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When water becomes a threat

Risk assessment and risk management plans for floods and drinking water in Swedish practice

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Abstract

Norén, V. 2016. When water becomes a threat. Risk assessment and risk management plans for floods and drinking water in Swedish practice. (När vatten blir ett hot. Riskbedömningar och riskhanteringsplaner för översvämning och dricksvatten i svensk praktik). *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology* 1416. 57 pp. Uppsala: Acta Universitatis Upsaliensis. ISBN 978-91-554-9673-9.

Water is an essential but vulnerable resource. A shortage of good quality drinking water is a threat to human health and society as a whole. Abundance of water in the form of floods can also be a serious threat which can have consequences for the drinking water supply. To reduce these risks there is a need for systematic risk reduction. In the last decades a *risk management approach* has been developed in the management of both flood and drinking water risks. This means that a reactive, *ad hoc* management is being replaced by a more proactive and systematic approach where risks are analysed and evaluated as a basis for prioritising counter-measures. The complex nature of water issues has also made it evident that there is a need for a holistic view of the management, involving a variety of actors and sectors. An *integrated management* approach to floods and water resources has emerged.

This thesis aims to examine how local level risk management, especially risk assessments, of floods and drinking water supply have been or can be performed in practice in Sweden. The existing practices have been characterised in relation to current risk management frameworks. Furthermore, the thesis aims to investigate how the effects of flood on drinking water supply have been considered in risk assessment methods and in flood risk management plans, as well as whether flood and drinking water risks have been considered in an integrated manner. The studies are based on interviews with flood risk managers in Swedish municipalities and Swedish water producers as well as on document studies of risk assessment methods and flood risk management plans.

There are large variations between different municipalities and water producers in how, and to what extent, risk assessments have been performed. Some have performed very little, if any, risk assessment while others have worked systematically. The tools used are often those that are promoted by national agencies and are often less advanced than those described in the literature. The risk assessments do not always cover all relevant aspects of the risk and few actors have discussed an acceptable risk level. Flood risk assessments focus mostly on the exposure of objects to flood and investigate the consequences of such an exposure only to a limited extent. The incomplete risk assessments may result in a biased view of the risk which in turn can lead to poor decision-making. The theoretical knowledge about risk management is in many cases low and there is still often a practical approach. Strategic and holistic approaches are mostly lacking.

The consequences of flood on drinking water supply are not known in detail and are not considered in detail in risk assessments commonly used in Sweden. There is an awareness of the need to coordinate the management of flood and water resources. However, despite the good intentions regarding integration, there are few signs in the risk assessments and risk management plans that integration is actually occurring.

Both the risk management approach and integrated management have started to be implemented in Swedish flood and drinking water risk management. It is however on a basic level and it is still a long way to go. Further guidance and knowledge about risk management as well as commitment from and collaboration among all actors concerned is needed to make this development possible.

Keywords: Flood, Drinking water supply, Risk management, Risk assessment, Flood risk management plan (FRMP), Integrated flood management (IFM), Tools and methods, Practice compared to theory, Sweden, Municipalities, Interview study, Document study

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Akademisk avhandling som för avläggande av filosofie doktorsexamen vid Uppsala universitet kommer att offentligen försvaras i Hambergsalen, Geocentrum, Villavägen 16, Uppsala, fredagen 14 oktober 2016, klockan 9:00. Fakultetsopponent: Professor Kurt Petersen (Lunds universitet). Disputationen sker på svenska.

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Norén, V. 2016. När vatten blir ett hot. Riskbedömningar och riskhanteringsplaner för översvämning och dricksvatten i svensk praktik. *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology* 1416. 57 sid. Uppsala: Acta Universitatis Upsaliensis. ISBN 978-91-554-9673-9.

Vatten är en livsnödvändig men sårbar resurs. Brist på dricksvatten av god kvalitet är ett allvarligt hot mot människors hälsa och för hela samhället. Även överflöd av vatten i form av översvämningar kan vara ett allvarligt hot och kan bland annat får konsekvenser för dricksvattenförsörjningen. För att minska dessa risker finns det behov av systematiskt riskreducerande arbete. De senaste decennierna har systematisk riskhantering (*risk management approach*) utvecklats inom hanteringen av översvämningar och dricksvattenförsörjning. Detta innebär att en reaktiv och osystematisk hantering ersätts med en mer proaktiv och systematisk hantering baserad på analys och utvärdering av risker som stöd för beslutsfattande. Den komplexitet som vattenfrågor omfattar har också gjort det tydligt att det finns behov av en helhetsyn på hur vatten hanteras och att ett flertal aktörer och sektorer behöver involveras. Teorier om integrerad hantering (integrated management) har vuxit fram och börjat implementeras.

Syftet med denna avhandling är att undersöka hur riskhantering, särskilt riskbedömningar, på lokal nivå utförs eller kan utföras i praktiken i Sverige. Praktiken har beskrivits och karakteriserats i förhållande till befintliga ramverk om riskhantering. Dessutom är syftet att undersöka hur konsekvenser av översvämningar på dricksvattenförsörjningen behandlas i metoder för riskbedömning och riskhanteringsplaner för översvämning liksom att studera om risker relaterade till översvämningar och dricksvatten har behandlats på ett integrerat sätt. Studierna är baserad på intervjuer med översvämningshanterare i svenska kommuner och svenska vattenproducenter samt dokumentstudier av metoder för riskbedömning och riskhanteringsplaner för översvämning.

Det är stora skillnader mellan hur och i vilken omfattning olika kommuner och vattenproducenter har gjort riskbedömningar. Vissa har knappt gjort någon riskbedömning alls medan andra har arbetat mer systematiskt. De verktyg som används är ofta de som finns i handböcker från svenska myndigheter och är ofta mindre avancerade än vad som beskrivs i litteraturen. Riskbedömningarna täcker inte alltid all relevanta aspekter av risken och det är få som har diskuterat vad som är en acceptabel risknivå. Översvämningsbedömningarna har fokuserat på vilka objekt som exponeras vid en översvämning och möjliga konsekvenser på drabbade objekt har undersökts i mycket begränsad utsträckning. Ofullständiga riskbedömningar kan ge en felaktig bild av risken och därmed vara ett inkomplett underlag för beslutsfattande. Den teoretiska kunskapen om riskhantering är i många fall låg och många har en praktisk inställning till riskhanteringen. Det saknas oftast strategi och helhetstänkande.

Kunskapen om konsekvenser av översvämning på dricksvattenförsörjningen är begränsad och behandlas inte heller i detalj i de metoder för riskbedömning som är mest vanligt förekommande i Sverige. Det finns en medvetenhet om behovet av att koordinera hanteringen av översvämning och vattenresurser. Trots de goda intentionerna om integrering visar riskbedömningar och riskhanteringsplaner få tecken på att integrering sker i praktiken.

Både systematisk riskhantering och integrerad hantering är synsätt som har börjat utvecklas och implementeras inom svensk hantering av översvämningar och dricksvattenförsörjning. Det sker dock fortfarande på en relativt grundläggande nivå och det är en lång väg kvar. Det finns behov av ytterligare vägledning och mer kunskap om riskhantering liksom engagemang från och samarbete mellan alla berörda aktörer för att stödja vidare utveckling.

Nyckelord: Översvämning, dricksvatten, riskhantering, riskbedömning, riskanalys, riskhanteringsplan, integrerad vattenförvaltning, integrerad översvämningshantering, metoder och verktyg, praktik jämförd med teori, Sverige, kommuner, intervjustudie, dokumentstudie

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“They're funny things, Accidents. You never have them till you're having them.”

A.A. Milne
The House at Pooh Corner

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I Norén, V., Hedelin, B., Bishop, K. (2016) Drinking water risk assessment in practice: the case of Swedish drinking water producers at risk from floods. *Environment Systems and Decisions*, 36(3): 239-252, DOI 10.1007/s10669-016-9588-3, © Springer 2016, re-printed with permission.

II Norén, V., Hedelin, B., Nyberg, L., Bishop, K. (2016) Flood risk assessment – Practices in flood prone Swedish municipalities. *International Journal of Disaster Risk Reduction,* 18: 206–217, DOI:10.1016/j.ijdrr.2016.07.003, © Elsevier 2016, re-printed with permission.

III Norén, V., Hedelin, B., Nyberg, L., Bishop, K. (2016) Assessment of Drinking Water Risks Due to Flood – Possibility of Integrating Methods. *International Journal of Disaster Risk Reduction. Under review.*

IV Norén, V., Hedelin, B., Nyberg, L., Bishop, K. (2016) Significance of EU Floods Directive Risk Management Plans for Drinking Water Supply. *Manuscript*

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Contents

Abbreviations

CAB	County administrative boards
FRMP	Flood risk management plans
GDP	Good disinfection practice
HACCP	Hazard analysis and critical control point assessment
HAZOP	Hazard and operability study
IFM	Integrated flood management
IWRM	Integrated water resources management
MBA	Microbial barrier analysis
MRA	Microbiological risk assessment
MSB	Swedish Civil Contingencies Agency
SMHI	Swedish Meteorological and Hydrological Institute
SWWA	Swedish Water and Wastewater Association
WHO	World Health Organization

Introduction

Water is essential for all life on earth, but sometimes water becomes a serious threat to human health and ultimately to the whole society. On one hand large parts of the world suffer from water shortage – constantly or during periods of drought. On the other hand many people worldwide are killed or lose their home and livelihood due to overabundance of water – in floods and during extreme precipitation. The most serious water problems are found in developing countries but water issues constitute a threat also in highly advanced societies. With climate change, growing population and increasing dependence on systems of technical infrastructure, these risks are likely to increase.

Floods and extreme precipitation are a direct physical threat to human life and property, but also influence the drinking water supply which in turn may affect human health. Facilities for drinking water production and distribution may be damaged or water can be polluted or contaminated. This can spread diseases or cause disturbances in the supply of drinking water. Drought can cause disturbances in the water supply due to the lack of water but can also affect the water quality. In this thesis the focus is on floods and abundance of water. Drought can cause disturbances in the water supply due to the lack of water but can also affect the water quality. In this thesis the focus is on floods.

The threat of flood and lack of drinking water is something societies have had to address through history and still need to manage. Management of floods and the supply of safe drinking water has developed and improved through the years. During the last decades a *risk management approach* has been developed in both these areas (Pollard *et al.*, 2004; Büchele *et al.*, 2006; Schanze, 2006; Macgillivray *et al.*, 2007; Klijn *et al.*, 2008; World Health Organization (WHO), 2011). This means that a reactive, *ad hoc* management is being replaced by a more proactive and systematic approach where risks are analysed and evaluated as a basis for prioritising measures. The complex nature of water as a resource and a threat has also made it more and more evident that there is a need to have a holistic view of the management, involving a variety of actors and sectors. Consequently, the concepts of *integrated water resources management* (IRWM) (Global Water Partnership Technical Advisory Committee, 2000) as well as *integrated flood management* (IFM) (APFM, 2004) have emerged and are starting to be implemented.

Both these approaches are well described and discussed in the literature and there is a broad agreement in science and policy about their usefulness. However, the implementation of the approaches in practical management has been slow and sometimes difficult (Macgillivray *et al.*, 2007; Grigg, 2008; Klijn *et al.*, 2008; Wisner, 2011). Progress has been made though, and the intention to adapt a risk management approach can be seen in policy and practice. For example Macgillivray *et al.* (2007) found that a risk management approach was becoming increasingly explicit in the drinking water sector although there were remaining barriers for its implementation. Klijn *et al.* (2008) saw that a real risk-based approach was seldom explicitly applied in flood management in selected EU member states, but that a change towards a risk management approach can be seen. Wisner (2011) reviewed the development of integrated disaster risk management, which comprises floods, and asks "Are we there yet?". His answer is that, although progress has been made to lay out the road-map, the journey has only begun. Several studies support these conclusions but the practice is not always well studied and documented. Few studies have been done on the use of risk assessment for flood and drinking water on a local level.

This thesis and underlying papers explore the practical risk management of flood and drinking water supply. Knowledge about the practice is essential in order to learn from what has already been done and to develop strategies and tools for developing risk management. The focus is on risk assessments and flood risk management plans performed on the local level. The studies are performed in a Swedish context.

Aim of the thesis

The aim of this thesis is to contribute to the knowledge about how risk management of flood and drinking water is or can be performed in practice and about the practice of integrated management in these fields and furthermore to characterise the practice in relation to current risk management frameworks. The studies have been performed in a Swedish context. More specifically, the objectives are:

- to examine how local level drinking water and flood risk assessments are performed in practice and to characterise the practice in relation to existing risk management frameworks (Paper I and II),
- to examine how the effects of flood on drinking water supply have been considered in commonly used risk assessment methods as well as in flood risk management plans (Paper III and IV) and,
- to examine the degree to which flood and drinking water risk can be assessed and have been considered in an integrated way in risk assessments and flood risk management plans (Paper III and IV).

Definitions and concepts

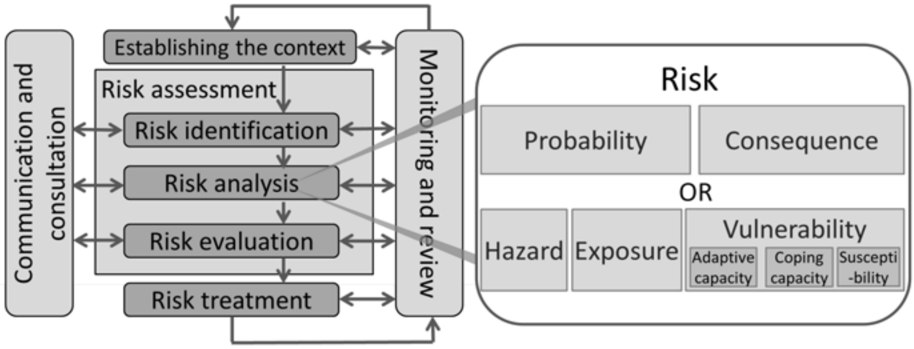
The terminology for risk and risk management differs between disciplines and sectors. More or less the same concepts are used but with varying meaning. Here a number of key concepts for this thesis are defined. They are also summarized in Figure 1.

Risk is generally seen as a combination of the probability of an event and its consequences. Within management of disasters (including flood) the risk concepts have been developed to better describe the context (e.g. Paul Samuels *et al.*, 2009; UNISDR, 2009). Again there is a multitude of similar definitions that are not fully compatible and sometimes even contradictory (e.g. ISO, 2009). Common for these views are however that the risk depends on the probability and magnitude of the natural event as well as on the extent to which they are exposed to the event and the characteristics of the values exposed. In this thesis the definitions suggested in a conceptual framework by the research program KULTURisk (Giupponi *et al.*, 2015) are used.

Risk (mainly flood risk) is therefore also seen as a combination of the components hazard, exposure and vulnerability. The ***hazard*** component represents the probability, magnitude and other characteristics of the flood event. The ***exposure*** represents the presence of people, property and other social, ecological and economic values in the flooded area. The ***vulnerability*** is the propensity or predisposition of humans and the society to be adversely effected by the flood. It is determined by ***susceptibility***, the likelihood that something exposed to the flood may be harmed, ***adaptive capacity*,** the preparedness of individuals and communities to combat hazard and reduce negative impact as well as ***coping capacity*,** the ability of individuals and the communities to cope with and overcome such negative impacts. (Giupponi *et al.*, 2015)

Risk management is defined by the international standard ISO 31000:2009 (ISO, 2009) as "coordinated activities to direct and control an organization with regard to risk" and the risk management process includes the steps in Figure 1. ***Risk assessment*** comprises identifying, analysing and evaluating risks. Papers I-III are concerned with the risk assessment steps while the risk management plans studied in Paper IV belongs to the risk treatment step.

Damages of a flood can be direct or indirect and tangible or intangible. ***Direct*** damages are those that occur in the flooded area during the flood event. Impacts outside the geographic area or the time frame of the event are the ***indirect*** consequences. ***Tangible*** consequences are those that easily may be valued in monetary terms while ***intangible*** consequences do not have an easily derived financial value. (Definitions according to KULTURisk framework (Giupponi *et al.*, 2015).



Risk identification aims to "generate a comprehensive list of risks based on those events that might create, enhance, prevent, degrade, accelerate or delay the achievement of objectives"

Risk analysis "involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur"

Risk evaluation is "the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable"

Risk assessment includes the steps of risk identification, risk analysis and risk evaluation

Risk treatment is the process to modify risk. It includes selecting and implementing measures to reduce risk and control and modify measures that have been taken

Figure 1. Risk management process with two alternative definitions of risk based on the international standard ISO 31000:2009 and definitions from KULTURisk (ISO, 2009; Giupponi *et al.*, 2015)

Risk management approach

What then is a risk management approach for flood management and drinking water security?

To produce and distribute safe drinking water to consumers has long been the goal and responsibility of the water producers. The traditional way to achieve this is to analyse the treated drinking water and to react when the quality is unsatisfactory. This has, however, been found to be insufficient (World Health Organization (WHO), 2011) and it has become clear that to secure a safe drinking water supply there is a need to systematically handle risks (e.g. Pollard *et al.*, 2004). In recent decades a proactive risk management approach addressing the whole drinking water system has developed, promoted by among many others the World Health Organization and their drinking water guidelines (World Health Organization (WHO), 2011). According to the report from the inquiry into the large disease outbreak in Walkerton, Canada, in year 2000, essential characteristics of risk management are:

- *being preventive rather than reactive*
- *distinguishing greater risks from lesser ones and dealing first with the former*
- *taking time to learn from experience and*
- *investing resources in risk management that are proportional to the danger posed (O'Connor, 2002)*

These characteristics of risk management should not be limited to drinking water but could also apply to flood management. For flood management a similar development towards risk management has appeared. Floods have historically been seen primarily as external events that hit the society and the focus of the management has been on protecting people and society by fighting or controlling the flood itself. The solutions have mainly been technical and physical protection to control the water. This view has been changing with an increasing understanding that a flood disaster is the result of interactions between the natural event and the society that is affected. It is also clear that traditional flood protection solutions may both fail and cause other severe damage. Flood defence or flood control is therefore gradually turning into flood risk management where not only the flood phenomenon is considered but also its impact on society and society's vulnerability (e.g.

Büchele *et al.*, 2006; Schanze, 2006; Klijn *et al.*, 2008). This requires other types of solutions and a continuous work. (Klijn *et al.*, 2008) have characterised flood risk management with the following three essentials:

- *One should not manage the flood, but the risk (i.e. the flood hazard and the vulnerability of the flood-prone area – as constituted by people, their property and their activities – equally).*
- *Equal consideration of physical and 'non-structural' measures, including regulatory/legal instruments, financial instruments and communicative instruments*
- *Flood risk management is a continuing cycle of assessing, implementing and maintaining flood risk management measures to achieve acceptable residual risk in view of sustainable development.*

Integrated management

Water is a vital but limited resource, an ecosystem sensitive to pollution and a potential threat to human society. The questions and problems related to water are numerous. So are the actors that manage or depend on water in some way, often with competing interests. Water has been managed within various sectors with little coordination but the complexity and the large global problems related to water have made it clear that another approach is needed. There is a need for a holistic view of all water issues - across interests, sectors and boundaries as well as in space and time. Sustainable management of water also requires expertise from numerous disciplines and sectors as well as the participation of a variety of stakeholders. Based on these insights the concept of *integrated water resources management* (IWRM) (e.g. Global Water Partnership Technical Advisory Committee, 2000; Thomas & Durham, 2003; Grigg, 2008; Savenije & Van der Zaag, 2008; Vogel *et al.*, 2015) has developed and the need of integrated management is acknowledged worldwide.

Floods are in themselves complex events. It is now well acknowledged that also for flood there is a need for a holistic view and that flood management needs to take into account the range of values and stakeholders involved. This has resulted in the development of the concept *integrated flood management* (IFM) that was promoted by for example the Associated Programme on Flood Management (APFM) concept paper in 2002 (updated in 2004 (APFM, 2004)) and described by for example Hall *et al.* (2003). Integrated Flood Management can be seen as a subset of integrated water resource management (IWRM).

In 2000 EU adapted the EU Water Framework Directive (European Commission, 2000) to enhance integrated river basin management in Europe. This directive aims at protecting and restoring clean water and ensuring sustainable use of water. It also creates administrative structures for the water management based on river basins not administrative borders. In line with this the EU Floods Directive was adapted in 2007 (European Commission, 2007). It aims to create integrated flood risk management in Europe but should also be coordinated with the Water Framework Directive.

There is an EU directive for drinking water quality and other directives that are relevant to drinking water supply (European Commission, 1998). None of these do however regulate the risk management of drinking water or the integration with other directives. The drinking water directive mainly establishes the standards for acceptable drinking water quality. Although there is no specific directive for integrated management of drinking water supply, this is an important factor in management of both water resources and flood. The concept *integrated urban water management* is used for the integrated management of water supply, wastewater and storm water (e.g. Braga, 2001; Mitchell, 2006)

Although the idea of integrated management has become widespread it has also been criticised for example for being too broadly and vaguely defined, for being too focused on technical aspects and for being difficult to implement (e.g. Braga, 2001; Saravanan *et al.*, 2009)

Flood risk and flood risk management

Flood risk and flood risk management in Sweden

Sweden has, so far, been spared from devastating floods relative to many other countries. The highest discharge generally appears at snowmelt, especially in the north, but long periods of rain can cause floods at other times of the year. Many of the large rivers are regulated for hydropower. This may decrease the flood risk but it also creates a new threat in dam breaks. Floods, especially those caused by extreme precipitation during a short period of time (urban floods and flash floods), are expected to occur more frequently in the future due to climate change. Society's vulnerability to flood is also increasing due to increasing exploitation of floodplains and the increasing complexity of technical infrastructure.

In Sweden it is primarily the responsibility of the municipalities to prevent and manage accidents, crises and extreme events that cannot be handled by individual inhabitants (SFS, 2003, 2006). Regarding floods, individuals should protect their own property but the municipalities have the responsibility for the overall flood risk management. Regional and national authorities are required to manage flood or the effects of flood within their own area of responsibility. The Swedish Meteorological and Hydrological Institute (SMHI) make forecasts and issues flood warnings. The Swedish Civil Contingencies Agency (MSB) has a general and coordinating responsibility for risk and crisis management on the national level and is the competent authority for the EU Floods Directive. SMHI and MSB have provided general flood hazard maps for the large rivers and lakes in Sweden.

The EU Floods Directive

The Floods Directive is becoming an important tool for flood risk management in EU and so too in Sweden. The directive requires the member states to work with assessments and plans for managing flood risk. The work should be performed in six-year cycles according to a schedule which is synchronised with that of the Water Framework Directive. The work is done in three steps:

Step 1. Preliminary flood risk assessments should be performed. Based on these, areas with potential significant flood risk should be identified. First cycle assessments were to be completed 22 December 2011.

Step 2. Flood hazard maps (showing the extent of floods with different probability) and flood risk maps (identifying values at risk of being inundated) should be produced for the areas identified as having potential significant flood risk. The adverse impacts on human health, the environment, cultural heritage and economic activity should be considered. The maps of the first cycle were to be completed 22 December 2013

Step 3. Flood risk management plans (FRMP), stating objectives and measures aiming at reducing the adverse impact of flood or the likelihood of flooding, should be produced. The plans of the first cycle were to be completed 22 December 2015. (European Commission, 2007)

The Floods Directive has been implemented in Swedish legislation as an ordinance. Eighteen areas have been identified as having potential significant flood risk. MSB is responsible for the preliminary risk assessment, selection of areas with potential significant flood risk and production of the flood hazard maps (steps 1-2). A large part of the work is made by the county administrative boards (CAB). They are responsible for producing the flood risk maps and the flood risk management plans (steps 2-3). The municipalities have, however, no formal responsibility in the Floods Directive work. They should be informed about and involved in the production of flood maps and FRMPs as the municipalities have considerable knowledge about the local conditions. Apart from the implementation of the Floods Directive there is no legislation for flood risk management.

Flood risk assessment

In a flood risk assessment the hazard, exposure and vulnerability should be investigated and are usually presented in maps. This comprises a combination of different methods. The hazard assessment is usually based on a system combining hydrological and hydraulic models. The assessment of exposure identifies exposed values, commonly by combining hazard maps and geographical information about land use, critical objects, etc. Vulnerability and consequences may be investigated by a range of methods (e.g. loss models, indices based models).

Flood hazard mapping is a well-established method. With the shift from a flood control approach to a flood risk management approach, the consequences of floods have increasingly been in focus (Messner & Meyer, 2006; Schanze, 2006; Klijn *et al.*, 2008). Assessment of exposure is more and more common. Methods for vulnerability assessments have also been developed but are applied to a lesser extent (Messner & Meyer, 2006; Klijn *et al.*, 2008; Cirella *et al.*, 2014; Balica *et al.*, 2015). Assessments of consequences primarily consider direct, tangible damage. Indirect and intangible damages are harder to capture in an assessment and are seldom considered (Messner & Meyer, 2006; Schanze, 2006; Giupponi *et al.*, 2015). Likewise it is economic and physical factors that dominate when consequences are assessed while the more abstract environmental and social factors are seldom included (Balica *et al.*, 2015; Giupponi *et al.*, 2015). Efforts have, however, been done to overcome these shortcomings. Meyer *et al.* (2009) have developed a GIS-based multicriteria flood risk assessment and mapping approach which includes non-monetary values. A model that allows spatial quantification of socio-economic vulnerability is presented by Kienberger *et al.* (2009).

Drinking water supply and risk management

Drinking water supply in Sweden

On the whole, Sweden has a large supply of water of good quality. In 2010 there were 1,757 municipal water treatment plants in Sweden. 10% of the water treatment plants use surface water and produce about half the volume of the water produced. 83% of the water treatment plants use natural groundwater and 7% use artificially infiltrated groundwater. Each method produces a quarter of the nation's drinking water (Swedish Water and Wastewater Association, 2010). The number of consumers served by water treatment plants varies from only a few to hundreds of thousands consumers, and most water producers have more than one treatment plant (Swedish National Food Agency).

On average there have been almost 50 boil-water advisories a year in Sweden (2000-2013) according to the National Food Agency (Swedish National Food Agency 2015, personal communication).There have also been some large outbreaks of gastrointestinal diseases due to contaminated drinking water, notably in Östersund and in Skellefteå in 2010-2011 (Widerstrom *et al.*, 2014). Recently several cases of contamination of groundwater sources with perfluoroalkyl acids (PFAA) have been discovered (Swedish National Food Agency, 2014).

With climate change the quality and supply of water are expected to change. Concentrations of natural organic matter are already becoming higher (Erlandsson *et al.*, 2008) and higher water temperature may increase the prevalence of pathogens. Extreme precipitation and floods are expected to become more frequent, which is an increasing threat (Swedish Water and Wastewater Association (SWWA), 2007). Although these risks are well-known in the water sector, a high quality drinking water is still taken for granted by most people in Sweden. Such a lack of awareness of risks may create vulnerability as producers, authorities and the public may not expect problems and therefore have a low preparedness for an emergency situation.

Responsibility and regulation

The municipalities are responsible to provide their citizens with good quality drinking water. The drinking water production is managed within the municipal administration or by a company owned by the municipality.

On a national level the responsibility for drinking water is shared by several agencies; the National Food Agency, the Swedish Geological Survey, the Swedish Agency for Marine and Water Management and the Swedish National Board of Housing, Building and Planning. These agencies formulate regulations within the scope of legislation issued by the parliament. They may also support municipalities and water producers with guidelines and handbooks, etc. Another key actor in the water sector is the Swedish Water and Wastewater Association (SWWA) which represents the interests of the water producers. The SWWA provides advice and handbooks and supports research and development.

There are several laws and regulations relevant to drinking water. Regulation SLVFS 2001:30 based on the European Community directive (98/83/EC) on the quality of water intended for human consumption (Swedish National Food Agency, 2001) comprises water quality standards and regulation about water treatment and control. According to this legislation water producers are required to perform self-control and a Hazard Analysis and Critical Control Point Assessment (HACCP). Other risk assessment is not legally required. The Swedish Environmental Code 1998:808 (SFS, 1998) regulates the environmental protection, including water protection areas.

Drinking water risk assessment

Drinking water risk is commonly assessed with tools developed in industrial, environmental or human health risk management contexts. Some tools have been adapted especially for the drinking water system or parts of it. Such adaptations have been made by the Swedish National Food Agency (National Food Agency Sweden (Livsmedelsverket), 2007) and SWWA (Abrahamsson Lundberg *et al.*, 2009; Swedish Water and Wastewater Association (SWWA), 2014, 2015).

Effects of flood on drinking water supply

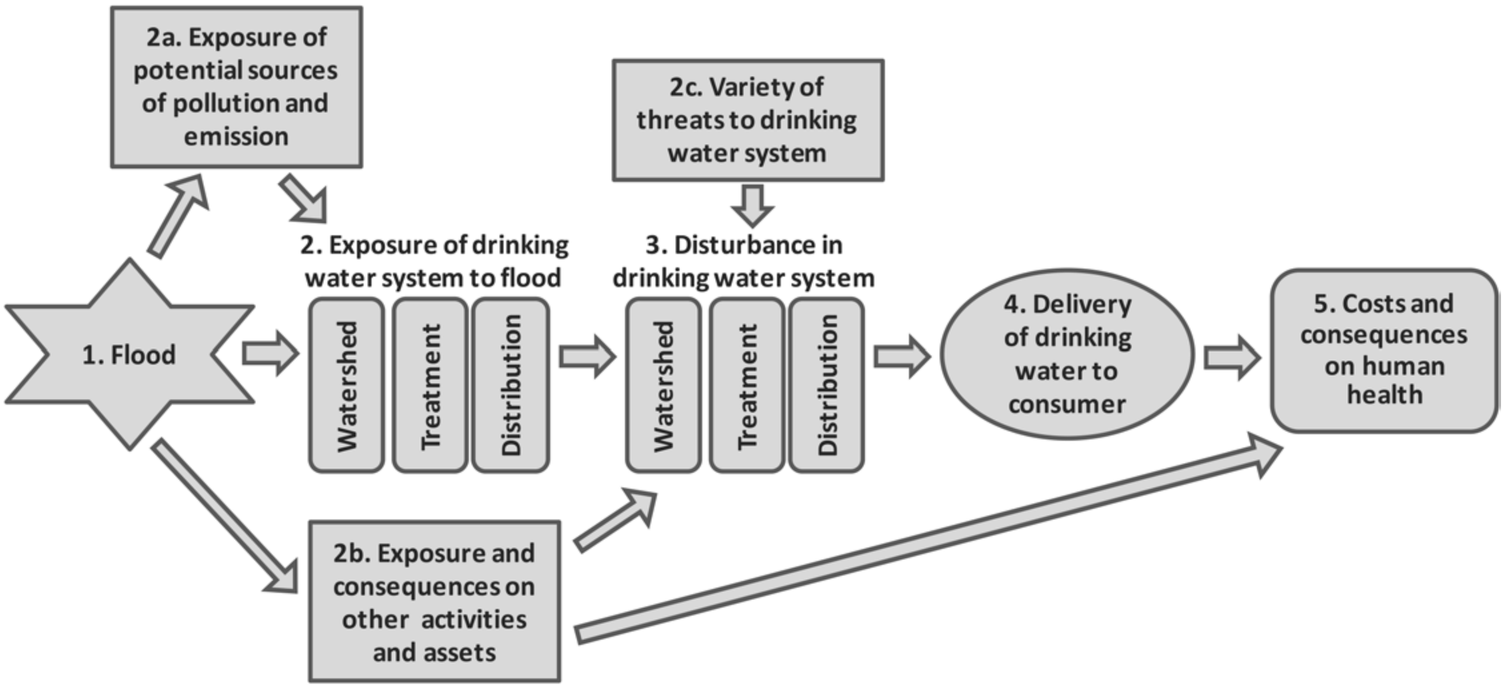
The impact of floods on drinking water supply can mainly arise in two ways. Firstly, physical impact by the flood can damage the drinking water facilities, including for example wells, water treatment plants, reservoirs, distribution system and all associated equipment. This may cause disruption in the production and delivery of drinking water to consumers. Secondly, emission or mobilisation of chemicals, microorganisms and particulate matter caused by the flood can result in poor water quality.

Generally there is little knowledge about how and to what extent floods and extreme weather events affect the drinking water and other infrastructure or the environment. Little attention is paid to these problems in guidelines and risk assessment methods (Bowering *et al.*, 2013; Carmichael *et al.*, 2013; Hammond *et al.*, 2013; Emanuelsson *et al.*, 2014; Murphy *et al.*, 2014; Khan *et al.*, 2015). Some studies have however been done and show that floods and extreme precipitation may have consequences on drinking water supply also in developed countries like Sweden (Kistemann *et al.*, 2002; Andersson-Skold *et al.*, 2007; Andersson-Sköld *et al.*, 2007; Göransson *et al.*, 2013; Tornevi *et al.*, 2013, 2014, 2015; Khan *et al.*, 2015)

Conceptual model

The assessments of consequences of flood on the drinking water supply can be said to cover a chain of causes and consequences from a flood event, via the drinking water system to the consumers. Based on the literature and the studies included in this thesis, a conceptual model of the effects of flood on drinking water and consumers and for the assessment of the corresponding risks has been developed. It is presented in Figure 2. Different steps of this chain may be relevant to cover depending on the purpose and context of the risk assessment. However, for an integrated risk assessment, it is also desirable to investigate the risks along the whole chain. Risk reducing measures could also be taken in different parts along this chain.

Figure 2. Conceptual model: Risk assessment chain for the effects of flood on the drinking water supply system and its consequences on human health



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At a flood event (1 in Figure 2), the water environment including *water-sheds*, the *water treatment facilities* and the *distribution system* may be exposed to the flood, inundated (2). Alternatively potential sources of pollution may be exposed to flood and result in emission and polluted water, which may in turn expose the drinking water system (2a). The exposure of the drinking water system may cause disturbances by *physical impact* or spreading of pollution resulting in *water quality problems* (3). The degree and character of these disturbances depend on the vulnerability in the drinking water system. Both types of impacts may cause difficulties in delivering drinking water of good quality in sufficient amounts to the consumers (4). This can in turn cause health consequence for the consumers or costs for water producers and actors dependent on water (5). Floods can also affect the drinking water supply indirectly by disturbances in other activities or services that the drinking water system depend on such as power supply, transportation, personal resources (2b). Drinking water disturbances can also have a large variety of other causes than flood (2c).

Methods

For the studies included in this thesis a case study approach has been used. Swedish local level risk management of floods and drinking water supply have been studied. Case studies are appropriate when, as in this thesis, there is a wish to understand a complex social and organisational situation by observation of current events and circumstances (Yin, 2009). The studies were based on interviews (Papers I and II) and document studies (Papers III and IV). The methods are described further below.

Papers I and II

Papers I and II were based on parallel interview studies. Telephone interviews were performed with key persons from sixteen water producers (Paper I) and risk or flood managers in seventeen municipalities (Paper II). Corresponding questions about drinking water and flood risk management were posed to the two groups.

Water producers (Paper I) and risk or flood managers (Paper II) from the same municipalities were included in the studies. A targeted selection was made to include water producers and municipalities that would experience both risk related to their drinking water supply and risk for flood. Municipalities with a risk that the drinking water would be affected by a flood were therefore selected. With this selection a good variety of water producers and municipalities was achieved.

The interviews included questions about how the water producers and municipalities had performed risk assessment, if and how they had identified hazards, analysed probabilities, consequences and risks and made decisions about risk and measures, what tools they had used and what challenges they experienced.

Apart from the interviews some additional data were collected from relevant documents and websites.

Interviews were transcribed and the content was analysed (c.f. directed content analysis; see (Hsieh & Shannon, 2005). The concepts and framework for risk management based on ISO 31000:2009 (ISO, 2009) and the KULTURisk conceptual framework (Giupponi *et al.*, 2015) presented under *Definitions and concepts* in this thesis, were used to analyse the practice in relation to theory.

Paper III

Paper III presents the results from a document study. From the findings of Papers I and II the most commonly used handbooks, guidelines and reports describing a method for risk assessment of either flood or drinking water supply were chosen for the study. These documents had been produced or promoted by Swedish national agencies or the Swedish Water and Wastewater Association (SWWA).

The documents were analysed using a directed content analysis approach (Hsieh & Shannon, 2005). The methods were characterised and compared with respect to how they analyse the risk associated with the effects of floods on drinking water information.

What aspects of risk assessment of flood and drinking water supply that the methods in the study covered, were also investigated. Especially, the conceptual model in Figure 2 was used to investigate how the methods covered the assessment chain *flood – drinking water – consumer*. The extent and manner in which the methods addressed the parts of the drinking water system and the types of risk were also analysed.

Paper IV

Paper IV is based on a document study. Here the flood risk management plans from 17 of the 18 areas[1] with potential significant flood risk were studied. The content has been analysed with regard to scope, described risk to drinking water supply, suggested objectives and measures relevant to drinking water supply as well as signs of integration with the Water Framework Directive and other activities relevant to drinking water. The objectives and measures have been categorised and analysed in relation to what they relate to in terms of type of risk, part of the drinking water system and part of the chain *flood – drinking water system – consumer/cost* (Figure 2) that they address.

[1] Due to data problems the risk maps for one area with potential significant flood risk have had to be revised which has delayed the production of the flood risk management plan for this area. Consequently, this plan is not included in the study.

Results

Paper I: Water risk assessment practices among Swedish water producers

Tools used by the water producers

The sixteen water producers in the study were asked if they had used certain risk assessment methods. Of these methods some were specifically adapted to drinking water while others were general methods that are recommended for or applicable to drinking water risks.

Among the methods specifically adapted to drinking water HACCP (Swedish National Food Agency, 2001; Swedish Water and Wastewater Association (SWWA), 2014) is compulsory for water producers to perform according to Swedish legislation. This was also done by most, but not all, of the water producers in the study. Several of the water producers had also performed the method described in the handbook from the National Food Agency (Risk and vulnerability analyses for drinking water supply (National Food Agency Sweden (Livsmedelsverket), 2007)) or similar assessments based on a coarse risk analysis methodology. Less than half of the water producers had performed analyses of microbiological risk using MRA) (Abrahamsson Lundberg *et al.*, 2009) and/or GDP[2] (Norwegian Water (Norsk Vann), 2009; Swedish Water and Wastewater Association (SWWA), 2015). Risk analysis is required for the establishment of water protection areas (Swedish Environmental Protection Agency, 2011). In most cases there was a water protection area established or work was in progress.

The methods mentioned above were those that were most commonly used. They all have in common that there are guidelines adapted specifically for drinking water supply in Swedish conditions issued by Swedish agencies or the national organisation Swedish Water and Wastewater Association

[2] After the submission of Paper I the name of the method that was called good disinfection practice, GDP, changed name to microbial barrier analysis, MBA. In this thesis the old name (GDP) is used when referring exclusively to paper I. In other circumstances the new name (MBA) is used.

(SWWA). The international guidelines for drinking water from the World Health Organization (WHO) were however generally not well known and the concept of Water Safety Plans promoted in these guidelines was recognised but had not been adopted.

More general risk assessment methods were hardly used at all. One respondent mentioned that they had performed a hazard and operability study (HAZOP). Two water producers had performed a modified fault tree analysis, which had been developed by a research group at Chalmers University of Technology.

Many of the water producers had used risk matrices for assessing the risk. Some had also complemented the risk assessment with cost-benefit analyses or calculations of cost to support decision-making. There was however few water producers that seemed to have discussed a level of acceptable risk. When asked about acceptable risk a few referred to risk matrices with predefined levels of probability and consequence as well as levels for when measures should be taken. Decisions were usually taken from case to case after discussions and sometimes a political process. Only one water producer had decided on a level for acceptable risk.

Compared to what is described in the literature (e.g. MacGillivray *et al.*, 2006; Hokstad *et al.*, 2009) the tools for risk assessment used by the water producers in the study are basic and provide a general view of the risks.

The water producers in the study claim that they have covered all parts of the drinking water system, at least from the raw water intake to the distribution. It is however mentioned that the water distribution system is poorly included in the assessments. Most of the tools used are aimed to cover, or may be used for, the whole system. A few assessments for only the watershed or the treatment process have been done.

Most water producers in the study seem to have investigated all types of risks. HACCP, MRA and GDP consider only microbiological water quality risks. Some assessments have been done for chemical quality, while no assessment specific for water quantity or physical risks have been seen.

Extent of risk assessment

There was a large variability between the water producers in how and to what extent the water producers had worked with risk assessment (Table 1). Some have done no or little systematic risk assessment and have not used any method or routine to identify risks. These producers respond that they know their system well and are aware of the problems. However, the theoretical knowledge about the concepts of risk management seems to be low in these organisations. They work more on intuition and have a practical approach where they solve problems when they are discovered.

A few water producers stand out for working more consciously and systematically with risk assessments. They have done several risk assessments, using different tools and have analysed the system as a whole as well as specific aspects or parts of it. One has defined a level for acceptable risk. They have a more holistic view on risk management and good, or rather good, knowledge about the concept of risk and the risk management process. They also participate in and learn from research and development projects.

Many water producers are somewhere between these two groups when it comes to how extensive risk assessments they have performed. They have some kind of risk assessment but not as part of a holistic risk management strategy. They have performed HACCP and many of them have done an assessment of the coarse risk analysis type, for example the one described in the National Food Agency handbook. A few have also done a specific investigation of microbiological risks using MRA or GDP. These water producers seem to depend mostly on handbooks, guidelines and regulations from national actors such as the National Food Agency and the SWWA. The theoretical knowledge of the risk concept and risk management process seem to be varying but limited in many cases, also among producers that have done risk assessment. Awareness of possible problems is, however, often high.

Comparison of the extent of risk assessment with the size of the water producer, in terms of number of consumers, and the type of water source reveals that the water producers with the most extensive risk assessment are large water producers, in larger cities and with a surface water source. Among those that have the less extensive risk assessment, generally the water source is groundwater and the water producers are small and often situated in sparsely populated areas. This suggests that those having the highest risk and largest resources are those that have engaged the most in risk assessment.

The risk assessment work of the water producers can be compared with the risk assessment steps in the risk management process (Figure 1). The water producers with the lowest level of risk assessment probably have done some sort of risk identification. It is however not systematically done and these producers have done none of the other risk assessment steps. All the other water producers have done systematic risk identification. They have also estimated probabilities and consequences to estimate the risk, which means that the risk analysis step is done. The risk evaluation step is not performed systematically and comprehensively by most water producers. Few water producers have discussed acceptable risk. The levels that are used are mostly the risk matrices in the handbooks used where the level of risk has been decided by the author of the handbook.

Table 1. Extent and character of risk assessment performed by the three categories of water producers included in the study related to knowledge of risk management and type of water producer. Summary of results in Paper I.

Extent of risk assessment	Type of risk assessment/ tools	Strategy/ holistic view in risk assessment	Theoretical knowledge of risk management	Type of water producer
Large extent	Various tools, covering different aspects and hazards	Yes, to some extent Active, preventive	Rather good Participate in research & development	Large water producer Surface water High risk?
Medium Extent	HACCP, CRA, (MRA/GDP)	Limited, varying Depend on national guidelines	Varying, often limited	Various
Low extent	No or little systematic risk assessment	No or little strategy Reactive	Poor Mostly practical approach	Small water producer Ground water Low risk?

Experienced challenges and needs

The challenges that the water producers experience are not related to development of new or improved tools. Instead the main challenge experienced is to implement a systematic risk management process and actually perform risk assessment. There is also a perceived lack of knowledge of risk management and that the work often becomes dependent on a few staff members as well as on consultants. Lack of continuity and difficulty to incorporate the risk management in overall drinking water management are also problems mentioned. The lack of data for risk assessment is mentioned as a problem. Some would like more guidelines for how to identify risks and estimate probabilities and consequences.

Paper II: Practices of local flood risk assessments in Sweden

Assessments performed

All municipalities in the study had flood hazard maps for one or more watercourse within the municipal borders. For all but one of the municipalities there were general flood inundation maps provided from MSB. Eleven of the municipalities had hazard maps according to the Floods Directive. Many of the municipalities had additional flood maps and some of these were created on their own initiative, often performed with the help of a consultant. Several of the municipalities were also included in flood mapping efforts for dam failure preparedness, initiated by the authority responsible for the electricity grid in Sweden, the Swedish National Grid (Svenska Kraftnät). A hazard map was also created in a Government commission about the consequences of flood in Lake Mälaren. Three of the municipalities in the study were covered by this map.

About half of the municipalities had performed their own, systematic, analysis of consequences based on the hazard maps. The analyses were of very different extent and most commonly it was the areas, buildings, properties and infrastructure that were in danger of being flooded that were identified.

The risk maps according to the Floods Directive were among the most extensive flood risk assessments that had been performed in Sweden. They were, compared to most of the municipalities' assessments, generally more systematic and coherent. Another thorough analysis of flood consequences was from the Lake Mälaren Commission where 236 objects with vital societal function were studied separately to value the consequences of every 10 cm rise of water level. Additionally a GIS analysis had identified and estimated the extent of exposure of areas and objects. A similar assessment had been commissioned by the municipalities around Lake Vänern. Investigation of floods and consequences in and around Lake Mälaren had also been performed for the planning of a new lake water level regulation system.

The assessments above are based on some kind of flood risk assessment methodology or used no real risk assessment method at all. No other risk assessments methods were used to investigate flood risk.

The municipalities' work with flood risk assessments as a whole

The extent of flood risk assessment that the municipalities had performed themselves differed considerably between the municipalities in the study. It spanned from municipalities that had done no or very little assessment of their own, to municipalities that had their own detailed flood hazard maps, had analysed consequences – in some cases including cost-benefit analyses –

had looked at effects of climate change and used these for strategies and risk management. There was a tendency that the municipalities that had done most risk assessment were those that had the largest flood risk, perceived the largest flood risk or who had experienced a severe flood while the smallest municipalities tend to have done least. This was however not an entirely clear and consistent pattern.

In many cases the approach to flood risk management was practical and *ad hoc*. Judging from the way many respondents talked about risk assessment their theoretical knowledge in risk management was low. The municipalities that had done most extensive risk assessments had relatively good theoretical knowledge but still a rather practical focus.

The flood managers experienced that the partition of responsibility was not so clear and that especially the owners of private property were not always aware of their responsibility. The distribution of responsibility had also been treated differently in flood risk assessments. Some municipalities had clearly stated that it was only the municipalities own assets and functionalities that were considered in their risk assessments. In the Floods Directive as well as in some municipalities, the scope of the assessments had been extended to include other values than the municipalities' properties and activities. It had sometimes been difficult to involve the private businesses, also those that deliver public services (e.g. power or water).

The flood risk management was rarely an independent activity in the municipalities, but part of a variety of other activities whereof risk management was one. Flood risk management was often closely related to or even mainly seen as a part of climate change adaptation. Emerging climate change adaptation efforts had also initiated flood risk management. Also at places where there had been a significant flood risk for a long time, the problem had only come into focus with discussion about climate change and was seen as a future problem rather than an existing one.

Practitioners' views on challenges and needs

The challenges and needs that the flood risk managers experience were not related to the development of improved tools for flood risk assessment but rather to the practice of risk assessments. They experience that it was a challenge to actually work with and prioritise flood risk assessment. A need for more knowledge and resources was expressed. To work with floods and climate adaptation, respondents had experienced challenges in motivating the organisation, in collaboration between various parts of the organization and in keeping the results from the assessments alive. Understanding of the problem as well as a wish and driving force to act, not least among the politicians, is a key to success according to some of the municipalities that had done a larger amount of work.

Practice in relation to theory

A complete flood risk assessment should include the assessment of hazard, exposure and vulnerability. In general the respondents were not well aware of these concepts. Using these concepts to describe what had been investigated in the assessment it can be said that the *hazard* had been assessed by all municipalities in the hazard maps. However, the hazard maps mainly covered large watercourses and lakes. The flood hazard from small watercourses and lakes had not been considered and only a few municipalities had considered flood hazard related to extreme precipitation.

When the municipalities had investigated consequences it is usually the *exposure* of values and assets that had been investigated. The types of consequences that had been considered are direct and tangible such as inundated areas, buildings and physical property as well as infrastructure or objects with societal function. Some efforts to capture the direct intangible consequences had been done. The number of inhabitants within the flooded area had been analysed in some cases. The environmental effects had been represented by identifying protected or valuable areas and drinking water assets as well as sources of pollution. Areas and objects with a cultural heritage value had also been considered. This is mainly done in the Floods Directive work, for the Government Commission about Lake Mälaren and by some municipalities.

The term *vulnerability* was touched upon in several of the interviews. The understanding and use of vulnerability as a concept differed between the respondents. Some had a clear idea of the concept but for many it was rather vague. Mostly it seemed to be understood as “weak points” or assets that may be harmed and relates to infrastructure and societal functions or the lack of capability in the municipality to resist or handle an extraordinary event. The respondents also talked of vulnerability in terms of vulnerable groups of inhabitants.

In the flood risk assessments, vulnerability, as defined here, had usually not been a factor that was estimated and included in the analyses. Two municipalities had, however, gone through infrastructure and objects with societal function to describe the consequences of a flood for each object (susceptibility). Some also mentioned that they had looked at the capacity to handle a flood (adaptive capacity) or that they had identified vulnerable groups of people (coping capacity). The Government Commission about consequences of a flood in Lake Mälaren had investigated the potential effects on a large number of objects and evaluated their capacity to handle such events (susceptibility and adaptive capacity). According to the instructions for the risk maps for the Floods Directive, the assessments should include short descriptions of the different types of consequences that may include vulnerability aspects.

Considering the steps of risk assessment in Figure 1, the first step of risk assessment - risk identification - had been performed in all municipalities in terms of identification of location and type of flood. For the risk analysis step we have seen that the hazard had usually been analysed while the exposure was analysed to varying degrees in some assessments. Generally the vulnerability had been given little consideration, if any at all. The risk analysis step was hence only partly performed.

Few flood risk assessments had considered risk evaluation in a systematic way. Most municipalities had no formal policy for acceptable risk and few seemed to have had serious discussions about how to relate to it. Some had, however, a policy that no critical functions or infrastructure and new buildings should be situated within what would be the inundated area of a certain water level.

A few municipalities said that they had used cost-benefit analyses or estimations of costs, primarily concerning evaluation of flood prevention measures, to support decision-making. Mostly however, decisions seemed to be taken *ad hoc* on a case-by-case basis.

Paper III: Effects of flood on drinking water in risk assessment methods and possible combination of methods

The flood risk assessments that were studied were all similar in that they investigate a rising water level and the resulting consequences of inundated areas and exposure to water. They provide a general overview of the flood risk. The drinking water risk assessment methods use various methodologies. One method (the risk and vulnerability analysis for drinking water supply) gives a general view of the risk while the others have more specific scopes in different ways. Risk is not defined as a concept in the flood risk assessment methods although it is defined in the Floods Directive (European Commission, 2007). Some of the methods for drinking water both define and quantify the risk.

In the flood risk assessments the consequences of flood on drinking water are considered as the inundation of water treatment plants, potential sources of pollution and environment and water protection areas. One method considers the functionality of drinking water facilities with rising water level. For drinking water only one method (the risk and vulnerability analysis for drinking water supply) explicitly includes flood as a cause of drinking water problems that should be investigated. Another method (MRA) recommends that the method is performed for both normal and extreme conditions, which may be a flood. The other methods do not explicitly consider flood or extreme events.

Compared to the chain *flood – drinking water – consumer*, in figure 2, the flood risk assessments focus on the first two steps (steps 1 and 2 in Figure 2) – flood and exposure of the drinking water system. To some extent they also address the disturbances in the drinking water system (step 3), mainly for physical impact. The drinking water methods are primarily occupied with disturbances within the drinking water system (step 3) and only consider the exposure to flood to a limited extent. Delivery of drinking water (step 4) and/or consequences on human health (step 5) are considered in some of the methods. Several of the methods for drinking water only consider risks related to water quality, especially microbiological water quality. Only one considers all types of risks.

It is mainly the watershed and the water treatment facilities that are considered by the flood risk assessments. Several of the drinking water methods aim to cover the whole drinking water system and some focus on the watershed and/or water treatment. The distribution system is little considered.

While the flood risk assessments consider rare events with a return period up to 10,000 years, the methods for drinking water focus more on frequent or even normal conditions. The risk and vulnerability analysis for drinking water and MRA may include rare events.

When studying the assessment chain *flood – drinking water – consumer* in Figure 2 and how they are considered in the methods we see that all steps are covered although the consequences for human health only are considered in one method and only for microbiological water quality risk. It is also only one method (the consequences analysis of the Lake Mälaren Government commission) that bridges the first two steps that are the focus of flood risk assessments with the latter steps which are the focus of the drinking water risk assessments. In this case it is only done for physical impact and not water quality risks. This means that there is a gap between what is investigated by the flood risk assessments and the drinking water risk assessments. In the former the actual consequences on the drinking water system are not well studied. In the latter flood is not well studied as a cause of drinking water disturbances.

Paper IV: Drinking water risks in flood risk management plans for the Floods Directive

The flood risk management plans (FRMPs) according to the Floods Directive for the 17 areas with potential significant flood risk municipalities are rather similar in scope and follow the structure of the instruction. One aspect that does differ between the plans is whose responsibility for flood risk management they comprise. Most plans do not have any restrictions concerning which responsible actors they included. Some do, however, state explicitly that they have only or primarily included topics that are the responsibility of the County administrative boards (CAB).who have produced them.

There is also a large difference in how much flood risk management that has been done previously for the areas included in the Floods Directive efforts. About half of the FRMPs mention previous work but only some include this in objectives and measures.

It is rather unclear from the FRMPs what the consequences of a flood on drinking water would be. Most likely this is because the consequences are not well known. Drinking water is, however, mentioned in all but two plans, but in a general way.

Many FRMPs mention possible consequences of flood on the drinking water supply as disturbances or interrupted water supply. The causes and consequences are, however, not described further.

It is most commonly the watersheds or water protection areas that can be exposed to flood. This is related to the water quality risks. Also potential sources of pollution are mentioned in most FRMPs and comprise the sewage system as well as industries and contaminated soil. The potential effects for drinking water are rarely mentioned but it seems that the risk is considered to be rather low.

Almost all FRMPs suggest objectives and measures for maintaining a functional drinking supply. Some, also or instead, have objectives and measures directed to vital societal functions that may include drinking water supply but also a wide range of other services e.g. schools, hospitals, municipality buildings, railway stations. Several objectives refer to an acceptable or unacceptable time for disruption, but no values have been given and only one FRMP has an objective about specifying the acceptable time for disruption.

Most FRMPs also have objectives and measures to secure little or no consequences of flood on the environment which may also be relevant to the drinking water supply as they concern water quality and possibly raw water quality. Drinking water quality is however rarely mentioned in these objectives and measures. Some of the objectives relating to the environment are focused on the potential sources of pollution and how these are affected by a flood and the spreading of pollutants, while the subsequent consequences on the environment are not mentioned. Others are more focused on or include the consequences on protected areas or the environment in general.

Many of the objectives and measures are of the kind that investigations should be performed or knowledge should be acquired about certain topics. Almost all measures that are directed to the drinking water supply and to the environment are of this kind. Developing plans and considering flood in other activities are also common kinds of objectives and measures that can be seen both for drinking water supply and the environment.

There are also objectives and measures that concern more general matters and objects that indirectly may affect the drinking water by decreasing the flood hazard or improving the capability to manage risk and handle a flood event. Objectives and measures relating to physical flood protection and concrete measures to decrease flood risk are relatively few. When it comes to an increased general capability, common categories of objectives and measures involve the consideration of flood risk in other activities like spatial planning and general risk management, to information and increased awareness about flood risk, to forecasts, water level measurements and flood warning as well as to collaboration and coordination between actors and activities.

The FRMPs give little information about integration of the flood risk management with the Water Framework Directive or drinking water issues. The plans mention that the water producers often have been involved, but it is unclear to what extent. Water producers have been assigned responsibility for suggested measures. The coordination with the Water Framework Directive is on a general level. Some objectives are related to the standards of the Water Framework Directive. A brief evaluation of how categories of measures that are suggested according to the Water Framework Directive may affect flood risk is included in some plans. There are few signs of integration of flood risk management within the catchment areas.

Discussion

It is clear from the studies included in this thesis that there is a large variation between different municipalities and water producers in terms of to how and to what extent risk assessment and risk management have been performed. There are also large differences between risk managers with respect to their knowledge and available resources. This is true both of flood and drinking water risk management and can mainly be seen in Papers I and II but also in Paper IV. These differences may be a problem as the safety level for the inhabitants may then vary depending on where they live, which is not consistent with the objectives of Swedish risk management legislation.

Despite these differences between municipalities or water producers the studies show a number of general issues concerning the implementation of a risk management approach and integrated management which are often similar for flood and drinking water risk management. This is discussed below.

The studies presented in this thesis are all performed in a Swedish context. Risk management of floods and drinking water are performed in various ways and to various extents around the world. Even the EU Directives are implemented differently among the EU Member States. Sweden therefore serves as an example of how the risk management has been performed. For generalisation of the results there is a need to perform similar studies elsewhere.

Application of risk assessments and implementation of a risk management approach

Risk assessments have been performed by the studied municipalities and water producers to different extents – both for flood and drinking water (Papers I and II). Some have performed no or very little systematic risk assessment and a few stand out for having made a more systematic and thorough work. However, there are aspects of the risk assessment process and the flood or drinking water risks that are not well covered in any of the risk assessments performed.

Currently, it is mainly flood risks from rivers and lakes that are considered (Paper II). Furthermore, the consequences of a potential flood are not well investigated. When assessments of consequences have been performed it is mostly the exposure to flood that has been investigated while the vulnerability is considered to a much lesser extent. It is mainly the direct, tangible consequences that are addressed. These observations are all in accordance with the literature about flood risk assessment methods (Messner & Meyer, 2006; Schanze, 2006; Klijn *et al.*, 2008; Jeffers, 2013; Giupponi *et al.*, 2015). In drinking water risk assessments (Paper I) the distribution system is poorly covered by the assessments and while there are several assessments performed specifically for microbiological risk, the chemical risks and physical impacts are less considered.

Risk identification has been performed by most municipalities and water producers both for flood and drinking water supply (Papers I and II). Assessments that have investigated consequences of floods or done a systematic drinking water risk analysis have at least partly done a risk analysis. However, the risk evaluation is weak for both flood and drinking water. Few municipalities and water producers have discussed and formulated what is considered as acceptable risk. Although cost-benefit analyses and estimates of costs have been made in some cases, there generally is an *ad hoc* approach to decision-making, where measures are discussed from case to case. Also in situations where assessments have been done, basic methods are utilised compared to the more advanced methods described in the grey and scientific literature.

The above shows that full risk assessments of the different aspects of the risk are often not performed in Swedish local practice. The incomplete risk assessments result in a view of the risk that may be limited or biased and provide insufficient support for decision-making. The respondents often perceive that risk assessments are not prioritised and that there is a need for allocation of more time as well as resources to perform risk assessment and implement risk management.

The theoretical knowledge about risk management is, with some exceptions, rather low (Papers I and II). The definition of risk as a combination of probability and consequences is the one that is most used - also for flood risk management. Flood risk managers are not well acquainted with the concepts of flood risk based on the concepts hazard, exposure and vulnerability, and they are not used in the methods that we have studied (Paper III). Instead there is mostly a practical approach to risk management often lacking strategy and a holistic view.

For flood, the flood risk management plans (FRMPs) (Paper IV) also show a lack of knowledge about the flood risk as the consequences of flood are described in a very general way. Many of the objectives and measures are concerned with providing new knowledge and investigating consequences. This indicates that full risk assessments have not been performed.

For drinking water the national agencies and the Swedish Water and Wastewater Association (SWWA) have provided handbooks and guidelines for risk assessments and related procedures (Paper I). Even if these are not always used, they provide some guidance for the risk management. It can also be seen that many water producers depended on these guidelines for their risk management. Guidelines and methods for general risk management are also available from, for example the Swedish Civil Contingencies Agency (MSB). There are no similar national guidelines specifically for flood risk management and there is an uncertainty about what should be done, what should be covered and how the responsibility is distributed (Paper II). In the work with the Floods Directive, guidelines have been developed. They are aimed to guide the CABs in the process for the areas that have been selected for the Floods Directive work, but it should be possible to use these also for flood risk management in other areas and by the municipalities. What has been done for the Floods Directive is however not familiar to most of the municipalities. Even those that are covered by the directive have often limited knowledge about the work.

Comparing the risk assessment and management for drinking water that has been done with the four characteristics of risk management suggested by O'Connor (2002) it can be said that even those that have done little risk assessment seem to have the intention to be preventive. Having done systematic risk assessment however provides a better base for being preventive, and it also helps in distinguishing greater risks from lesser risks. This seems to be done at least to some extent.

Risk assessment is not a prioritised activity for many water producers which suggests that learning from experiences may be lacking in many cases. While this thesis has found that there is generally poor knowledge about risk management as well as little strategic and holistic thinking, a risk management approach has started to be adapted by many of the water producers, albeit to varying degrees. The drinking water risk management tends to be at a basic, or at its best, a medium level.

With a corresponding way of reasoning, similar conclusions can be drawn for flood risk management. The intention may be to be preventive but in many municipalities flood risk management is not prioritised. Lack of comprehensive risk assessments indicates that distinguishing greater risks from lesser risks and learning from experience is not always done. There are however some municipalities that have done an extensive amount of systematic risk management work. The Flood Directive is also introducing elements of flood risk management, at least for those areas that are covered by the directive.

Klijn *et al.* (2008)state that in flood risk management the risk, not only the flood, should be managed and that more than physical measures should be used. Much focus is still on the hazard and protecting values from the water. However, the exposure is considered in some assessments. And even if vulnerability is not systematically included in the risk assessments there is at least some awareness that it should be considered (Paper II). In the FRMPs (Paper IV) there are several suggested objectives and measures concerning “non-structural” measures such as warning systems, information as well as improved collaboration and integration. Spatial planning and environmental management to decrease consequences are also suggested.

The many objectives and measures about providing more knowledge do however also show that the process is rather immature and in its beginning. Many municipalities have only recently initiated systematic flood risk management and the Floods Directive has just completed its first cycle. The continuing cycle that Klijn *et al.* (2008) mention as the third essential for flood risk management cannot yet be seen. Flood risk management has started to be implemented though. Hopefully these early efforts will develop and become a continuous flood risk management process.

To achieve further development of risk management there is a need for risk managers and water producers to prioritise risk management and to acquire more knowledge about risk and risk management. The respondents do not experience a need of new risk assessment tools but a need to actually use the tools that are available and find the time and resources to perform risk assessment. National agencies and organisations already have an important role in guiding the risk management efforts, especially for drinking water. This support should continue and be enhanced. Similar guidance is also needed for flood risk management. Preferably agencies should develop and promote best practices. Education in risk management adapted for the water producers and flood risk managers is also needed.

Some municipalities and water producers do not perceive large risks relating to flood or drinking water supply. Considering the limited resources that many municipalities and water producers live with, it is important to balance the requirements for risk management with the risk and not demand unnecessarily extensive work.

For flood risk management it may be relevant to discuss whether the municipalities really should have the main responsibility, or whether more responsibility should reside at the regional level. With a regional responsibility it may be easier to provide the knowledge needed and use resources more efficiently. It would also facilitate coordination within catchment areas. This however contradicts the decentralised Swedish government system with a large degree of independence for the municipalities. The results in Paper IV also show that there is a need to clarify the responsibilities for and scope of flood risk management at least in relation to the Floods Directive.

Effects of floods on drinking water and integrated management

The effects of flood on drinking water supply are included in the flood risk assessments and some of the drinking water risk assessment methods that were studied in Paper III. It is however investigated in a very general way. The flood risk assessments study the flood and exposure of the drinking water system (steps 1 and 2 in Figure 2) while drinking water risk assessments mostly consider disturbances in the drinking water system, as well as to some extent the delivery of drinking water and effects on human health (steps 3-5 in Figure 2). The link between exposure of the drinking water system to flood and the disturbances in the drinking water system is not well covered in the methods, which means that the potential consequences of a flood on the drinking water supply are not well investigated. That there is a lack of knowledge about the actual consequences of flood, on both infrastructure and the environment has been identified in several of the FRMPs (Paper IV) where the problem is, at least partly, addressed by suggesting objectives and measures to investigate this. No specific method has been suggested.

It should be possible to combine or integrate several risk assessment methods to enable a more complete and detailed understanding of the risks for both flood and drinking water. However it would require additional methods to cover the gap between exposure to flood and disturbances (steps 2-3 in Figure 2). Combining methods would mean using the results from one method (primarily a flood risk assessment) as in-data for another method (primarily a drinking water risk assessment) and these would need to match. Considering the differences in type of method, purpose, level of detail and scope, this might be a challenge. Existing methods may be used but may need to be slightly adapted to match.

Consequences for drinking water supply caused by a flood are also considered in the FRMPs of the Floods Directive. Most FRMPs have objectives and measures related to the drinking water supply and for the environment, including water quality. The presence of drinking water in the risk assessments and the FRMPs indicates that it is considered to be an important issue, maybe more in flood risk management than in drinking water risk management, where it seems less present. The risk related to the effects of flood on drinking water is however considered to be rather small although it is not well known.

The methods in Paper III show little signs of conscious integration between flood and drinking water risk assessments. For the FRMPs there is an explicit requirement that the flood risk management should be integrated with the water resources management according to the Water Framework Directive. There are also attempts to initiate such integration although they are very general and brief in character. Integration specifically with drinking water risk management is not an explicit aim for the FRMPs, and it is limited to some involvement of water producers in the development of the plans and responsibility for measures. Improved collaboration and integration of flood risk management into various areas such as general risk management, spatial planning and environmental management is suggested in objectives and measures. There is an awareness of the importance of integration and ambitions seem high. However, there are few concrete suggestions and how it will succeed remains to be seen. Something that can be noted from Paper II is that the flood risk management often is connected to or a major part of the climate change adaptation plans for the municipalities. This is in contrast to the problems that attempts to integrate disaster risk reduction and climate change adaptation often face in science and policy.

In summary there is a need to better investigate the effects of flood on drinking water and to develop, or combine, risk assessment methods to better cover this issue. Further the integration between flood risk management and drinking water risk management should be improved to better manage the consequences of flood on drinking water supply.

Conclusions

Although there are large differences in how municipalities and water producers have performed risk assessments for flood and drinking water, there is generally a need to improve the local level risk assessments in Sweden. Strategies and holistic approaches are generally lacking. In many cases risk assessments are not prioritised and a practical, *ad hoc* approach is often taken to risk management. Without risk assessments the support for decision-making may be incomplete and biases may lead to inappropriate decisions about risk reducing measures. A risk management approach has begun to be implemented but it is still at a basic level and knowledge about risk management is generally low. There is a need to engage more comprehensively in risk assessment and to use the tools that are available. Further national guidance and education could be a way to improve risk management.

The consequences of flood on drinking water are not well known and the possibilities to assess the risks are limited when applying the risk assessments most commonly used in Sweden. While flood risk assessments primarily investigate the exposure of the drinking water system and not the actual consequences, drinking water risk assessments do not in detail consider flood as a cause of drinking water disturbances. Sharing of information and combining methods for flood and drinking water risk assessment could provide a better overview of the risk. Several of the flood risk management plans developed for the EU Floods Directive address the lack of knowledge about consequences of floods by suggesting further investigations.

Especially in flood risk management there is an awareness of the need to coordinate and integrate between actors and sectors. However, the results of the studies included in this thesis show only few signs that such integration is taking place. The parallel implementation of the Floods Directive and the Water Framework Directive provides an opportunity for integration. It remains to be seen if the actors involved will seize this opportunity. To enable and facilitate this process the roles and responsibilities of the relevant actors needs to be clarified.

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Sammanfattning på svenska

Summary in Swedish

Vatten är nödvändigt för allt liv på jorden, men det är också en sårbar resurs. Många delar av världen lider brist på rent dricksvatten medan extrema händelser som översvämning hotar människoliv och skadar samhällen. Översvämningar kan även störa dricksvattenförsörjningen genom att skada utrustning för vattenproduktion och -leverans eller sprida föroreningar till dricksvattnet. Detta kan sprida sjukdomar och leda till vattenbrist. Problemen med både tillgången till dricksvatten och översvämningar är störst i utvecklingsländer men är även en risk i utvecklade länder i till exempel Europa. De pågående klimatförändringarna innebär troligen en försämrad vattenkvalitet och mer vanligt förekommande översvämningar.

För att säkra dricksvatten och minska översvämningsriskerna behövs ett systematiskt riskreducerande arbete. Synsättet på hur man bör hantera risker har förändrats genom åren. Traditionellt har man löst problem när de uppstår och haft praktiska, tekniska lösningar. För dricksvatten har till exempel kvaliteten på den färdiga produkten analyserats, men när detta görs kan det vara försent att åtgärda problemet innan någon blir drabbad. Översvämningar har i stor utsträckning betraktats som oundvikliga händelser som man behöver kontrollera och skydda sig emot med vallar och barriärer. Under senare årtionden har det utvecklats en mer systematisk och riskbaserad hantering som bygger på analys och värdering av riskerna, det vill säga vad som kan hända, hur sannolikt detta är och vilka konsekvenser det kan medföra. Utifrån detta görs prioriteringar och beslut om åtgärder fattas. Mer fokus läggs på att förhindra att problem uppstår än att lösa dem i efterhand. När det gäller översvämningar lägger man inte allt fokus på själva naturhändelsen utan även på att analysera och minska sårbarheten hos de samhällen som drabbas av dem.

Det finns många intressen kopplade till vatten och många aktörer som är involverade. Traditionellt har olika frågor hanterats var för sig vilket i många fall har resulterat i konflikter och problem. Ökad förståelse för vattenfrågornas komplexitet har lett till insikten att aktörer behöver samarbeta och olika frågor koordineras. En integrerad vatten- och översvämningshantering är önskvärd.

Systematisk riskhantering och integrerad hantering diskuteras både inom den vetenskapliga litteraturen och inom policyområdet. Att implementera dessa synsätt och strategier är däremot inte så lätt och en del aspekter av implementeringen är inte heller så välstuderade.

Syftet med denna avhandling har varit att undersöka hur riskhantering, särskilt riskbedömningar, har genomförts i praktiken. Studierna har gjorts i Sverige och eftersom det praktiska ansvaret för både översvämningshantering och dricksvattenförsörjning ligger på kommunerna har dessa, samt de kommunala vattenproducenterna, stått i fokus. Praktiken har jämförts med teoretiska ramverk för riskhantering. Dessutom har syftet varit att undersöka hur konsekvenser av översvämningar på dricksvattenförsörjningen behandlas i metoder för riskbedömning och riskhanteringsplaner för översvämning samt att studera om risker relaterade till översvämningar och dricksvatten har behandlats på ett integrerat sätt. Studierna är baserad på intervjuer med översvämningshanterare i svenska kommuner och svenska vattenproducenter samt dokumentstudier av metoder för riskbedömning och riskhanteringsplaner för översvämning.

Studierna visar att det är stora skillnader mellan hur, och i vilken omfattning, olika kommuner och vattenproducenter har gjort riskbedömningar. Vissa har knappt gjort någon riskbedömning alls medan andra har arbetat mer systematiskt. De metoder som har använts är ofta de som finns i handböcker från svenska myndigheter, vilka ofta är mindre avancerade än vad som beskrivs i litteraturen. Riskbedömningarna tar inte alltid upp alla relevanta aspekter av risken vilket gör att bedömningarna kan vara ofullständiga. Det är få som har diskuterat vad som är en acceptabel risknivå och beslut fattas vanligen från fall till fall och inte utifrån en helhetssyn av riskerna. Översvämningsbedömningarna fokuserar på vilka objekt och verksamheter som kan bli översvämmade. Vilka möjliga konsekvenser det faktiskt kan få för de verksamheter som drabbas undersöks i mycket begränsad utsträckning. Det är också främst konsekvenser inom översvämningsområdet som inkluderas. Följdeffekter och konsekvenser som inte lätt kan mätas i pengar undersöks i mycket begränsad omfattning. Ofullständiga riskbedömningar kan ge en felaktig bild av risken och beslut riskerar att fattas utifrån bristfälligt underlag.

Många översvämningshanterare och dricksvattenproducenter har begränsade teoretiska kunskaper om systematisk riskhantering. Däremot känner dricksvattenproducenterna ofta sitt dricksvattensystem väl. Det saknas dock oftast strategi och helhetstänkande i riskhanteringen.

Kunskapen om potentiella konsekvenser av översvämningar på dricksvattenförsörjningen är begränsad. Detta behandlas inte heller i detalj i de metoder för riskbedömning som är mest vanligt förekommande i Sverige. Bedömningar av översvämningsrisker undersöker framför allt översvämningens utbredning vid ett antal scenarier med olika sannolikhet samt vilka byggnader och verksamheter som blir översvämmade men inte konsekvenserna på dessa. Riskbedömningar för dricksvatten fokuserar på händelser inom dricksvattensystemet och översvämning behandlas översiktligt som en möjlig orsak till störning. Genom att kombinera riskbedömningsmetoder för översvämning och för dricksvatten på ett genomtänkt sätt skulle man troligen kunna få en bättre bild av riskerna kopplat till konsekvenser av översvämning på dricksvatten.

Dricksvattenrisker finns med i riskhanteringsplanerna för översvämning som har studerats. Mål och åtgärder för att säkra dricksvattenförsörjningen vid en översvämning finns med i de flesta planerna liksom mål och åtgärder för att begränsa effekterna på vattenmiljön vilket kan påverka dricksvattenförsörjningen. Planerna och intervjuerna visar att det finns en osäkerhet om hur översvämningsrisker bör bedömas och hanteras och hur ansvaret är fördelat. Riskhanteringsplanerna för översvämningar visar att det finns en medvetenhet om behovet av att koordinera hanteringen av översvämning och vattenresurser däremot visar de få tecken på att integrering sker i praktiken.

Studierna i avhandlingen visar på att både systematisk riskhantering och integrerad hantering är strategier som har börjat utvecklas och implementeras inom svensk hantering av översvämningar och av dricksvattenförsörjning. Det sker dock fortfarande på en ojämn men relativt grundläggande nivå och det är en lång väg kvar. Ytterligare vägledning från ansvariga myndigheter och intresseorganisationer och mer kunskap om riskhantering liksom engagemang från alla berörda aktörer behövs för att stödja vidare utveckling.

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