Quantification of risk reduction measures in urban areas due to increasing heavy summer rain. Case study – Skien municipality

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The article is written for a PhD course in infrastructure asset management at NTNU.

Sammendrag

På grunn av endringer i klima konfronteres vann- og avløpssystemeiere med et økende antall av korte, men intense nedbørperioder. Disse endringene av ytre omstendigheter påvirker forutsetningene for daglig drift og vedlikehold, og medfører endringer i og nye utfordringer til infrastrukturforvaltningen generelt. Skien kommune ønsker å ha en proaktiv holdning til klimaendringene og har derfor en pågående prosess ved bl.a. å analysere etterslep og behov for tilrettelegging av åpne flomveger som ett av flere risikoreduserende tiltak relatert til fremtidige ekstremværhendelser. Samtidig revurderes de eksisterende krav til prosjektering og dimensjonering av avløpsnettet og åpne flomveger, med grunnlag i noen utvalgte nedbørepisoder som har skjedd i regionen i løpet av de senere årene. Metodikken som er benyttet i studiet er en risikobasert tilnærming utviklet det EU-finansierte forskningsprosjektet PREPARED hvor fokus har vært på de tre hovedstegene innen risikostyring; 1) risikoidentifisering, 2) risikoanalyse og evaluering, og 3) riskobehandling. Analysen er avgrenset til å betrakte kun flom forårsaket av intens nedbør i Skien sentrum.

Resultatet av analysene viser at etablering av de foreslåtte risikoreduserende tiltakene gir en markant reduksjon i antall berørte eiendommer og bygninger. Av de to tiltakene som er analysert; «Separering av felles avløpssystem» og «Tilrettelegging av åpne flomveger», anbefales det sistnevnte tiltaket på bakgrunn av en kost-nytte vurdering. Basert på analyse av historiske flomhendelser i regionen anbefales videre en revurdering av kommunens eksisterende krav til både dimensjonering av overvann ledningssystemer og til prosjektering av åpne flomveger.

Abstract

Due to climate changes the water utilities more often experience a significant variation of periods with increased precipitation. These changes in external operational conditions affect the existing situation and bring along new challenges in infrastructure asset management. Skien municipality is in a process of analyzing the need for facilitating more open flood ways due to increasing risk of flooding events in the future. In parallel, the municipality is evaluating their existing rules and regulations for design and capacity

calculations for storm water systems which are in general based on analysis of historical flooding events in the region over the past years. This case study is a contribution to the ongoing process of assessing and implementing risk reduction measures. The methodology used is based on a risk driven approach from the PREPARED Water Cycle safety Plan (WCSP) framework focusing on the three core risk management steps at system level; Risk identification, Risk analysis and evaluation, and Risk treatment. The analysis is focusing on a small catchment area and limited to only investigating hazardous events of urban pluvial flooding in Skien city center.

The results show a significant reduction in flooded properties and buildings implementing risk reduction measures. The two measures taken into account were, "rebuilding of combined sewer" and "facilitation for open flood ways", the latter is recommended based on a cost-benefit-analysis. Further, it is recommended to update the existing requirements for capacity calculations of storm water pipes and design of open flood paths.

Introduction

Background

Due to climate changes the water utilities more often experience frequent periods with increased precipitation. These changes in external conditions for the operational range affect the existing situation and bring new challenges to infrastructure asset management (IPCC report 2014, /1/).

Over the last years an increasing amount of heavy rainfall events in different parts of Norway have resulted in heavy damage on nature and infrastructure, subsequently given large costs for repair and damages for the affected municipalities and infrastructure owners. The municipality of Skien has not yet experienced extreme situations in the central areas due to heavy rainfalls. Periods with strong precipitation have not caused any severe damage. With other words these rainfalls have mainly not exceeded the capacity of existing infrastructure. On the other hand areas outside the city center and residential areas in Skien, and in the surrounding region, have experienced heavy rainfalls. These events have occurred in very small and limited catchment areas and resulted in severe damage on railway, roads and pipe network systems. With this in mind the Water and Sewer department in Skien municipality wants to implement a proactive approach to prepare for future flooding events.

According to municipal staff /10/, Skien has a considerable lag in the renewal work of water-, waste- and storm water systems. The long term work on renewal has not yet started. The networks were mainly established in 1930-1990, and it is assumed that the next 20 years is needed to handle the lag. Thus, Skien have their focus on analyzing the lag regarding both pipe renewal and establishing storm water floodways.

The main purpose of this case study was to contribute to the analysis of the needs and assessment of risk reduction measures related to potential flooding events in urban areas. Such events may happen due to increasing heavy rainfalls, in particular in summertime. It is also of interest to evaluate the current existing requirements for design and capacity of storm water systems in general.

Methodology

The methodology used for this case study is based on a risk driven approach within the PREPARED Water Cycle Safety Plan framework focusing on the three core risk management steps at system level;

- Risk identification
- Risk analysis and evaluation
- Risk treatment

Methods for assessment and quantification of risk reduction measurements are also adapted from PREPARED ("Quantification of risk reduction measures" - October 2013 /4/). Additionally historical rainfall events are collected and used as foundation for the calculations. To support assessment of the specific catchment area in Skien city, maps and a digital terrain model (TIN) are used as a simplified analyses of the surface water flooding.

Problem formulation and research questions

Following the PREPARED WCSP framework this case study deals with risk management on system level. Derived from the introduction the main question for this case study is; "What will happen if rain fall occurs in Skien city center, with same intensity as experienced in areas 10-65 km away?" Subsequently three question must be asked "How likely is this to happen?", "What are the consequences?" and "What can be done to reduce the risk?"

To answer this questions a quantitative risk assessment approach is followed, and more specific question were formulated:

- Is there a need for improvement of and increase the number of open flood ways?
- What are the economic consequences of flooding buildings and infrastructure?
- What can be done to reduce the risk?
- How can the effect of alternate risk reduction measures be assessed in terms of costs vs benefits?
- Is there a need for re-evaluation of requirements regarding design and capacity calculation for storm water systems?

Case study

Introduction – Description of Skien

Skien is the largest municipality measured by population in the county of Telemark. This is also the location of the county administration. Skien has approximately 53 500 inhabitants, making it the 13th largest municipality in Norway. Skien covers an area of 779 square kilometers. Forests make up 479 square kilometers, cultivated land 46 square kilometers, freshwater lakes 57 square kilometers and 197 square kilometers city areas, residential areas and industrial areas.

The municipality is in charge of the water-, waste- and storm water systems, which has the following characteristics; 325 km with waste water pipes, of which 100 km is combined sewers. Separate storm water pipes have a length of 170 km. Skien is connected to two waste water treatment plants; *Elstrøm WWTP*, which is located near the city center, and *Knarrdalstrand WWTP*, which is located in the neighbouring city Porsgrunn, respectively treating 40 and 60 percent each of the waste water from Skien.

Risk identification

The first of the three core steps in the PREPARED Water Cycle Safety Plan framework is risk identification. In this case the hazardous event already has been identified through the main input question from Skien water- and sewer department; "What will happen if extreme rain fall occurs in Skien city center?". Using the PREPARED risk identification tool, RIDB (*Almeida et al., 2013, /3/*), "Flooding in public areas or private properties" is found as definition to this hazardous event.

Urban flood events can originate from coastal, fluvial, pluvial flooding or a combination of these. Thus a system characterisation was performed to establish the boundary of the case study. Based on this characterisation, the case study was limited only to investigate a small catchment area in Skien city center for urban pluvial flooding.

Historical rainfall events

Six historical rainfall events are used as reference in this case study as input to the risk analysis.

1. Skien – August 2006 /10/

- Flooding event in scattered populated area (Kilebygda).
- Affected area located approximately 10 km southwest of Skien city center.
- The rainfall intensity was not measured, but the event resulted in severe damage on road infrastructure.

2. Skien – August 2008 /10/

- Flooding event in densely populated area (city center)
- Measured rainfall intensity 46 mm in 3 hours
- The event resulted in flooding from sewer systems into private buildings
- About 70 basements got severe damage

3. Notodden – July 2011 /8/

- Flooding event in densely populated area
- Affected area located approximately 45 km from Skien city center

- Because of frequent rain the last months large forest areas contributed to the runoff
- Measured rainfall intensity 56 mm during 6 hours. Severe damages on buildings and infrastructure

4. Larvik – June 2012 /9/
- Flooding event in densely populated area
- Affected area located approximately 30 km from Skien city center
- Measured rainfall intensity 34 mm in 1 hour

5. Øvre-/Nedre Eiker – August 2012 /6,7)
- Flooding event in densely populated area
- Because of frequent rain the last months large forest areas contributed to the runoff
- Affected area located approximately 65 km from Skien city center
- Measured rainfall intensity Øvre Eiker 52 mm during 2 hour, and Nedre Eiker 70 mm during 40 min
- Severe damage on buildings and infrastructure

6. Notodden – August 2013 /8, 10/
- Flooding event in scattered populated area
- Affected area located approximately 43 km from Skien city center
- Measured rainfall intensity 55 mm during 1 hour and 90 mm during 2 hours (private measurement)
- Severe damage on buildings and infrastructure

Risk analysis and evaluation

Preliminary to the next step of analysis and evaluation, the analysis criteria were developed in cooperation with Skien municipality /10/. To estimate the financial consequences of urban pluvial flooding, direct tangible costs on properties are used. Rainfall events with statistical return period of 2, 5 and 10 year where chosen. Probability for each event to happen is calculated as the reciprocal of its return period.

Based on the municipalities experience regarding "normal rainfall situations" and analysis of regional historical rainfall events, the following criteria were used to calculate the number of flooded properties;

- Rainfall < 20 mm/hour; the existing road drainage system will have enough capacity
- Rainfall = 20 - 24 mm/hour; small effect
- Rainfall = 25 – 28 mm/hour; medium effect
- Rainfall > 28 mm/hour; large effect

Maps were established based on the criteria, and the number of flooded buildings was analysed for each rainfall event. Subsequently the total average damage cost was calculated as the sum of average damage cost per building (CB) multiplied with number of flooded buildings (NUM). Flood damage cost was defined as:
- COST = 0, if rainfall < 20 mm/hour
- COST = CB * NUM, if rainfall > 20 mm/hour

Risk treatment and cost-benefit-analysis

Generic proposals for risk reduction measurements are presented in the PREPARED tool risk reduction database, RRDB (*Almeida, et al. – 2011, /3/*). From the database two measures are taken into account: "Separation of combined sewer" and "Flood attenuation" (and preparing for open flood paths). Rebuilding of the combined sewer system to separate sewer system, defined as risk reduction measure nr.1 (RRM1), will increase the rainwater storage capacity. Flood attenuation and preparation for new flood ways, defined as RRM2, will decrease the risk for water to flood properties and buildings, and hence reduce the flooding damage.

To perform the cost benefit analysis (CBA) input values were provided by Skien municipality (Mosevoll, 2014, /10/). The timeframe was set to 40 years, the discount rate to 4%, and average damage building cost to a fixed price of 200.000 NOK.

Following the PREPARED risk based CBA approach (Strehl, *et al. – 2013)* it is needed to assess the expectable annual benefit. The benefits are commonly defined as avoided flood damage in monetary terms. To be able to assess the avoided annual damage, the expected annual damage (EAD) is calculated for the Status Quo situation, without any flood risk reducing measures at first. After that, the EAD including the measures is calculated. The difference between these two calculated values is defined as the benefit (ΔEAD). Finally expected benefits and costs are discounted over the given timeframe and summed up as net present value for each measure.

Sensitivity analysis

Dealing with the uncertainty for all scenarios under investigation it is necessary to alter the deterministic input variables. This can be done by analysing different climate change conditions and their potential effect on the outcome of the cost-benefit analysis. A common management approach is followed by assuming three situations; *Best case* (no change, referred to as Status Quo. Rainfall event collected from Skien intensity-duration curve), *Mid case* (moderate change in precipitation) and *Worst case* (extreme change in precipitation).

Based on analysis and interpretation of historical rainfall events mentioned earlier, the assumed increase in cumulated rainfall for moderate and extreme change in precipitation as presented in table 1. The matrix was adapted in cooperation with Skien municipality.

In order to account for climate change it is assumed a decrease in return period for Moderate and Extreme situations. This indicates an increase in probability for moderate and extreme events to happen. Thus their return periods were recalculated following the methodology of PREPARED, assuming linearity between the return periods (Strehl, et. al - October 2013). The result is presented in table 2.

The recalculated return periods are used in the expected annual damage (EAD) calculation, and later on to find the net present value (NPV) and benefit-cost ratio (BCR) for assessment of the suggested risk reduction measures.

Results

The number of flooded buildings was calculated based on map analysis and digital terrain run-off analysis, combined with the agreed criteria for the three rainfall events. Figure 1 shows the result from analysis of flooded building together with risk reduction measures.

Due to the small catchment area the outcome of the analysis reflects a limited number of buildings affected. Based on these numbers and with an assumed fixed damage value per flooded building the total damage costs were calculated. Taking risk reduction measures into account for the three rainfall events the proposed measures give overall very good effect with respect to the number of flooded buildings, consequently strongly influencing the reduction in the financial consequences for each of the three situations. To increase the effect it would be necessary to increase the separation of the combined sewer system in sub areas and facilitate for more open flood ways.

After estimating the cost for all flooded buildings the next figure present the calculated expected annual damage (EAD) which subse-

Rainfall event (i)	Return period (Ti)	Status Quo mm/h (SQi)	Moderate mm/h (MCCi)	Extreme mm/h (ECCi)
1	2	17	20	23
2	5	22	25	29
3	10	26	33	39

Table 1. Cumulated rainfall.

Rainfall event	Return SQ	Return MCC	Return ECC
1	2	1,7	1,5
2	5	3,2	2,3
3	10	5,6	4,5

Table 2. Recalculated return periods for the three situations.

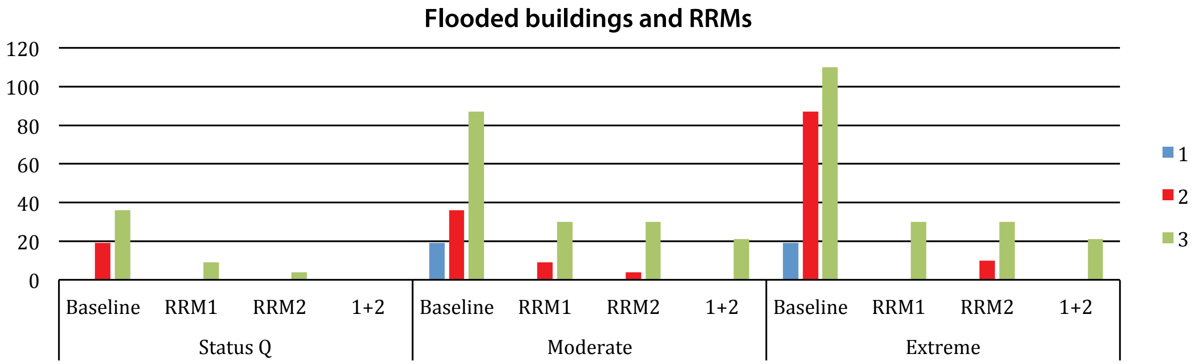

Figure 1. Flooded buildings and risk reduction measures for rainfall event 1, 2 and 3.

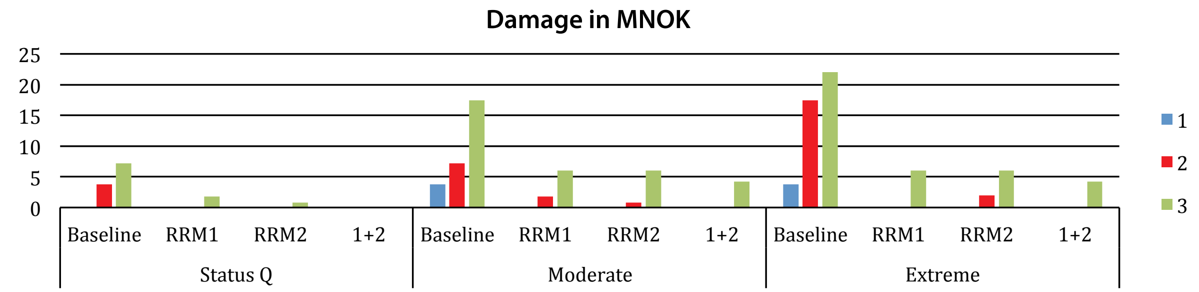

Figure 2. Damage cost in MNOK for rainfall event 1, 2 and 3.

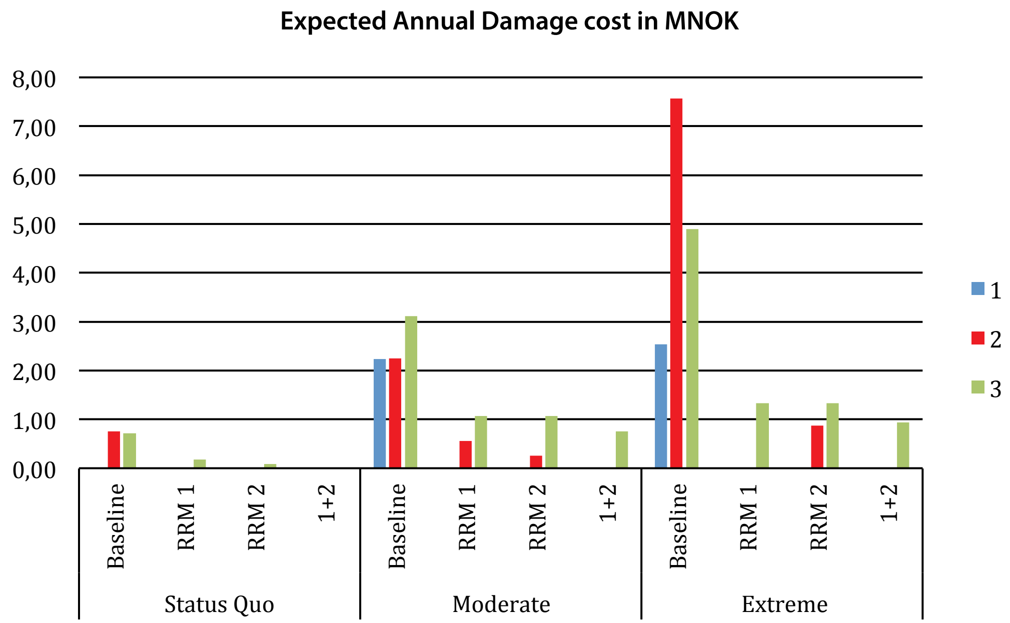

Figure 3. Calculated EAD in MNOK for the three situations.

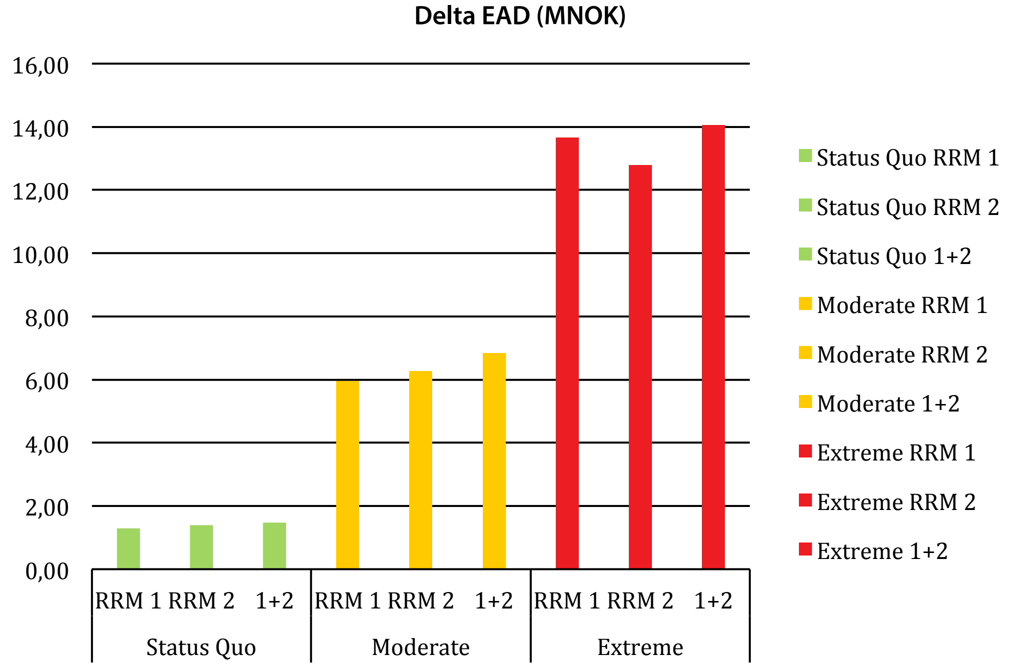

Figure 4. Delta Expected Annual Damage cost for all three rainfall events.

quently is used to find the net present value (NPV) and benefit cost ratio (BCR).

Results from the EAD calculations are presented in figure 3.

In the figure 4 the calculation of "delta EAD" (ΔEAD) (benefit of avoided annual cost) show that the risk reduction measures reach between 1.3 MNOK in a Status Quo situation to 14.05 MNOK in the Extreme situation.

Finally, the overall benefit of a measure was discounted and summed as present values. The results are shown in figure 5.

Figure 5 shows that Net Present Value related to RRM1 and RRM 1+2 for Status Quo situation are negative, meaning that the benefits do not outweigh the cost. But for all other scenarios the NPV is positive and thus the benefits outweigh the cost in the long perspective. For all three rainfall situations RRM2 gives the highest NPV.

When calculating the Benefit-Cost Ratio we see the same overall picture for RRM2, and that the rainfall event for extreme situation gives the highest rate. Only baseline and RRM1 and "1+2" for Status Quo situation do not pay off (BCR<1). BCR calculation results are presented in figure 6.

Discussion and conclusion

This case study exemplifies how risk management approach can be used to assess risk reduction measures analysing heavy rainfall events due to climate change in urban areas. The methodology used is based on PREPARED Water Cycle Safety Plan framework (WCSP) focusing on the three core risk management steps at system level; Risk identification, Risk analysis and evaluation, and Risk treatment.

The results presented are the outcome of a deterministic assessment. Criteria used in the analysis of damage buildings have been adapted to this specific case study. The analysis is focusing on a small catchment area and limited to only investigate hazardous event of urban pluvial flooding in Skien city center. Only direct tangible costs are included in the calculations to simplify the task. Idealistically since the PREPARED WCSP is an integrated process a more

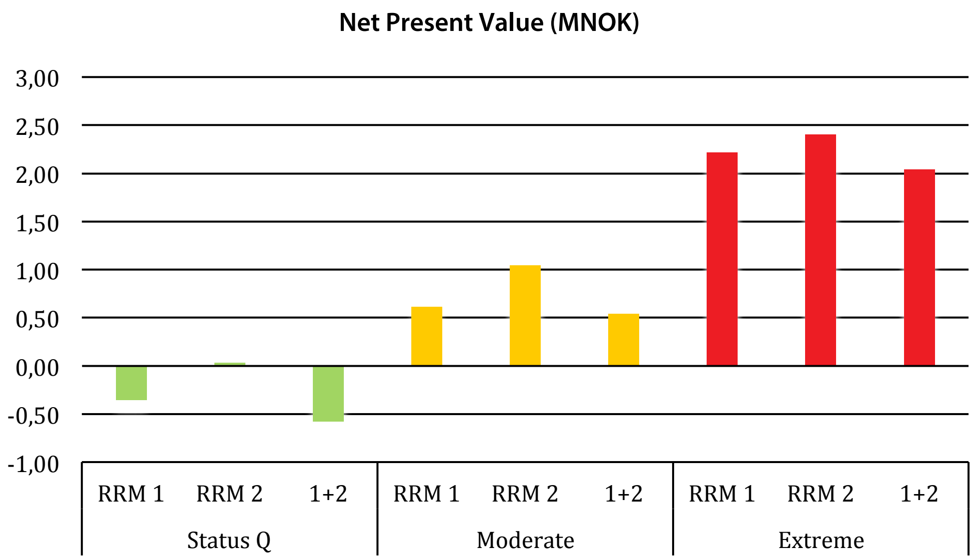

Figure 5. Discounted overall benefit of measures summed as present values.

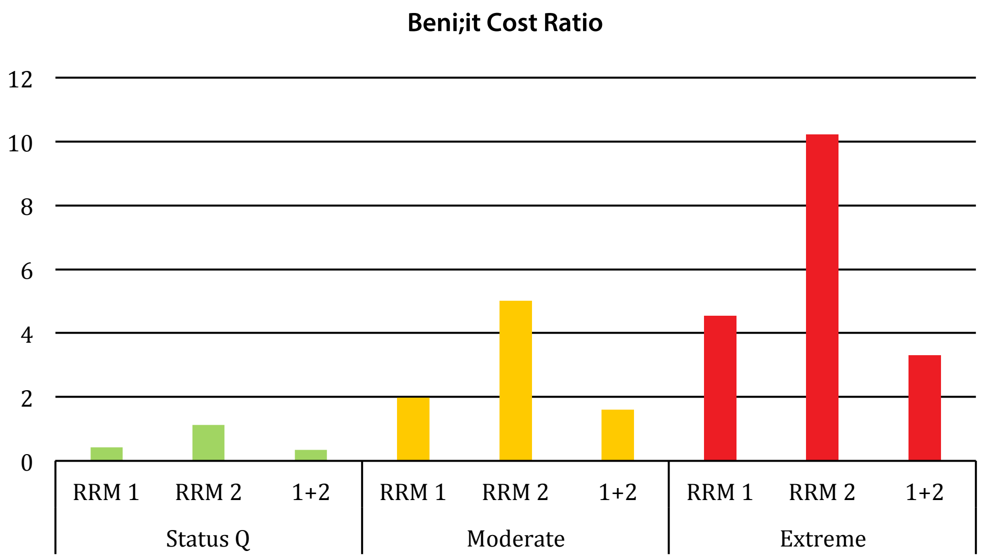

Figure 6. Benefit-Cost Ratio for all three rainfall events.

comprehensive calculation should have been carried out. Incorporating cost savings due to reduction of combined sewer overflow to rivers and fjords, less load to the waste water treatment plant due to rebuilding of combined system and other damage effects like traffic and business interruption are examples of benefits that also could have been quantified.

Referring to the first question asked for the case study, it can be said that more than hundred properties and buildings will be affected by flooding if an extreme rainfall occurs in the same amount as experienced in neighbouring community areas and no reduction measures are implemented. In the overall perspective the amount of affected buildings is relatively small.

Skien has a relatively hilly topography and this affect the consequences of flooding events. Looking at the historical rainfall event in Skien, august 2008, however, only 70 of 12000 residential buildings got severe damage.

Taking into account the financial consequence dimension of hazardous rainfall events, the cost-benefit-analysis (CBA) has been used as decision support. The outcome of the net present value (NPV) calculation shows that the benefit outweighs the cost of implementing the risk reduction measures for both moderate and extreme situations. Both proposed measures will decrease the risk for water to hit properties and buildings, and hence reduce annual damage cost. Implementing risk reduction measures for status quo situation will not pay off. This indicates that the existing storm water system in Skien is designed for today's situation and not for the future.

Assessing the question regarding need for facilitation of more open flood paths in urban areas it is clearly recommendable to implement measures to avoid hazardous events during heavy rainfalls. Since the final decision is based on a financial dimension measure, defined as risk reduction measure nr.2, "Flood attenuation and preparation for new flood paths", gives the highest benefit-cost rate, and hence should be chosen as the prioritized action point.

General in an asset management point of view the cost is only one of several decision criteria that must be taken into account. Looking at the net present value (NPV) calculation this case study is simplified by only considering tangible costs. Integrating more damage effects and intangible costs would directly alter the result of the NPV calculations.

Intangible costs are not easy to define in monetary terms because they incorporate many aspects. For the municipality administration, in the context of climate change, the value of image loss by not implementing measures in situations of flooding causing flooding in basements buildings is one example when assessing costs. From an economic point of view the cost of implementing measures might be high and there at risk of not being prioritized, however from a political point of view this event could be an issue of high importance and therefore result in re-prioritizing and project refunding because of investment willingness for providing service to the public. This exemplifies that decision processes are multi criteria based, and therefore dynamic.

Having more than one thought in mind the technical staff of Skien continuously review projects based on minimum two criteria. E.g. when doing pipe rehabilitation in roads, the road surface is not put back to the existing state, but are redesigned to adjust the long- and cross section slope to optimize storm water run-off.

Other decision criteria can be discharge reduction of storm water overflows and in inflow water to the wastewater treatment plant. With this as background the municipality choose to separate main parts of the combined sewer systems, which also contribute to reduce the danger of flooding in basements.

Historical rainfall events in the region combined with the case study analysis of flooded buildings gives an indication that existing requirements for capacity calculations and design of storm water pipe network in Skien municipality may be re-evaluated. The following is recommended;

- Rainfall events with duration of 1-3 hours with 50 years return period should be a design parameter with reference to current Intensity-Duration-Frequency curve. This will handle a moderate increase in rainfall events.
- For design of open flood ways handling more extreme rainfall events, design parameters should be the difference between the rainfall events corresponding to the 200 and 50 years return period.

This case study can be used as an input to the municipality operational level of management, and be a part of holistic assessment of upcoming projects related to improvement of and increase the number of open flood ways and flood risk reduction measures.

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