 2010). This method has been further developed to use number of employees and net stock of fixed assets at

replacement costs as in-data. Value of content assets was calculated for five economic activities using a percentage rate of the net stock of fixed assets at replacement costs.

5. Another German study calculated asset value per square metre for five types of economic activities: agriculture, energy and water supply, manufacturing industry with construction, trade and service, transport and communication (Seifert et al., 2010).

As previously mentioned, Seifert et al. (2010) have evaluated these methods and found strengths and weaknesses. The American method identifies various economic activities, but is questionable regarding spatial distribution of damages. The Japanese and the German methods distinguish few economic activity categories. The Australian method does not consider inventories. Furthermore, only one of these methods, number 4, is questioning its applicability.

The department of natural resources and mines in Queensland, Australia, has developed guidance on the assessment of tangible flood damages (NRM, 2002). For commercial properties, it is recommended to use depth-damage relationships. Depth-damage curves can either be created based on local conditions or from previous flood damage studies. The method to assess the damages consists of five steps:

1. *Identification of affected properties through flood hazard mapping*

2. *Selection of appropriate stage-damage curves*
   Commercial properties are differentiated by three size categories: small property < 186 m^2; medium property: 186-650 m^2; and large property: > 650 m^2. The content assets within each commercial property size category are evaluated by classes ranging from one to five, Table 4.20 and Figure 4.1.

Table 4.20 Stage-damage relationships for commercial properties (NRM, 2002)

	Value class	0 m	0.25 m	0.75 m	1.25 m	1.75 m	2 m
Small commercial properties (<186m^2)	**1**	$0	$2,202	$5,506	$8,258	$9,176	$9,726
	2	$0	$4,405	$11,011	$16,518	$18,352	$19,454
	3	$0	$8,809	$22,023	$33,034	$36,705	$38,907
	4	$0	$17,618	$44,046	$66,069	$73,410	$77,814
	5	$0	$35,237	$88,092	$132,137	$146,819	$155,628
Medium commercial properties (186-650m^2)	**1**	$0	$6,975	$16,884	$25,693	$28,445	$30,281
	2	$0	$13,948	$33,768	$51,387	$56,893	$60,564
	3	$0	$27,896	$67,537	$102,773	$113,785	$121,126
	4	$0	$55,791	$135,074	$205,574	$227,570	$242,252
	5	$0	$111,583	$270,147	$411,094	$455,140	$484,504
Large commercial properties (>650m2)[a]	**1**	$0	$7	$39	$81	$132	$159
	2	$0	$15	$78	$162	$267	$318
	3	$0	$32	$154	$326	$533	$636
	4	$0	$61	$308	$649	$1,065	$1,272
	5	$0	$122	$619	$1,297	$2,129	$2,545

[a] Units of USD per m^2

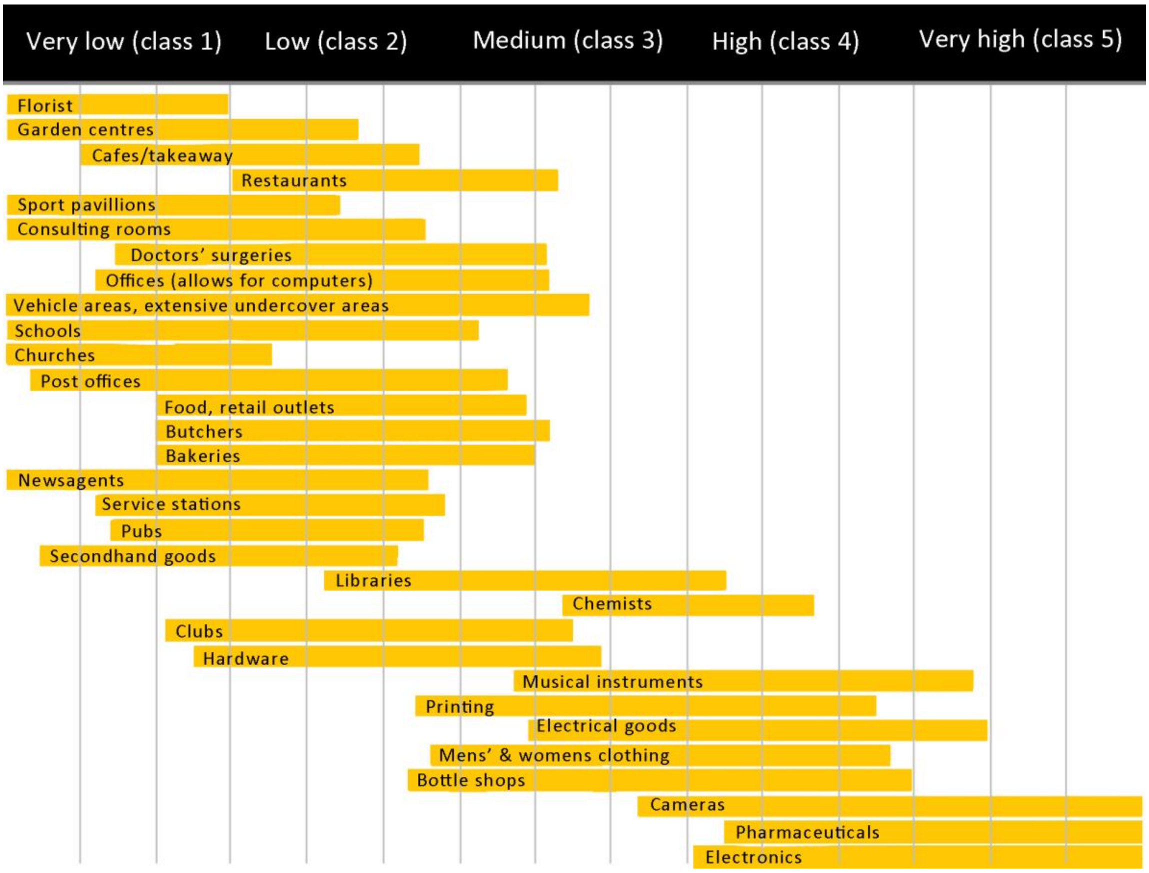

Figure 4.1 Damage categories for commercial properties (NRM, 2002)

3. *Estimation of direct damages by application of stage-damage curve*
   The likelihood of the building structure to fail due to flooding is studied. This requires information on the flood depth and velocity. Figure 4.2 can be used as a guide of the need to consider depth and velocity. If there is a risk of structural damages, then the damage estimation should include cost of replacing both the building and the contents. If not, it is enough to apply the depth-damage curve to estimate potential damage.

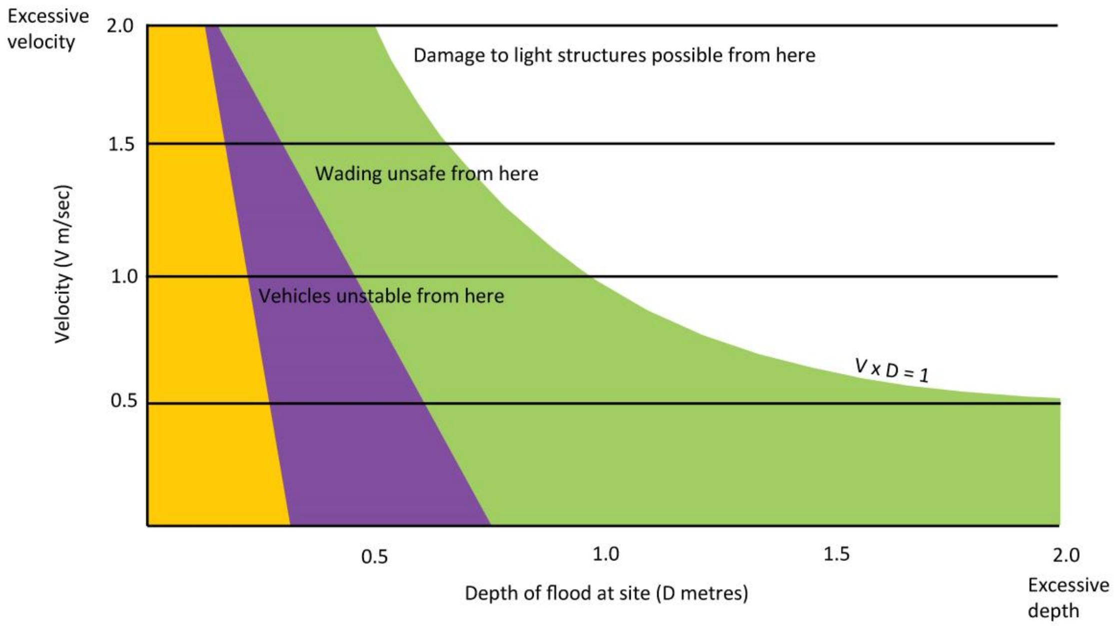

Figure 4.2 Critical depth-velocity relationship (NRM, 2002)

4. *Estimation of indirect losses*
   The indirect losses of commercial assets (in this case: loss of production, extra expenditure, clean-up costs, reduced wages, non-provision of public services) are estimated to 55 % of direct commercial damages.

5. *Calculation of total damages*
   The total cost of damages is the sum of direct and indirect damages.

Conclusion

When reviewing literature of methods for assessing damage to industrial and commercial assets, no best-practice method has yet been identified. Five different approaches were distinguished in a literature review by Seifert et al. (2010). The first approach was to use the floor size of a building occupancy and to multiply it with a cost per area and a factor. This approach is difficult to include in current CBA-model since a separate study is necessary to decide standard values for the different types of occupancies. The second approach from Japan using unit prices per employee and type of business can be integrated to the Sweco model, but there is a level of uncertainty connected with translating values from a market that may differ from Sweden. The third approach with relation ratios from a study in Australia is discarded of the same reason. The two German approaches depend on market values, which as for the first approach needs further studies that have not been possible to conduct within this master thesis. Finally, another example of an approach to assess industrial assets was given by NRM (2002), which suggested a division into size and type of activity. This method seems interesting as long as it can be used for object-based assessments instead of depth-damage assessments. To conclude, it seems reasonable to continue using insurance values in the Sweco model at this point.

4.6.2. Loss of production

If a business or commercial building is flooded it is reasonable to assume that production might get interrupted leading to economic losses. Similarly, if a road leading to the business gets flooded and its workers therefore cannot reach their workplace, or if a power outage due to flooding shuts down the production, economic losses might occur. The current Sweco model uses a standard value of 193,933 SEK/industry (Sweco, 2011a) to determine loss of production, which has been calculated based on insurance values. Stone et al. (2013) uses the following function to estimate the cost of business interruption:

$$COST_{Bus,i,j} = (D_{flood} + D_{clean,i,j} - D_{minBus,i,j}) \times DAM_{Bus,i,j} \times AMOUNT_{Bus,i} \ , \qquad \textbf{(8)}$$

where:
$COST_{Bus,i,j}$ = Total damage due to business interruption (€);
D_{flood} = Duration of the actual flooding (h);
$D_{clean,i,j}$ = Time required to clean-up, restore and restart for business of type i (h);
$D_{minBus,i,j}$ = Minimal time at which business of type i starts to encounter damages (h);
$DAM_{Bus,i,j}$ = Average damages per hour for business interruption of type i (€/h);
$AMOUNT_{Bus,i}$ = Number of affected businesses of type i.

The classification of business types (i), can be made in various ways, such as size of business, profits or number of employees. As for the clean-up time, it is assumed that this action can only start once the flood water has drained away. The study does not provide times for clean-up, but states that according to surveys 75 % of municipalities suffering from flooding report that the flood hindrance duration is less than one hour (Stone et al., 2013). No information about minimal time at which a business starts to encounter damages is available. When estimating the average damages per hour it is assumed that one hour of interruption corresponds to one hour of profit (although mentioned that this can cause overestimations since the flooding might only affect business on ground floor). The study performed by Stone et al. (2013) has extracted numbers on hourly profit depending on business type using data obtained from The Dutch Central Bureau for Statistics (CBS), see Table 4.21.

Table 4.21 Average business results, 2010 year price level (Stone et al., 2013)

Business branch	Average business profit per company per day (€/day)	Average business profit per company per hour[a] (€/h)
Industry	1082.02	45.08
Energy supply	17,063.61	710.98
Drinking water companies and water treatment	2,533.39	105.5
Construction industry	163.66	6.82
Trade	376.37	15.68
Transport and storage	504.77	21.03
Hotel and catering	136.40	5.68
Information and communication	472.09	19.67

[a] The average business profit per company hour assumes that the business is active 24 h a day. For industry, the profit for one day would thus correspond to 24*45.08=1,082.02 EUR. If the industry is open 8 h a day, then the hourly profit would be 1,082.02/8=135.25 EUR.

Based on interviews with seven companies, Tyréns (2009) made estimations of loss of production, see Table 4.22. The figures are based on interruption costs in case a companies need to shut down due to stop in water supply.

Table 4.22 Costs due to loss of production (Tyréns, 2009)

Type of activity	Loss of production
Small industry	15,000 SEK/day
Process industry	600,000 SEK/day
Grocery store	50,000 SEK/day
Supermarket	500,000 SEK/day
Restaurant	20,000 SEK/day

4.6.2.1. Quantification of business interruptions and recovery

One way of measuring business interruptions is by using *full-day equivalents lost (FDEL)* (Burrus et al., 2002). This method has been used in a study of hurricane impacts on regional economic activity, but it is not limited to only one type of natural hazard. This evaluation method of business interruption is based on surveys with affected businesses. The formula, see equation 9, is based on four levels of normal operations: 25, 50, 75 and 100%. These values are converted to decimal form named P_j, where j = 1, …, 4.

$$FDEL_i = (1.25 - P_1) \cdot D_{i,1} + \sum_{j=2}^{4} (1.25 - P_j) \cdot max(0, D_{i,j} - D_{i,j-1}) \quad \textbf{(9)}$$

where:
$D_{i,j}$ = number of days reported by the respondent i that are necessary in order to reach the percentage of normal operations j. Table 4.23 gives an example of how FDEL can be used.

Table 4.23 Example of FDEL

A company i has reported that it takes 4, 6, 8 and 10 days to return to 25, 50, 75 and 100% of normal operations, respectively. This means that the company is completely shut down for four days (four FDEL's), operates at 25% for next two days (1.5 additional FDEL's), operates at 50 % of normal operations for the next two days (one additional FDEL) and operates at 75% of normal operations for the final two days of business interruption (0.5 additional FDEL's). The sum of FDEL's equals 7 days.

Conclusion

The Sweco value of production loss provides one single standard value for all types of industries and commercial. This value cannot be seen as reliable to represent all these different economic activities. The method for calculating production loss presented by Stone et al. (2013) may seem suitable theoretically. However, the calculation builds upon in-data that can be difficult to find. The standard values provided from the study by Tyréns (2009) might be applicable in a Swedish context, even though the values are estimated on the assumption that the interruption is due to water shortage, since the reason for interruption is of no relevance. The method of using FDEL's to estimate business interruptions can be used in detailed studies, e.g. if there is one significant business which is willing to provide required information needed for the assessment. The updated Sweco model will use standard values of insurance claims for industries as before, but updated with standard values for grocery stores, supermarkets and restaurants presented by Tyréns.

4.7. Health care, education and emergency services

This section assesses a collection of interruptions in important societal services: health care, education and emergency services (here pumping of water).

4.7.1. Health care and hospitals

The study conducted by Tyréns (2009) also deals with potential interruptions in emergency hospitals, dentists and care centres. These cost parameters are expected to arise as a result of contaminated drinking water supply.

Table 4.24 Damage costs to health care and hospitals (Tyréns, 2009)

Object	Cost
Big emergency hospital[a]	9,000,000 SEK/day
Care centre	90,000 SEK/day
Public dentist	52,300 SEK/day
Private dentist	20,000 SEK/day

[a] *Based on the yearly revenue of a big hospital in Stockholm. Most likely, small floods will not have an impact to this extent. Therefore, this value should be used with caution.*

Conclusion

The standard values presented by Tyréns (2009) are based on revenues. A study of people's WTP to protect these services may result in different values. The new Sweco model will use the data from Tyréns (2009), since no values were previously provided in these categories.

4.7.2. Education

In case a school or pre-school is shut down, one parent may need to stay home from work with the child (Tyréns, 2009).

Conclusion

In case a school or pre-school appears to be flooded in the hazard maps, it is assumed that one parent needs to stay home per child under 12 years old. The cost for a parent to stay home is estimated to 1,500 SEK/person and day (Tyréns, 2009). Försäkringskassan, the Swedish Social Insurance Agency, requires that only one parent stays home regardless the number of children in the family. Therefore, the cost estimation of home staying parents can be further detailed if contact is made with the specific school to acquire information on number of parents.

4.7.3. Emergency services

The most significant cost parameter associated with emergency response as a result of inundation events is assumed to be pumping of water, e.g. water accumulated in basements or local depressions. This action is usually performed by the rescue services in Swedish municipalities and therefore arises as a cost in addition to that of the physical damage on property. Internationally, such as in the Netherlands, the authority in charge of pumping flooded basements is the fire brigade. In a study performed by Stone et al. (2013) the cost for the fire brigade assistance is used as the basis for estimating the total cost of emergency responses in relation to flooding events. The equation used for estimation of the cost is the following:

$$COST_{FBAss} = (AMOUNT_{FloodBuild} \times COST_{EmAss}) + (AMOUNT_{FloodPB} \times COST_{EmAss}) \quad \textbf{(10)}$$

where:
$COST_{FBAss}$ = Total cost of emergency assistance by the fire brigade (€);
$AMOUNT_{FloodBuild}$ = The number of flooded buildings with basements;
$COST_{EmAss}$ = Cost per turn-out emergency assistance by fire brigade (€);
$AMOUNT_{FloodPB}$ = The number of flooded roads and public spaces.

The cost estimated for the turn-out of the fire brigade is expected to be €1,000 (Stone et al., 2013).

According to Swedish regulations, the purpose of the rescue services is managing accidents and risk of accidents in order to limit damage to humans, property or the environment (SFS 2003:778). According to experiences from a former Chief Fire Officer in Gothenburg, this means in terms of flooding of basements that as long as the water level is increasing the rescue services will assist in pumping at the cost of the municipality, since the risk of further damage to property is still threatening (Alexandersson, 2014). However, as soon as the water levels are not increasing anymore, no more damage is expected to arise immediately and the rescue services will only assist pumping out water in exchange for a fee (called residual pumping cost), see Table 4.25 Residual pumping cost (Gustafsson, 2014). This cost will be compensated by the insurance company if the house owner is insured, and otherwise by the house owner in question. Normally, the house owner pays a deductible fee that usually ranges between 1,500-10,000 SEK (Gustafsson, 2014). It takes approximately four man hours to pump a single family basement using one pump, which will result in a cost of 2,931 SEK. This value is however very uncertain, as it depends on a number of case specific factors.

Table 4.25 Residual pumping cost (Gustafsson, 2014)

Service	Cost
Basic fee	583 SEK
Operating fee	513 SEK/man hour
Pump	á 296 SEK

As mentioned in chapter 4.1, the current Sweco model uses insurance records in order to estimate the average cost per flooded residential building. Thus, in cases where the rescue services were summoned after the water level had stopped increasing, the cost of pumping is included in the insurance claim value. In other cases, the municipality paid for the cost of pumping. Data from past events may be used to estimate this cost.

Conclusion

The cost for emergency services in terms of pumping of enclosed flood water is separated between private or municipal properties. At present, the only cost estimation that is available is the one provided by Gustafsson (2014), which is an approximate cost for the rescue service to pump basements when water has stopped rising. This cost is assumed to be included in property insurance values and therefore it is not possible to account for cost of pumping on private properties. However, if hydraulic modelling shows that municipal properties with significant value will be flooded (e.g. main roads) a suggestion is to use the same value to estimate the cost of pumping. It should be observed that these standard values do not consider the events such as limitation in amount of staff and available pumps.

4.8. Human health

Impacts on human health due to flooding can be a high cost to society; flooding can cause both structural and functional damages on important societal services, which in turn can affect the water and electricity supply, wastewater management, traffic and health care (SOU, 2007). This could further lead to hindered emergency response, unsecure electricity and increased risk of fire or even increased risk of traffic accidents by aquaplaning and fallen trees. There is a high level of uncertainty concerning consequences of flood to human health (Vredin Johansson & Forslund, 2009). The reasons for this are many: lack in research of links between exposure and response, partly due to the difficulties to assess the links since human health depends on many complex factors and, not the least, people’s ability to respond and adapt to climate changes. Further, the health effects can range between direct and short-term effects to more long-term impact (Caldin & Murray, 2012). Health assessments related to flooding can be defined by: scientific thresholds (water depth, duration and flooded area), population effects (medical, social and economic disruption to normal life and number of deaths or people affected) and temporal health perspective (immediate, short-term and long-term effects). Obviously, there are many ways of categorizing health effects of flooding. One separation used by Caldin & Murray (2012) distinguishes *immediate effects*, which are directly caused by the flood, and *post flood effects* related to exposure to flood water, clean-up process and mental health effects. In the same manner as with damage to objects, health effects can be further divided into *direct* and *indirect* effects, where the direct effects occur due to contact with flood water, and indirect effects include impacts on health due to damage on infrastructure, food and water supplies. Effects on human health can also be divided into type of impacts: mortality, injury, infection, chemical hazard, vector borne diseases, mental health, impacts on vulnerable groups and impact on health services (Caldin & Murray, 2012; EC, n.d.). Further, there are three phases in which a flood event can be categorized: *pre-impact*, *impact* and *post-impact*. By doing so, it is possible to make a separation between the flood disaster and the potentially associated impacts (Jonkman & Kelman, 2005). In addition to the division of health impacts that occur in immediate or post flood event, the health impacts may also appear by *short-term effects* (such as injury) or *long-term effects* (such as mental health) (Caldin & Murray, 2012). Examples of possible health impacts caused by flooding are shown in Figure 4.3.

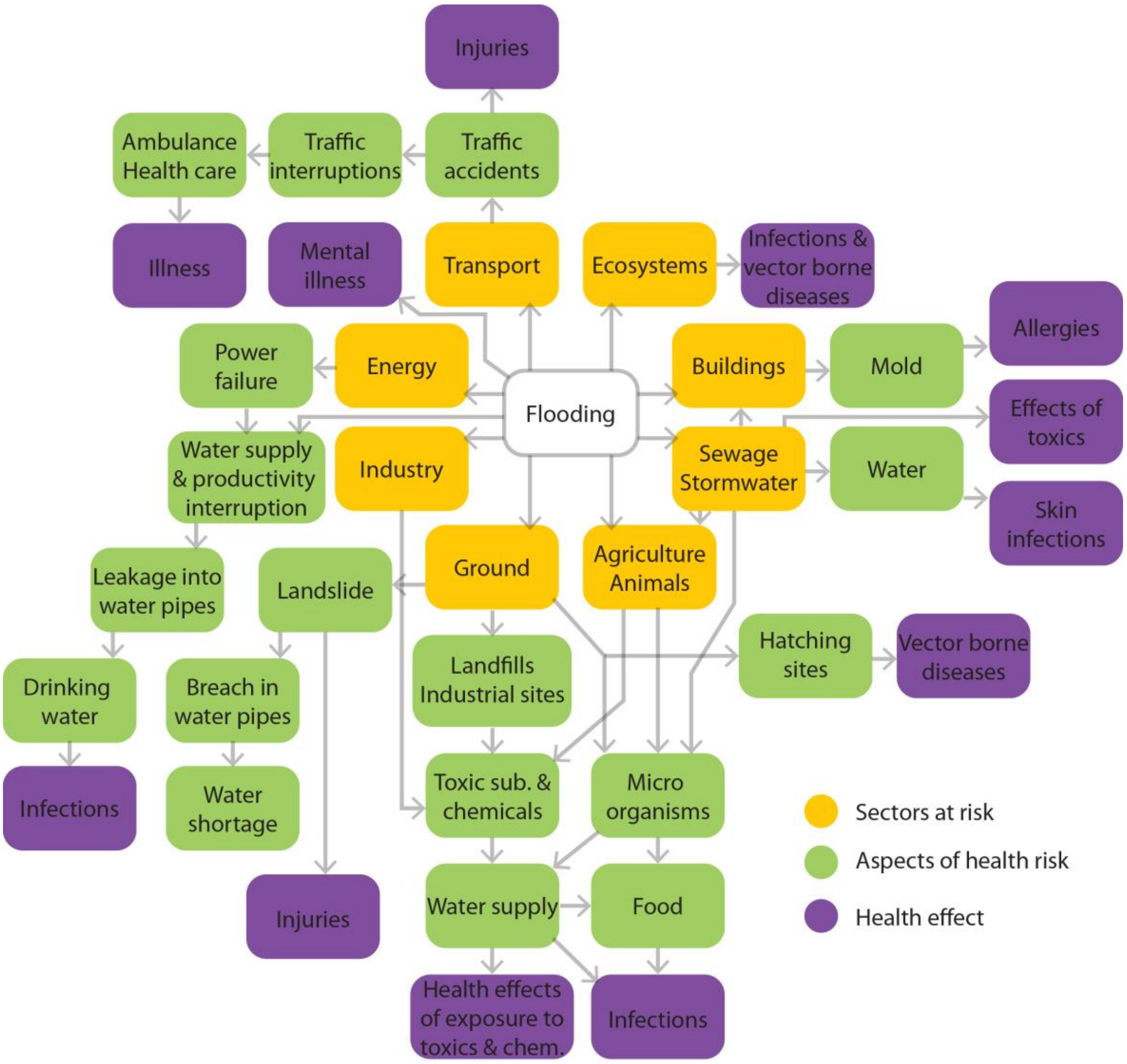

Figure 4.3 Possible direct and indirect health effects due to flooding (SOU, 2007)

4.8.1. Mortality

Cause of mortality may for example be drowning, heart attacks, hypothermia, trauma and vehicle-related accidents (EC, n.d.). EM-DAT[11] contains global information about deaths that are associated with flooding disasters. The data shows that drowning or trauma, such as being hit by objects in fast-flowing waters, is the main reason for flood deaths. According to a report by Jonkman and Kelman (2005), two thirds of the global flood victims suffered death from drowning. The other third died from physical trauma, heart attack, electrocution, carbon monoxide poisoning or fire. In another report by Jonkman et al. (2008), the number of fatalities is estimated based on: 1) flood characteristics, 2) analysis of exposed population and evacuation possibilities, and 3) estimation of mortality amongst exposed population. The flood characteristics are acquired from flood modelling (step 1 in the Sweco model) where relevant characteristics consist of water depth, rate of water rise and flow velocity. The exposed population is determined from the number of inhabitants in the area subtracted the number of inhabitants that are able to escape the area[12]. The rate of mortality is calculated by dividing the number of lost lives with the number of people exposed, using 'mortality functions'. The mortality functions have been developed by data from historical floods and relates to specific flood characteristics, such as water depth, flood water rise rate and flow velocity, see Figure 4.4. However, mortality related to pluvial flooding is very rare (Stone et al., 2013).

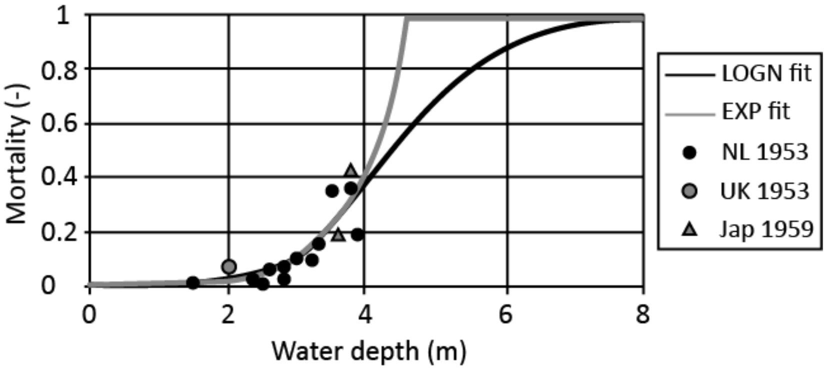

Figure 4.4 Mortality function (Jonkman et al., 2008)

Conclusion

With support from the report by Stone et al. (2013), mortality should not be included as a damage category in the Sweco model unless it can be proven that there is a high risk of mortality. One metre is suitable to use as a threshold value for when the water level gets critical to people's lives, and if exceeded, the mortality function by Jonkman et al. (2008) in (Figure 4.4) will be used.

4.8.2. Morbidity

This section will present a number of morbidity effects that can be related to pluvial flooding, and whether or not they should be included in the Sweco model.

4.8.2.1. Injury

During the initial phase of a flood, it is likely that water carries debris and other objects that may cause injuries (Caldin & Murray, 2012). Injuries may also occur during the recovery and clean-up after the

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[11] Emergency events database, http://www.emdat.be/database

[12] Analysis of evacuation is done by a model developed by van Zuilekom, K.M., van Maarsseveen, M.F.A.M, van der Doef, M.R. (2005). A decision support system for preventive evacuation of people. Proceedings of the First International Symposium on Geo-informaion for Disaster Management, Delft, The Netherlands. Springer Verlag. 21-23 March 2005.

flood event. These injuries can for example be wounds caused by sharp objects, concealed hazards, chemical hazards and electrical hazards or by contact with animals.

Conclusion

If it is possible to determine the risk of being injured, this aspect should be included in the Sweco model. However, these kinds of figures have not been possible to find and will not be included in the updated model.

4.8.2.2. Infection

Flooding may affect the environment in such way that vectors of disease and bacteria are allowed to flourish (Caldin & Murray, 2012). Flood water may carry along pollutants, for example sewage, human and animal faeces, pesticides and insecticides, fertilizers, oil, asbestos and rusting material that can lead to infections (Minamiguchi, n.d.). Though outbreaks of infectious diseases due to natural hazards do not usually occur, the risk of a rise in disease transmission can increase during certain circumstances (Caldin & Murray, 2012). However, the Health Protection Agency in the United Kingdom has stated that there was no evidence of increased outbreaks of illness due to the floods in the United Kingdom in 2007, and that infection from flood is unusual as the substances get diluted. In Denmark, a health cost of 6,887 DKK per residential basement was estimated for people exposed to sewage due to cleaning of flooded basements (Zhou et al., 2012; Matthiesen & Rokkjaer Dahl, 2012).

Conclusion

Based on the conclusion of the Environmental Agency, as well as lack of data, there is currently no urgent need to include a general risk assessment of infections caused by pluvial flooding. However, basement flooding with sewage back flush is a common effect of pluvial flooding. The Danish studies have found a relationship between exposure to sewage and a corresponding cost that will be used in the updated model.

4.8.2.3. Chemical hazard

Two major risks of chemical hazards associated with flooding can be distinguished: carbon monoxide poisoning and polluted water (Caldin & Murray, 2012). The former is often caused by fuel-powered equipment in a poorly ventilated environment, which for example is used to dry buildings or to produce electricity. The results of the 2004 hurricanes in Florida resulted in 6 deaths and 167 cases of poisoning due to carbon monoxide emissions. In Sweden, the storm Ivar resulted in two fatalities in 2013 (DN, 2013). Contamination by toxic chemicals during floods is seen as theoretically possible, but there is no information to support or verify it (EC, n.d.). The chemicals are likely to become diluted and thereby pose low risk (Caldin & Murray, 2012). An exception may be if there are chemicals released from waste storage facilities or industrial plants. It should further be noted that flooding caused by high-intensity and short-duration rain may pose a greater risk as the contamination levels may be higher.

Conclusion

As there seem to be many cases of carbon monoxide poisoning in international literature as well as accidents in Sweden, this can be relevant to include in the CBA model. Unfortunately, it is difficult to assess the level of risk and this has therefore not been considered. Contamination by toxic chemicals should not be included in the model, which is supported by EC (n.d.) and Caldin & Murray (2012). However, it is recommended that consequences of chemical emissions are investigated separately in study areas containing significant facilities.

4.8.2.4. Water borne disease

Heavy rainfall increases the risk of flooding and landslide and thus the risk of damage on water and sewer systems (Vredin Johansson & Forslund, 2009). This may in turn increase the occurrence of water borne diseases. There is one example from the Swedish municipality of Lilla Edet, where a heavy rainfall led to a flooding in the sewage system in 2008, causing leaking of water into the raw water supply. The raw water supply was infected with *Calici virus* (Norwalk-infection) and *coliphages* causing 2,400 cases of infections (around 18 % of the inhabitants in the municipality was affected). It has been concluded from a study of *campylobacter* that about 40% of people that are exposed to water borne disease through municipal water supply get infected (Tyréns, 2009).

Conclusion

Water borne diseases are relevant to consider in terms of pluvial flooding; there are several cases where entire communities have been infected with severe damages as a result. It is recommended to evaluate this further if the CBA-study area includes a raw water supply.

4.8.2.5. Vector borne disease

Diseases can be carried and transferred by animals, such as mosquitoes, ticks, flies and snails (Vredin Johansson & Forslund, 2009). These are called vectors. Rain may create more habitats for the vectors to grow, thus increasing the risk of vectors to spread diseases.

Conclusion

Vector borne diseases will not be specifically included in the Sweco model.

4.8.2.6. Mental illness

Flooding may cause psychological post-flood effects in terms of anxiety, stress, mental disorder, anger, depression and sleeplessness (SOU, 2007; Vredin Johansson & Forslund, 2009; Minamiguchi, n.d). The evidence that flood adversely affect mental health and well-being is well established, even though there are some methodological issues to assess the effects (Caldin & Murray, 2012). One issue is the difficulty to ensure that research of mental health after a flood uses a population sample that has not had previous mental illness prior to the flood event. A study of directly and indirectly flood-affected households and non-affected control groups found that up to 75% of a population affected by flooding will experience mental health impacts.

Conclusion

It has not been possible to determine a method to estimate the cost and degree of impacts on mental health, despite many sources of information that support mental effects due to flood (e.g. Defra & Environmental Agency, 2004).

4.8.2.7. Allergy

Contact with mould and mildew in clean-up processes may cause allergies and asthma (Minamiguchi, n.d.). Mould grows in the short period of 1-2 days and here are some groups of people that are considered more vulnerable to suffer health issues from contact with mould, such as infants, children, elderly and pregnant women.

Conclusion

It has not been possible to estimate the risk of the costs of allergy related to flooding, since there is no statistics on how many people are sensitive to mould. Furthermore, it is likely that a significant number of houses have mould problems prior to flooding; inserting health costs due to mould into a cost-benefit analysis could therefore lead to costs that are not correct.

4.8.3. Valuation of health effect costs

There are two types of economical tools for valuation of human life and health: indirect and direct methods (Vredin Johansson & Forslund, 2009). Indirect methods are those that are called revealed preferences, see chapter 3.3.1. The benefit of using RP's is that the valuation of lives and health are based on people's behaviour, however they do not account for all values of a non-market priced product or service. Direct methods, called stated preferences, are based on surveys. In the following section, the methods for assessing health costs have been divided into those that are applicable for mortality calculations, and those regarding morbidity.

4.8.3.1. Mortality

Value of a statistical life (VOSL) and value of a life year (VOLY) can be used when it is desired to take life expectancy into consideration (Vredin Johansson & Forslund, 2009), as mentioned in chapter 3.3.8. This can for example be the case regarding prioritization of measures, e.g. whether or not it is better to reduce flood risk for an elderly home or for a multi-family housing. VOLY is usually calculated from VOSL, where the constant yearly sum that is summarized for the remaining life expectancy has a discount rate equal to VOSL. Each saved life year has equal economic value no matter of the age of the saved person. ASEK 5 recommend to use VOSL = 31 MSEK (Trafikverket, 2012).

Conclusion

As was mentioned before, loss of life will not be accounted for in the updated model as long as the flood depth does not exceed 1 metre. If exceeded, the mortality function by Jonkman et al. (2008) will be used (see Figure 4.4).

4.8.3.2. Morbidity

The total cost of sickness or disease can be calculated with the following equation (Vredin Johansson & Forslund, 2009):

$$Total\ cost = Health\ care\ costs + Loss\ of\ production + Discomfort \tag{11}$$

Health care costs

Swedish figures of health care costs can be obtained from the 'Kostnad per patient' (KPP – cost per patient) which is a free database[13] provided by the Swedish Association of Local Authorities and Regions (Sveriges kommuner och landsting). The database contains both total and average costs based on the costs of resources arisen during patient treatment.

Loss of production

Loss of production is divided in direct costs of: salary, extra personnel and overtime and loss of service or production time; and indirect costs of: reduced quality of products and services, less satisfied customers and potential future loss (Vredin Johansson & Forslund, 2009). The European Commission (n.d.) attempted to estimate the direct and indirect costs that resulted in following mean values: 1,073 SEK a day in direct costs and 1,581 SEK a day in indirect costs. However, it has also been stated that the latter might be an overestimation due to few respondents in the survey, and instead a value of 527 SEK a day can be used as a lower indication of indirect costs. In a study by Tyréns

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[13] http://www.skl.se/vi_arbetar_med/statistik/sjukvard/kostnad-per-patient/databas

(2009), an average value of 2,000 SEK a day was used for sick leave. ASEK 5 (Trafikverket, 2012) recommends the following values for accidents, see Table 4.26. These values include both material costs in terms of health care and administration and productivity loss, as well as risk costs that aim to mirror the cost for the suffered individual.

Table 4.26 ASEK 5 recommendations for accident values (2010 year price level) (Trafikverket, 2012)

	Short term planning perspective (less than 10 years)	Long term planning perspective (40 years)
Mortality	23,739,000 SEK	31,331,000 SEK
Serious injury	4,412,000 SEK	5,672,000 SEK
Slight injury	217,000 SEK	267,000 SEK

Discomfort

Discomfort is valuated based on CV studies (Vredin Johansson & Forslund, 2009), see chapter 3.3.2. Examples of values of discomfort are given in Table 4.27. Values of WTP to avoid specific symptoms have been used where values are missing. If WTP values also are missing, or if the reliability of the valuations can seem unsatisfactory, there are tables from Trafikskadenämnden[14] with guidelines for assessment of compensation for pain and suffering. The base amount of compensation varies between 39 – 171 SEK/day depending on type of care, level of damage and the period of illness.

Table 4.27 Examples of health evaluations. 2007 price level (Vredin Johansson & Forslund, 2009).

Health impact	Care costs	Loss of production	Discomfort	Total value per day
Weather related natural hazard	No figure	2,381 SEK	504-615 SEK	2,885-2,996 SEK
Water borne disease	6,762 SEK	2,381 SEK	528 SEK	9,671 SEK
Vector borne disease	7,032 SEK	2,381 SEK	483 SEK	9,896 SEK

In the UK, an investigation of the WTP to prevent health effects of flooding was performed in a series of questionnaires in thirty locations across England and Wales (Defra & Environment Agency, 2004). The results showed a mean WTP of £200/year and household to avoid health impacts of a flood.

Conclusion

The methods to determine health effects of flooding found in literature are often based on peoples' income, which makes it difficult to assess whether or not inclusion of multiple parameters will lead to double-counting. Therefore, to obtain a conservative approach, the only health effect that will be considered in the new Sweco model is exposure to sewage (6,887 DKK/basement), since the method has been used in previous studies and considers basements, which is a significant damage category of pluvial flooding.

4.9. Cultural heritage

The meaning of the term cultural heritage has gradually changed over the years (Vecco, 2010). Nowadays, it has become common to acknowledge both tangible physical values such as monuments, objects or sites, and intangible non-physical values related to culture. The World Heritage Convention has listed criteria for monuments, building or sites to be considered as cultural or natural heritage (UNESCO, 2013).

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[14] http://www.trafikskadenamnden.se/Ersattningstabeller/

4.9.1. Identification of cultural heritage

The International Committee of the Blue Shield, ICBS, is an independent organization that works to protect culturally significant objects from war and climate (SGI, 2011b). Sweden has not yet identified and reported their cultural values. It is the Swedish National Heritage Board that is responsible to identify significant objects on a national level, and the county boards that are responsible on the regional level. The county board of Västra Götaland has developed an open online GIS service[15] with objects of significant cultural value.

4.9.2. The value of cultural heritage

The value of cultural heritage can be estimated in terms of *use* or *non-use values* (Armbrecht, 2012). Use values represent both *direct* and *indirect values* that can be gained from using a good or service. In this context, direct values consist of those created by the activity, e.g. museum exhibition or theatre play. Indirect values are constituted by additional experiences related to the activity, e.g. spending time with friends or enjoying the bar attached to the theatre while waiting for the show. Non-use value represents the value of a cultural institution, regardless if it is used or not. It can be further divided into *option value*, *bequest value* and *existence value*. The former is attached to the possibility to benefit from a cultural heritage, e.g. for an individual to be able to visit a museum, even if it would be unlikely that the same individual would make a visit. Bequest value is referring to the benefit from knowing that a cultural heritage is preserved for future generations. Existence value is simply the benefit of just knowing that the good or service exists. The different aspects of cultural heritage are summarized in Figure 4.5.

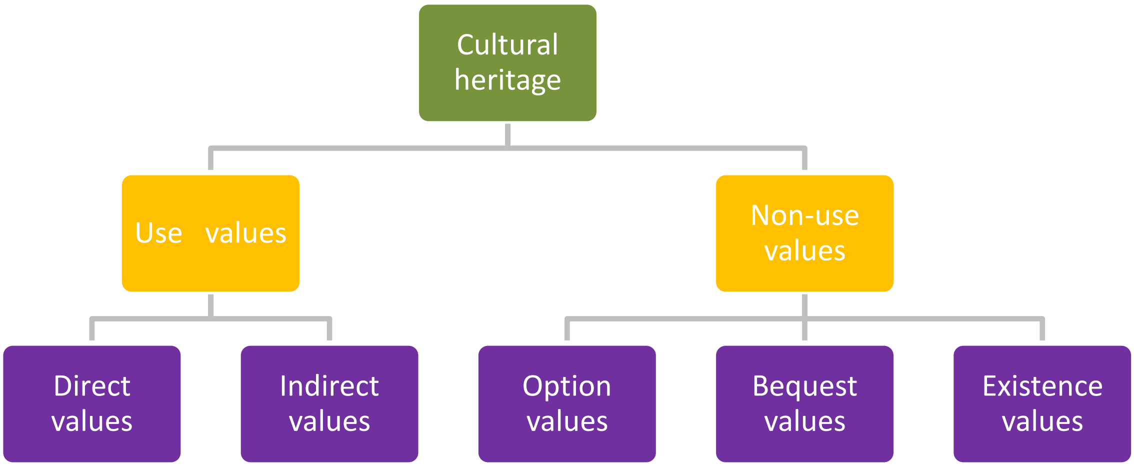

Figure 4.5 Values of cultural heritage (Armbrecht, 2012)

4.9.3. Quantification of cultural values

An individual may gain many types of values from cultural heritage, e.g.: aesthetic, recreational, enjoyment, education, relaxation and so forth (Armbrecht, 2012). It is difficult to use market values to measure use and non-use values of cultural objects. Stated and revealed preferences, see chapter 3.3.1, are two possible alternative categories of methods for non-market valuation.

4.9.3.1. Contingent valuation

Armbrecht (2012) has carried out a CV study of the value of two cultural institutions in Sweden, the Vara Concert Hall and the Nordic Watercolour Museum in the municipality of Tjörn, of which both use and non-use values are assessed. Two types of questions were used to estimate peoples WTP:

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[15] http://ext-webbgis.lansstyrelsen.se/Vastragotaland/Infokartan/

1) Use value: “What is the highest amount you can imagine paying for …
    a. … the ticket?” (Direct use value)
    b. … the whole experience from leaving home until you get back home?” (Direct + indirect use value)
2) Non-use value: “What is the maximum amount you can imagine paying in tax per year to …
    a. … have an opportunity in the present situation to enjoy cultural experiences in the museum/concert hall?” (Option value)
    b. … preserve the museum/concert hall and its value for future generations?” (Bequest value)
    c. … preserve the museum/concert hall when you consider all aspects?” (Total value including existence value)

Regarding the use value, the phrasing of the survey questions enables a calculation of the *consumer surplus*, which is the value of what people are willing to pay in addition to the total expenditures for the whole experience (such as entry fee, meal, travel cost). The questions regarding non-use value provides information on how the WTP for non-use value is divided by type of value; option, bequest and existence value. Table 4.28 summarizes the average WTP for use and non-use value of the studied objects, divided by subcategories and origin differences of the visitors.

Table 4.28 CV study of Vara Concert Hall and Nordic Watercolour Museum (Armbrecht, 2012)

Study object	Use value (SEK)	Non-use value (SEK)	Aggregated WTP (MSEK) (use + non-use value)
Vara Concert Hall	Local visitors: WTP: 534 CS[a]: 326	Local visitors: WTP: 309 OV[b]: 122 BV[c]: 149 EV[d]: 38	6,700 local visitors: WTP: 3.9 CS: 2.4 Non-use: 4.0
	Regional visitors: WTP: 526 CS: 283	Regional visitors: WTP: 203 OV: 84 BV: 90 EV: 29	27,800 regional visitors: WTP: 18.5 CS: 7.9 Non-use: 261.4
Nordic Watercolour Museum	Local visitors: WTP: 389 CS: 187	Local visitors: WTP: 314 OV: 136 BV: 108 EV: 70	38,500 local visitors: WTP: 11.8 CS: 3.4 Non-use: 3.8
	Regional visitors: WTP: 480 CS: 179	Regional visitors: WTP: 158 OV: 68 BV: 61 EV: 29	111,500 regional visitors: WTP: 44.7 CS: 13.0 Non-use: 199.3

[a] CS = consumer surplus, [b] OV = option value, [c] BV = bequest value, [d] EV = existence value

The study shows that regional visitors value the experience lower, but on the other hand, their actual costs are a bit higher. Non-use values vary with the distance to each cultural institution; the local population values it significantly higher. There was also a relationship between knowledge and the perceived value as the individuals that had visited the cultural institution before value them higher than those who had not. However, the majority of respondents living in both regions indicated an interest in investing tax funds to maintain the institutions.

4.9.3.2. Travel cost method

Another study by Armbrecht (2012) used the travel cost method to assess the economic values of Vara Concert Hall and the Nordic Watercolour Museum. The results show that TCM is only applicable when the studied institution is the core activity. For example, visitors from far away often combine activities and errands during one trip, which make it difficult to estimate the economic value of one institution in particular. The TCM can be useful as cultural institutions often have low, if any, entrance fees. Therefore, the travel cost can be an indicator for the benefits provided by the institution. The method assumes that the travel cost increases with distance. Armbrecht (2012) uses the zonal TCM, which is based on the zone of the visitors' origin and the cost for travelling from each zone. The study was carried out using web-based surveys with open-ended questions (see chapter 3):

1) "Where do you live (please enter your postcode)?"
2) "How often have you visited the Nordic Watercolour Museum/ Vara Concert Hall during the last 12 months?"
3) "How many persons travelled in the same vehicle as you and belonged to your party?"

The respondents were also requested to answer their means of travel with information on duration and costs of the transport, as well as socio-economic questions such as age, income, gender and education. The travel cost was calculated using a function for the total per-capita cost that includes the return trip for the average visitor from each zone to the cultural institution, see equation 12-14. The zones were defined based on postcode areas with 20 km of distance between each circle.

$$C_i = k_i + m \cdot t_i + f \qquad \textbf{(12)}$$

$$k_i = \frac{2 \cdot \delta_i \cdot b}{g_i} \qquad \textbf{(13)}$$

$$m = \frac{w}{3} \qquad \textbf{(14)}$$

where:
C_i = total per-capita cost of a return trip for the average visitor from zone i;
k_i = per-capita vehicle cost for the average visitor from zone i;
m = per-capita time cost per minute for all visitors;
t_i = travel time in minutes for all visitors;
f = average entrance fee for all visitors (2.8€ for the museum and 15€ for the concert hall);
δ_i = the one way distance, in km from zone i to the cultural institution;
b = average vehicle cost per km (0.195 €/km[16]);
g_i = the average number of passengers travelling in the same vehicle from the zone i;
w = average per minute income, based on the average annual income in the sample (in this sample, w = 33,800€).

The next step is to use the travel cost (C_i) in a so-called "trip generating function", which is used to predict the number of visits (V_i) per zone i in relation to the population (P_i), see equation 15. More detailed description to this step is presented in the original source.

$$\frac{V_i}{P_i} = f(C_i) \qquad \textbf{(15)}$$

Finally, a demand function is used for hypothetical increasing entrance fees in relation to predicted number of visitors. It is assumed that the behaviour in relation to entry fees is the same as for the cost

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[16] According to the Swedish Tax Agency: http://www.skatteverket.se

to travel to the institution. The final result of the study, where the economic valuation by TCM and CV method is studied, is presented in Table 4.29.

Table 4.29 TCM study of Vara Concert Hall and Nordic Watercolour Museum (Armbrecht, 2012)

Study object	CV study	TCM study
Vara Concert Hall	1.96 M€	1.558 M€
Nordic Watercolour Museum	5.96 M€	5.053 M€

As mentioned in the beginning, zonal TCM is not entirely suitable regarding measurement of the total experience when it consist of multiple experiences. On the other hand, the study results can be interpreted as showing that both of the institutions generates great values on a local and regional basis, and that the use values exceeds the cost of entrances and travel.

4.9.3.3. Hedonic pricing

The impact of cultural heritage on real estate values in urban areas has been investigated through a spatial model in a paper by Lazrak et al. (2014). The study aims to measure the difference in market price between listed buildings and regular buildings. The effect of listed buildings on the market price of surrounding properties in the area concerned was also examined. The results show that the WTP to purchase a listed building is an additional 26.9%, and that the value of surrounding properties increases by 0.28% for each additional listed building within a 50 metres radius. Further, houses sold within a conservation area have price increase by in average 26.4%.

Conclusion

The identification of objects with significant cultural value must be assessed from case to case, since there is currently no tool available to easily determine objects significance. If a tool such as the GIS-service used in the county of Västra Götaland could be developed for the entire nation, it could easily be integrated with flood hazard maps and facilitate the identification of objects at risk. Currently, the best way to determine the significance is probably to contact the local municipality or county board.

Contingent valuation and travel cost method are the two methods that seem to be most suitable to assess economic values of cultural institutions that include intangible aspects such as visitors' total experiences of the institution or their wish to protect an institution for future generations. However, both of these methods rely on responses of questionnaires, which require abundant work in order to obtain useful results. If there is enough time or resources available to do such studies in a CBA of flood risk measures such surveys could be performed. If not, it should be mentioned in the CBA that there can be large use (and non-use) values connected to a cultural institution, as has been proven by Armbrecht's studies.

The recommendation is to not use any standard values for cultural heritage at this point, since there is a wide range of objects and institutions of different economic values that can be considered cultural heritage, and that peoples' WTP for a cultural heritage object or institution may vary. If insurance values are found for cultural heritage objects, approximations of the percentage of damage that a flood would amount to could then be assessed. This could be done by using depth-damage functions, but as mentioned previously much literature points to that they do not render reliable results.

5. MITIGATION MEASURES SUITABLE FOR PLUVIAL FLOODING

Measures to adapt to pluvial flooding presented in this chapter are mainly included to highlight valuation of intangible aspects, for example how green storm water management adds amenity values to the community. Therefore, it is not the cost of implementing the measures that is in focus, but the value of the benefits that can be derived. It is not possible to provide standard values of the benefits of each measure, as these are specific to each case and respective prerequisite.

5.1. Sustainable urban drainage systems and ecosystem services

Traditionally, storm water management has mostly been a matter of removing water by conveying it through sewer systems directly to the receiving water (Stahre, 2008). Between the years 1975-1995, the trend shifted towards design to protect the recipient from pollutants in the urban runoff. By the end of 1990s, the concept of sustainable urban drainage systems (SuDS) was introduced, which included the social aspect of storm water management. Today, ‘integrated’, ‘sustainable’ and ‘alternative’ storm water management have become buzzwords, especially regarding implementation in urban environments. What these concepts all have in common is that they include technologies where vegetation is used to treat storm water. Plenty of literature on the subject exists; it is certain that SuDS can offer more values to the society than traditional means of water management. Some of these values are illustrated in Figure 5.1.

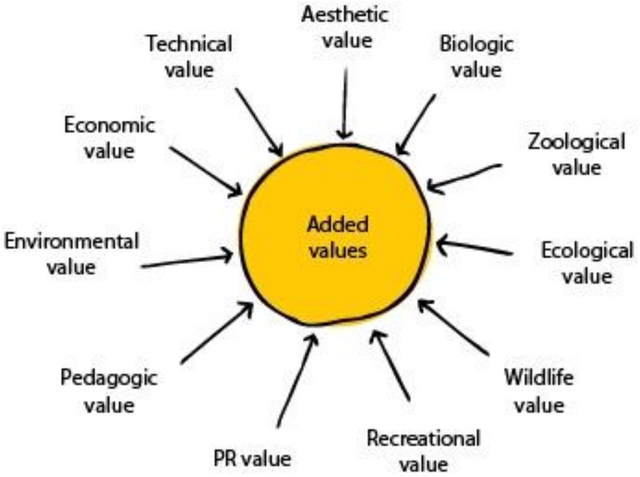

Figure 5.1 Benefits of SuDS (Stahre, 2008)

Vegetation used in storm water management has the ability to slow down runoff, enable infiltration, absorb, purify and evaporate water and thereby reduces the risk of flooding;the higher the flow and volume of storm water, the harder it is for the ground and vegetation to absorb the water, and the bigger the risk of downstream flooding (Länsstyrelsen Västra Götalands län, 2013). In addition, vegetation improves the air quality, reduces noise, wind and temperature as well as provides aesthetic and recreational values to the urban environment (Boverket, 2010). All these values are benefits derived from ecosystem services, defined by Millennium Ecosystem Assessment (2005) as follows: “*Ecosystem services are the benefits people obtain from ecosystems”*. The benefits that ecosystems provide can further be divided into three categories: *goods* (such as harvest or drinking water), *services* (such as recreational benefits or regulatory ecological functions) and *cultural benefits* (such as spiritual or heritage related functions) (Hanley & Barbier, 2009). One of the greatest challenges for economists and ecologists is how to value ecosystem services; they do indeed provide human welfare through services and goods but are nonetheless often disregarded.

Flood protection is one example of many ecosystem services. This is a feature that occurs naturally in various ecosystems, such as wetlands or urban green areas. In a cost-benefit analysis concerning flood mitigation strategies, it might therefore be possible to include the technical flood mitigating service provided by for example a natural wetland as benefit, as it reduces damage costs from flooding. This could even be monetized in terms of avoidance of loss of property due to reduction in flood depth or similar and act as a reason to why the wetland should be protected. Furthermore, ecosystem services often provide additional benefits other than just the flood protection. To exemplify, Woodward & Wui (2001) list several important ecosystem services that can be provided by a wetland (see Table 5.1). Most of these are difficult to monetize and include in a CBA, but one tangible example is eutrophication mitigation as described in chapter 4.3.1. Discharge of nutrients to a water body will generate damage costs in terms of reduced water quality – a condition that WTP-research shows that people are willing to pay for avoiding. Reducing the amount of discharge is thereby regarded as a benefit that can be estimated in monetary terms.

Table 5.1 Example of ecosystem services provided by a wetland (Woodward & Wui, 2001)

Function	Economically valuable goods
Recharge of ground water	Increased water quantity
Discharge of ground water	Increased production of downstream fisheries
Water quality control	Reduced costs of water purification
Retention, removal of nutrients	Reduced costs of water purification
Habitat for aquatic species	Improvements in commercial or recreational fisheries. Non-use appreciation of the species.
Habitat for terrestrial and avian species	Recreational observation and hunting of wildlife. Non-use appreciation of the species.
Biomass production and export	Production of valuable food and fibre for harvest
Flood control and storm buffering	Reduced damage due to flooding and severe storms
Stabilization of sediment	Erosion reduction
Overall environment	Amenity values provided by proximity to the environment

In the same manner as natural ecosystems provide services such as amenity value and water purification, SuDS can generate benefits in addition to those related to flood mitigation. Therefore, when using SuDS as a measure in a CBA, it is feasible to include both the avoided flood damage and any additional ecosystem service as benefits.

SuDS can be categorized into four groups: *source control*, *onsite control*, *slow transport* and *downstream control*, as shown in Figure 5.2 (Stahre, 2008; SWWA, 2011; Boverket, 2010). Source control is actions taken on private properties; small-measures such as green roofs, permeable paving, rain gardens and local ponds, which can reduce the runoff. Onsite control also includes small scale facilities, for example permeable paving, rain gardens, floodable areas and ponds; the difference is that they are implemented on municipally owned land. Slow transport includes different means of conveying water, for example through swales, ditches/creeks and open canals. Finally, downstream control encompasses large facilities for temporary detention; wetlands, large ponds and lakes are examples of such.

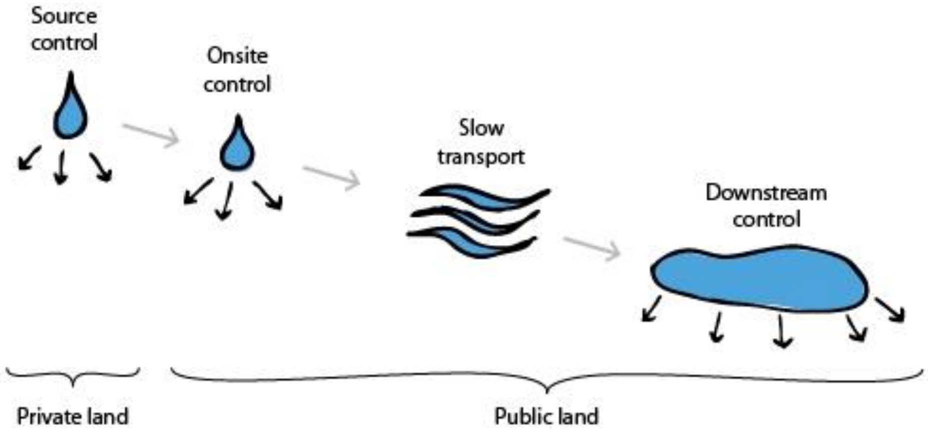

Figure 5.2 Four types of urban drainage actions (Stahre, 2008)

5.1.1. Storm water measures and corresponding benefits

The following section will give examples of measures that can be used in the four stages of SuDS (source control, onsite control, slow transport and downstream control) with descriptions of the benefits each measure can provide.

5.1.1.1. Source control

To manage rainfall at source is the first and fundamental stage in the concept of SuDS (Graham et al., 2012). The water flow is reduced and the water quality improved through interception of silt and pollution. A critical requirement for amenity and biodiversity is to keep a high water quality in surface SuDS features.

Green roofs

Urban environments are characterized by abundant areas of hard surfaces contributing to unnecessary volumes of storm water that pushes the capacity of the sewage systems and treatment plants (Graham et al., 2012). These areas of hard surfaces can be reduced by converting ordinary roofs to green roofs. Environmental benefits provided are: reduced runoff, attenuation, supply of filtered water suitable for wildlife, reduced heat island effect through evaporative cooling, capturing of air borne pollutants and reduced noise. Amenity values are: increased visual and physical access to green space, provision of community resource and educational opportunities. Green roofs also support wildlife by creating habitats, providing opportunities for feeding and foraging as well as breeding. Further, the energy required to heat or cool a building is reduced. Green roofs are expected to reduce yearly runoff by 50-75% (SWWA, 2011), but in case of an extreme rain event, green roofs are not as efficient (MSB, 2013); they will only capture the first 5 mm of rain (SWWA, 2011).

Rain gardens and bio retention areas

Surface water can be attenuated and purified in rain gardens or bio retention areas (Graham et al., 2012). These are easy to integrate in urban settings and are space efficient. Bio retention facilities can be designed to store a large volume of water. Environmental benefits include reduced flooding, cleaning and filtering of surface water and mitigation of urban heat island effect. They provide aesthetical and recreational values and may also be used for urban farming of vegetables. Wildlife benefit is gained by the creation of 'stepping stone[17]' habitats.

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[17] 'Stepping stone' habitat refers to small green corridors enabling wildlife to move about in urban environments.

Permeable surfaces

Most parking lots, streets and paths with surfaces of asphalt, concrete or bricks can be transformed to permeable surfaces (Graham et al., 2012). These attenuate the runoff and allow water to infiltrate into the ground or to an underlying storage facility. Water borne pollutants is controlled by being limited to spreading in soil. Amenity values are provided in terms of firm dry surfaces for walking and parking on after a heavy rain, as well as visual appeal for the urban landscape. Permeable paving, such as grass concrete pavement, is expected to reduce the runoff by 30-40% (SWWA, 2011).

Filter strips

Filter strips are broad vegetated areas with a slight slope that can be used to intercept runoff from roads or other surfaces. In the same manner as green roofs, they reduce and purify storm water and mitigate urban heat island effect. If they are appropriately designed and large enough, they may provide informal relaxation in public open spaces. They also act as a resource for the wildlife in terms of habitat creation.

5.1.1.2. Onsite control

Graham et al. (2012) describe site control as features between private and public land that provide the next stage of treatment. Onsite control can for example be structures to store runoff that has been conveyed from source control.

Detention basins

Detention basins refer to dry depressions with vegetation that can hold water temporarily, thus reducing flood risk downstream (Graham et al., 2012). These structures allow water to gradually infiltrate while pollutants are removed through bioremediation. Detention basins can be designed to support multi-functional uses, such as children’s play areas, football pitches and picnic areas. They support biodiversity, for example by providing nectar sources and habitat for wetland plants.

Ponds

Storm water ponds are designed to capture runoff and provide treatment of water. These are often appreciated objects in urban settings.

5.1.1.3. Slow transport

Conveyance features can be designed in various manners in terms of details such as chosen materials, adding under-drain for water storage or arranging small series of dams to support wetland plants. Two types of structures for transport of water are vegetated swales and open channels, which are described below.

Bioswales

Bioswales are characterized as wide, shallow features that slow down runoff, intercept sediments and allow water to infiltrate (Graham et al., 2012). They can be designed with a series of small dams or under-drainage, and they are possible to incorporate in hard landscapes. The main environmental benefits are the reduction of runoff, opportunity for natural infiltration and interception and filtering of pollutants. Further, they provide aesthetic appeal and informal space for recreation and relaxation.

Drainage canals and corridors

Water can be conveyed in canals in numerous ways. Even without vegetation, the structures can be designed to separate debris and slow down the flow, e.g. by adding “water drops” gutter in the bottom as has been done for example in Augustenborg (Stahre, 2008). Visual water is an element that provides amenity values and is a resource for the wildlife.

5.1.1.4. Downstream control

The final step in SuDS is the downstream control, which constitutes facilities for temporary detention of storm water and treatment before the water is released to the recipient.

Retention basins and wetlands

Structures such as retention basins and wetlands provide capacity to store additional storm water, which can be released in a controlled rate when a flow peak has passed and thus reduce the flood risk (Graham et al., 2012). The structures contain permanent water and wetland habitats, providing food and shelter for animals and plants. They are also attractive in public open space providing opportunities for social interaction and activities, adding aesthetical and recreational values. The extended retention period in a wetland removes even more pollutants before the water is released to the catchment.

It should be noted that all measures presented above may not be suitable for a cold climate. Permeable surfaces, bioswales and wet ponds are structures that are fairy efficient, but infiltration structures such as bio retention areas, rain gardens, filter strips and detention basins may be less efficient (Viklander & Bäckström, 2008). It has not been possible to further investigate the aspect of cold climate in this thesis.

5.1.2. Measuring benefits of storm water measures

In the context of this thesis, the most important benefit gained from implementing flood adaptation measures is the reduced risk of flooding, i.e. damage costs that are avoided as a result of the applied measure. There is a wide and diverse collection of possible measures to assess storm water. In order to estimate their efficiency during a flood, knowledge of their capacity to reduce runoff is required. This assessment can for example be carried out using hydraulic or hydrodynamic modelling. In spite of all the benefits that alternative storm water management provide, there are still many who prefer to use traditional methods. This could be a result of a lack of information about how efficient green solutions are, and how to quantify and monetize the benefits they deliver (Boverket, 2010). Risk-based economic assessments of climate adaptation measures are normally carried out to only account for the impacts in a hydraulic context (Zhou et al., 2013b). It is essential to find an approach to include the intangible non-market effects such as recreational values, in order to obtain a CBA-study that more accurately can reflect the reality.

5.1.2.1. Amenity values

Sustainable urban drainage systems provide ecosystem services which in turn offer amenity values. In the same manner as for cultural values (chapter 4.9), these values can be divided into *use values* and *non-use values* (EFTEC, 2010). The former relates to values with direct or indirect interaction with a resource while the latter is related to altruistic thinking (i.e. values such as a resource existing for another person’s well-being). Below, a number of studies on the amenity value of ecosystem services are presented.

Several studies using hedonic valuation (see chapter 3.3.6) conclude that the otherwise intangible values derived from ecosystem services contribute to increase in market values of houses. Frey et al. (2013) present an approach to estimate the economic value of living near an urban multi-use wetland using hedonic valuation. The wetland investigated provides several ecosystem services such as habitat provision, flood protection, storm buffering and carbon sequestration as well as recreational benefits (such as swimming and fishing) for the people living in the urbanized proximity. In the study, data on home sales is used to assess the value of proximity to the wetland. The result of the study indicates that home owners place a premium on living close to and/or with a view of the urban wetland; one percent increase in distance between house and wetland yields 0.069 percent decrease in sale price and houses with a view of the wetland sell for 16% more than those without. Yet another study of property values revealed that a combination of green streets, bioswales and culvert removal increased a property value by 3.5-5% (BES, 2010). A tree in front of a house could increase the property value by up to 8,000 US$.

Another case study performed in Aarhus, Denmark, uses a hedonic approach to assess intangible values for implementation into a cost-benefit analysis (Zhou et al., 2013b). The case study investigated open decentralized flood mitigating solutions, such as lakes and green spaces, and their non-market value impact on housing prices in a cost-benefit analysis. Four strategies to adapt to extreme rainfall events were tested in the study: no adaptation, increased drainage capacity through expansion of sewer network, infiltration with underground rainwater trenches and open green rainwater basins. The purpose was to investigate the additional value in relation to recreational services that the fourth alternative would bring. The risk and vulnerability analysis were conducted according to a framework tested in an Odense case study performed by Zhou et al. (2012). The case-study (Zhou et al., 2013b) covers a housing area in Aarhus called Risskov and the hedonic price valuation includes 12,339 properties. The four scenarios were assessed, with the no-adaptation scenario acting as a base line for comparison to the other scenarios, using hydraulic modelling. Pipe enlargement as well as local infiltration is assumed to have no further benefits other than increasing capacity of excess flows and slowing down flows respectively. The open green drainage systems on the other hand, were assumed to not only serve as detention sinks for precipitation, but also as amenity service to the neighbourhood in terms of recreational opportunities. This service would in turn contribute to an increase in house price in the neighbourhood, which was measured assessing people’s WTP for proximity to different types of urban green spaces. Each property was geocoded with location in order to enable valuation of the amenity services depending on the distance between the implemented open drainage systems and the property in question. Using a model based on previous studies the impact on house prices could be estimated. It was found in the study that green areas containing features such as lakes and trees could be aggregated into one group. The proximity to green areas (measured in 100 m) and their size (measured in hectares) were included in a hedonic price function. Results showed that reduced proximity to green areas that included lakes or trees or both affected house prices by 0.6% per additional 100 m distance. The scale of the urban area increased the property value by 0.01% per additional hectare of green space. A 1% increased distance to lakes, including those that are not integrated in a green area, reduced property values by 1.7%. Another group of green areas was defined as areas without trees or lakes, for example open grass areas with no other features.

The result of the case study reveals that all three adaptation scenarios delivered positive net present values and were therefore economically beneficial compared to the non-adaptation scenario, see Figure 5.3. However, the largest benefit was found in the green drainage system scenario where the net present value was higher than the other alternatives. This indicates that the implementation of green open flood solutions can provide significant societal benefits not only through flood proofing but also through its impact on the hedonic value of house prices through amenity values.

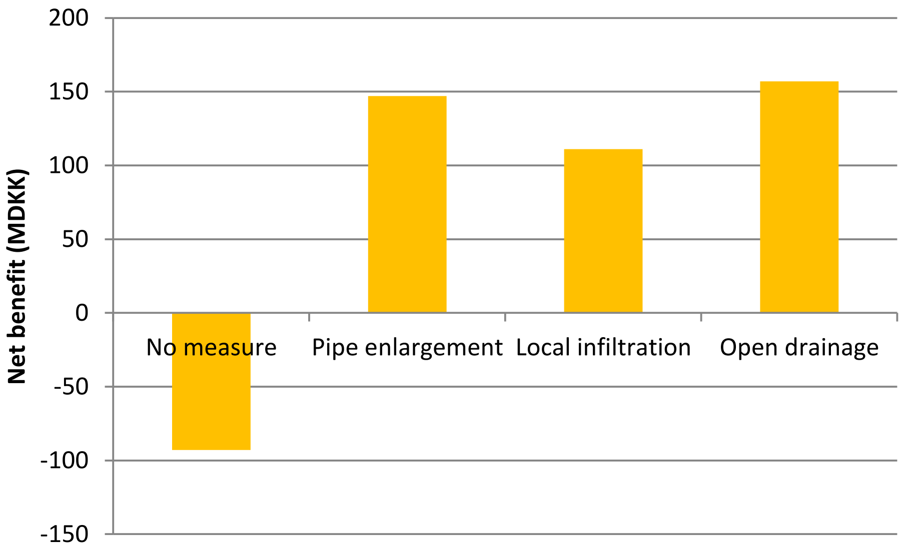

Figure 5.3 Comparison of the benefits of the four adaptation strategies (Zhou et al., 2013b)

The uncertainties in the result of the Aarhus case study include several factors. For example, maintenance of the green drainage systems has not been included in the cost-benefit analysis. Furthermore, it is unclear whether the amenity value would be present in all types of housing areas; if an area already contains plenty of greenery it is not certain that a further increase would upsurge the house pricing.

In another study performed in Stockholm, Sweden, the relation between different urban amenity values and property prices was investigated (Stockholms läns Landsting, 2011). The study aims to identify qualities that make an urban area attractive and quantify these factors monetarily. Records on approximately 7,000 sold apartments around Stockholm were analysed in price per square metre together with the proximity to about 1,000 urban green areas. The study examined various types of urban environments, on of which is considered relevant for this thesis namely proximity to parks. The analysis of the value of proximity to parks has been estimated looking at square metres of park area within 1 km radius. The study shows that on average a household has 17 hectares of park area within 1 kilometre distance, and an increase in 10 hectares increases the price of the apartment with 600 SEK/m^2. Only parks with entertainment facilities, e.g. for playing and working out and that are bigger than 0.5 hectares have been included. When assessing the relation between amount of green areas or nature in general no significant results could be found.

Conclusion

From the three case studies presented above it is obvious that the amenity related ecosystem services that urban green areas contribute to increase property prices. This is also supported by Saraev (2012) who in a critical review of evidence of economic benefits related to creation of green space concludes that a large amount of evidence exists proving that aesthetic values associated with green space increases land and property prices. In order to implement these societal benefits as monetary aspects in the updated Sweco model assumptions have been made for the sake of generation of standard values and equations.

Most likely, the case study performed in Stockholm is the one most relevant for the update of the Sweco model since the general appreciation of urban green areas could be assumed to be similar on a national scale. However, it is probably necessary to consider that the sales prices in Stockholm are different from those of other parts of Sweden. One way to include this would be to use value transfer and assume that the estimated hedonic price of additional urban green spaces as estimated by apartment buyers in Stockholm varies linearly with the property square metre price. The average price for sold apartments in Stockholm (Nov 2013-Jan 2014) was 41,832 SEK/m^2. The equation below shows the amenity value of park area within 1 km in any given Swedish urban area, using a linear ratio of prices of the municipality evaluated and the property price in Stockholm.

$$V_{hed} = \frac{P_{prop}}{41832} \times S_{prop} \times 600 \times \frac{A_{1km}}{10} \times NUM_{prop} \qquad \textbf{(16)}$$

where:
V_{hed} = Total hedonic amenity value of a park in a neighbourhood [SEK];
P_{prop} = Average apartment or house property prices in the area of investigation [SEK/m^2];
S_{prop} = Average size of the properties considered [m^2];
A_{1km} = Park area [hectares];
NUM_{prop} = Number of properties within 1 km of the considered park.

If several smaller parks are spread over a bigger area, it is unclear how to assess the amenity value. It is therefore deemed more reliable to use this method for one specific, larger park (preferably more than 0.5 hectares). The average property value per municipality can be obtained from Svensk Mäklarstatistik (2014). It is important to consider whether these average values are representative for the municipality in question, which might not always be the case if the analysis for example is to be performed on a very characteristic area (such as with ocean view, or high crime rates). The size of apartments and houses can be hard to estimate and if information is not available standard values could be used. In Sweden the average area of an apartment is 92.8 m^2 (SCB, 2012) but there is no data available on the size of the average residential house. Although a Swedish single family house in an urban area in Sweden ranges between 100 and 150 m^2 in size it is recommended that the average area is examined for the specific study site. Furthermore, the Stockholm study is based only on apartment sales prices. In order to use the equation on houses it therefore has to be assumed that a house buyer appreciates green areas to the same extent as an apartment buyer. It should be noted that in the study mentioned above performed by Zhou et al. (2013b) only houses were assessed but nonetheless the result showed increase in prices if close to urban green areas.

Other large-scale studies similar to the one performed in Stockholm exist for other cities. One example is a study made in greater London (GLA economics, 2010) where it was concluded that for each hectare of green space within 1 km sale prices increase by approximately 0.08%. If a regional park is present within 600 m, the property price increases further with around 1.9-2.9%. In the study, socio-economic parameters such as housing density, crime and education were included as well. According to Saraev (2012) there are enough reliable studies showing evidence that nearby green areas increase property prices, in some cases up to as much as by 10%.

The method recommended using in this thesis (equation 16) only takes larger park areas into consideration. As discussed, amenity values can probably be applied to small-scale storm water measures as well. However, they are most likely too small to be considered making a significant difference in a cost-benefit analysis (Zhou et al., 2013b). Instead of focusing only on small scale solutions such as green roofs and rain gardens, it could be more beneficial to redesign the urban landscape with ponds and green areas. Large-scale open drainage systems offer more recreational services for the public than the small-scale solutions do, as well as provide more capacity of storing water during extreme rain events. However, it should be noted that occupying large urban spaces can lead to a reduction in other benefits; if they are reserved for open green areas other opportunities for development are lost. Therefore, if there are other possible usages of the area considered for green solution implementation that are of interest to society (such as construction of new apartments) the total benefit of creating for example a park could be lower than estimated.

5.1.2.2. Other values associated with ecosystem services provided by flood measures

Despite several attempts by various researchers, there is very little data on how to estimate other values that ecosystem services provide monetarily. Although no price tags can be put on these services, they should not go unnoticed but be considered in the cost-benefit analysis as potential benefits. Some of these values are presented below.

Economic growth and investment

It is believed that investments in green areas can help improve the image of a society and thereby attract new industries and entrepreneurs (Saraev, 2012). This would in turn reduce unemployment. There are studies that claim to show that investments in green space have actually led to benefits such as created jobs. However, these are case specific and could therefore lack in general applicability.

Labour market employment and productivity

It is believed that more and better green areas help reducing stress, improving health and attracting and motivating people (Saraev, 2012). Thus a better employer's workforce is believed to be developed. This can be supported by theories such as that the work environment affects people's efficiency and that green space makes a difference when skilled staff are deciding work location.

Tourism

New green areas are believed to play a large part in a city's possibilities of creating tourism opportunities (Saraev, 2012).

Recreation and leisure

By implementing more green areas, the possibility of leisure and recreational activities can be improved, e.g. for walking and bird watching (Saraev, 2012). Although entry fees are usually not associated with park visits, people still value spending time in green space and methods could be applied in order to estimate the monetary value. For example, WTP could be used for such estimations. In a study performed by Brander & Koetse (2011) investigating the value of urban green open spaces it is concluded that both contingent valuation and the hedonic price method indicate positive economic benefits. It is established that urban parks result in higher benefits than other green open spaces.

Health and wellbeing

In terms of well-being urban greenery can reduce air pollution, reduce stress and enable physical activity (Saraev, 2012). This can be translated into monetary benefits such as reducing costs for healthcare and economic output due to fewer sick leave days as well as reduction in premature death.

Quality of place

An increased amount of green space is believed to result in improvements of quality of life for the inhabitants in a city (Saraev, 2012). Recreation and amenity values as well as community participation increase while crime levels decrease altogether resulting in an environment that is more attractive for businesses and skilful workers. Research suggests that people are of the opinion that green areas create nicer living environments. Furthermore, there are correlations between educational performance and childhood development and the amount of and access to green space and parks. On the other hand, as improved or added qualities generates an increase of property values, there is also a risk of gentrification[18] when wealthy families move to the area and pushes families with lower economic status further away.

Climate change and mitigation

Green areas with plenty of trees provide the ecosystem service carbon sequestration (Regeneris, 2009). It is estimated that one hectare of timber sequesters three tonnes of carbon per year. Regeneris (2009) uses the Stern Review of £25 (2007 prices) in an assessment of estimating the economic contribution of the Mersey Forest, England. Furthermore trees can provide natural air conditioning effect due to shading and wind speed reducing effects on nearby buildings. If these benefits are achieved thus reducing the need of a conventional electric air conditioner, not only will the house owners save money due to a lowered electricity bill, but carbon reduction will also appear as an extra benefit.

5.1.2.3. Reduced cost for water treatment in WWTP

Measures reducing storm water will hopefully result in a decrease of the amount of water that is distributed to the treatment plant, thus generating less cost for treatment. With information on the reduced volume of water conveyed to the treatment plant, it is possible to calculate the saved cost of treatment using the price per purified volume water. As mentioned in chapter 4.3.1 the price for treating wastewater is 5 SEK/m^3.

Conclusion

Besides the reduced flood risk, the main arguments for using integrated storm water measures are that they reduce flow and load on current sewer systems, and thus the maintenance and renewal costs, while they also provide additional benefits in terms of recreational and aesthetic values that can increase property prices. Further, open storm water solutions provide ecosystem services in terms of purification, micro climate, air quality and evapotranspiration.

5.2. Warning system

A flood warning is a warning message from an official authoritative source communicated to people at risk before a flood event that is conveyed using a variety of communication tools (Messner et al., 2007). Flood warning systems can be useful in preventing loss of life and injury as well as flood damages and economic losses. When dealing with pluvial flooding and flash floods, it is difficult for flood forecasters to inform in time. Flood warning lead time usually needs to be more than two hours in order to be able to account for possible benefits. The actual effects of a warning system include:

1) Prevention of loss of life and injury: evacuation of people, animals and property in advance of flooding. Possible avoidance of some health and stress effects. Warning messages can urge people not to take risks, e.g. walking in flood water, and thereby reduce their health risks.
2) Prevention of damages to property: strengthen existing defences, implementing temporary defences and moving property out of reach in order to minimize direct damage.

When assessing the efficiency of a warning system the important question to ask is whether or not it supports actions that can translate into damage and loss reduction (Molinari et al., 2013). In order to assess such a measure in a CBA it is also crucial to understand the benefit that can be obtained from these reductions.

The procedure of flood emergency management starts when a flood is monitored or forecasted (Molinari et al., 2013). Civil protection personnel will then take decisions according to emergency

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[18] Gentrification is defined as a social process where people with high socio-economic status moves to areas that traditionally have been dominated by individuals from lower social classes or ethnical minorities (http://www.ne.se/gentrifiering).

plans. These decisions are likely to be made on thresholds; depending on the forecasted threshold value the decided warning level and mitigation actions will vary. The purpose of the mitigation actions is to reduce exposure, vulnerability and flood intensity. The warning is sent out in order to enable people to respond; a step in flood emergency management where seemingly many factors play important parts:

- Situational context (time of the day or week as well as lead time)
- Local context (preparedness, disaster education, previous experience, community involvement.)
- Community context (age, personality, gender, duration of residence, family context etc.)

Depending on these variables, people might or might not notice the warning, and even if they do they can choose to act or not to act.

As discussed in chapter 1, flood risk is a combination of probability of hazard occurring and flood damage. Flood damage in turn depends on exposure and vulnerability. Flood emergency management and warning systems possess the ability to lower the exposure and vulnerability (Molinari et al., 2013). This is to be compared to other measures such as physical ones who primarily reduce the hazard probability and extent. Mitigation actions for reducing the hazard can in most cases easily be estimated by means of hydraulic analysis, while evaluations of actions reducing exposure and vulnerability is scarce in current literature. Nevertheless, lately focus has shifted from structural flood measures to flood risk management where human aspects are more integrated (Parker et al., 2007). Some studies even suggest that a change in societal characteristics would have more impact on risk enhancement than climate change; flood risk management is gradually shifting from being water-cantered to people-cantered.

Tunstall et al. (2005) presents statistics for household inventory saved from flood damage by people who were warned compared to those that were not (see Table 5.2). The figures were obtained by asking people after a flood incident to identify which objects on a list of 100 they had moved and if they had been warned or not. The respondents were not asked what type of warning he or she had received. It is clear that there is a difference in how much inventory that could be saved with and without a warning. However, when comparing health issues in the same manner, warning systems do not seem to have any significant impact, as can be seen in Table 5.3.

Table 5.2 Saved household inventory during a flood event depending on if respondent had received warning or not (Tunstall et al., 2005)

	Warned	Not warned	All
Mean	£2,373	£1,552	£1,860
Standard deviation	£2,334	£1,964	£2,145
Number of cases	128	213	341

Table 5.3 Self-reported health effects of respondents exposed to a flood event (Tunstall et al., 2005)

Respondents	Warned	Not warned	All
Immediate physical effects reported	51%	56%	54%
Longer term physical effects reported	31%	34%	33%
Psychological effects reported	71%	72%	72%
Number of cases	229	716–7	945–6

The study performed by Tunstall et al. (2005) concludes that with a flood warning lead time exceeding 8 hours, 71 % of the respondents who got some kind of warning chose to act. For those with warning lead time shorter than 8 hours, 55 % chose to act. Parker et al. (2007) concludes that these results, combined with the inventory possible to save indicate that warning systems contributes to rather low economic benefits in flood management. However, a functioning warning system is essential in the collective, public safety and security contexts, and the total benefits might therefore be significantly larger.

The willingness to act of people who have received a warning depends on various factors (Parker et al., 2007). For example, stress can impair the ability to act during hazardous events. Furthermore, peoples past experiences tends to shape their image of the future meaning that the response to a flood warning will be partly based on previous experience of receiving flood warnings as well as being exposed to flooding.

Attempts to quantify the benefits obtained from flood warning systems have been made and one common method is described by Sene (2008), where the damage reduction on residential property and vehicles are assessed (equation 17 and 18).

$$FDA = R \times P_i \times P_a \times P_c \times PFDA \tag{17}$$

where:
FDA = Flood damages avoided;
$PFDA$ = Potential flood damages avoided (equation 18);
R = Service Effectiveness;
P_i = Probability that the individual will be able to be warned;
P_a = Probability that the individual is physically able to respond;
P_c = Probability that the individual knows how to respond effectively.
R equals the proportion of properties which were sent a message and $PFDA$ is calculated from annual damages as follows:

$$PFDA = DR \times C \times AAD \tag{18}$$

where:
DR = Damage reduction factor (the proportion of damage that realistically could be avoided by flood warning, i.e. inventory but not damage to structure);
C = Coverage of flood warning (proportion of properties receiving the warning);
AAD = Annual damage.

In a technical report issued by the Environment Agency and Defra, UK (Fielding et al., 2007) data from 1,395 households are investigated in order to assess public response to flood warning. A group of 456 people that responded in a survey had both been flooded and received a warning message. Of this group, 67.8% of the respondents reported that the actions they took during a flood were effective; 61 % of respondents with an above floor level flooding reported to act effectively while the number for those with below floor level flooding amount to 71%. People who had received clear and comprehensive warnings reported that their response was more effective and that the rate of effective action was significantly higher with those who had experienced previous floods and were familiar with what actions ought to be taken. The results are shown in Table 5.4. Judging from these, clear and informative warnings and advice on how to act are regarded as highly important in order to increase the ability of people to respond wisely during a flood event.

Table 5.4 Relationship between understanding what to do in a flood event and reported effectiveness of action (Fielding et al., 2007)

Question	Response	Percentage reporting actions as effective
Understood what supposed to do?	Yes/No	72.8/56.5
Previous flood experience	Yes/No	74.1/57.9
Received warnings before this episode?	Yes/No	78.3/63.3
Aware of Environment Agency Leaflet	Yes/No	74.3/64.6
Given enough information about what to do?	Yes/No	75.7/57.7
Was information clear?	Yes/No	73.2/59.1
Given enough advice to prepare	Yes/No	77.4/55.7
Remembered any advice when prompted	Yes/No	71.9/57.4

Conclusion

It is clear that information of various kinds supports effectiveness in actions taken during floods. Possibly, these differences in ability to respond effectively, as shown in Table 5.4 could be implemented in equation 17 and 18 above as parameter P_c. However, the benefits derived from implementing a warning system must be investigated on case specific basis since it has not been possible to find standard values for the number of people who will be able to receive a warning compared to before implementation of the measure. Nonetheless, it is clear that increased and improved information distribution aids in preventing damage costs due to flooding and if any values on efficiency of specific measures can be identified, they could be implemented in a CBA.

6. IMPLEMENTATION TIMING

A CBA looks at the sum of the costs and benefits that might arise when implementing a measure during a time period (variable but most commonly set to a period of 100 year in the Sweco model). The usual way to do this is to assume that measures are implemented in year one, which means that investment costs and maintenance costs (and any other cost or benefit) are discounted for the studied time period. However, it is interesting to examine the effects of delaying the implementation. Doing so would lead to advantages due to delayed investment costs and cost of maintenance during the studied period (i.e. 100 year) as well as disadvantages due to delay in protection that the investment provides. By assuming that implementation of a measure is beneficial as soon as the benefits exceed the costs, it can be possible to find a breakeven point in time. By knowing this, it is possible to identify during which time span investments preferably should be done. Needless to say, the goal is to optimize the usage of capital and obtain maximized benefit.

It is necessary to perform a number of simulations in the CBA model in order to identify the breakeven point. This can be achieved by changing the year of implementation in the CBA model and adjust the damage and risk cost scenarios to correspond to the year of implementation of the measure.

It is clear that it is of interest to look further into the effects of the implementation timing of measures, both for decision-making in planning processes and since the effect on CBA-results can be significant. To make a simplified example, it can be more economically beneficial to implement a measure 10 years from now if the risk of a flood event is low at first but steadily increases over time. Doing so, 10 years of maintenance could be avoided and the measure would be implemented when the risk of flooding and thereby the benefit of the investment get significantly higher. This type of scenario could be possible when climate change is considered; an area that is flooded rarely today might in some years have more frequent flood events. However, not delaying implementation of the measure would also generate various non-quantifiable effects. For example, it will increase the sense of security amongst the public and shows that actions are taken. This could especially apply to places where flooding has historically caused problems. If the opposite is true instead, a negative non-quantifiable effect could arise, namely that people loose trust in decision-makers since money is spent on seemingly unfounded incitements.

7. CASE STUDIES

Case studies have been performed in the municipalities of Staffanstorp and Norrköping in order to illustrate and evaluate the suggested changes in the model.

7.1. System boundaries

The case studies include benefits and costs that can be directly linked to the selected study areas. Thereby, the effects that some damage costs as well as additional benefits and disadvantages have on the society in a bigger perspective might go unnoticed. For example, the cost of flooding of a factory will in the case studies only include damage to property and loss of production; it will not include secondary damage imposed on distant consumers whose order of goods produced at the factory will be delayed. Likewise, benefits will only be taken into account for the immediate proximity; increase in house prices due to implementation of green storm water measures will be accounted for, whereas the fact that people due to price increase no longer can buy a house and have to relocate will not be considered. Although the CBA's attempts to include all costs and benefits in order to identify solutions that are the most beneficial from a societal point of view, it has been deemed too difficult to monetize the secondary effects and thus they are omitted as described above.

7.2. Staffanstorp

The case study covers a housing area in the northern part of Staffanstorp, which also contains a few industries and a couple of schools, see Figure 7.1. A ditch, Borggårdsdiket, conveys storm water through the area where it bypasses the treatment plant (WWTP) without getting treated and is further transported to the wetlands north of the area. The wetlands in turn discharge into the river Höje. According to VISS[19], the river will not be able to reach good ecological or chemical status until 2015, which is a goal set in accordance with the EU Water Framework Directive (2000/60/EC), and is in risk of not doing so by 2021 (VISS, n.d.). The environmental problems associated with the river are eutrophication and contamination of toxic substances as well as physical changes on habitats. The parameter causing eutrophication is phosphorus where sewage treatment plants as well as agriculture are regarded as sources. Several measures to reduce the amount of phosphorus have been taken, such as protection zones between agricultural land and the river and improved treatment ratio in wastewater treatment plants along the river.

Three rain scenarios have been used to study pluvial flooding in Staffanstorp; rain with 10-, 50- and 100 year return periods. These are chosen to represent both common and rare events. The former is associated with smaller consequences while the latter is associated with extensive damages. The rain scenarios are used to calculate an approximate total risk cost in a 100 year time period.

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[19] Database of surface water bodies governed by the Swedish Water Authorities http://viss.lansstyrelsen.se/

Figure 7.1 Dashed lines marks the area of study in Staffanstorp

7.2.1. Historical events

The area has previously suffered from floods as a result of intense precipitation. The 9th of August in 2006, the rain caused flooding of 50 basements (Sweco, 2009). The rain was estimated to a 40 year rain event with block duration of 20 minutes. In July 2007, another rain struck the municipality causing 130 basement floods. The registered rain intensity had a return time of 40-50 years. The 14th of August 2010 a pump failure in combination with a 45 minutes rain of 24 mm caused 36 basement floods (Sweco, 2011b).

The sewer system is considered to be a combined system with the capacity of a 10 year rain event (Ohlsson, 2014). The reason for flooding in Staffanstorp has mostly been due to additional water from rain and surrounding “soft” areas, which adds load to the wastewater system causing hydraulic overload. This in turn results in overflows and flooding of basements. Since the three floods in 2006-2010, Staffanstorp has put a lot of effort to improve their water management, for example through building a pumping station by the WWTP (2009) and relining pipes.

7.2.2. Method for CBA in Staffanstorp

The eight step procedure developed by Sweco (see chapter 2) with updates according to chapter 4 will be used to conduct the CBA in Staffanstorp. An uncertainty and sensitivity assessment will also be carried out.

7.2.2.1. Step 1: Hydraulic and hydrodynamic modelling

Identification of areas and objects at risk is carried out using a hydraulic model of the sewer network from 2009, see Figure 7.3. The sewer network suffers from severe intrusion from storm water, and catchments with rain for the different alternatives (10-, 50- and 100 year rains) act as loads. The outlet of the sewer water network is located in the north of the area at the wastewater treatment plant. As mentioned before, the ditch Borggårdsdiket discharges into the wetland just next to the WWTP. A newly constructed pumping station at the end of the ditch with a capacity of 4.5 m^3/s pumps the storm water into the wetland. Due to the high pumping capacity, the ditch can be considered to have infinite capacity when represented in the hydraulic model. Surface flooding separate from the sewer system has not been included.

7.2.2.2. Step 2: Economic valuation of flood costs

The effects of not taking actions to protect the studied part of Staffanstorp from flooding are assessed below. This scenario will further on be related to as *status quo*.

Flooding of buildings

In areas where the pressure head in the sewer system exceeds 0.5 metres above the upper level of the pipe where the building is connected to the sewer system it is assumed that connected houses are potentially flooded. It has been assumed by the municipality of Staffanstorp that 50% of the residential houses have basements (Ohlsson, 2014). Therefore, the number of actually flooded basements is calculated by multiplying 50 % with the number of potentially flooded buildings, see Table 7.1.

Table 7.1 Number of flooded buildings and basements within the study area – status quo

	10 year	50 year	100 year	100 year
Housing basements (potentially[a]/estimated[b])	68/34	173/86.5	289/144.5	144.5
Industry[c]	-	4	12	-
School[d]	-	-	1	-

[a] Potentially flooded basements are those where pressure head exceeds the pipe by 0.5 metres.

[b] Estimated number of flooded basements are 50% of the identified potentially flooded basements.

[c] It is assumed that industries do not have basements and are therefore not flooded.

[d] Borggårdsskolan has 110 pupils under 12 years age. It is assumed that the school will be closed for one day.

Surface flooding via sewer network

Table 7.2 presents the number of buildings where the hydraulic head is high enough (exceeding ground level) in the sewer network to cause surface flooding of wastewater. These are all considered flooded, regardless if they have a basement or not. It should be observed that the houses that are calculated as surface flooded have not been included in the basement floods in Table 7.1, thus double-counting is avoided.

Table 7.2 Number of surface flooded buildings – status quo

	10 year	50 year	100 year
Single-family housing	-	22	47

Flooded vehicles

Houses where water level exceeds ground level are assumed to have flooded vehicles. The damage depends on water depth, see Table 7.3.

Table 7.3 Number of flooded vehicles – status quo

	10 year	50 year	100 year
0.5m	-	22	45
0.5-0.7m	-	-	2
>0.7m	-	-	-

Sewer overflow

The model does not contain any standard overflow locations. However, if the combined volume of water through the pipes connected to the WWTP exceeds the capacity of the WWTP, the difference in combined volume and capacity will be regarded as sewer overflow released into the environment, see Table 7.4. The maximum capacity of the WWTP is 1,200 m^3/h.

Table 7.4 Volume of sewer overflow – status quo

	10 year	50 year	100 year
Overflow	-	225 m^3	540 m^3

Wastewater treatment cost at WWTP

In order to estimate the effects of implementing storm water measures, i.e. the reduced cost of treating storm water that has been conveyed by other means, it is necessary to determine the cost for treatment of storm water (in the WWTP), see Table 7.5. The volume accounted for is the total inflow minus the base flow (black water flow rendered from residential use). The base flow to WWTP is 65 m^3/h.

Table 7.5 Volume of water treated in WWTP - status quo

	10 year	50 year	100 year
Status Quo	1,669 m^3	2,609 m^3	2,945 m^3

Emergency pumping

A 100 year rain event will result in flooding of Borggårdsskolan, see Table 7.1. It is assumed that the school needs pumping, and the standard cost of 2,931 SEK has been used for the school.

Human health

The cost of sewage exposure is calculated based on the number of flooded basements, which is the same as presented in Table 7.1.

Standard deviation and distribution

The uncertainty associated with damage cost estimation has been represented by adding uncertainty distributions on various parameters in the CBA model. It was assumed that the value of the damage cost, as well as quantities, varies according to a lognormal distribution. This can be thought of as representing the variation in prices and costs and possible uncertainties in the hydraulic model respectively. It is assumed that the standard deviation for both the standard values and number of affected objects is the same. The standard deviation has been chosen to fit the conditions in Staffanstorp, and is expressed in percent of mean value (Table 7.6). Furthermore, a factor of “proportion of damaged objects” has also been applied, in order to illustrate that although exposed only a certain amount of the objects are assumed to actually be damaged. Since more than 100% of the objects in risk of being damaged cannot actually be damaged, a Beta-distribution has been applied.

Table 7.6 Standard deviation for cost categories relevant to Staffanstorp

Category	Standard deviation	Comment	Proportion of exposed objects that are damaged	Comment
Housing (single, multi-family and inventory)	10 %	The area is fairly homogeneous and insurance mean value (standard value) is assumed to be representable.	80 %	Most houses will be flooded if critical levels are exceeded.
Vehicles	35 %	There is a high uncertainty connected to the mean value of the value of a car and the number of existing cars in the area.	100 %	Vehicles are already represented by depth damage function.
Sewer overflow and storm water emission (release of phosphorus)	5 % for storm water, method 1 and 2 for sewer[a]	Values for storm water overflow obtained through hydrological modelling. Values for contaminants in sewer overflow can be estimated with two different methods.	95 %	Some contaminants might not reach the recipient.
WWTP (additional treatment cost)	5 %	Value obtained through hydrological modelling. Price of treatment is not likely to differ much.	95 %	Some storm water might not reach the WWTP
Emergency pumping (school)	20 %	It can take shorter or longer time to pump flooded object. It is also possible that more pumps could be needed.	75 %	The likelihood of the school needing pumping is fairly big.
Human health (sewage exposure)	5 %	Average values are assumed to be applicable.	95 %	If sewage exposure health issues are assumed.
School (number of students)	15 %	One parent could have more than one child in school and loss of income could differ.	100 %	Flooding will certainly lead to interruptions.

[a] As described in chapter 4.3 two different methods can be used to identify the level of contamination in sewage water. The results of these two methods have been set to the standard deviation in the CBA model.

7.2.2.3. Step 3: Cost-estimations of risk

The aggregated risk cost during a 100 year period is presented in Figure 7.2. The figure presents the risk cost with 5th and 95th percentiles certainty where a discount rate of 3.5 % has been used (see chapter 2.7).

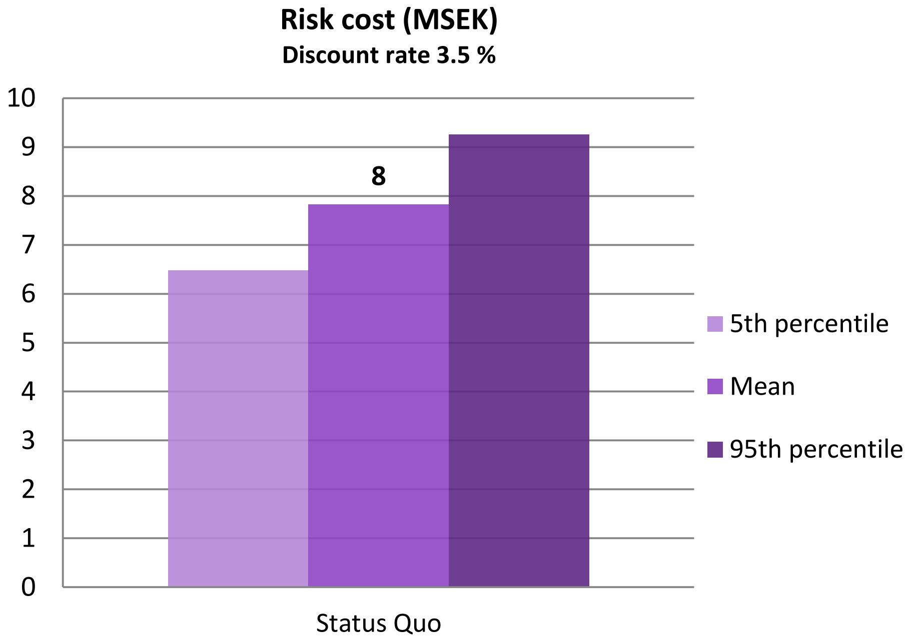

Figure 7.2 Risk cost in Staffanstorp if no measure is taken

7.2.2.4. Step 4: Identification of measures

Two alternatives of measures have been assessed in Staffanstorp.

Alternative 1 – Pipe refurbishment and separation of pipes

The first alternative consists of relining and separation of storm water and sewer pipes in a large part of the investigation area. The actual effect of this measure is that no storm water can leak into the sewer system, since it is diverted into the ditch Borggårdsdiket. In the model, the relining measure has been illustrated by removing the catchments that stress the sewer system thus relieving it. The disconnected areas are shown in purple in Figure 7.3.

Figure 7.3 Map of the sewer network: blue lines are the pipe system, purple lines the disconnected areas in alternative 1.

Alternative 2 – Sustainable urban drainage systems

The second alternative constitutes of constructing two dry ponds and swales distributing water to the stream Borggårdsdiket from one specific block in the study area. The volume of the ponds and the capacity of the swales will be designed in order to cope with a 100 year rain event. In the catchments connected to the ponds and swales it will be assumed that the 10 year rain volumes will be swallowed by the sewer system and the remainder of water volume will be led via swales and ponds to the stream. The catchments affected have thus been modified accordingly in the hydraulic model, resulting in less stress to the sewer network system. The locations of the two ponds have been chosen by studying the result of hydrodynamic modelling in GIS that shows where water would gather due to topographic conditions, see Figure 7.4.

Figure 7.4 Water depth in closed areas

The ponds and the surrounding green area will be constructed in such a way that they can act as recreation spots and will therefore render amenity value. They currently do consist of green space such as lawns and a couple of trees, but in order to obtain the benefit of amenity value it is necessary to design the area into a park that will be used and appreciated by the public. The location of pond number 1 (see Figure 7.5) coincides with an existing soccer field that will be submerged and thus be part of one of the storm water ponds. This means that the soccer field will not be usable during heavy rain events. In the park area a versatile ball court (for sports such as volley ball and basketball) will be constructed. Furthermore, a small garden with flower beds and a fountain will be built. Also, a jungle gym and a small ropeway for children will be placed in the park. Other facilities include a kiosk, a public toilet and benches at suitable locations. Trees will also be planted around the area.

Figure 7.5 Conceptual illustration of alternative 2: the dry ponds have been marked with blue and numbered 1-2

7.2.2.5. Step 5: Cost-estimation of measures

The cost to implement each alternative is assessed below.

Alternative 1: Pipe refurbishment and separation of pipes

The cost of implementing the first alternative of measures is separated into cost of relining and of adding new storm water pipes, which are illustrated in Figure 7.6. There are 4,351 metres of wastewater pipes to reline. The approximate cost has been calculated to 4,372,000 SEK assuming an average cost of 1,000 SEK per metre (4,351 metres of pipes in total). Start-up fees have been considered.

Alternative 2: Sustainable urban drainage systems

Two dry ponds and swales will be constructed to release pressure of storm water. The cost of constructing the swales and the ponds (including passing under roads through ducts etc.) is estimated to 1,173,000 SEK.

Maintenance of open storm water facilities is necessary to retain its function, such as the treatment ability (SWWA, 2011). Surfaces of grass, such as bioswales and dry ponds, need to be fertilized and cut to keep the flow capacity. There may also be a need to remove sediments and re-dig the swales after a few years due to clogging. Maintenance costs have not been included in this case study since the sites where the swales and dry ponds are to be implemented already are green areas and it is assumed that no additional maintenance costs will occur. Further, maintenance cost of urban furniture, such as repainting of playground equipment, is seen as small costs in the bigger context. Besides from the price of the storm water diversion system, the cost of implementation of facilities for the park rendering amenity value has to be included in the CBA. The approximate cost of implementing a park area including urban furniture and playground equipment is estimated to 1,300,000 SEK. Thus, the total implementation cost of alternative 2 is: 2,473,000 SEK.

For both alternative 1 and 2, the CBA model has accounted for a possible uncertainty of 50% over- or underestimation of the implementation costs since these were obtained using rough estimations.

Figure 7.6 Purple lines are pipes to be relined in alternative 1

7.2.2.6. Step 6: Reduced risk costs as a result of measure implementation

This section accounts for benefits of implementing measures, including additional benefits other than those gained from protection against flooding.

Flooding of buildings

The number of flooded buildings is presented in Table 7.7. In the same manner as for status quo, industry is omitted from the assessment.

Table 7.7 Number of flooded buildings – alternative 1 and 2

	10 year	50 year	100 year
Alternative 1 - Relining			
Single-family housing	19	33	102
Industry	-	4	4
Alternative 2 - SuDS			
Single-family housing	68	174	208
Industry	-	4	4

Surface flooding via sewer network

Table 7.8 summarizes occurrence of surface flooding.

Table 7.8 Number of surface flooded buildings – alternative 1 and 2

	10 year	50 year	100 year
Alternative 1 - Relining	-	-	-
Alternative 2 - SuDS	-	22	47

Flooded vehicles

Houses where water level exceeds ground level are assumed to have flooded vehicles. Table 7.9 presents the number of flooded vehicles.

Table 7.9 Number of flooded vehicles – alternative 1 and 2

	10 year	50 year	100 year
Alternative 1 - Relining			
0.5m	-	-	-
0.5-0.7m	-	-	-
>0.7m	-	-	-
Alternative 2 - SuDS			
0.5m	-	22	45
0.5-0.7m	-	-	2
>0.7m	-	-	-

Decreased amount of sewer overflow

In alternative 1 and 2 storm water is conveyed through Borggårdsdiket instead of the pipe system and WWTP. Therefore, the volume of overflow at the WWTP will decrease during heavy rain events, leading to reduced phosphorus emission costs, see Table 7.10.

Table 7.10 Volume of sewer overflow – alternative 1 and 2

	10 year	50 year	100 year
Alternative 1 - Reling	-	-	315 m^3
Alternative 2 - SuDS	-	45 m^3	252 m^3

Decreased cost for WWTP due to storm water being diverted to stream

The cost of treating the water at the WWTP will decrease with a reduction in water volume in alternative 1 and 2. Table 7.11 presents the volume to treat at the WWTP.

Table 7.11 Storm water treated in WWTP – alternative 1 and 2

	10 year	50 year	100 year
Alternative 1 - Relining	1309 m^3	1872 m^3	2197 m^3
Alternative 2 - SuDS	1451 m^3	2094 m^3	2450 m^3

Storm water contaminant emissions

Although conveying storm water into the ditch without passing the WWTP reduces the stress on the sewer system and the WWTP, this method will lead to contaminants entering the wetland ecosystem since water does not pass by the WWTP. The expected increase in cost due to release of phosphorous is calculated based on the volumes presented in Table 7.12. The bioswales and dry ponds in alternative 2 will provide a treatment effect up to 30% of phosphorus levels, which has been included in the calculations by setting the contaminant level to 70% (Larm, 2010). However, this value must be seen as a very rough indication of the treatment effect of phosphorus in these facilities.

Table 7.12 Volume of water reaching WWTP and decrease after measures implementation (=untreated storm water diverted into wetland)

	10 year	**Decrease**[a]	**50 year**	**Decrease**[a]	**100 year**	**Decrease**[a]
Status Quo	1,734 m^3	-	2,674 m^3	-	3,010 m^3	-
Alternative 1 - Relining (N.B. purified in ponds!)	1,374 m^3	360 m^3	1,937 m^3	737 m^3	2,262 m^3	748 m^3
Alternative 2 - SuDS	1,516 m^3	218 m^3	2,159 m^3	515 m^3	2,515 m^3	495 m^3

[a] Amount of water diverted into the stream

Human health

The cost of sewage exposure is calculated based on the number of flooded basements, which is the same as in Table 7.1.

Amenity value

Alternative 2 with SuDS will generate extra benefits in terms of amenity values. The park area is one hectare, and housing within one kilometre amount to 961 single-family houses and 408 apartments. This generates a total benefit of 3,924,523 SEK.

After implementation of alternative measures 1 and 2 the risk cost will decrease. The total risk cost of status quo and the alternatives are shown in Figure 7.7.

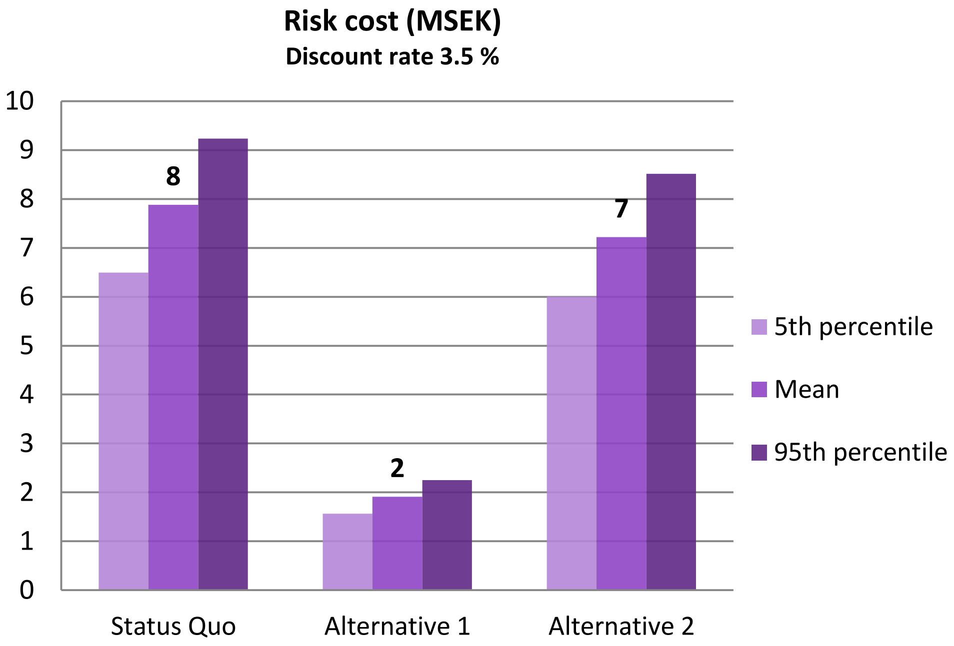

Figure 7.7 Risk cost for status quo and the measure alternatives

7.2.2.7. Step 7: Cost-benefit analysis

Alternative 1 and 2 result in a reduced risk cost, as shown in Figure 7.8.

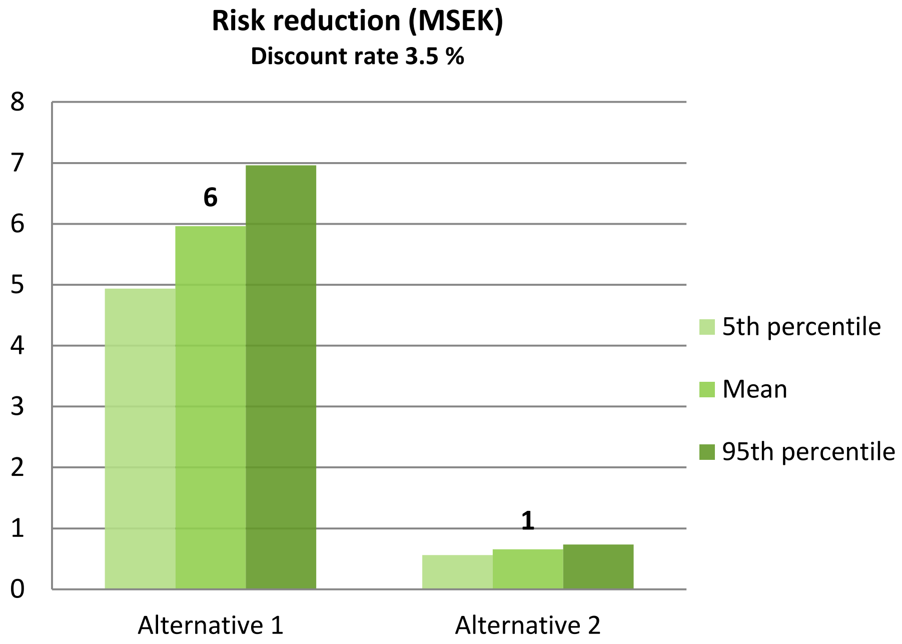

Figure 7.8 Risk reduction of alternative 1 and 2

The result of the cost-benefit analysis, i.e. the net present value of the two alternatives where risk reduction is weighted against the implementation cost, is shown in Figure 7.9.

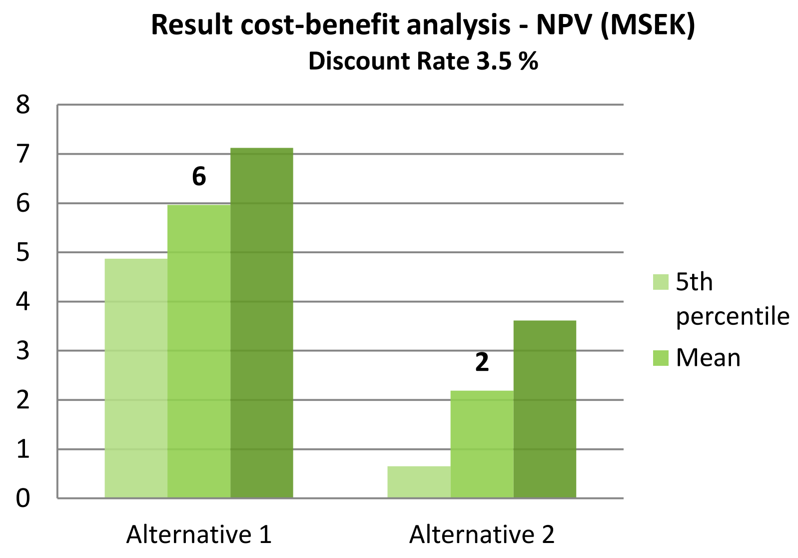

Figure 7.9 Net present values of the two alternatives

7.2.2.8. Step 8: Prioritization of measures

As can be seen in Figure 7.10, the probability of a positive outcome is very high and considering the factors included in the CBA both measures are feasible to implement.

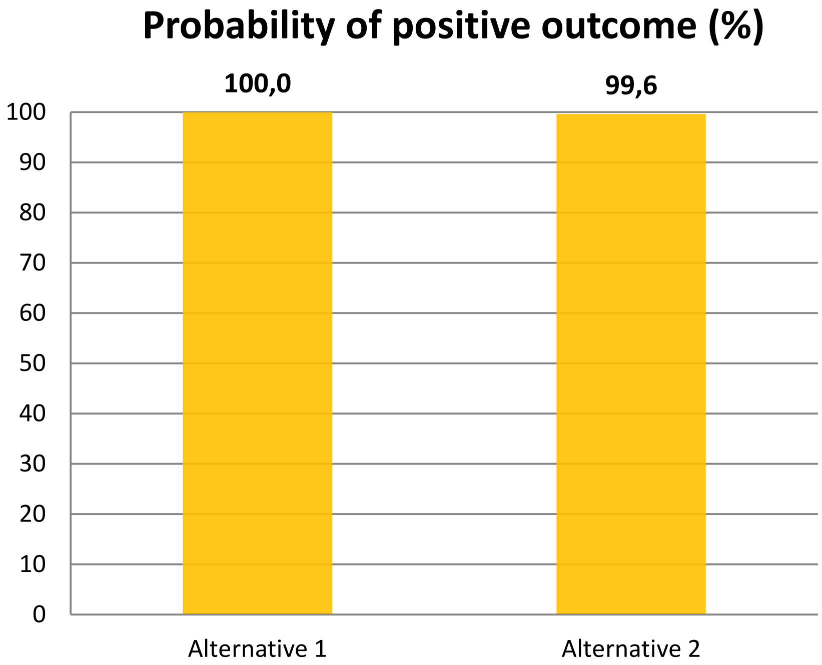

Figure 7.10 Probability of alternatives rendering positive outcome

7.2.2.9. Uncertainty and sensitivity analysis

The CBA enables studying of the uncertainties of the calculations; for each parameter it is possible to see how much it contributes to the total uncertainty. The charts in Figure 7.11 and Figure 7.12 show the parameters that contribute with more than 1 % (the rest is fairly equally distributed over the remaining parameters).

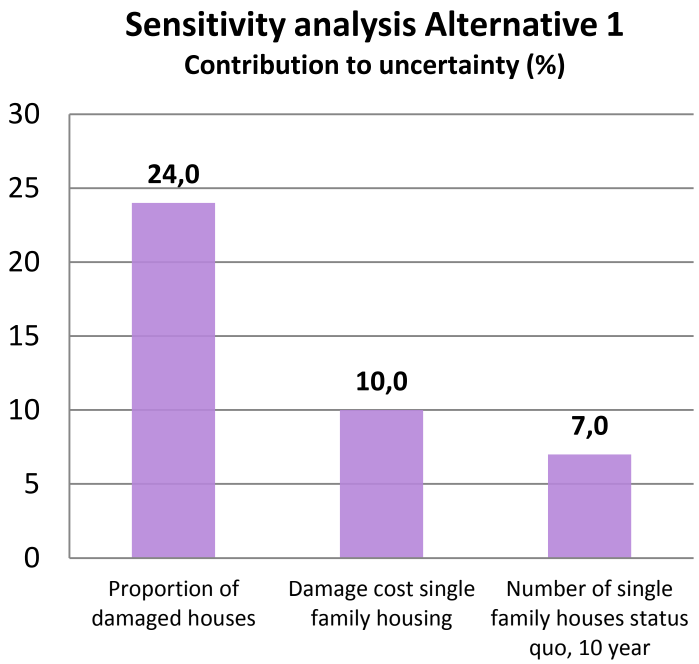

Figure 7.11 Sensitivity analysis of alternative 1 (relining)

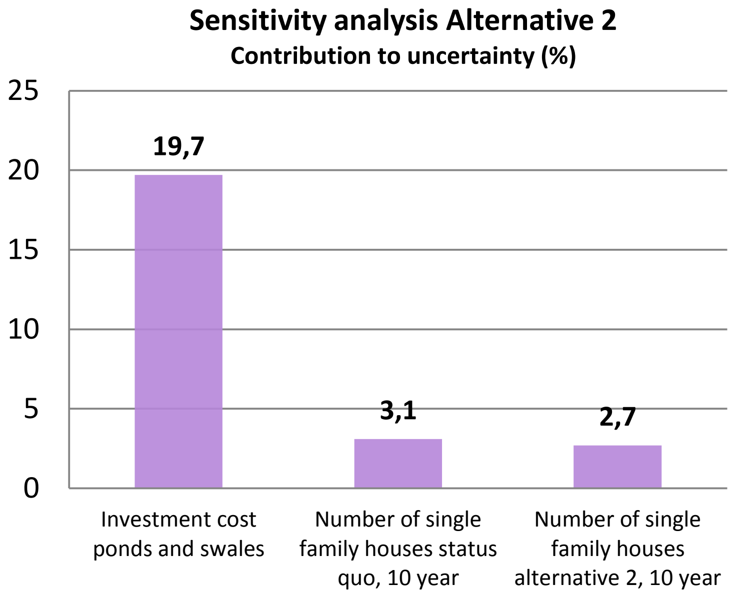

Figure 7.12 Sensitivity analysis of alternative 2 (SuDS)

7.2.2.10. Discussion and conclusion

The CBA conducted in Staffanstorp is discussed in the following sub-chapters.

Step 1: Hydraulic and hydrodynamic modelling

The hydraulic model of the sewer system used in the case study was created in 2009. A number of measures have been implemented since, and it is therefore questionable how accurate the model is. On the other hand, as for the comparison between the measure alternatives and status quo, the model should be sufficient even if the exact figures of risk reduction and so on are likely to be quite uncertain.

Step 2-3: Economic valuation of flood costs and cost-estimation of risk

The identification of flooded objects has been carried out manually, meaning that the number of affected properties has been counted by hand using model results and comparison with maps. In this specific case study this has been possible to do, but in a larger area it will demand much time and effort.

Step 4: Identification of measures

When identifying measure alternatives for the CBA of Staffanstorp, the intention was to pick solutions that could render interesting results where new parameters could be included in the CBA model. As mentioned earlier, the Sweco CBA model has not been used for pluvial flooding assessment and since pipe refurbishment of any kind is the most common measure towards this alternative 1 with relining was of big interest. This alternative is also similar to measures currently being taken in Staffanstorp. The choice to include alternative 2 with SuDS in the CBA was based on the desire to observe other aspects than hydraulic, such as improvements in the urban landscape. Also, the goal was to test the ability to assess ecosystem services, hoping to include a somewhat more sustainable approach into the analysis. It is possible that alternative 2 could have been designed differently to render even more benefits; currently it provides a rather limited risk reduction.

Step 5: Cost-estimation of measures

The cost-estimation of relining in alternative 1 was performed only using one source and is based on rough assumptions. It is therefore likely that this number is either over- or under-estimated. In the CBA model, it has been represented with a big uncertainty.

Step 6: Reduced risk costs as a result of measure implementation

The two measure alternatives represent two different approaches for dealing with pluvial flooding in a typical Swedish housing area that has repeatedly suffered from flooding. As for parameters inserted in the CBA the two alternatives only differ in one respect: amenity values. There are other parameters that probably are present but have not yet been possible to include in the assessment. Some of these are listed below:

- Biodiversity in new park area (alternative 2)
- Sense of security due to measures being taken (alternative 1 and 2)
- Confidence in municipality amongst the public (alternative 1 and 2)

This implies that both measures probably contribute to more beneficial results than the CBA shows.

One new parameter added to the assessment is vehicles, which proved to be a significant parameter. The total cost of flooded vehicles amount to around 3 MSEK for a 100 year rain event. Stated in chapter 3.1, damage to vehicles often makes up a large portion of the total value of assets at risk. It can thus be concluded that vehicles should be included in a CBA.

Another parameter that proved to make out a substantial part of the total damage is health issues due to basement flooding. For the 100 year event of status quo, the cost is approximately 1,500,000 SEK. It is interesting to observe that by only inserting health aspect, the outcome is significantly affected. This implies that more health parameters should be included, especially since they reflect other parts of social welfare other than material damage.

Step 7-8: Cost-benefit analysis and prioritization of measures

The results of the CBA show that alternative 1 renders the highest net present value and can therefore be seen as the most beneficial for the society to implement. Alternative 2 also shows a positive net present value. However, when removing the extra benefit of amenity value the net present value becomes negative.

In a CBA performed using the original Sweco CBA model, alternative 2 would have given a negative result. It could be considered strange to derive a net present value in a flood risk CBA from something that is not connected to a reduced pluvial flood risk. If making the decision to implement this alternative, it should be understood that the amount of floods avoided are limited. The societal benefit will increase, but not so much due to decreased flood risk as originally intended. Is it reasonable to add extra benefits, or will they render misguiding results where decision makers faultily believe that a measure leads to a decreased risk cost? Furthermore, can the value of amenity really be “exchanged” for the value of flood protection? This is also relevant in terms of responsibilities; the municipal department that is responsible of flood risk should not be in charge of implementing a park that mainly benefits the society through amenity values. Further, the estimation of amenity value can be considered to be fairly rough and the actual value might be higher or lower. It is not certain that alternative 2 will make as much difference to the prices of houses compared to a larger town or city, especially since the area was already “green” from the beginning. Some of the inhabitants may prefer open green area over a lively area that has been suggested in this alternative. If alternative 2 is considered for implementation, it is recommended to further investigate the relevance of the amenity value calculations. Factors such as substitute sites, the public opinion for building new parks and other aspects affecting house prices could be examined.

Uncertainty and sensitivity analysis

The results of the sensitivity analysis show that the implementation cost is the biggest contributor to uncertainty for alternative 2. Surely this is due to the fact that 50 % variation was assigned to this parameter. The number of houses was also significant leading to the assumption that a better performed identification of damaged object will lead to a more accurate assessment.

Conclusion

From a societal point of view both alternatives are feasible to implement, alternative 1 being the most beneficial.

7.3. Norrköping

The area of study is called Lagerlunda (Figure 7.13), which is a residential area north of Norrköping’s city centre and the stream called Motala ström. The area was built in the 1950s-1960s and the drinking water and sewer network has not been updated since then. The sewer system is combined, which has previously resulted in basement floods. The area is surrounded by railway embankments, being one of the reasons for the difficulties to convey surface water. Others are the low infiltration capacity, high groundwater level and low elevation. There is one point for overflow at Linnégatan where water is discharged to Motala ström.

Figure 7.13 Case study area Lagerlunda in Norrköping

7.3.1. Historical events

There were eleven damages reported from the area after the flooding in July 22nd-23rd of 2011, which occurred from a rain of 27 years return time (Kalm, 2014).

7.3.2. Method for CBA in Norrköping

The cost-benefit analysis of alternatives for Lagerlunda will follow the eight step procedure developed by Sweco (chapter 2) with updates according to chapter 4, including an uncertainty and sensitivity analysis.

7.3.2.1. Step 1: Hydraulic and hydrodynamic modelling

The hydraulic modelling of Lagerlunda has been carried out by Sweco. A model was created in MIKE Urban to reflect the current network dimensions in the area. Three CDS rain scenarios have been executed in the model: 10-, 20-, and 100 year rain events. A climate factor of 1.2 % has been used. MIKE Flood has been used to assess surface flooding of rain scenarios of 20 and 100 year return periods. The model has not been calibrated.

7.3.2.2. Step 2: Economic valuation of flood costs

The results from the hydraulic modelling of current conditions, i.e. status quo, are used to identify damages of the three different rain scenarios that occur in current network system.

Flooding of buildings

In areas where the pressure head in the sewer system exceeds 0.5 metres over the upper level of the pipe, where the building is connected to the sewer system, it is assumed that connected houses are *potentially* flooded (Table 7.13). The number of *actually* flooded basements is calculated assuming that 80 % of all residential houses in the area have basements. Surface flooding of storm water and wastewater has been identified using results from MIKE Flood.

Table 7.13 Number of flooded buildings – status quo

	10 year	20 year	100 year
Sewer flooding (houses/houses with basements)	68/54	81/70	115/92
Surface flooding	-	-	2

Flooded vehicles

Houses where surface water level (from either sewer or storm water) exceeds ground level are assumed to have flooded vehicles (Table 7.14). The damage depends on the depth; 0-0.5 m; 0.5-0.7m and >0.7m.

Table 7.14 Number of flooded vehicles – status quo

	10 year	20 year	100 year
0-0.5m	-	-	2
0.5-0.7m	-	-	-
>0.7m	-	-	-

Sewer overflow

One overflow location has been identified in the area. The volume of overflow at this point is presented in Table 7.15. The threshold for when overflow starts is not known and it is not possible to use method 2 (see chapter 4.3) for estimating amounts of contaminants. Furthermore, information about contamination levels at the WWTP is not known which is why method 1 and 3 cannot be used either. Instead, contaminants will be calculated assuming that when a rain event occurs, the same percentage of storm water that goes to the WWTP and overflow location respectively will be applicable to the wastewater. The storm water emissions at the overflow location will be assessed by using the standard value for average phosphorus content in storm water, which is 0.00025 g/l (see appendix 2). For the assessment of wastewater contaminants level the following figures will be used. One person produces P_{tot}= 0.0021 g per day and consumes on average 188 litres (SWWA, 2004) of water, which is assumed to be the same amount as the produced wastewater. With these values the phosphorus level per wastewater volume unit can be calculated. This will then be multiplied with the total volume of produced wastewater in the area (calculated assuming average number of people per household), which equals 136 m^3 for a 3 hour period. Then, the percentages of water going to WWTP and overflow location relevant for storm water will be applied.

Table 7.15 Storm and wastewater overflow and to WWTP – status quo

	10 year	20 year	100 year
Storm water emitted to river	1717 m^3	2311 m^3	4349 m^3
Storm water to WWTP	643 m^3	653 m^3	691 m^3
Percentage of total	73 %	78 %	86 %
Wastewater emitted to river[a]	99 m^3	106 m^3	117 m^3
Wastewater to WWTP	37 m^3	30 m^3	19 m^3

[a] The total amount of wastewater produced in the area multiplied with the percentage (middle row) going to overflow location.

Flooding of roads

Model results show that a 100 year rain event will lead to surface flooding of roads, which has been measured to a total distance of 100 metres. However, no data is available on traffic flows for these roads and since alternative routes exist within little distance it is assumed that no travel cost value will be relevant for this study.

Human health

The number of people exposed to basement flooding is estimated based on the number of flooded basements (see Table 7.13).

Standard deviation and distribution

The uncertainty associated with damage cost estimation has been represented by adding uncertainty distributions on various parameters in the CBA model. The value of damage cost varies as well as quantities according to a lognormal distribution. This can be thought of as representing the variation in prices and costs and possible uncertainties in the hydraulic model respectively. It is assumed that the standard deviation for both the standard values and number of affected objects is the same, with the only exception of number of damaged houses. In Norrköping a large uncertainty distribution been applied to this parameter since the hydraulic model has not been calibrated and the actual relationship between damaged buildings and water levels is not known. For other parameters, the standard deviations have been chosen to fit the conditions in Norrköping. They are expressed terms of percent of the mean value (Table 7.6). Furthermore, a factor of “proportion of damaged objects” has also been applied, in order to illustrate that although exposed, only a certain amount of the objects are assumed to actually be damaged. Since more than 100% of the objects in risk of being damaged cannot actually be damaged, a Beta-distribution has been applied.

Table 7.16 Standard deviation for cost categories relevant to Norrköping

Category	Standard deviation	Comment	Proportion of exposed objects that are damaged	Comment
Housing (single, multi-family and inventory)	10 % for damage cost and 30 % for number of damaged houses	The area is fairly homogeneous and insurance mean value (standard value) is assumed to be representable. The model is not calibrated so the number of damaged buildings is uncertain.	80 %	Most flooded houses are assumed to be damaged.
Vehicles	30 %	There is a high uncertainty connected to the mean value of the value of a car and the number of existing cars in the area.	100 %	Vehicles are already represented by depth damage function.
Sewer overflow and storm water emission (release of phosphorus)	5 %	Values for storm water overflow obtained through hydrological modelling.	95 %	Some contaminants might not reach the recipient.
WWTP (treatment cost)	5 %	Value obtained through hydrological modelling. Price of treatment is not likely to differ much.	95 %	Some storm water might not reach the WWTP.
Human health (sewage exposure)	5 %	Average values are assumed to be applicable.	95 %	If sewage exposure health issues are assumed.

7.3.2.3. Step 3: Cost-estimations of risk

The aggregated risk cost during a 100 year period is presented in Figure 7.14. The figure presents the risk cost with 5 and 95 percentiles certainty where a discount rate of 3.5 % has been used (see chapter 2.7).

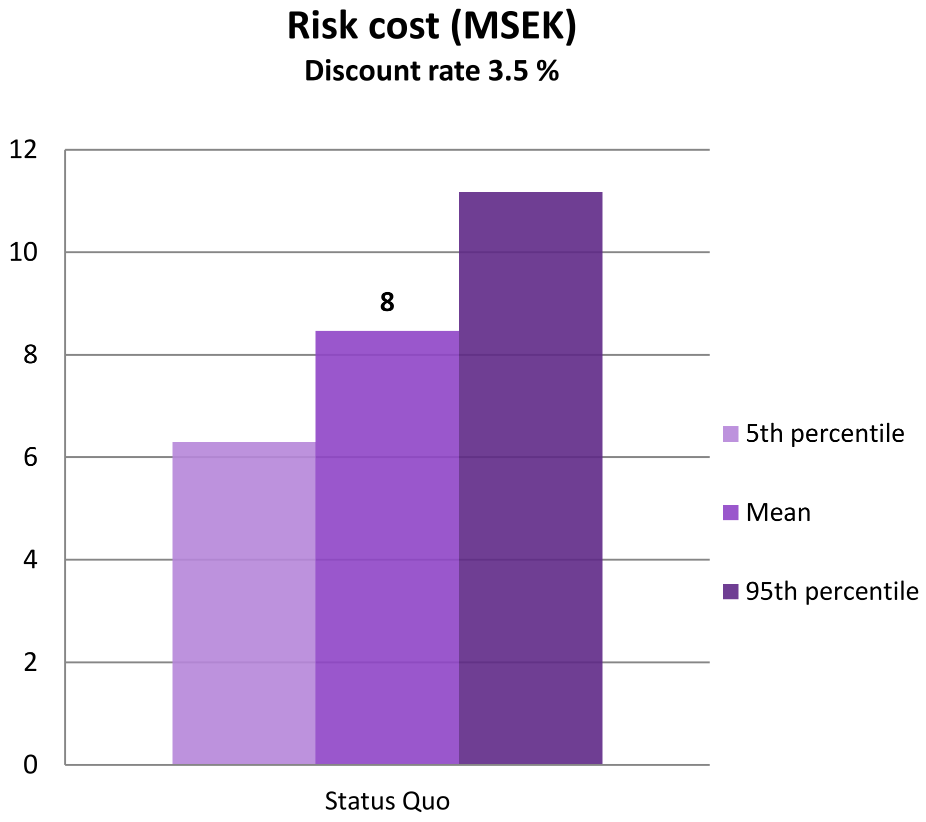

Figure 7.14 Risk cost in Norrköping if no measure is taken

7.3.2.4. Step 4: Identification of measures

Two alternatives of measures to status quo will be assessed in Norrköping, see below.

Alternative 1 – SuDS

The first alternative constitutes of an open storm water solution (SuDS) developed by WSP (2013) where the rain water is conveyed on the surface instead of through the combined sewer systems (WSP, 2013). The idea is to decrease the load on the sewerage and WWTP as well as to incorporate storm water as an asset in the urban landscape. Figure 7.15 shows where the various solutions are supposed to be located. The measure is designed to reduce the volume of a 100 year rain event to a volume corresponding to a 10 year rain event. The combined system will instead be used mainly for sewer since storm water is assumed to be retained and diverted by ponds and swales. Benefits besides reduced flooding include less volume to WWTP, less sewer overflow as well as purification of water. WSP has used a climate factor of 1.2 and in order to enable comparisons between the alternatives, it has been chosen to use the same factor in the entire case study.

Figure 7.15 Illustration of alternative 1, Norrköping

Alternative 2 – New piping system

The second alternative consists of adding new storm water and wastewater pipes, see Figure 7.16. The aim is to investigate the extra benefits generated due to coordination of works that requires earthwork, shafting and suspension of roads or other impacts. By doing this, planned future work can be included (e.g. replace pipes or add optical fibre) and thus shafting and interruptions are only needed once instead of for every single action. In this case study, specifically the benefits of adding drinking water pipes will be studied.

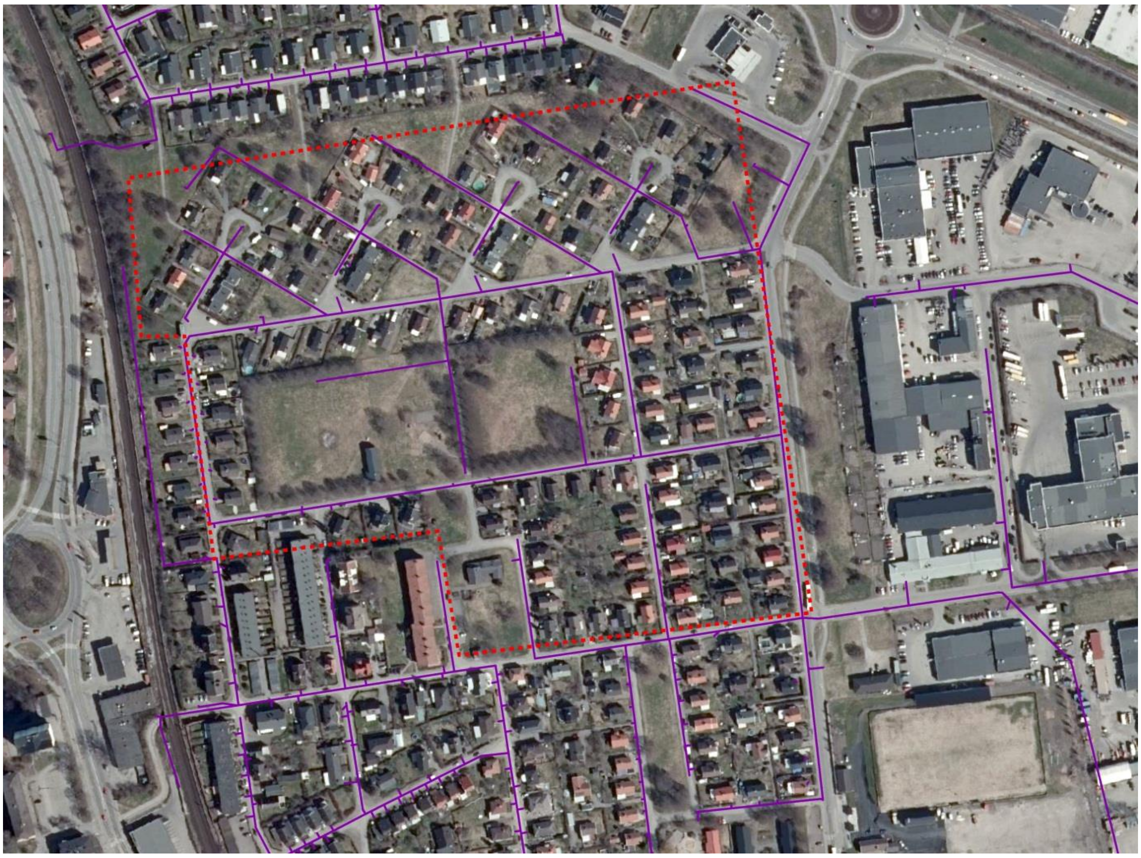

Figure 7.16 Sewer network (purple) within study area (red dashed line)

Alternative 2 is simulated in a hydraulic model where the current combined sewer system will be used to only convey storm water. The dimension of the current system has been modified to cope with storm water of a 20 year rain event. Wastewater pipes have not been constructed in the hydraulic model since the measure results in that the sewer system is completely disconnected from the storm water system and thus not affected by rain.

7.3.2.5. Step 5: Cost-estimation of measures

The total cost of implementing alternative 1 in Norrköping is 17,800,000 SEK (WSP, 2013). Costs for planning are not included in this figure. Maintenance costs could not be considered in this case study.

The total cost of implementing alternative 2 has been estimated from cost of new storm water pipes and wastewater pipes and amounts to 13,000,000 SEK. This includes a price for shafting which is 5,600,000 SEK. This is also considered as a benefit since a future work can be saved, see step 6.

7.3.2.6. Step 6: Reduced risk costs as a result of measure implementation

Implementation of the two alternatives presented in step 4 will result in a reduced risk cost.

Flooded buildings

The numbers of flooded buildings when the alternatives are implemented are presented in Table 7.17. Alternative 1 using SuDS is expected to generate the same damages as a 10 year event in the current sewer network for all rain scenarios (see description in step 4).

Table 7.17 Number of flooded buildings – alternative 1 and 2

	10 year	20 year	100 year
Alternative 1 - SuDS			
Sewer flooding	54	54	54
Surface flooding	-	-	-
Alternative 2 - Pipes			
Sewer flooding	0	0	0
Surface flooding	-	-	2

Vehicles

The amount of vehicles flooded in alternative 2 is presented in Table 7.18. Alternative 1 will not render any surface flooding and therefore no damage to vehicles.

Table 7.18 Number of flooded vehicles – alternative 2

	10 year	20 year	100 year
0.5m	-	-	2
0.5-0.7m	-	-	-
>0.7m	-	-	-

Flooded roads

Alternative 1 is not expected to have any surface flooded roads since the SuDS are supposed to cope with the storm water. A 100 year rain event in alternative 2 will however, according to model results, lead to surface flooding of roads. The total distance of flooded roads has been measured to 140 metres. In the same manner as for Status Quo, due to alternative roads being present the flooding of roads has been omitted from the CBA.

Decreased amount of sewer overflow

Alternative 1 will lead to a decreased amount of sewer overflow (Table 7.19). In alternative 2 no overflow of sewer water will take place, but the storm water will be distributed to Motala ström instead of to the WWTP, resulting in that some phosphorus emissions still will take place. The amount of contaminants in storm water will be assessed as in status quo.

Cost of treating storm water (less volume to treat)

Alternative 1 will lead to a decrease in volume of storm water to treat in WWTP, thus reducing the treatment cost. For alternative 2 the new sewer system has not been modelled (hydraulic) and it is assumed that the original residential base flow is now going to the WWTP instead of into Motala ström during rain events, contributing to a higher treatment costs. The volumes are shown in table Table 7.19.

Table 7.19 Storm and wastewater overflow and to WWTP – alternative 1 and 2

	10 year	20 year	100 year
Alternative 1 - SuDS			
Storm water emitted to river	1717 m^3	1717 m^3	1717 m^3
Storm water to WWTP	643 m^3	643 m^3	643 m^3
Percentage of total	73 %	73 %	73 %
Wastewater emitted to river	99 m^3	99 m^3	99 m^3
Wastewater to WWTP	37 m^3	37 m^3	37 m^3
Alternative 2 - Pipes			
Storm water emitted to river	2842 m^3	3565 m^3	6048 m^3
Storm water to WWTP	0	0	0
Percentage of total	100 %	100 %	100 %
Wastewater emitted to river	0	0	0
Wastewater to WWTP	136 m^3	136 m^3	136 m^3

Table 7.20 Amount of water to WWTP – alternative 1 and 2

	10 year	Treated rainwater/ wastewater	20 year	Treated rainwater/ wastewater	100 year	Treated rainwater/ wastewater
Status quo	643 m^3	17 m^3	653 m^3	27 m^3	691 m^3	65 m^3
Alternative SuDS	643 m^3	17 m^3	643 m^3	17 m^3	643 m^3	17 m^3

Human health

The number of people exposed to basement flooding is estimated based on the number of flooded basements (see Table 7.17).

Extra benefits: avoided cost of future shafting for drinking water pipes

In alternative 2 it is assumed that while refurbishing storm water and wastewater pipes the opportunity to also exchange drinking water pipes is taken. The drinking water pipes would have needed to be exchanged within 20 years in any case, and since shafting is a substantial cost it would be beneficial to do this operation at the same time to avoid cost for work twice. The avoidance of a future cost for shafting for drinking water pipes is included in the CBA as a onetime amount 20 years from the present and discounted accordingly. The amount used is 5,600,000 SEK, which is the total work cost for alternative 2. An uncertainty of ±30 % has been assigned for this value.

After implementation of measures alternative 1 and 2 the risk cost will decrease. The total risk cost of status quo and the alternatives are shown in Figure 7.17.

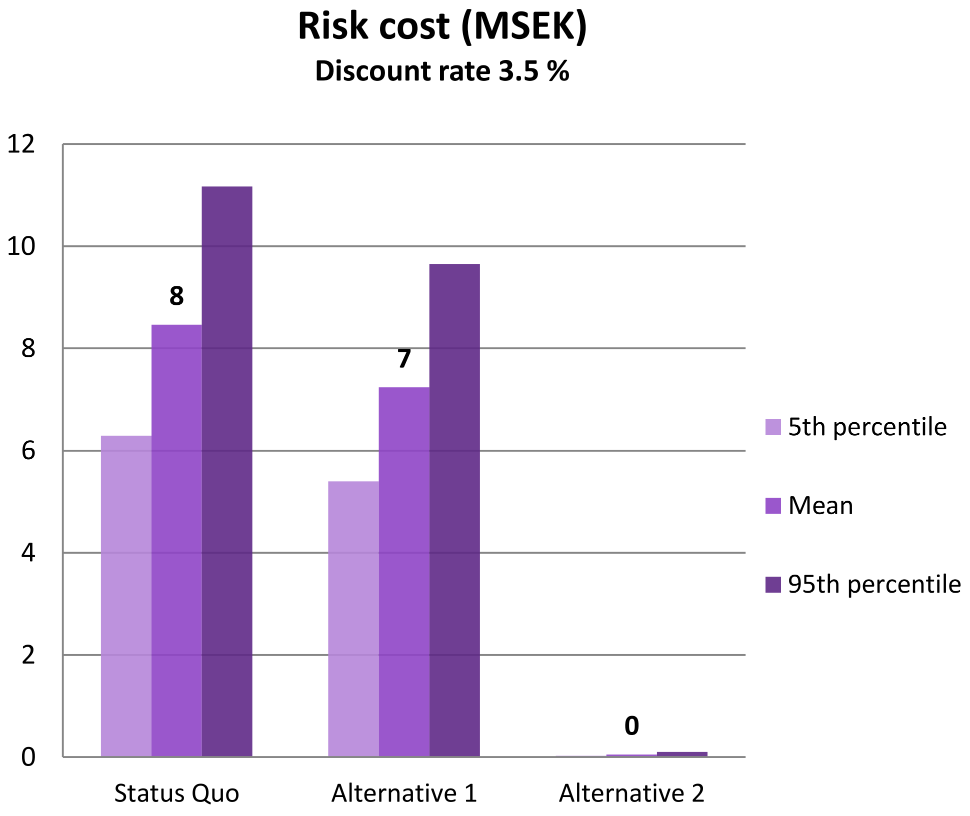

Figure 7.17 Risk cost for status quo and the two alternatives

7.3.2.7. Step 7: Cost-benefit analysis

The differences in risk cost between status quo and alternative 1 and 2 that is presented in Figure 7.17 is the risk reduction, as shown in Figure 7.18.

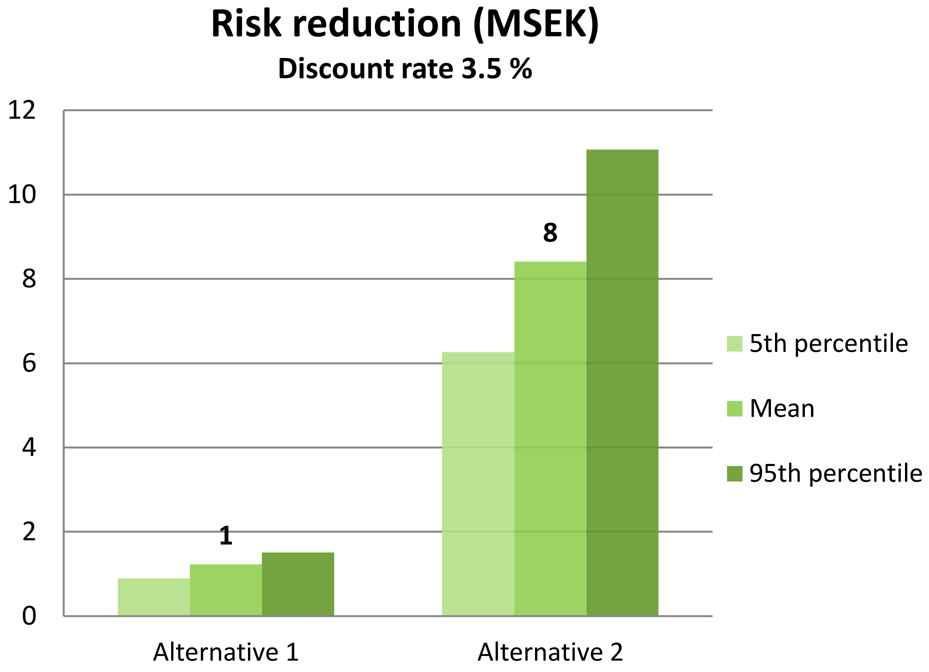

Figure 7.18 Risk reduction of the two alternatives

The result of the cost-benefit analysis, i.e. the net present value of the two alternatives where risk reduction is weighted against the implementation cost, is shown in Figure 7.19.

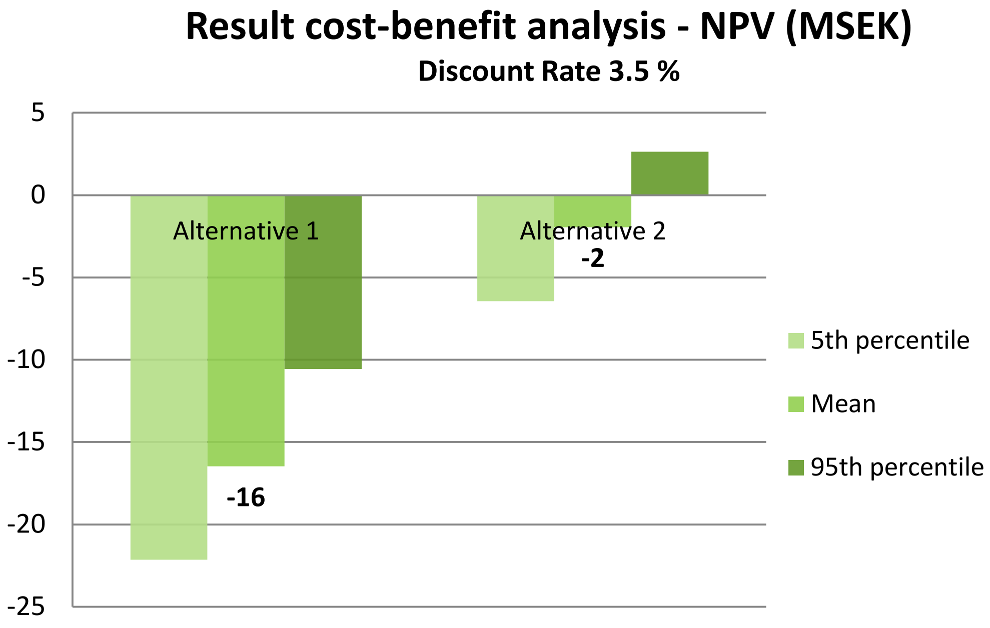

Figure 7.19 Net present value of alternative 1 and 2

7.3.2.8. Step 8: Prioritization of measures

Alternative 1, to construct SuDS, will according to the CBA (Figure 7.19) provide a negative value, which is a result of high implementation costs and low efficiency in terms of risk reduction. Alternative 2 is, compared to alternative 1, both less costly and more efficient, but most likely not enough to render a positive result in a societal 100 year perspective (25.7 %, as can be seen in Figure 7.20).

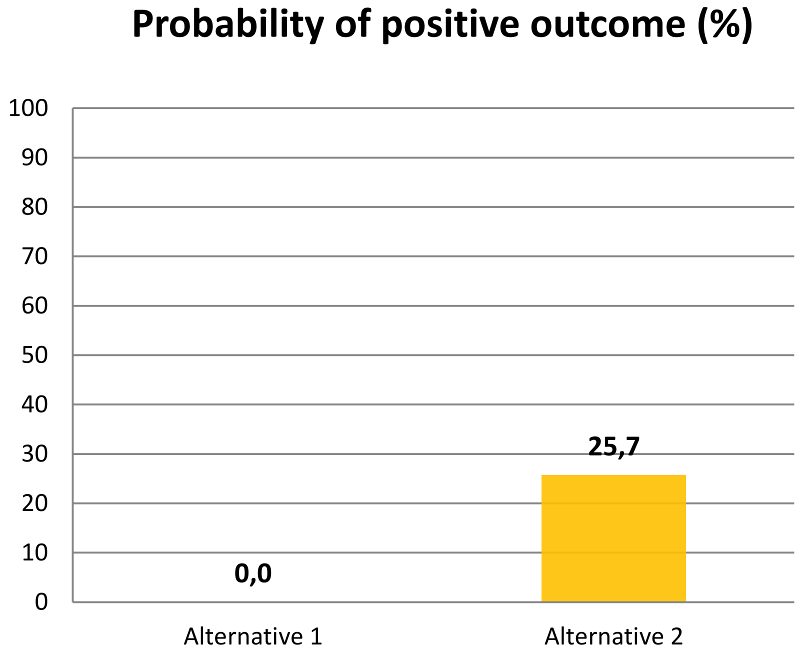

Figure 7.20 Probability of positive outcome

Uncertainty and sensitivity analysis

The uncertainties that have been given to each parameter in the CBA model are reflected in a sensitivity analysis, see Figure 7.21. It shows that the investment cost is the biggest contributor to uncertainty in alternative 1, followed by number of flooded single family houses.

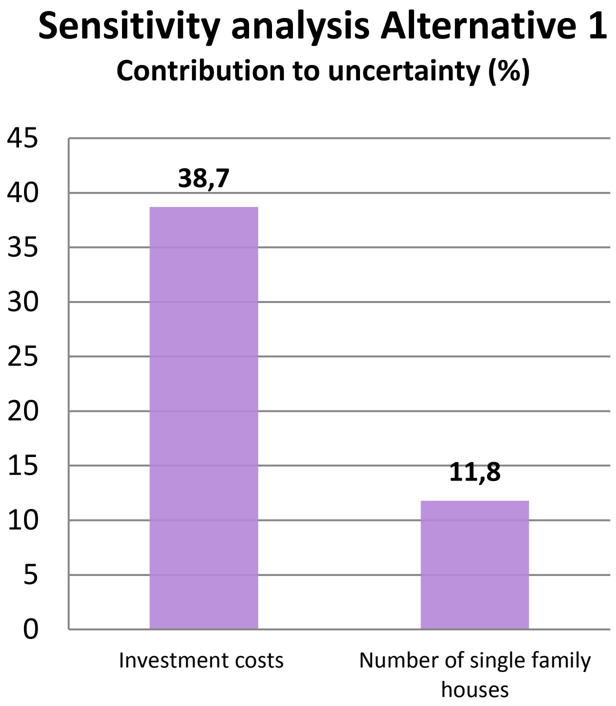

Figure 7.21 Sensitivity analysis of alternative 1 (SuDS)

In alternative 2, the sensitivity analysis (Figure 7.22) show that the investment cost is the most uncertain parameter, followed by number of flooded single family houses.

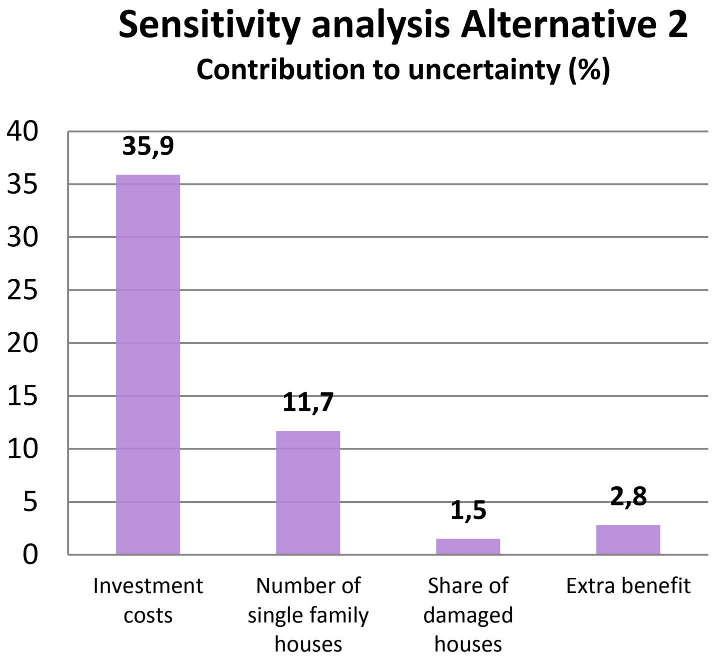

Figure 7.22 Sensitivity analysis of alternative 2 (new pipes)

7.3.2.9. Discussion and conclusion

The CBA conducted in Norrköping is discussed in the following sub-chapters. Some topics that cover the over-all application of the updated Sweco model have already been discussed (such as vehicles) and will therefore not be mentioned in this section.

Step 1: Hydraulic and hydrodynamic modelling

The hydraulic model of the sewer and storm water system was created for the purpose of this case study. This model has not been calibrated to any actual rain event and therefore the performance of the model is associated with high uncertainties.

Step 2-3: Economic valuation of flood costs and cost-estimation of risk

The identification of flooded buildings has been performed manually. As mentioned above, the performance of the hydraulic model is unknown and therefore a standard deviation of 30% of number of flooded buildings has been assigned in the CBA model.

Step 4: Identification of measures

The selection of measures was based on one existing suggestion (alternative 1 – SuDS) and one suggestion that the municipality of Norrköping had been considering (alternative 2 – refurbishment of pipes). The SuDS measure was assumed to perform as intended by the company responsible for the design.

Step 5: Cost-estimation of measures

The cost-estimation of alternative 1 was performed and assessed by the company responsible for the design. The cost-estimation of alternative 2 was calculated by a professional consultant working with relevant issues and can therefore also be assumed to be correct. The uncertainty related to these figures has therefore been assigned to lower numbers than for example in Staffanstorp (±30%).

Step 6: Reduced risk costs as a result of measure implementation

The two measure alternatives represent two different approaches for dealing with pluvial flooding. The extra benefit of avoided extra shafting that was included in alternative 2 is the biggest difference in the parameters that have been assessed. Several other parameters could probably have been included. For example, no amenity value was assigned to alternative 1 since the green areas are not big enough and their recreational value is uncertain. Other ecosystem services related to this measure that were not possible to assess include habitat creation, purification of air and possibly more. Furthermore, as in the case study of Staffanstorp other benefits such as feeling secure knowing that one's house is flood proofed could not be included.

The extra benefit of not having to perform the work related to drinking water pipes in 20 years' time is included. However, only the benefit of avoiding this cost is accounted for, not the fact that drinking water pipes have to be bought and replaced earlier (which will render a lower NPV than if done in 20 years). However, the state of the current drinking water pipes is probably not very good, and by refurbishing them now instead of later, costs associated with leakage and repairs might be avoided. In general, this estimation is quite uncertain but it is assumed that the current estimation of the extra benefit is close enough to reality.

Step 7-8: Cost-benefit analysis and prioritization of measures

The CBA result shows that alternative 1 is not economically feasible to implement and it can also be seen that the risk reduction of the measure is not very high (around 1 MSEK). The aim of this measure was to decrease all rain events up to a 100 year return period to that of a 10 year return period. However, the damage costs for the 10 year level are quite high, but do not get considerably higher for the 20 and 100 year return times which is why the risk reduction of the alternative is low. However, even if the risk reduction could be improved, the implementation cost is likely to be too high to be able to obtain a positive net present value; the aggregated maximum risk cost of status quo is 11 MSEK and the cost of the measure is 17.8 MSEK.

Alternative 2 also results in a negative net present value and can therefore not be seen as feasible to implement (although there is a slight chance of a positive outcome). The cost of implementation is lower than for alternative 1, and the risk cost reduction is higher. In order to find a measure that can generate a positive net present value one idea might be to look at small scale solutions where some critical pipes are refurbished instead of the entire system. This would result in a smaller investment cost but if changes to the pipe system are done in optimal locations the risk cost reduction might be substantial. Furthermore, maintenance cost for the current system is not included. Possibly, a substantial extra benefit relevant to alternative 2 could be derived since the pipes would be refurbished. One negative aspect that perhaps should have been included is the value of discomfort due to the disruption and inconvenience that the measure causes, for example a willingness to pay value to avoid noise and traffic disruption.

The CBA result shows that the risk costs associated with status quo as well as alternative 1 have very big gaps between the 5th and the 95th percentile (e.g. 6 MSEK and 11 MSEK respectively in status quo). This is seemingly due to the fact that the number of damaged houses was given a large uncertainty due to lower precision of the hydraulic model. Depending on how the standard deviation is altered, the results will vary accordingly. In order to get a more accurate assessment of the flood risk cost and thus prioritization of measures, it is recommended to calibrate the model to an actual rain event in order to identify a proportion that is reasonable to assign to these values. Thus, a lower uncertainty can be given to the values and the results will be more accurate.

Uncertainty and sensitivity analysis

The results of the sensitivity analysis show that the implementation cost is the biggest contributor to uncertainty for alternative 1. The 30 % variation and the high cost are believed to be the reason for this. Almost the same conditions apply to alternative 2.

Conclusion

From a social profitability point of view, none of the alternatives should be implemented. Instead, it might be a good idea to investigate small scale solutions that provide small reductions in risk costs to a lower price. In order to get a more accurate result calibration of the hydraulic model is recommended.

8. RESULTS

The main results of this thesis consist of three parts. The first is a holistic overview of the current best practices of CBA used in flood risk assessment that was gained from literature review. Secondly, the thesis has resulted in a development and an update of the Sweco CBA model that includes new parameters and methods of assessments. The third result is the application of the CBA model through case studies. The major findings of each result are summarized in the following sub-chapters.

8.1. Literature review

Main findings from literature review:

- Micro scale and high level of precision should be used for CBA's performed on municipal level since big variations in cost are likely to apply. A more detailed assessment gives lower uncertainty.
- Depth-damage functions should not be used, other than in cases where very relevant. One such case is vehicles where the susceptibility varies with depth.
- It is feasible to use insurance data.
- Social impacts can be more severe and important to victims than the economic loss of an object. In general, intangible values should be included in a CBA, e.g. by performing WTP studies. However, the degree of uncertainty is high when it comes to using these kinds of studies.
- Extra benefits such as amenity value of ecosystem services should be identified and included in the CBA. Hedonic valuation is one way to estimate this. The values are very case specific and caution is recommended when extra benefits constitute major parts of the result.
- Value transfer can be used when sites are similar and data is lacking, however, caution when it comes to e.g. substitutes is recommended.
- Except for sewage exposure in basements, no other health parameters have been included. It is possible to identify cost of getting ill, but the probability and susceptibility have not been identified. Therefore this category fails in the CBA context, although including it is desirable.
- Literature lacks in damage to freight transport on road and by rail, although these categories can possibly be major contributors to the total damage cost.
- Literature also lacks in damage to industry and loss of production; many attempts have been identified but few are feasible and applicable to Swedish conditions.
- The literature is minimal when it comes to assessing duration of flood, although several studies recommend using this parameter in damage cost estimation. Knowledge of flood duration would enable assessments of several parameters.
- Warning systems have not been possible to assess further since it is not a commonly suggested measure; in general, physical solutions are traditionally most recommended. It is desirable that more literature deals with alternative measures.
- The usage of standard values is acceptable although site specific values always are preferred.

8.2. The updated Sweco model

Main findings from model development:

- Due to lack of other ways of estimating damage, insurance values will be used.
- Vehicles constitute a substantial part of flood damage and are now included in the updated model.
- Damage to ecosystem services is included to some extent through the assessment of eutrophication were WTP values are used.
- Treatment of wastewater, interruption in societal services, compensation for electricity outage and compensation for insufficient drinking water supply are included as new parameters.
- Traffic delays require substantial investigation for alternative routes and flows etc. The category is very complicated; even if data on flooded roads is possible to extract, the assessment will be time consuming and connected to uncertainties. If found relevant, such studies could be performed.
- No appropriate new method for estimating industrial damage could be included. In reality, this is probably a major part of the total damage costs which should be remembered observing CBA results. Likewise, loss of production could not be included in the updated model.
- Cultural heritage is problematic due to trouble in identification as well as due to the fact that individual assessment is needed. Travel cost and WTP can be used.
- CBA is tool for decision making and depending on implantation timing the decision-making can change.
- Identification and estimation of extra benefits should be better incorporated both in the CBA process and model.
- If warning systems are implemented; damages to inventory can possibly be avoided.
- Health impacts of sewage exposure have been added and more issues related to health are desired to include in the model.

8.3. Case studies

Main findings from the case studies:

- Eutrophication was assessed and although not a big part of the result, it is important to include this parameter in order to shed light on the issue.
- Assessment of extra benefits resulted in that amenity values gave positive NPV. Including extra benefits results in positive outcomes not related to flood risk reduction.
- Vehicles is a significant parameter since it renders great cost.
- Health impacts of sewage exposure also proved to be a parameter resulting in rather big costs.
- Two parameters that probably are relevant but could not be assessed are: sense of security due to measures being taken and confidence in municipality amongst the public.
- The uncertainty of the data inserted in a CBA highly reflects the result. Carefully collected in-data will generate a more accurate result and this assessment should be performed thoroughly.

9. DISCUSSION AND CONCLUSION

The following chapter includes discussions and conclusions of this master thesis and has been divided into sub-chapters representing general and specific issues.

9.1. CBA and social welfare

When using cost-benefit analysis different measures are compared from a societal welfare point of view. However, social welfare is a phenomenon that is both difficult to define and fully reach. In the context of flood management it may seem clear that the goal is to implement measures in order to benefit the society, but some measures to pluvial flooding improve social welfare for certain groups in the society while they, at the same time, may lead to impairment for others. For example, to build a park with constructions for storm water will use land that could also have been used for housing, thus reducing income for the municipality as well as putting restrictions on people who are in need of somewhere to live. The park will provide flood protection and new amenity values that probably will increase the market value of the surrounding neighbourhood. This can start a gentrification process, which in turn could affect market prices in other areas and result in equality issues. In other words, a measure that improves social welfare by bringing economic benefits through amenity value as well as other ecosystem services such as habitat provision can result in less obvious but nevertheless important negative effects. As described in chapter 1.1.1 the CBA is based on the Hick's-Kaldor criteria that as long as the "winners" compensate the "losers" a change in society is regarded as beneficial and should be performed. The issue with the CBA is that it traditionally strives to identify the gains of the winners (i.e. avoided loss in the case of flood risk management) and thereby unintentionally disregards the loss of the losers. When performing a CBA it is therefore recommended to consider what social welfare means to affected target groups. A distributional analysis should always be performed with a CBA in order to avoid an unfair distribution of costs and benefits.

9.1.1. Intangible and indirect values

Since cost-benefit analysis is used to evaluate whether or not a decision or measure is beneficial in a societal perspective, it demands that an economic value is assigned to all possible aspects. Therefore this thesis attempts to include intangible and indirect losses to a further extent. There are, however, opinions that the monetization of intangible values is controversial (Klijn, 2009). This is understandable since attaching a value to for example cultural heritage, personal belongings with sentimental values or even a person's life might seem impossible since they are considered "invaluable". However, if these values are not included in a CBA there is a high risk that they will be overseen. For example, it is not unlikely that people experiencing a flood will grieve the loss of beloved memorabilia more than a TV, although the former has no or little actual market value. An obvious question is whether or not the society should pay for things such as emotional losses. On the other hand, personal belongings with a market value are compensated through insurance and are thus included in a CBA, although memorabilia might be valued more by the person in question. Therefore tangible aspects should also be valued and included in the CBA, in order to reflect societal justice. Decision-making is question of democracy and excluding intangible values ignores people's feelings and emotions.

9.1.2. Decision-making

One prerequisite throughout this project has been that a CBA cannot provide the basis for sustainable and accurate decision-making process unless all perspectives of sustainable development are considered. A CBA can be misused by decision-makers; the ones ordering the CBA have the opportunity to influence the results by deciding which parameters or measures to consider in the assessment. There is also a risk that CBA results are misinterpreted by decision makers; it is very easy to simply observe numbers and not contemplate what underlies the results. If intangible values are chosen to be excluded from the assessment, it might be necessary to illustrate and discuss such aspects in addition to the monetary CBA results. It is very important that any CBA assessments include clear and well formulated descriptions of contents and scope.

9.2. Uncertainties connected with a CBA

The aim of CBA is often to justify funding for important decisions. It cannot be stressed enough that it is important to have in mind that the results of a CBA are connected to high levels of uncertainties. Sensitivity analysis of the CBA results should always be performed. The Sweco CBA model enables identification of which in-data that contributes to the greatest uncertainties in the assessment; thereby it is possible to acknowledge which parameters to give special attention. Undoubtedly, uncertain in-data can only provide uncertain results, but at least a CBA can provide an attempted estimation, which should be more worth as basis for decision-making than only decision-makers' opinions. It can be concluded that there are incentives to develop the CBA model to be more accurate and to further evaluate standard values and cost categories.

9.2.1. Using standard values

Since it is possible to use standard values in the CBA model, one of the aims of this thesis was to evaluate existing standard values as well as finding or creating new ones where lacking (with focus on pluvial flooding). Site-specific data is always preferable to standard values in order to reduce the level of uncertainty connected to CBA. There is always a risk that standard values change over time, for example WTP values may vary if the prerequisites change, and therefore values should be updated when information and in-data change. There is no objection as to the usage of standard values. Since extracting new values for each case study would be time consuming it can even be recommended. Nonetheless, each time standard values are applied it is important to evaluate whether they are pertinent to the specific case.

9.2.2. Uncertainty distributions

In the CBA model, all costs and benefits and number of damaged objects are represented by uncertainty distributions. Statistical distributions, e.g. mean values and standard deviations, should be chosen case-specific. For example, a homogenous residential area can have smaller deviation of damage cost than an area with both single family and multi-family housings. The focus of this thesis has been limited to identify standard values for various cost categories and uncertainty distributions were chosen more or less using personal judgement.

9.2.3. Discount rates

Another factor that has large influence on the CBA results is the discount rate. Special attention has not been given to which discount rate/-s to use in the CBA. However, depending on differences in implementation timing and maintenance cost amongst compared measures, the result could vary which should be kept in mind.

9.2.4. Seasonal changes

Seasonal changes have not been considered in the model at present, but could be developed further. This would improve assessment of for example number of cars being flooded, since it might vary between night and day, as well as other parameters such as purification of water (depending on season).

9.2.5. Estimation of intangible values

Chapter 9.1.1 discusses whether or not to use intangible values. Another question is how to estimate the values. Three intangible categories assumed to be relevant to effects of flooding have been investigated in this thesis: ecosystem services, human health and cultural heritage. As exemplified in the literature study many attempts to valuate intangibles are based on different types of studies of people's willingness to pay (SP and RP), see chapter 3.3. Several authors discuss the accuracy of the derived values, especially regarding people's self-awareness; it is close to impossible to imagine a scenario without a specific item and when push comes to shove the actual valuation tend to prove different from the imagined one. Likewise, other values might have been omitted. For example, people are paying for insurance not only get compensated when an accident occurs, but also to feel secure. Accordingly, knowing that your memorabilia will not be flooded might give an additional value besides the actual value you associate to the item in question.

When a CBA is used in a larger project, where more resources are available for planning, it may be possible to perform WTP studies of peoples' preferences in the specific area instead of using standard values from other studies. Especially when there are special matters of interest, such as a cultural heritage site, this can be recommended. Not only does this give more reliable damage cost estimations, but it also gives an opportunity to involve the public leading to both better understanding to the importance of the object, education regarding flood risks as well as social inclusion.

9.2.6. Insurance values

Insurance data previously used in the Sweco model is regarded as valid for future assessments (see chapter 4.1); they are based on historical events and reflect Swedish conditions. However, these values only represent a small part of Sweden as they originate from damage claims in Göteborg and the counties of Bohuslän and Värmland. It is possible that values in other areas of the country could generate different results. It is not known what the damage claims are based on other than that they are results of a flooding. Even if they reflect impacts from flood events they might not be representative to future events. On the other hand, as they are based on quantitative data of approximately around 3,000 cases, the mean value can possibly be seen as reliable. Ideally, insurance statistics that cover entire Sweden should be collected and categorized further.

9.2.7. Uncertainties connected to new parameters

Value transfer has been used to assess damage cost of water contamination. The value derives from surveys of contamination levels in the Baltic Sea and peoples' WTP to avoid this. The value transfer can result in over- or under-estimations. For example in the case study of Staffanstorp, people are probably not as interested in swimming in the river Höje å as in the sea. On the other hand, the stream is suffering from eutrophication and need remediation. Although the transferred value does not exactly reflect the reality, it is probably better to include it than not, also for the sake of stressing the issue of eutrophication. As for human health, the value for sewage exposure in basements is also obtained through value transfer. Unfortunately, it has not been possible to gain information on the process to extract these figures, possibly leading to double-counting or other issues. For example, if the values are based on loss of income not only will the average income vary between the original site (Denmark) and the study site, but it is also a parameter that for example already is included in the flooded school category.

Hedonic pricing is a method used for valuation of amenity values of parks. One of the uncertainties associated with hedonic pricing is market values. Although the hedonic values are adjusted to the local market prices, it is not certain that the inhabitants in that area value green space in the same way as in Stockholm where the original study was performed. In urban dense areas, the amenity value is also more likely to be higher and other extra benefits such as noise and air purification will probably be measurable.

9.3. Further development of the CBA

The following section suggests possible updates to continue the development of the Sweco model.

9.3.1. Extra benefits

The current procedure of the CBA assessment does not include a suitable “place” for where to consider extra benefits. The same is valid for the CBA model (the Microsoft Excel-model). In the conducted case studies in this thesis, extra benefits such as amenity value and coordinated work underground have been calculated in step 6 that consider reduced risk costs as a result of measure implementation. In order to assess additional benefits in the future, they should be added as a step both in the step-by-step procedure as well as in the model.

In general, it is desirable that there is some kind of distinction between benefits due to reduced risk cost and the extra benefits. Although the overall result is positive from a societal point of view it is appropriate that the outcome of the CBA model clearly shows separations in the economic benefits, which is not displayed in the current CBA excel model result diagrams (see chapter 7.2.2).

9.3.2. Parameters

In the context of urban pluvial flooding it is certain that the urban system is complex, and that it is likely that flooding in such areas causes a spectrum of consequences that have not been possible to study within this thesis. At present, the CBA model only takes single objects into account without considering all complex systems that are likely to be found in a densely urbanized area. It would be interesting to include flood impacts on critical spots in a city, e.g. traffic nodes and critical services. These are of interest since they are likely to render various secondary effects and many people are affected although they do not reside in the area (for example in the case of a flooded train station). One way to explore the possible damage costs of such a spot could be through case studies which could then be transferred to studies with similar areas.

There are also many distinctive issues that can be connected to pluvial flooding that have not been mentioned in this thesis, for example debris blockage in sewer network and clean-up costs. This type of matters could be assessed separately in future risk assessments. Beside untreated consequences, there are also extra benefits that have not been possible to include. One concrete example is feeling secure from knowing that one’s house is protected against flooding. There is probably a close to infinite amount of gains and losses that could be included on the benefit side of the cost-benefit analysis. Nevertheless, it should be kept in mind; the intention with a CBA should not be to include all gains and losses, but rather to give an indication to whether or not a measure is beneficial (a positive or negative CBA result). Adding new parameters will not necessarily affect the final result to the extent where it compensates for the work of identifying and calculating values for each parameter. As an example, in this thesis fairly much time was spent on evaluating the monetary effect of releasing phosphorus through storm water, although the final damage cost can be seen as overall negligible (in the case of Staffanstorp a 100 year rain amounts to around 1000 SEK). Therefore it is necessary to strive to identify the most important parameters and enhance the estimation of these.

Duration of flooding has not been included in this thesis although many damage categories require knowledge of this aspect, e.g. interruption in economic activities, traffic delay and transport. Energy supply and water services could also depend on the duration if damaged. Currently, the lack of information about this parameter is the main reason why these categories cannot be thoroughly assessed and since they could result in big damage costs this is a problematic situation. It should be possible to use hydraulic modelling to determine the flood duration, but it is difficult since the necessary in-data such as runoff capacity on specific sites as well as soil conditions (saturation, soil type) varies. Furthermore, even if the flood duration is known, there is little knowledge of how to estimate recovery time for different activities, in order to for example estimate loss of production in a factory.

9.3.3. Methods for better damage cost estimations

The following are some of the categories that are considered especially important for which to find improved methods when performing a CBA.

9.3.3.1. Ecosystem services

In current literature there is little information on how to measure the value of ecosystem services, especially in connection to flood risk. In a time of deforestation, urbanisation and contamination of natural environment and other general ecosystem deterioration it should be a matter of course to include ecosystem services in any decision-making process. It is thus desirable to develop further methods other than purification of phosphorus and amenity value in order to facilitate this. As mentioned before, the EU Water Framework Directive imposes by law that water bodies should reach certain conditions. In Sweden the so-called national environmental objectives[20] are a foundation for the environmental work and most of these are related to ecosystem services, such as a *rich diversity of plant and animal life* and *a non-toxic environment*. One interesting method to value services related to laws and goals would be to attach some kind of monetary value to the regulations, i.e. punishment fees if not reached or rewards if improved. By doing so could for example give restoration of a lake a more obvious monetary role in a CBA.

9.3.3.2. Industry and commercial assets

As mentioned in chapter 4.6, an array of ways to estimate damage to industry and commercial assets exists, but none seems to be sufficient enough for estimation of accurate damage costs. Probably, the best way to create a method for estimating these damages would be to gather statistics on inventory assets and business types. In the current model every company needs to be contacted separately in order to obtain this information; this is both time consuming and non-efficient since many companies cannot or do not want to respond. Therefore it would be ideal to have standard values for a number of different sectors.

9.3.3.3. Human health

It seems feasible to carry out calculations of damage costs on human health (both mortality and morbidity, see chapter 4.8) from knowledge attained in literature studies. However, relationships between flood risk and health impacts are lacking and need further investigation. For example, figures of care service, salary loss and even discomfort when a person is ill are possible to determine, but the risk that someone will be ill is not. It is difficult to speculate in what methods could be used to identify these risks. Maybe relationships between flood duration, weather and possibilities of evacuation could be considered. However, these factors are probably more relevant when it comes to major flooding events. These usually do not occur due to heavy precipitation in Sweden, which is why other methods need to be identified in order to be applicable to national conditions. Using surveys to identify what kind of health issues that occurred during a specific flood could be one efficient method. In general, it is recommended to investigate on how flood events were perceived by affected populations in order to create in-data for different types of damages related to flooding.

9.3.3.4. Roads

For some parameters, such as physical damage to roads, it is difficult to estimate the risk and vulnerability. Even if it is possible to through hydraulic modelling identify when a road is flooded,

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[20] http://www.miljomal.se/Global/24_las_mer/broschyrer/Swedens-environmental-objectives.pdf

without knowing the vulnerability, it is impossible to assess whether it will suffer from any physical damage. Ideally, information on vulnerability of roads in flood contexts should be gathered either through statistics or through expert judgment.

9.3.3.5. Cultural heritage

As mentioned in the conclusions of chapter 4.9.3, knowledge of where to find cultural heritage as well as how to estimate the values is lacking. Obviously, it is difficult to discuss cultural heritage in a general manner, and the best way would be to perform WTP studies if possible, or else to use damage claims from insurance companies if available. As in chapter 9.2.6, this once again emphasises the need of collecting and categorizing insurance data in a more comprehensive way.

9.3.3.6. Vehicles

Vehicles is added as a new parameter in the CBA model and is calculated in relation to water depth. If insurance values are available, this might be better to use for average flood damage claims.

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Appendix 1 – Standard values

Standard values in 2014 year price level.

Housing		
Single family housing	32,489	SEK
Multi-family housing	122,834	SEK
Inventory	17,839	SEK
Vehicles		
Car	59,715	SEK
Technical infrastructure		
Value of phosphorus release (freshwater)	2,665	SEK/kg
Value of phosphorus release (sea)	522	SEK/kg
Value of nitrogen release (sea)	67	SEK/kg
Compensation for drinking water outage	11	SEK/day, household
Transport		
Physical damage roads	1,000	SEK/m^2
Physical damage rail	11,998	SEK/m
Time value private traffic	375	SEK/h
Time value freight traffic	89	SEK/h
Energy supply		
Substation	232,304	SEK
Compensation >4h	305	SEK
Compensation 4h-periods	174	SEK
Industry		
Office building	122,832	SEK
Commercial building	224,265	SEK
Industrial building	278,231	SEK
Loss of production	193,894	SEK/day
Grocery store	51,955	SEK/day
Supermarket	519,550	SEK/day
Restaurant	20,782	SEK/day
Health care		
Care centre	93,519	SEK/day
Hospital	9,351,900	SEK/day
Public dentist	54,345	SEK/day
Private dentist	20,782	SEK/day
School	1,559	SEK/pupil, day
Emergency pumping		
Pumping - 4 hours	2,931	SEK/4h
Human health		
Sewage exposure	7,914	SEK/basement

Appendix 2 – Calculations of damage costs

This is a general step-by-step description of assessment of damage cost parameters. The damage costs are used to estimate the benefits of implementing measures to reduce flood risk. All costs derive from the conclusions in chapter 4 and have been recalculated to 2014 price level (see Appendix 1).

Housing

Required information:	• Number of flooded houses (obtained through hydraulic modelling) • General data: **A_1** Insurance value of single family housing: 32,489 SEK **B_1** Insurance value of multi-family housing: 122,834 SEK **C_1** Insurance value inventories: 17,839 SEK
Damage cost estimation:	• Single family: number of flooded properties * A_1 • Multi-family: number of flooded properties * B_1 • Inventory: number of flooded households * C_1

Vehicles

Required information:	• Number of flooded households (obtained through hydraulic modelling) • Water depth (obtained through hydraulic modelling) • General data: **A_2** Value of an average car: 59,715 SEK **B_2** Damage of car flooded < 0.5m: 15% **C_2** Damage of car flooded 0.5-0.7m: 60% **D_2** Damage of car flooded >0.7m: 100%
Damage cost estimation:	• Number of damaged cars: 1.07 * number of flooded households • Damage costs: o 0-0.5 m: number of flooded cars * A_2 * B_2 o 0.5-0.7 m: number of flooded cars * A_2 * C_2 o >0.7 m: number of flooded cars * A_2 * D_2

Sewer overflow

There are three methods to assess the damage cost of released untreated wastewater. Available in-data determines which method to use. If possible, all methods should be used for evaluation of the results. Required information:	• Case specific data: **A_3** Sold drinking water: (m^3/day) **B_3** Incoming wastewater: (m^3/year) **C_3** Amount of water assumed to be sewage: (m^3/day) **D_3** Nitrogen content: (kg/m^3) **E_3** Phosphorus content: (kg/m^3) **F_3** Amount of contaminants in overflow at WWTP: (kg/m^3) **G_3** Flow just before overflow occurs: (obtained through hydraulic modelling) (m^3/day) **H_3** Amount of sewer overflow: (obtained through hydraulic modelling) (m^3) **I_3** Number of inhabitants • General data for relevant contaminants **a_3** Eutrophication cost of freshwater (P) = 2,665 SEK/kg **b_3** Eutrophication cost of sea (P) = 522 SEK/kg **c_3** Eutrophication cost of sea (N) = 67 SEK/kg **d_3** specific standard value P_{tot}= 0.0021 kg/person and day **e_3** specific standard value N_{tot}=0.0135 kg/person and day **f_3** standard value for average nitrogen content in storm water =3.15 mg/l **g_3** standard value for average phosphorus content in storm water = 0.25 mg/l
Damage cost estimation:	• Method 1: Amount of contaminants overflow at WWTP (value **F_3**) equals amount of contaminants in any sewer overflow water in the same system. Damage cost estimation: F_3 * H_3 * (a_3 or b_3 or c_3) • Method 2: Calculation of standard mean value using values for sold drinking water (**A**) and flow just before overflow (**G_3**). Damage cost estimation: ((d_3 or e_3)*I_3/A_3) * (C_3/G_3) * H_3 * (a_3 or b_3 or c_3) • Method 3: Assumption that 20-25% of incoming contaminant level at WWTP (values **D_3** and **E_3**) are present in overflow water. Damage cost estimation: (0.2 or 0.25) * (D_3 or E_3) * H_3 * (a_3 or b_3 or c_3) • Contamination from storm water: released storm water * f_3 or g_3

Drinking water supply

Required information:	- Surface flooding (obtained through hydraulic modelling) - Duration of flood - Case specific data: **A_4** Time to restore the facility to function **B_4** Production volume (m^3) - General data: **a_4** Produced water that is sold to households: 60% **b_4** Production cost: 0,025 SEK/m^3 **c_4** Compensation: 11 SEK/household and day **d_4** Average water consumption per household: 0.3648 m^3/household (0.16 m^3 (SWWA, n.d.) * 2.28 persons per household (SCB, 2012))
Damage cost estimation:	- Production loss: (duration + A_4) * B_4 * a_4 * b_4 - Compensation: affected households (B_4 * a_4 / d_4) * c_4

Wastewater treatment plant

Required information:	- Case specific data: **A_5** Base flow **B_5** WWTP capacity **C_5** Volume of inflow to WWTP - General data: **D_5** Treatment cost: 5 SEK/m^3
Damage cost estimation:	- Treatment cost (increased due to larger volumes of wastewater): if $C_5 > (B_5 - A_5)$ then, $(B_5 - A_5) * D_5$, else $(C_5 - A_5) * D_5$ - Cost of releasing untreated water (ecosystem): *see Sewer overflow*

Transport

Required information:	• Flooded roads (obtained through hydraulic modelling) • Private traffic flow (obtained through http://vtf.trafikverket.se/SeTrafikinformation#) • Freight traffic flow (obtained through http://vtf.trafikverket.se/SeTrafikinformation#) • Additional time to use alternative routes (hydraulic modelling to identify possible non-flooded routes, speed limits to calculate travel time) • Flood duration • General data: **A_6** Time value private traffic: 375 SEK/h **B_6** Time value freight traffic by truck with trail: 89 SEK/h
Damage cost estimation:	• Traffic interruption: traffic flow * additional time * flood duration * A_6 • Freight transport: traffic flow * additional time * flood duration * B_6

Energy supply

Required information:	• Number of flooded substations (hydraulic modelling) • Connected houses to the substations in questions • Flood duration • General data: **A_7** Cost of damaged substation: 232,304 SEK **B_7** Compensation flooding >4h: 2,726 SEK **C_7** Compensation flooding additional 4 h-periods: 1,557 SEK
Damage cost estimation:	• Physical damage cost substation: number of flooded substations * A_7 • Outage compensation: B_7 + C_7 * remaining time/4

Industry

Required information:	• Flooded industries (obtained through hydraulic modelling) • Type of industry/economic activity (study of maps/yellow pages) • Damage cost inventories (obtained through general data or individual contact) • Interruption cost (obtained through general data or individual contact) • Duration of flood • Recovery time (individual contact) • General data: **A_8** Insurance value of office building: 122,832 SEK **B_8** Insurance value of commercial building (business + property): 224,265 SEK **C_8** Insurance value of industry (industry + property): 278,231 SEK **D_8** Loss of production (general): 193,894 SEK **E_8** Loss of production – grocery store: 51,955 SEK/day **F_8** Loss of production – supermarket: 519,550 SEK/day **G_8** Loss of production – restaurants: 20,782 SEK/day
Damage cost estimation:	• Physical damage: number of flooded buildings * (A_8, B_8 or C_8) • Loss of production: number of flooded buildings *(D_8, E_8, F_8 or G_8)

Interruption to societal services

Required information:	• Number of flooded: care centres (**c_9**), hospitals (**h_9**), dentists (**d_9**), schools (**s_9**) • Number of pupils in school under 12 years age (**n_9**) • Duration of flood • General data: **A_9** Cost of interruption in care centre: 93,519 SEK/day **B_9** Cost of interruption in hospital: 9,351,900 SEK/day **C_9** Cost of interruption of dentists: 54,345 SEK/day **D_9** Cost of interruption of schools: 1,559 SEK/day per pupil less than 12 years
Damage cost estimation:	• Interruption care centre: $c_9 * A_9$ • Interruption hospital: $h_9 * B_9$ • Interruption dentist: $d_9 * C_9$ • Interruption of schools: $s_9 * n_9 * D_9$

Emergency pumping

Information needed:	• Flooded objects/sites where insurance values are not applicable (i.e. do not include flooded housing) • General data: $\mathbf{A_{10}}$ Cost of 4 man hours of pumping: 2,931 SEK
Damage cost estimation:	• Service cost: objects/sites * $A_{\mathbf{10}}$

Human health

Information needed:	• Flooded basements • General data: $\mathbf{A_{11}}$ Cost of sewage exposure: 7,914 SEK/basement
Damage cost estimation:	• Sewage exposure: Flooded basements * $A_{\mathbf{11}}$

Amenity value

Information needed:	• Average prices: single-family villa ($\mathbf{s_{12}}$) or apartment ($\mathbf{a_{12}}$) • Park area ($\mathbf{p_{12}}$) (hectares) • Number of properties within one km ($\mathbf{N_{12}}$) • General data (unless specific values can be obtained): $\mathbf{A_{12}}$ Average size single-family housing: 125 m^2 $\mathbf{B_{12}}$ Average size apartment: 70 m^2
Damage cost estimation:	• Amenity value: (s_{12} or a_{12}) / 41,832 * (A_{12} or B_{12}) * 600 * (p_{12} / 10) * N_{12}