Urban flood management in a changing climate

By Linmei Nie, Oddvar Lindholm and Bent C. Braskerud

Linmei Nie is a research scientist in Water and Environment, Dept. of Infrastructure, SINTEF Byggforsk
Oddvar Lindholm is a Professor at Dept. of Mathematical Science & Technology, UMB
Bent C. Braskerud is a research scientist at Dept. of Hydrology, NVE

Sammendrag

Hensikten med denne artikkelen er å bidra til en bedre håndtering av overvann og flommer i byer, slik at man kan møte endringer i klimaet på en best mulig måte. Hovedproblemet med overvannet i byer er oversvømmelser og økt forurensning til byvassdrag, fjorder og sjø. Problemene vil øke betydelig med klimaendringene. Analyser fra flere norske byer har vist at 50 – 100 % flere bygninger kan bli flomskadet og 50 – 100 % mer overløpsutslipp vil kunne komme fra fellesavløps-systemene. Optimale tiltak med langsiktig perspektiv, tilpasset den lokale situasjonen er derfor meget viktig. Artikkelen tar opp spørsmål om planlegging og tiltak i avløpssystemene. Urban avrenning bør sees i sammenheng med en total risikoanalyse for vassdrag og avløpssystemer i byer i henhold til vanndirektivet og flomdirektivet.

Summary

The aim of the paper is to contribute to a better urban flood management (UFM) prepared for the future changing climate. The major consequences of urban floods in Norway are flooding in basements and increased pollution to receiving waters, mainly rivers in cities and the sea or fjords, caused by combined sewer overflows (CSOs). The problems will become more severe in a changing climate. In particular several large cities will also have serious flood problems with rising sea levels. Appropriate adaptation and mitigation activities fitting for local situations are accordingly utmost

important. The authors in this paper discuss approaches of planning and design of urban drainage systems, handling of local runoff (LOD), climate change and short and long term activity plans for adaptation and mitigation. Moreover, UFM should be considered as an integrated part of the total flood risk management for river basins under the EU's Flood Directive and the EU's Water Frame Directive.

Background information

Significant flood consequences

Floods has been one of the major natural hazards that caused loss of lives, economic damage, damage on the environment, loss of cultural heritages, community disorder and health problems. Figure 1 shows the statistics during 1986-1995 from the International Decade for Natural Disaster Reduction (1987-1997). During 1998 – 2004, Europe suffered over 100 major floods which caused some 700 fatalities, the displacement of about half a million people and insured economic losses totally at least €25 billion (Ashley et al., 2007). The numbers of flood and storm occurrence were much higher than other natural disasters, according to the statistics of the United Nations International Strategy for Disaster Reduction (UNIDR) for average 2000-2007 and 2008 (Figure 2).

Common flood problems in Norway are flooding in house basements and Combined Sewer Overflows (CSOs). According to 2007 annual report of sewage and regulation of Oslo VAV, flooding in basements and CSOs were mainly caused by intensive precipitation and incidents in sewers, which results in economic damage and affects seriously the water quality in bathing waters and in the Oslo fjord. The reported numbers of basement flooding were extremely high during

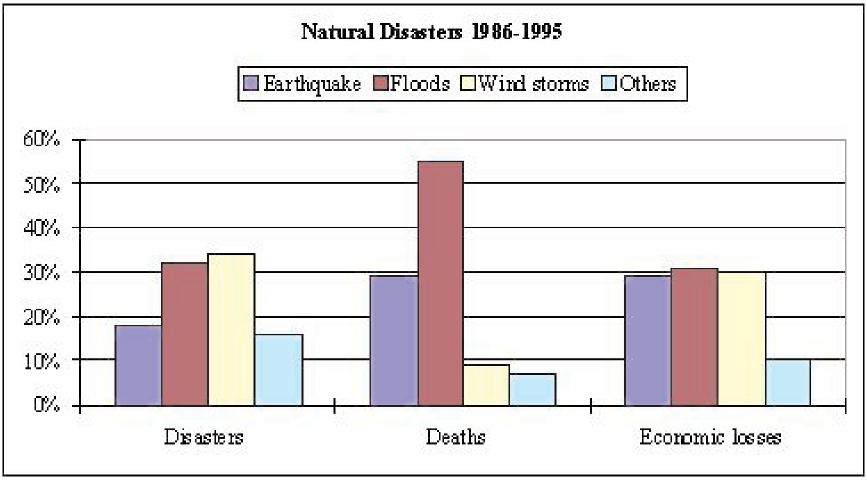

Figure 1. Casualties and losses caused by natural hazards

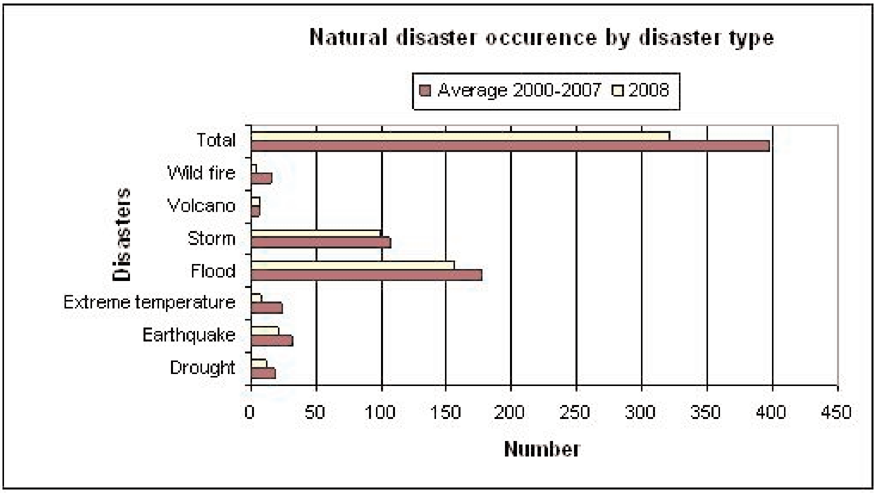

Figure 2. Natural disaster occurrence by disaster type (UNISDR, 2009)

1999-2002. Luckily, the numbers have not shown a significant increasing in following years, except 2007 (Figure 3). Measured CSOs were high in 1996, 2002, 2004-2006 (Figure 4) (Oslo VAV, 2008). In Trondheim, intensive precipitation increased in the last two decades. Some rainfalls in 1997 and 2001 were estimated to have a return period of 50 years and the rainfalls in 29 July and 13 August 2007 had a return period that reached 100 years design rains for durations of 5, 10, 15 and 20 minutes (Thorolfsson et al, 2008).

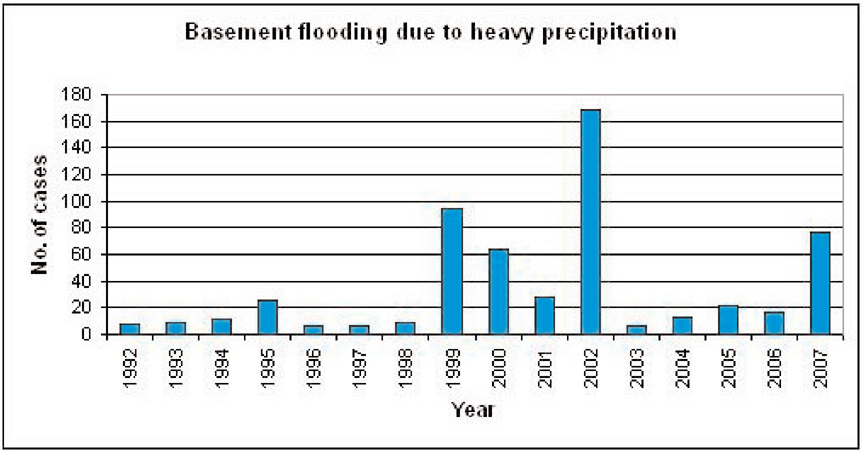

Figure 3. Cases of basement flooding due to heavy precipitation (Oslo VAV, 2008)

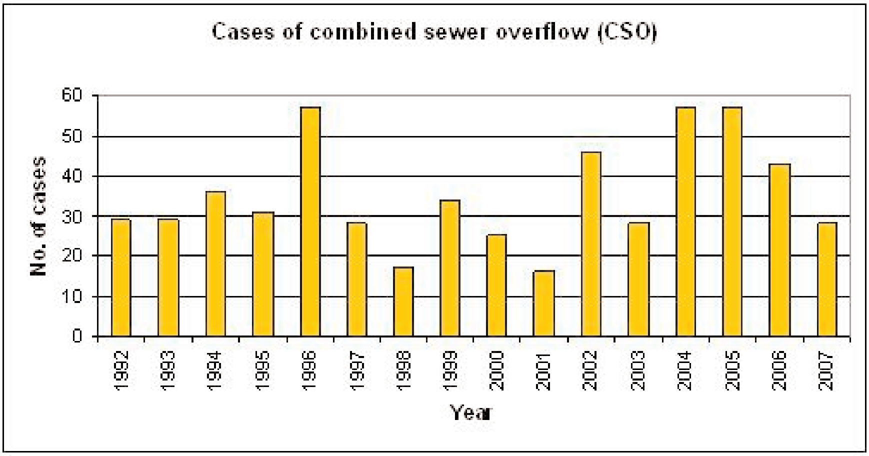

Figure 4. Cases of CSO due to heavy precipitation (Oslo VAV, 2008)

Analyses from several research projects in Norwegian cities have shown that in a future changed climate 50-100% more buildings may be damaged because of sewerage flooding, and an increase of 50-100% CSOs are predicted to be discharged from the combined sewers because of the future changed climate (Lindholm et al., 2007).

In order to reduce flood-related risk and vulnerability and enhance community resilience to climate change and other undesired events, comprehensive flood risk management and integrated approach for planning and design are required to deal with the relevant problems and the resulting adverse impacts.

Objectives of flood management

Protection of human beings, property, the environment and socio-economical activities from the danger of flooding is the primary aim and major challenge of flood control. Earlier emphasis was set on floods in rivers, and reliance was on structural engineering measures to control the volume of floodwater until 60s. Due to the expansion of urban areas and socio-economical activities along the river basins, urban flooding has been a significant part of the total river flooding. This caused significant economic damages and other adverse consequences. At the end of the 20th century, the awareness of "living with flooding" was perceived. Policies were therefore made combining structural and non-structural measures, and priority was given to non-structural mitigation measures, such as restricting the development in flood plains in order to preserve the natural water ways and reduce potential damages. Moreover, the ability to address socio-economic factors and conservation for local and global eco-environmental systems requires involvements of stakeholders at different levels, knowledge and understanding of local conditions.

EU flood directive and performance in Norway

The EU flood directive states that flood risk management plan should focus on prevention, protection and preparedness (EU, 2007). The methodology for flood risk management should therefore be developed to include both structural- and non-structural measures in different stages. In order to have effective information and basis for priority setting and further technical, financial and political decisions regarding flood risk management, it is necessary to provide information for the establishing of flood hazard maps and flood risk maps showing the potential adverse consequences associated with different flood scenarios and including information of potential pollution to the environment. Flood risk will present the product of frequency of flood events and corresponding consequences.

In Norway the Norwegian Water Resources and Energy Directorate (NVE) coordinates the EU Flood Directive (FD). NVE will perform flood risk analysis for major rivers and river catchments in three stages:

• Perform preliminary flood risk analysis – The analysis, based on existing hydrological data and gross analysis of consequences for people, environment and economy, and cultural heritage will decide where to make the flood risk maps.

• Make flood risk maps – For areas that are evaluated to have large flood risk, NVE will perform detailed analyses of flood hazard maps and consequence maps for three flood scales of medium, large and very large.

• Make regional water flood management plan – For those areas that have high potential risk, a flood management plan will be made. The plan will be made according to water regions such that it will be consistent 'with EU's Water Framework Directive. Moreover the flood management plan will target at risk levels related to people, environment, cultural and economic activities. Changing in flood risk due to climate change and land uses must be taken into consideration in the plan.

• Detailed planning will probably be done by the affected municipalities.

Approach of stormwater management for flood control

Urban drainage systems and approach for storm runoff planning and design

Urban stormwater drainage systems are composed of two separate components:

1. Surface systems, also called "major" systems, are composed of streets, gutters, ditches, and various natural and open artificial channels, which are mainly used for extreme flood situations.
2. Subsurface storm sewer network or "minor" system, which is designed to drain stormwater or sewage for designed rainfall values.

Design rain frequency[a] (1 in "n" years)	Main type of area	Design flooding frequency[b] (1 in "n" years)
5	Low damage potential areas	10
10	Residential areas	20
20	City centre/Industrial/ Commercial areas	30
30	Very high damage potential areas	50

a. No surcharge is allowed above the top of pipes
b. Surcharge is not allowed above the basement floor level, usually 90 cm above top of pipes.

Table 1. Minimum return periods (years) for design rain and flooding in Norway (Lindholm et al., 2008)

Planning of storm runoff must consider both normal rainfall and flood situations. If the minor system is overloaded or clogged, there must be a drainage system on the surface in which storm water can drain away without unacceptable adverse effects. In Norway, the minor system is designed to carry the runoff from a storm of 10 - 30 years return periods, whilst the surface system is designed to handle events of 20–100 years return periods. Norsk Vann guideline for stormwater disposal are made based on the European Standard EN 752 for design rains and for flood return periods for minor systems, see Table 1.

Dual drainage principles, which involve both the major and the minor systems, should be considered in the planning of urban stormwater runoff systems and for flood checking. These systems are linked via street curb inlets which convey designed amounts of storm runoff into the storm sewer system. Manholes also link the two systems during surcharge. Surface flooding is a special case of sewer surcharge, where the flood water discharges from the manhole and pond on the surface or flow down the street following the topographic gradients. The major system must be providing proper street flow gradients and capacities for the safe conveyance of surface flows.

Storm sewers can overflow and the excess volume can either return via the original manhole or travel overland to another manhole in the sewer system. A dual drainage system may incorporate parks and other open areas to store an amount of the flows from the major system to further reduce the peak discharge from an urban area. Specific inlet control devices may be considered to restrict major system flow into the minor system so as to avoid flooding in basements and overloading of the storm sewers.

Flood ways should be planned at both the high overall plan level and at the detailed plan level according to a cost – benefit analysis. Flood ways should be analyzed for what is needed for a capacity equal to 100-year flood (Lindholm et al., 2008). When selecting the floodways capacity, in terms of a return period, one should weigh estimated damage and intangible consequences against the cost of construction of the flood ways. There exists an optimal capacity of the flood way when the total sum of investment, operation and maintenance costs, flood damage and other adverse consequences are minimal (Total life costs). The calculated capacities of floodways and the corresponding return periods of the floods should be shown on flood risk maps. It must be controlled that downstream areas can handle the added water flows from floodways above. Lower lying areas must be able to receive the discharge from the higher areas. Streets, roads, park areas etc. may be a part of the flood way. Flood ways should preferably only pass public areas. If the flood way must pass private ground, this should be incorporated in the area planning process and deals should be negotiated with the owners of the area. Flood ways should slow down and retain water as much as possible. Terrain models need to be used when calculating directions of the flood ways, flood levels and the flooded areas.

<u>Stormwater management at municipality and local levels</u>

Even though the Norsk Vann guideline is recommending what return period one should use for dimensioning of flooding, it is important that each municipality does a local calculation on what the economic optimal return period really is in the certain area one looks upon. When choosing an optimal dimensioning return period, the damages and consequences must be weighed against the costs for building and operating the system. In this evaluation of the optimal rain return period it is interesting to note that the rate of interest one uses is very decisive for the outcome of the optimal return period.

To achieve the goals of handling the storm runoff on the surfaces, as much as possible, and to plan for increased rain intensities in the future climate, it is of utmost importance to bring area planners and landscape architects into the storm water runoff planning. Hence handling of storm runoff should be an integral part of the municipal area planning (Figure 5).

Examples of Sustainable Urban Drainage Systems (SUDS) measures that could be enforced by the Plan and Building Act are:

- Saving and strengthening of the vegetation like trees, grass areas, etc.
- A width of the roads that gives as little as possible of impermeable surfaces.
- Permeable road and parking surfaces.

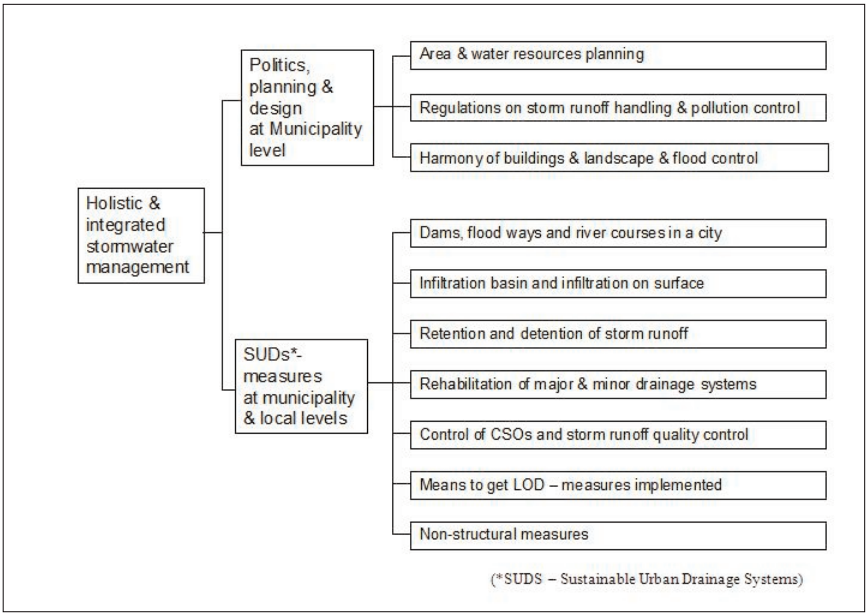

Figure 5. A holistic approach of integrated stormwater management

- Use of infiltration solutions, like infiltration trenches, ponds and rain gardens.
- A maximum allowable discharge to the municipal pipe network.
- Use of swales instead of conventional trenches and gutters.
- Use of absorbing soils on top of more impermeable soils.
- Use of vegetated "green" roofs.
- Cisterns for collection of runoff from the roofs.

Climate change, adaptation and mitigation

Climate change scenarios

Significant changes in climate and their impacts are already visible globally, and are expected to become more pronounced, according to IPCC's main assessment reports in 1990, 1995, 2001 and 2007, and other national and international research outcomes.

Projected scenarios of regional climate change are among the main results of "climate in Norway in 50 and 100 years" (RegClim, 2000; 2005) and some other climate research publications. The Bjerknes centre has estimated sea level rise and storm flow in 2050 and 2100 for Norwegian municipalities (Bjerknes Centre, 2008). These results are important basics to predict the change in hydrology, water resources, and potential natural hazards. However, the projected regional climate changes, mainly precipitation and temperature, are too coarse to predict the possible responses in urban drainage systems. Some projected future climate change with fine temporal and special resolutions fitting for urban catchments have been projected by special requests, whilst such scenarios are not available for most cities. According to the investigation in several municipalities regarding climate change and adaptation, some municipalities think they still need knowledge of climate change and how it will change in the future before they will take efficient mitigation measures. Other municipalities have already included climate change into their work of planning, design, operation, maintenance and services.

Risk and vulnerability assessment

Risk and vulnerability analysis (RVA, so called "ROS" in Norwegian") have been carried out in some counties and municipalities since the DSB guideline for ROS analysis were published (DSB, 1994). Tools to estimate the risk levels and associated scenarios have been developed for general RVA analysis and modified for selected case studies (Vatn, 2007; Trøndelagfylkene, 2003; 2008; Nie et al., 2009). Such analyses have been made or are being updated to take the future climate change into account in several other municipalities. The studies can help municipalities to identify external risk causes and incidents in the systems in combination with the impacts of associated societal and vulnerable influence factors, and assist communities to put weight on the defined priority risks for further detailed analyses and mitigation measures.

However, such risk analyses cannot estimate the quantitative consequences in changing climate. Additional simulation tools are accordingly needed to achieve a qualitative prediction of possible impacts. Such preliminary studies have been carried out in Bergen, Fredrikstad, Oslo and Trondheim with projected or artificial climate change scenarios. In some of the project, preliminary cost-benefit analyses have been carried out to evaluate the costs of different mitigation measures that are among key information to help choose optional solutions (Lindholm et al., 2007).

Short and long term plan for adaptation and mitigation

The understanding of climate change and models to predict future scenarios, tools to assess the potential risk and vulnerability, and adaptation and mitigation to predicted adverse consequence, have been and will be improved gradually. Therefore the projection, assessment, adaptation and mitigation activity plan towards climate change should be performed in two stages:

- Short term activity plan and preliminary analysis – assess flood risk and vulnerability by risk assessment, and simulate possible responses in the urban drainage systems caused by projected climate change scenarios. This will assist municipalities to achieve a preliminary picture of future flood risks and needs for adaptation and mitigation.

- Long term activity plan and detailed analysis – Perform simulation for consequences in urban drainage systems according to climate change scenarios at urban catchment scale, and then a cost – benefit analysis should be followed to test the different mitigation measures in order to achieve an optimal solution at which the total life costs of investment, operation and maintenance, flood damages and intangible consequences is at the minimum.

The 13 largest Norwegian cities have participated in the program of Future Cities (www.framtidensbyer.no) that is coordinated by Directorate for Civil Protection and Emergency Planning (DSB). Climate adaptation is one of the topics for cooperation, and diverse activities are planned by the participating municipalities. An interreg IVb project SAWA is implementing the WFD and the FD through practical exercises in the North Sea region (www.sawa-project.eu).

Challenges in the future

Many preliminary studies have already confirmed the increasing risk of urban floods due to climate change in combination with other drivers of urbanization and aging of infrastructure. Sewers designed several decades ago in old towns or city centres have usually insufficient capacity to detain or drain increasing storm and sewage flows. Except for new planning and designing areas, appropriate rehabilitation technology is in great need in these areas and it is a universal challenge.

There is a strong need to examine and develop local runoff handling measures (LOD) in Norway. Many framework management plans refer to detention basins and other solutions as mitigation measures. However, information and local guidelines regarding the application are often missing. The needs can be divided in these three parts:

- Better local regulations to evaluate and use of LOD measures;
- Research based information on the use and costs of measures;
- Investigation about how to change the residents' behaviour to improve private measures.

Take account of the fact that changing climate and increased urbanization both affect the urban hydrological regime in a similar way. As a result, municipalities should have both short- and long term plan for integrated urban flood management.

Acknowledgment

We would like to thank the interreg 4B project SAWA and the Research Council project AdaptCRVA for financial support in preparing this manuscript.

References

Ashley, R., Garvin, S., Pasche, E., Vassilopoulos, A., Zevenbergen, C., (Edited) (2007). Advances in Urban Flood Management. Taylor & Francis

Group. Lomdon / Leiden / New York / Philadelphia / Singapore.

Bjerknes Centre (2008). Havnivåstigning - Estimater av fremtidig havstigning i norske kystkommuner. Bjerknes rapport for Det Kongelige Miljøverendepartment.

Direktorat for sivilt beredskap (DSB) (1994). Veileder for kommunale risiko- og sårbarhetsanalyser.

EU (2007). Directives on the assessment and management of flood risks. DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007.

Lindholm, O., Nie, L.M., Bjerkholt, J.T. (2007). Klimaeffekters betydning for oppstuvninger og forurensningsutslipp fra avløpssystemer i byer. IMT rapport nr. 16/2007, UMB. ISSN 1503 – 9196.

Lindholm, O., Endresen, S., Thorolfsson, S., Sægrov, S., Jakobsen, G., Aaby, L. (2008). Veiledning i overvannshåndtering for klimaendringer (manuskript). NORSK VANN BA rapport 162/2008.

Nie, L.M., Heilemann, K., Hafskjold, L.S., Sægrov, S. (2009). Risk and vulnerability analysis for urban flooding and sewer surcharge problems in a changing climate. Manuscript of Sintef report

Oslo VAV (Water and Wastewater Works of Oslo Municipality) (2008). Avløpsvann- mengde og regularitet, Oslo 2007. Fagrapport nr. 5/2008.

RegClim (2000). Climate in Norway in 50 years (Klimaet i Norge om 50 år). Brochure of RegClim project group, 11 May 2000.

RegClim (2005). Climate in Norway in 100 years – Uncertainty and risk (Norges klima om 100 år; usikkerter og risiko). Brochure of RegClim project group. 14 Sept. 2005.

Thorolfsson, S.T., L.P. Risholt, O. Nilssen, A. Ellingsson, V. Kristiansen, Ø. Hagen, E. Karlsen (2008): Extreme Rainfalls and Damages ion August 13 2007 in the City of Trondheim Norway. Proceedings of XXV Nordic Hydrological Conference. Nordic Association for Hydrology. Volume 1. pp. 295 – 301. Eds. O.G. Blöndal Sveinsson, S.M. Gjar_arson og S. Gunnlaugsdóttir. Reykjavik, Iceland August 11-13, 2008. ISBN 978-9979-68-238-7

Trøndelagfylkene (2003). Risiko- og sårbarhetsanalyse for Trøndelagfylkene (Hovedrapport).

Trøndelagfylkene (2008). Risiko- og sårbarhetsanalyse for Trøndelagfylkene (Del rapport).

UNISDR (2009). 2008 disasters in numbers. UN International Strategy for Disaster Reduction.

Vatn, J. (2007). DECRIS – Beskrivelse av verktøy InfraRisk. Department of Production and Quality Engineering, Norwegian University of Science and Technology.