Review of flood vulnerability and damage assessments in three Nordic countries

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Front page image	Economic damage of 100-year storm surge in 2115 (RCP8.5) in Nyborg, Denmark. Calculated as part of the Floods Directive in 2019 by the Danish Coastal Authority.

Content

Summary

Flood vulnerability and damage assessments are vital to understanding current and potential future flood-related consequences. The Nordic countries are comparable in many aspects and the purpose of the review is to investigate how Nordic countries perform flood related vulnerability and risk assessments. In this review, methods used by national authorities in Denmark, Finland and Norway are examined, and for Denmark and Finland, focus has been on methods used in implementing the EU Floods Directive.

All three countries perform tangible damage analysis in smaller areas using damage models to determine flood consequences for a wide range of tangible vulnerabilities. The specific models and methods vary between the countries. As the only country, Finland has calculated the potential future flood risk including possible effects of socio-economic development, combining Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). Denmark and Finland both show number of people affected by floods, while Norway has made economic calculations for people affected by flood.

In order to include a wide range of both tangible and intangible vulnerabilities, Denmark has performed an index-based national risk assessment for the PFRA in the second cycle of the Floods Directive, while Norway in their quantitative method uses a pointsystem to describe intangible consequences.

One of the Norwegian methods examined is a cross-sectoral quantitative risk and vulnerability analysis, where the main prupose is to create a comprehensive understanding of hazardous events. Unlike the other methods examined, these analyses are workshop-based rather than being calculations of floods and their consequences.

In literature, tangible flood damage models are the most widely used as well, but with an increasing focus on intangible consequences of flooding and resilience towards flooding. Intangible consequences are either determined by using an index or by economising the intangible values. The increasing focus on connections between resilience, vulnerability and flood risk management, will support the growing focus on non-structural flood risk reducing measures.

As practitioners performing risk analyses, it is important to remember that (i) the method used to analyse the consequences must rely on data availability and scope of the analysis and to (ii) follow the development in academia to include the most important findings that can improve our work on risk management.

1 Introduction

This document contains a short review of flood related vulnerability and damage assessments carried out in the three Nordic countries Denmark, Finland, and Norway. Being comparable in many aspects, the purpose of the review is to investigate how Nordic countries perform flood related vulnerability and risk assessments, to share experiences and insights. Potentially, this it may also lead to future collaboration in the field or common development of vulnerability assessments.

The review is based on the methods used by Denmark and Finland when implementing the second cycle of EU Floods Directive (FD), Directive 2007/60/EC[1], described in the respective countries' methodology reports.

Denmark has performed an index-based national risk assessment for the preliminary flood risk assessment (PFRA) and damage analysis in the areas of potential significant flood risk (APSFRs). The method used, mapping the flood risk in the APSFRs, was used for an additional national risk analysis in 2020. These two methods are described for Denmark.

For Finland, the method used for risk analysis in the APSFRs is reviewed, including the projection of future flood risk, for which, as the only country, Finland has used Shared Socioeconomic Pathways (SSPs) to project the flood risk.

Norway is not implementing the Floods Directive and has not carried out the same analyses as Denmark and Finland, as required by the directive. However, Norway is still assessing flood consequences, and these methods are examined in this review.

In the following, a short description of the methods used in each country are described followed by recommendations for further development of vulnerability, damage and risk assessments looking into literature and the author's experience in the field.

The review is made as part of a civil servant exchange between the Finnish Environment Institute, SYKE, and the Danish Coastal Authority, DCA, in the autumn 2021.

Delimitation of this review

Only documents describing methodologies used or recommended by national authorities are included in this review. Though other organisations, universities, national and local authorities, consultants etc. may have performed and described flood vulnerability and risk assessments in their respective countries, these are not included in this review, or if so, as part of the general literature review.

Among other things, one of the Norwegian methodologies described in this document was used for a national risk assessment of several hazards, similar to the assessment done by all EU member states according to Decision No 1313/2013/EU of the European Parliament and of the Council of 17 December 2013 on a Union Civil Protection Mechanism[2]. However, the approach used for this analysis by Denmark and Finland are not included in the review, as the main focus for these countries was methods used in implementing the Floods Directive.

[1] https://eur-lex.europa.eu/eli/dir/2007/60/oj

[2] https://eur-lex.europa.eu/eli/dec/2013/1313/oj

2 Assessments in Denmark

When implementing the Floods Directive in Denmark, the Danish Coastal Authority (DCA/KDI) has performed a national index-based risk assessment for coastal and fluvial flooding, including both tangible and intangible vulnerabilities, as described in the methodology report KDI (2018). Following that, DCA has made economic damage and risk calculations in the APSFRs and later used the same methodology for a national flood risk mapping in the project Kystplanlægger[3] (Coastal Planner). The method used is described in the reports KDI (2020 & 2021). Finally, DCA made a simple model illustrating some of the consequences of critical infrastructure being damaged by flooding, also described in KDI (2020).

2.1 Index-based risk assessment

With the purpose of including a wide range of vulnerabilities important to society, both tangible and intangible, DCA performed an index-based national risk assessment for the PFRA for the second cycle of the Floods Directive. The method was developed in the EU funded project RISC-KIT[4] and recommended to DCA by Deltares (Briere, et al., 2017). The concept is to index both the flood hazard and vulnerability on a scale ranging from 1 to 5, representing very low to very high, and thus determining the risk by multiplying the hazard and vulnerability index. The index-based risk assessment is only performed for current floods and not projected to analyse future flood risks.

2.1.1 Indexing the vulnerabilities

Since the main intent was to compare vulnerability across tangible and intangible values, eight vulnerability categories were included in the analysis, complying with the purpose of the FD:

- Inhabitants
- Land use
- Cultural heritage
- Infrastructure
- Hazardous industries
- Emergency response
- Critical infrastructure
- Economic activity

Each category was mapped based on national datasets in a national 100 m × 100 m grid-net. In most cases the index was determined with experts in the field, and for the rest, the DCA did the indexing. The vulnerabilities were indexed using the concept described in Table 1, assigning the index value based on the importance of the value for society and the consequences if the value is damaged or destroyed.

Each 100 m × 100 m grid-cell was appointed one value for each category, representing the highest value within that category in the cell. Meaning that if a cell contained both a local road and an international airport, the cell was appointed the value 5, corresponding to the highest infrastructural vulnerability in the cell. If there were no values in the cell within any category, the cell was not assigned a value. The final indexing can be seen in Figure 1.

Following this, the total vulnerability was determined by summarizing the index of the eight vulnerability-categories and statistically indexing the total vulnerability on a final scale from 1 to 5, using Natural Breaks, thus resulting in map of the vulnerabilities, nationally distributed form very low to very high.

The result of the assessment, including the total vulnerability map and the maps for each vulnerability category, are presented in a webGIS[5].

[3] https://kystplanlægger.dk/
[4] http://www.risckit.eu/
[5] https://oversvommelse.kyst.dk/webgis: Data fra plantrin 1: Den nationale risikovurdering og udpegning af risikoområder

Table 1 The concept of indexing the vulnerabilities.

Index	Description
1	Very low vulnerability No significant or very small and local consequences
2	Low vulnerability Local and small consequences Values of mainly local importance
3	Medium vulnerability and consequences Values of local or regional importance
4	High vulnerability High consequences with regional or national impact Values of regional or national importance
5	Very high vulnerability Very serious consequences Values of national or international importance

Vulnera-bility	Index	Population density	Land use	Cultural heritage	Infrastructure	Hazardous industries	Emergency services	Critical infrastructure	Economic activity
Very Low	1	<10 persons per hectare	Other areas	Protected ancient monuments (cat. 0) Listed buildings (cat. 8, 9 & others) Church areas and burial sites Cultural heritage areas	Local roads Railway stations	Coastal landfills	-	Drilling sites of water plants and water supplies Smaller water plants for 1-2 households	Not spec-ified
Low	2	10-20 persons per hectare	-	Protected ancient monuments (cat. 1) Listed buildings (cat. 5, 6 & 7)	City- and regional roads Leisure and local airports	Column 2 hazard industries Industrial activities listed D210 & C201 (chemical industries & oil storage) Industrial activities listed 1.1a & 1.1b (energy supply)	Danish National Police	Tele mast Industrial water plants Water supply system General water plant	1-9 employees
Medium	3	21-30 persons per hectare	Farm land and mine excavation	Churches Protected ancient monuments (cat. 2) Listed buildings (cat. 2, 3 & 4)	National main roads	Column 2 hazard industries and industrial activities listed D201 & 201 and 1.1a & 1.1b located less than 100 m apart	Police	Decentralised heating plant Hydropower Industrial water plant	10-49 employees
High	4	31-40 persons per hectare	-	Protected ancient monuments (cat. 4) Listed buildings (cat. 0 & 1)	Railways Governmental highways National airports Ferry connections and harbours	Column 3 hazard industries Industrial activities listed 4 (chemical industries) Industrial activities listed D201 (storage of liquids) Industrial activities listed 5.1, 5.4 & 5.5 (disposal, re-covery and storage of hazardous waste and landfills)	Fire service Local units of the National Emergency Management Agency	Water purification Districtial heating plant	50-499 employees
Very High	5	>40 persons per hectare	Built-up areas	World UNESCO	International airports	Domino effect appointed industries	Hospitals Local emergency management	Centralised power heating plant	>500 employees

Figure 1 The eight vulnerability categories and index of values. Translation of Table 5.13 from KDI (2018).

2.2 Economic damage calculations

For the risk mapping in the APSFRs, DCA made calculations for potential flood damage for six vulnerabilities:

- Buildings
- Movables
- Businesses
- Cleaning of infrastructure
- Life stock
- Agriculture

This method was also applied in the national risk analysis, Kystplanlægger, in 2020 and was extended to cover coastal erosion as well. The method for determining damage caused by coastal erosion varies from the method used for floods, as there will always be at least total damage for the values eroded. The method for erosion damage calculations is not described here.

The results for the mapping in the APSFRs are presented in a webGIS[6] and so are the results of Kystplanlægger[7]. For the APSFRs the damage calculations were determined in 25 m × 25 m cells and 100 m × 100 m cells. Only the 100 m × 100 m cells are presented online. In Kystplanlægger all damage calculations were performed in 100 m × 100 m cells.

Damage for future floods are determined only based on changes in the flood extent and depth using climate change projections and glacial isostatic adjustments. Changes in vulnerabilities are not included in calculations of potential future floods.

2.2.1 Damage to buildings and movables

Damage to buildings are determined using a depth-damage function and the average flood depth in the cell of interest. The depth-damage function is determined from insurance pay-outs from two specific coastal floods in three areas in Denmark. The damage is determined based on the value of the house, resulting in higher damages in areas with more expensive houses. No damage is assumed for water depths lower than 20 cm.

Damages for movables are a percentage of the building damage.

2.2.2 Business damage

The business damage model is Dutch developed and transferred to Danish conditions (Burzel, et al., 2018). The model includes direct damage on movables and stationary goods such as the building, movables, machinery, stock etc., and business interruption. Only damage to private businesses is determined and the damage is calculated based on water depth, number of employees, and the business type, divided into three categories: industry, stores and offices, using statistics for each business type. The loss due to business interruption is determined based on the water depth, as well. The depth-damage functions are shown in Figure 2. The damage calculations are done for each specific business from the company's main address. This results in both over- and underestimations of business damage, if the company covers a large area, i.e. has many warehouses, or if the company has several offices at different locations.

[6] https://oversvommelse.kyst.dk/webgis: Data fra plantrin 2: Kortlægningen af faren og risikoen for oversvømmelse i risikoområderne
[7] https://kystplanlægger.dk/webgis

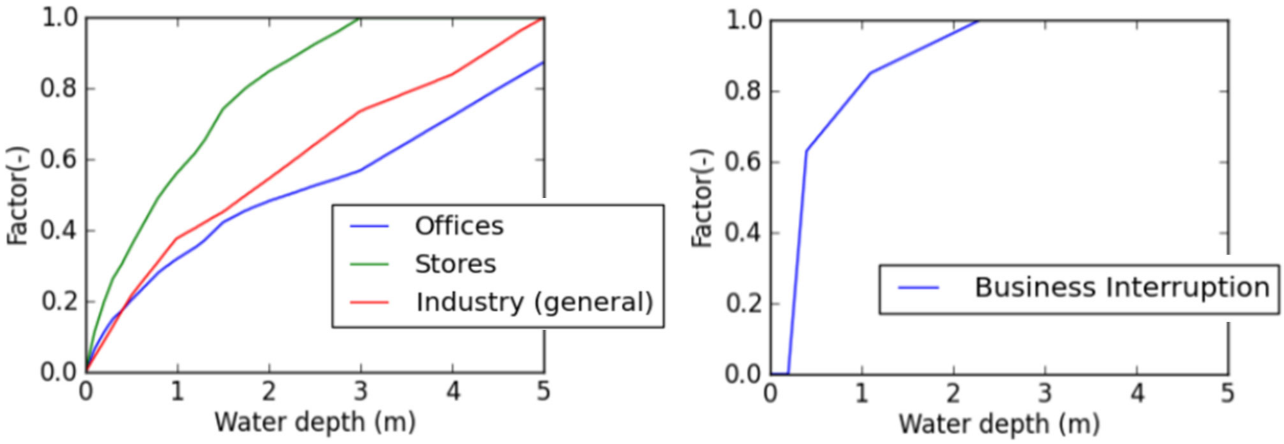

Figure 2 Depth-damage function for direct damage for each business category as a factor of maximum damage (left) and business interruption as a factor of one year (right). Figure 2.1 and 2.2 from Burzel, et al. (2018) adjusted.

2.2.3 Cleaning up infrastructure

From the floods included in the analysis, no damage to infrastructure are assumed and only cost of cleaning up infrastructure after a flood is included in the damage calculations. Cleaning is assumed to be required only at water depths higher than 10 cm. Cleaning costs are determined based on cleanings costs after a carnival, as amount of debris is expected to be approximately the same. The cost is determined from a square meter price and calculated for flooded roads, railways, and airport strips.

2.2.4 Life stock

The life stock model is developed in collaboration with a farming organisation and the model includes damage to pigs and cattle. The model assumes loss of life stock at specific water levels as the animals will have to be put down without profit due to stress. The model includes the loss of expected income from each animal lost, as well as the cost of acquiring new animals. The model uses information about the number and type of life stock farmers have.

2.2.5 Agriculture

The agriculture damage model is also developed in collaboration with a farming organisation. The model assumes flooding between October and March, as it is developed for storm surge related floods, and that the fields are flooded for more than a month, as most fields are protected by dikes. Damage is only calculated for flood depths higher than 10 cm, but other than that, the model is not depth dependent, as salt water is assumed to penetrate the soil and reduce the harvest yield.

The model includes different types of winter crops and uses information from the farmers about their crops. The damage includes loss of sown seeds, loss of crops and delayed sowing of spring crops.

2.2.6 Intangible consequences

In both the risk maps of the APSFRs and in Kystplanlægger, DCA has included intangible vulnerabilities by showing them on the map, but not performing any damage calculations, with one exception, only. For the APSFRs DCA has made a simple model of houses potentially affected if critical infrastructure (ameneties) is flooded. In the model, houses are connected to the nearest point of critical infrastructure within each of four categories. If a critical infrastructure is flooded, the connected houses are flagged in the model. An example of this result is shown in Figure 3.

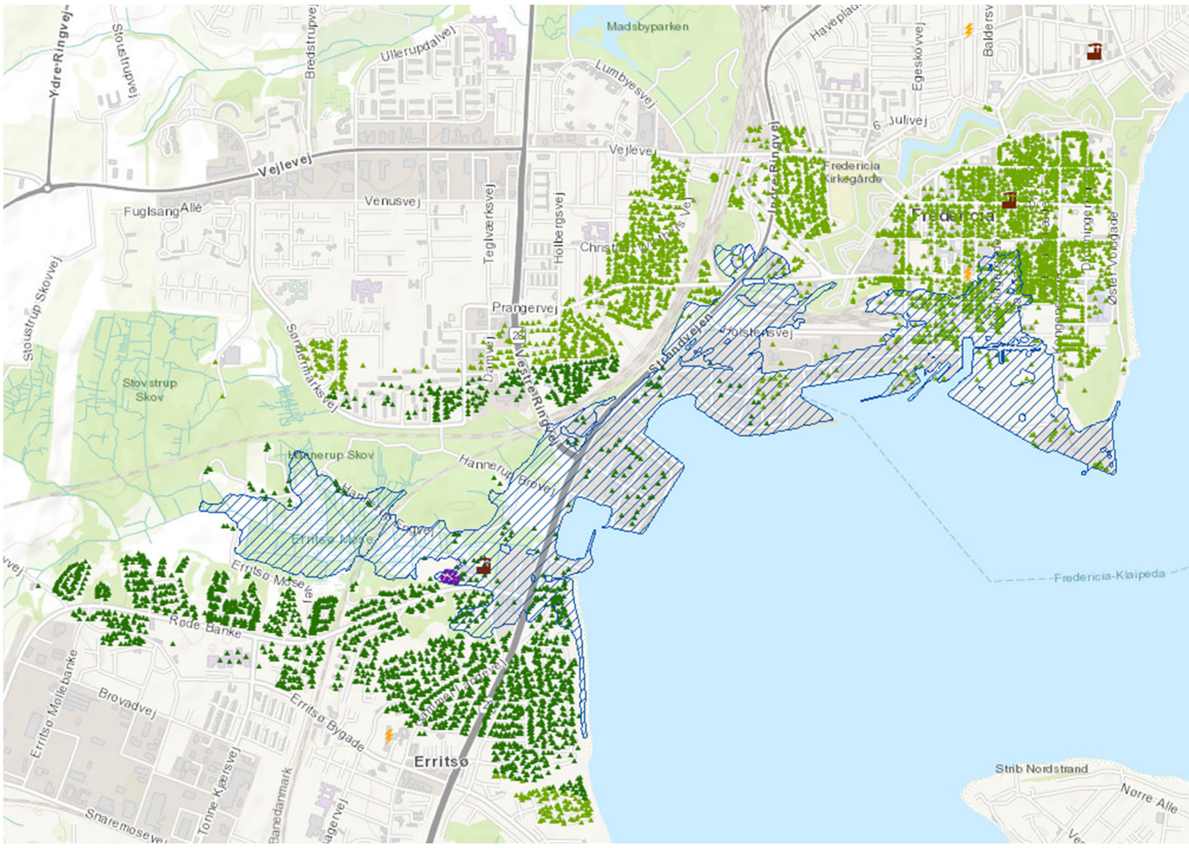

Figure 3 Showing houses potentially affected by flooded critical infrastructure. Light green means that the house is affected by one flooded critical infrastructure and dark green means two. The flooded area is marked in hatched blue and critical infrastructure is shown with icons. Map from DCA's webGIS[8].

[8] https://oversvommelse.kyst.dk/webgis: Data fra plantrin 2: Kortlægningen af faren og risikoen for oversvømmelse i risikoområderne

3 Assessments in Finland

When implementing the Floods Directive in Finland the Finnish Environment Institute, SYKE, has calculated potential flood damage in the APSFRs for either fluvial flooding, coastal flooding and in some areas both. The methodology is described in Silander & Parjanne (2013) in Finnish and the report is translated into English online for this review. Finland has also made calculations of how the flood risk will change in the future, using both climate and socio-economic development scenarios. This is described in Parjanne et al. (2018), which has also been translated from Finnish into English using an online-translator.

3.1 Current flood exposures and damage

In the APSFRs Finland has made vulnerability assessments mapping intangible objects exposed to flooding and flood related damage calculations for several specific flood scenarios.

For intangible objects exposed to flooding, SYKE has used available data of the objects and their location, as well as data from the regional centres and consultants. The exposed elements are identified using overlap analysis, and the objects included in the analysis are shown in Figure 4. Likewise, the number of potential affected inhabitants are mapped based on their home addresses and the modelled flood extent. The exposed objects and numbers of affected inhabitants are shown in the online Flood Map Service, available through SYKE's webpage[9].

For the potential economic damage SYKE has calculated:

- damage to buildings, including structural damage, damage to movables and cleaning costs,
- traffic-related costs, including damage to infrastructure and additional travel time,
- damage to vehicles, and
- flood related rescue costs.

SYKE perform the damage calculation on each object for several flood scenarios and summarize the damage and the flood risk, presented as expected annual damage (EAD), for each whole APSFR. The result of the damage calculations is presented online[10].

In the report, damage to agriculture and forestry, industrial and business disruption, and losses due to water and energy supply disruptions are specifically mentioned, but are not included in the analysis.

Figure 4 Vulnerable objects prone to flooding presented in flood maps online

3.1.1 Building damage

As mentioned above, the building damage is calculated as structural damage to the building, damage to movables, and cleaning costs.

All the costs are flood depth dependent, where the flood depth is determined in specific intervals used for the depth-damage model. Damage is only expected, when the water level around the building is higher than the foundations so the ground floor is flooded, using 0.3 m as the default value. The flood depth intervals are shown in Table 2.

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[9] https://www.environment.fi/floodmaps

[10] https://app.powerbi.com/view?r=eyJrIjoiMzM3ZmI4YzktOGRkZS00ZWExLWFiMGUtNGFhNzAzNGM0YTkyIiwidCI6IjY2MTAzOGQ5LTEyMTEtNGE4NS1hZGI5LWU3YjQ4OGVmNGUxMiIsImMiOjh9

Structural damage are determined using the square meter price of a new building of same type and the floor area of the flooded building. Additionally, prices can be adjusted according to the age of the building and regional differences between three cross country areas:

1. Helsinki Metropolitan Area
2. Surrounding municipalities
3. The rest of Finland

Damage to movables is a depth damage function, where the damage to movables depends on the damage on the building and cleaning costs are determined based on the new square meter price of the building.

Table 2 Flood depth intervals used in the Finnish damage models, the repair factor used for the infrastructure repair costs estimations, and the damage rate for flooded vehicles.

Flood depth intervals	Infrastructure repair factor	Vehicle damage rate
0 – 0,5 m	0,05	25%
0,5 – 1,0 m	0,1	50%
1,0 – 2,0 m	0,15	75%
2,0 – 3,0 m	0,2	100%
> 3,0 m	0,3	100%

3.1.2 Traffic-related costs

Traffic-related costs include costs of additional travel time due to flooded infrastructure and repair of infrastructure. Infrastructure included in the analysis is different categories of roads, electrified railways, and non-electrified railways.

The cost due to additional travel is determined based on the formula:

Additional travel costs = extra distance × traffic volume × costs × flood duration × number of flooded sections

The extra distance is assumed to be 2 km for roads and 20 km for railways per flooded section in the network, *flooded sections* are for instance the number of flooded road junctions, assumed to be 4 per 1 km road, *traffic volume* is determined using data from the Finnish Transport Agency, *flood duration* from the flood model, and *costs* are determined from government travels allowances for road traffic and compensations costs for railway traffic.

The damage repair costs are determined using the unit price of constructing the infrastructure, the length of the flooded infrastructure and a water depth factor resulting in higher repair costs after a deeper flood as shown in Table 2.

3.1.3 Rescue costs

Rescue costs include cost of rescue operation and costs of temporary accommodation for the evacuees. Cost of rescue operation includes costs of local rescue service and flood control at regional centres and covers expenses such as temporary structures, temporary road repairs, evacuation, flood prevention, fire department and police operations.

The rescue cost is determined as 5% of building damage in more densely populated areas, such as the Helsinki Metropolitan Area and surrounding municipalities, and 6.5% of building damage in the rest of the country.

3.1.4 Damage to vehicles

Damage to cars are determined based on the number of inhabitants in the flooded area, average vehicle density, average price, a flood depth dependant damage factor shown in Table 2, and the expected effect of early warning resulting in only 10% of cars being damaged due to coastal and fluvial flooding. The early warning factor for heavy rain fall-events is assumed to be 50% due to shorter warning time, however flood damage is only calculated for coastal and fluvial flooding.

3.2 Future flood risk

Finland has projected the flood risk into the future, using not only climate change scenarios, but also socioeconomic development scenarios. They have used the Shared Socioeconomic Pathways (SSPs) established by the international climate change research community (Riahi, et al., 2017) and developed by the International Institute for Applied System Analysis (IIASA) for the IPCC[11]. The SSPs are combined with the RCPs and Finland has decided to use three RCPs and three SSPs; RCP 2.6, 4.5, and 8.5 and SSP1, 2, and 3, combining them for six future scenarios in total, as shown in Table 3.

Table 3 Overview of the combined SSPs and RCPs used for the Finnish future flood risk estimations. Table 5 in Parjanne et al. (2018) translated to English.

	SSP1	**SSP2**	**SSP3**
RCP 2.6	**"Tough goal"** • emissions will fall after 2020 • equality between states and economies • rainfall increases approx. 5% by 2100 • mortality decreases by 20-25%	**"Emission reductions first"** • emissions to decline after 2020 • current socio-economic developments • rainfall increases approx. 5% by 2100 • projected demographic trends	
RCP 4.5	**"Global development"** • emissions to 2040 • equality between states and economies • rainfall increases 10-15% by 2100 • mortality is reduced by 20-25%	**"Medium"** • emissions to 2040 • current socio-economic developments • rainfall increases 10-15% by 2100 • projected demographic trends	**"Fragmented adaptation"** • emissions to 2040 • major challenges in adaptation • low economic growth • rainfall increases 10-15% by 2100 • fertility decreases by 20-25%, mortality increases by 20-25%, migration decreases by 50%
RCP 8.5			**"Climate disaster"** • continuous increase in emissions • major challenges in adaptation • low economic growth • rainfall increases 20-25% by 2100 • fertility decreases by 20-25%, mortality increases by 20-25%, migration decreases by 50%

The flood damage has been projected into the future by means of the commonly used equation (Neumayer & Barthel, 2011) normalising the damage to the desired year:

$$D_{t1} = D_{t0} \times B_i \times V_i \times H_i$$

Where D_{t0} is the current damage at time t_0 and D_{t1} is the future damage at time t_1. B_i is the change in the GDP deflator, V_i is the relative change in population and H_i is the relative change in wealth per person. The subscript i indicates that it is a forecast for a specific flood risk area, which has been used when possible. If site-specific forecasts were not available, general forecasts were used.

Changes in adaption or flood mitigation have not been included in the projection of the flood damage.

[11] For more information about SSPs see also IIASA (2013) and Hausfather (2018).

The change in population has been determined for each risk area, using a Finnish municipal housing planning tool, KASSU[12]. Population scenarios have been determined using the assumptions corresponding with the three SSPs to project changes in birth rate, mortality, and migration. It should be noted that the GDP forecast of Finland has been used in the regional population forecast.

Change in GDP deflator does not include regional differences and is determined partly based on forecasts by the Finnish Ministry of Finance and the Bank of Finland for short- and mid-term development and by IIASA for long-term development. The expected change in the GDP deflator is shown in Table 4.

No change in wealth per person is assumed.

Table 4 GDP growth forecast (%) used in calculation future flood damage in Finland. From Parjanne et al., (2018).

Year / SSP	**SSP1**	**SSP2**	**SSP3**
2020	2.2	2.2	1.1
2050	1.7	1.4	0.6
2100	1.1	1.0	0.2

The results of the projection of future flood risks are presented online in SYKE's Power BI[13] and an example of the results is shown in Figure 5.

[12] https://www.syke.fi/fi-FI/Tutkimus__kehittaminen/Tutkimus_ja_kehittamishankkeet/Hankkeet/Kuntien_asumisen_suunnittelun_sahkoisen_tyokalun_kehittaminen_KASSU2

[13] https://app.powerbi.com/view?r=eyJrIjoiMzM3ZmI4YzktOGRkZS00ZWExLWFiMGUtNGFhNzAzNGM0YTkyIiwidCI6IjY2MTAzOGQ5LTEyMTEtNGE4NS1hZGI5LWU3YjQ4OGVmNGUxMiIsImMiOjh9

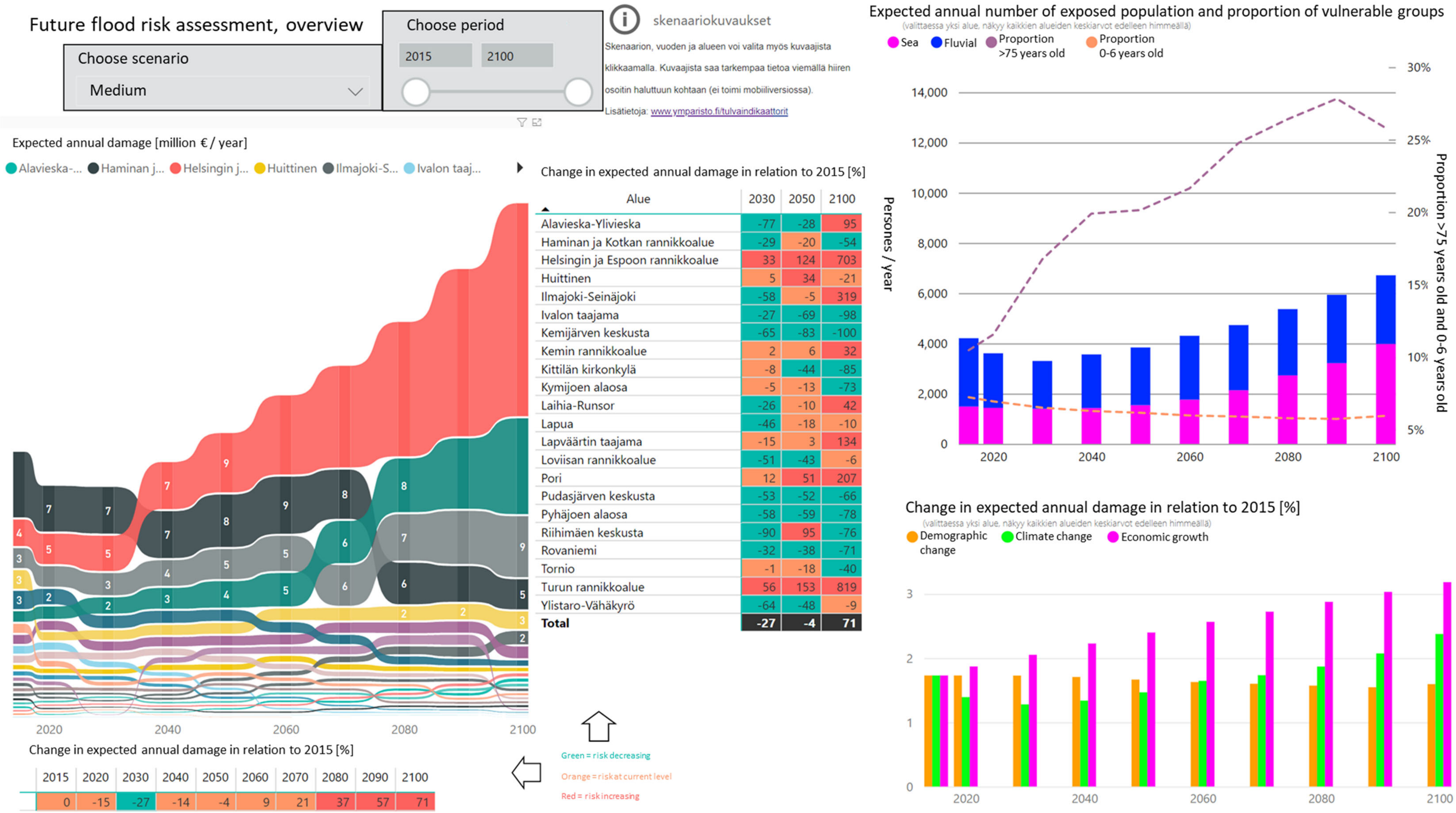

Figure 5 Screenshot of online presentation of future flood risk in the Finnish APSFRs. Text translated to English.

4 Assessments in Norway

Norway has decided not to implement EU's Floods Directive but is still performing various analyses of flood risks. In the spring of 2021, The Norwegian Energy Regulatory Authority (NVE) published a report presenting a national analysis on the need for protecting settlements against fluvial flood and landslides (Kalsnes, et al., 2021). The Norwegian Directorate for Civil Protection (DSB) has also performed a national risk assessment of several hazards, including flooding, using a qualitative method (DSB, 2014a), and has developed a guide for municipalities for a similar qualitative and comprehensive risk and vulnerability analysis (DSB, 2014b).

The two methodologies used by NVE and DSB, respectively, are quite different in their general approach, with the NVE analysis being quantitative and the DSB approach being qualitative. The two approaches are therefore described separately in the following.

4.1 Quantitative risk analysis by NVE

NVE has performed a national analysis of the need for protecting settlements against floods and landslides. For the socio-economic analysis described in Appendix B of the NVE report (Kalsnes, et al., 2021) they have used a tool developed for cost-benefit analysis of specific projects protecting against several types of hazard, described in a guidance document (NVE, 2021).

The purpose of the national analysis is to determine the need for flood and landslide protection and the tool described in the guidance document is to determine cost-benefit for specific projects.

The tool offers the opportunity to calculate tangible damage for the following:

- Buildings
- Loss of life
- Agriculture
- Public areas
- Infrastructure
- Cars
- Additional travel costs
- Other costs

Besides that, the tool also includes indirect and intangible damage. The methodology is described briefly in the following.

In general, in order to determine the damage, the tool depends on very detailed information about numbers of values or areas flooded.

4.1.1 Indirect damage

In the guidance document, it is described that indirect damages are difficult to quantify, and different event-related calculations have estimated different results. The guidance document recommends calculating indirect damages as 50% of tangible damage in dense areas with several businesses and 25% for more rural areas.

4.1.2 Intangible damages

In the cost-benefit analysis tool NVE has not tried to calculate the economic consequences related to intangible values being flooded but has instead listed five potential categories of intangible damage, which can each be attributed a point depending on one of two factors. Firstly, if the vulnerability is of local, regional, or national value, it is assigned a number from 1-3, respectively. Secondly, the extent of the consequence if the value is flooded is assigned a point on a scale from -3 to +3, with -3 counting as the maximum negative consequence and +3 the maximum positive. Subsequently, the importance for each intangible damage is determined by multiplying the value- and extent-points. The tool also offers the opportunity to define your own category to do this analysis.

It is recommended to always write down the reasoning behind the points in connection with the assessment.

4.1.3 Damage to buildings and movables

The tool calculates the damage of many different types of buildings, e.g., villas, garages/sheds, apartment-blocks, offices, industrial buildings, schools, day care, hospital etc. For each type of building, a standard building-area and area-price is pre-defined. This includes a standard area-price for movables. The standard building-area for the building types can be adjusted in the tool.

The damage on buildings and movables are then determined based on the flooded area, flood depth, if the building has a basement or not, and the building material, distinguishing between wood, concrete, and metal.

4.1.3 Damage to human lives

The tool also includes calculations of damage to human lives. The number of persons in a building is determined from standard values based on the different building types and how long a person would spend in each specific building type per year. The damage is then determined from the number of buildings in danger, a vulnerability factor based on type of building, and the statistical value of a human life.

4.1.4 Agriculture

Damage on agriculture includes two types of damage, damage to crops and total damage to agricultural land. Damage to crops include one-year full loss of crops and 50% reduction of expected yield the following year. The total damage to agricultural land is determined from the cost of permanently renting a similar area. The damage is determined based on the type of crops.

4.1.5 Public areas

Damage to public areas such as parks are determined as the cost of rebuilding a park of the same size.

4.1.6 Infrastructure

Infrastructural damage is determined for different types of roads, railways, and the electricity supply network. The damage is determined as a factor of the costs of rebuilding similar infrastructure, depending on the flood resistance of the infrastructure.

4.1.7 Vehicles

Damage to vehicles is determined based on the flooded area of parking lots, an average number of vehicles in parking lots, a typical value of vehicles in Norway and a vulnerability factor depending on the hazard type. For floods the factor is 0.2.

4.1.8 Additional travel costs

Additional travel cost is determined by default, using same values for different types of road, but this can be changed in the tool. The additional costs are determined based on the expected time of closure of the road, additional travel distance, traffic density and number of vehicles. For traffic density and number of vehicles, the calculation distinguishes between passenger cars and heavy vehicles.

4.1.9 Other costs

Other costs include cleaning and rehousing, emergency response, as well as the opportunity to add things not included in the tool.

4.1.9.1 Cleaning, renovation, and rehousing

The tool assumes that all buildings flooded at the ground floor will need cleaning, and renovation or rebuilding. The cleaning cost is a set number per building.

The rebuilding/renovation cost depends on the type of building material and water depth, with the percentage of wooden houses being totally damaged being higher than is the case for brick- or concrete buildings. No apartment buildings are totally damaged and rebuilding will not be required.

For renovating a house there is the additional cost of rehousing for 6 months, while the rehousing is assumed to be 24 months when rebuilding is needed.

4.1.9.2 Emergency response

Describes the societal costs of the flood and is set at 5% of the material damage.

4.1.10 Further calculations in the tool

As the tool is developed for cost-benefit analyses, it includes damage profiles before and after a protective measure, costs of the protecting measure, and calculation of residual risk. This document will not describe these but will just touch upon an interesting value included in the benefit-calculations, the feeling of safety.

Appendix B of the NVE report (Kalsnes, et al., 2021) describes the feeling of safety, how it is important to society but difficult to calculate. However, some work in the field has been done, and the tool's benefit calculation does include a capitalized value of the feeling of safety. The calculation method is not described thoroughly in the guidance document, but it states, that the added bonus of people feeling safe is tentatively set to 2000 2015-NOK per household protected (NVE, 2021), corresponding to approximately €200.

4.2 Qualitative risk and vulnerability analysis by DSB

DSB has carried out a national risk assessment of several hazards, similar to the assessment done by all EU member states according to Decision No 1313/2013/EU of the European Parliament and of the Council of 17 December 2013 on a Union Civil Protection Mechanism[14]. However, the approach used for this analysis by the other Nordic countries are not included in this review, as the main focus was methods used in implementing the Floods Directive.

The qualitative methodology used by DSB performing the risk assessment is described in the report (DSB, 2014a) and a guide to perform a comprehensive risk and vulnerability analysis in municipalities contains a similar method (DSB, 2014b). The following describes the concept of the qualitative methodology based on both documents.

4.2.1 Creating a comprehensive understanding of hazardous events

The purpose of the comprehensive analysis is to identify the consequences and side effects of a specific event, as well as estimating the probability of that event. In their analysis, DSB describes, how, even though quantitative and objective risk analysis are performed, risk assessments are always performed by someone and therefore always performed from a perspective, thus making them, at least a bit, subjective. Furthermore, DSB's purpose is to work across disciplines and sectors to get and create a comprehensive understanding of the hazardous events and their consequences.

4.2.2 The methodology

In performing the risk analysis, DSB uses the bow tie-model, as shown in Figure 6. The bow tie-model is a framework to describe an event, from left to right in Figure 6, identifying:

- causes of and factors contributing to the event,
- barriers reducing the probability and extent of the hazard,
- the event itself,
- barriers reducing the consequeces and effects of the event, and
- consequences of the event.

[14] https://eur-lex.europa.eu/eli/dec/2013/1313/oj

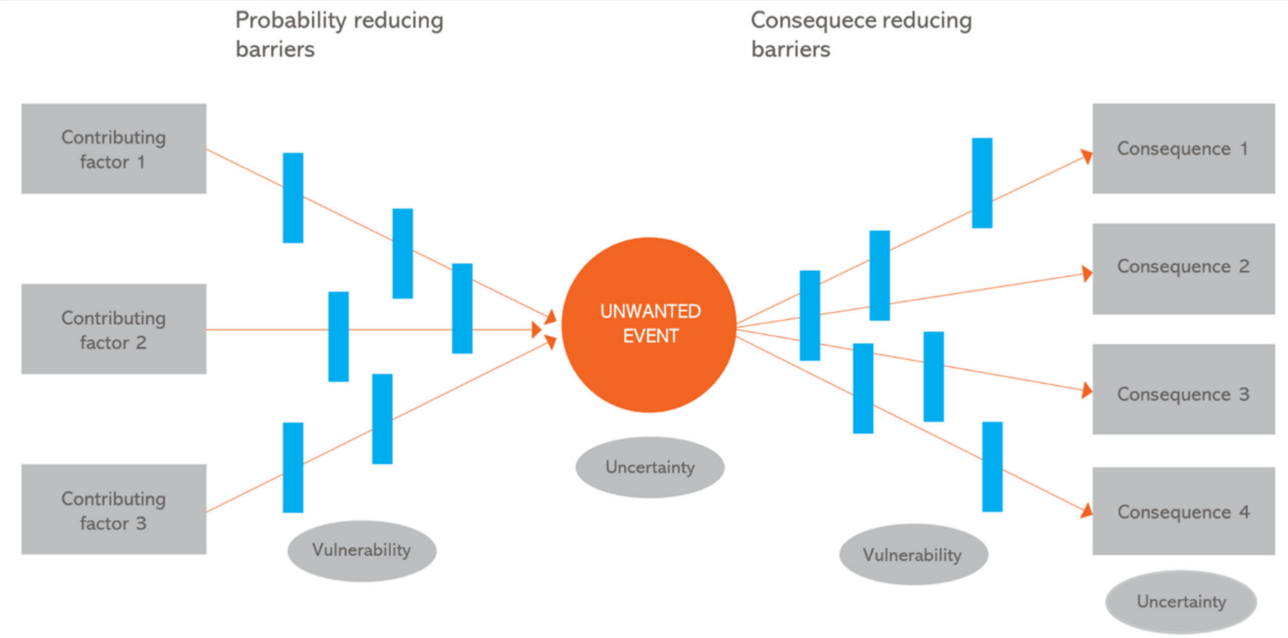

Figure 6 Bow tie-model for performing risk analysis. Figure 9 from DSB (2014a) translated into English.

The bow tie-model is used to describe the many factors affecting the event, the outcomes of the event, and how these are interlinked. The bow tie can consist of many small bov ties, as large unwated events often are a combination of other events cascading.

Following this, DSB uses and recommends filling out a form describing into more detail the probability of the event, as well as consequences in different categories of vulnerabilities, as illustrated in Figure 7. The details in the form differ a bit between the national risk assessment and the guide, but the overall concept is the same. The event is measured on a scale from 1 – 5, or insignificant to immense, and an overall estimate of the consequences on the same scale is marked in the bottom of the figure. Thus, ranging both the probability and consequences on this scale, the magnitude of the risk can be compared between differnet hazards.

Finally, DSB also fills out a form describing the uncertainties related to the event and the consequences.

4.2.3 Preparing the risk analysis

Both in the national risk assessment and guidance document (DSB, 2014a & b) the comprehensive risk and vulnerability analysis is part of a larger proces consisting of several steps both preparing and following up on the analysis.

The preparation includes identifiying societal values, such as, but not limited to; social and democratic values; economy; critical societal functions; life and health; nature and cultural values etc. The preparation also includes identifying the unwanted events into three categories: natural events; large accidents; and intentional events. Gathering all this informaton about events and vulnerabilities and gathering information about national and international experiences about similar events is important background information for creating the scenarios.

4.2.4 Analysis through work-seminars

The whole concept of the methodology is that it is interdisciplinary. For this reason, the development of scenarios and the risk analysis itself is performed and recommended carried out through one or a series of work-seminars including relevant experts and stakeholders across severals sectors.

At the seminars, the scenarios are developed by using the bow tie-model to investigate how events could develop. The scenarios should be probable events with extensive, cross-sectoral consequences that requires an extraordinary effort.

During this process it is improtant that the experts in the different fields contribute with their respective knowledge to get a wide understanding of how an event could develop.

Another important aspect of the seminar is also to estimate the probability of the events happening and how comprehensive the consequences are. Though it is a qualitative analysis, it is important to quantify the risk as much as possible. This is done using the form of analysis as shown in Figure 7. Further, the uncertainties should be determined, as illustrateded in the figure, where the circles are coloured to show the uncertainty, with the light brown representing low uncertainty, blue and dark colours, respectively, representing medium and great uncertainty.

Probability assessment

	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH	EXPLANATION
Probability of event happening in a year: 0.1-0.2 %			◎			Once every 500 – 1 000 year based on statistics and sector analyses

Consequence assessment

SOCIETAL VALUE	TYPE OF CONSEQUENCES	VERY SMALL	SMALL	MEDIUM	LARGE	VERY LARGE	
Life and health	Deaths				◎		More than 100 deaths as a consequences of flooding or landslide
	Damages and illness				◎		500 – 2 500 damaged or ill as a direct of indirect consequence
Nature and environment	Lasting damages	◎					Minor lasting damage
Economy	Financial and tangible losses				◎		5-10 billion Norwegian kroner
Society stability	Social disturbances			◎			Inadequate preparedness (under-dimensioned flood defenses) and difficult rescue work
	Stresses in daily life			◎			Approx. 10 000 people need evacuation, roads and railways destroyed, power failure.
Governance and control	Weakended national governance						Not relevant
	Weakended control of territory						Not relevant
TOTAL ASSESSMENT OF CONSEQUENCES				◎			In total major consequences

Small uncertainties ◎ Moderate uncertainties ◎ Large uncertainties ◎

Figure 7 Filled form of a flood risk assessment. Table 7 from DSB (2014a) translated into English.

4.2.5 Following the seminars

Both in the guide and national risk assessment, the seminars are followed by developing reports and presenting the results, and in the guide, it is recommended to the municipalities to identify measures and actions to reduce the risk, as well as to monitor the development of the plan.

5 Discussion and recommendations

Performing and improving vulnerability analyses, either flood related or in a different context, is not necessarily an easy task. Firstly, vulnerability analysis is a broad field, covering a wide range of aspects from direct tangible to indirect intangible damage, over physical, economic, societal, and mental consequences, to mention some. Additionally, the term vulnerability has many different definitions in literature, as described by e.g., Joakim et al. (2015) and Jurgilevich et al. (2017), and can for instance mean a threshold, an outcome, exposure, or a pre-existing condition. The latter is the most dominant framework (Jurgilevich, et al., 2017) and also the one used in this work, but it is important to be aware that the understandig of the word differs even within the same field.

Furthermore, when performing vulnerability analyses, there is no one fit all solution. For a local risk or vulnerability analysis it may be possible to do a more indepth analysis including local and detailed information compared to what might be possible or feasible for a national analysis, in which case national data may be more essential for the work. Also, the methodology chosen should depend on the scope of the analysis, as different information may be relevant for an analysis directed towards decision making on specific projects, compared to an analysis with the purpose of giving an overview or identifying hot spots. Additionally, for a risk analysis, the level of detail of the vulnerability analysis should correspond with the hazard analysis, as it, for instance, could be futile to prepare a very detailed damage model, if there are large uncertainties in the flood depth results.

When performing and prioritising where to improve vulnerability analyses, it is therefore important to first define the understanding of the concept, the purpose of the analysis, resources available, as well as technical and other requirements and/or limitations framing the analysis. One method for doing so could be using Preston et al. (2011), who suggest and use four questions "*that should be posed and answered in the design and execution of an [vulnerability] assessment*" to review vulnerability approaches in literature:

1. What are the goals and objectives?
2. How is the assessment of vulnerability framed?
3. By what methods will vulnerability be assessed?
4. Who participates and how are results used to facilitate change?

Thus, framing the analysis will help provide a scope for the work and define priorities in the vulnerability analysis and further development, because, as mentioned above and demonstrated in the previous chapters, vulnerability analyses cover a broad field.

Analysis of the described Nordic methods

Historically, in the field of flood risk management, the focus has been on the hazard analyses (Merz, et al., 2010), but the literature on vulnerability assessments is increasing (Jurgilevich et al., 2017, Díez-Herrero & Garrote, 2020), with more work on tangible damage assessments compared to intangible (Díez-Herrero & Garrote, 2020). This is supported by the review of the analyses performed by Denmark, Finland, and Norway, as the main focus and most developed models relate to tangible damage. All three countries have performed tangible damage assessments, with some differences as described in the previous chapters and shown in the overview of the damage models in Appendix A. To summarise, as expected, the most prevalent damage models are for direct tangible damages, for buildings, infrastructure, transport, business, farming etc. All three countries perform some depth-dependent damage calculations, but all differently, and there are several categories, for which not all countries have made flood damage calculations. However, some indirect damage is included in the economic analyses. Norway, for instance, has included an estimate for indirect damage as a percentage of the tangible damage, while Finland has included it in some specific models and Denmark only in the business model. Denmark on the other hand, has made a simple analysis of houses affected by flooded critical infrastructure, also covering houses outside the flooded area. Norway has included critical infrastructure for electricity supply network in the economic infrastructure damage calculations as the only country, and both Norway and Finland have calculated flood related additional travel costs and costs for cleaning of houses in their work. Norway has also included intangible damage in the cost-benefit analysis using a score, whereas Denmark and Finland have presented them on maps.

As the only country, Norway has made economic calculations for people affected by flood, using the statistical value of a human life as the input along with a building vulnerability factor. This is very different from the approaches in both Denmark and Finland that only show the number of people affected by flood, but do not include them in a specific damage calculation.

The method for the analysis also differ between the countries. Denmark has performed all the damage assessments in grid cells and presents the results in the cells, making it possible to see how the risk varies in the project areas. On the other hand, doing all the calculation in cells also means that some uncertainties has been inflated, if e.g. only a portion of the cell is flooded but the damage is deteremined for the whole cell. Both Norway and Finland, on the other hand, perform the damage calculation for specific objects, but get a result for the project area as a whole, without being able to show variations in damages or risk within the area.

Finland has, as the only country, calculated the potential future flood risk including, not only the effect of climate change, but also the possible effect of socio-economic development. Finland has done this combining three SSPs with three RCPs for six different scenarios, and performed the analysis for whole APSRFs. However, the main purpose of the Norwegian method described in section 4.1 was not to determine future flood risk, so it is not fair to judge their methodology by this standard.

Looking at the non-tangible risk analyses, Denmark has performed an index-based risk assessment and Norway has performed a comprehensive risk analysis. These two methods are very different, but the scope of them have also been significantly different. The scope of the Danish index-based assessment was to do a national assessment, including both tangible and intangible values in one analysis to identify APSFRs and show variations in the flood risk both nationally and more locally. The challenge with an assessment like this is to compare consequences across several categories – Are they equally important? If not, how should they be weighted? Denmark chose not to weight between the categories, thus making them all be equally important in the flood risk assessment. This was done based on an EU-project[15], but it is unknown wheter this mirror the “actual” risk or the prioritization of stakeholders, politicians or citizens, if they were involved in the process. And if stakeholders are involved, the result will depend greatly on the method used for and extent of the stakeholder engagement.

Regarding the Norwegian comprehensive risk- and vulnerability analysis, the scope of the national analysis was to get an overview of risks and vulnerabilities in society across several sectors, including how events may develop in order to prepare for catastrophies. The purpose of the guidance document is to help municipalities do the same. Though the overall purpose of this analysis is similar to the former mentioned analyses, to prepare for and reduce flood risk, the method is completely different. Where the other analyses are quantitative, using statistical data of hazards, number of vulnerable objects, damage models etc., this method is qualitative. The purpose was not to measure the risk, but to develop scenarios for probable but unwanted events with catastrophic consequences for society across sectors, in order to describe how they develop and thus define risk reducing measures. The main concept is the cross-sectoral collaboration developing the scenarios. However, though it is a qualitative method, the involved experts still have to estimate the extent of the consequences and the probability of the conseqences, so it is possible to compare the consequences and risk across sectors.

As briefly mentioned in section 4.2.1, in their report, DSB prioritizes a description of their choise of analysis-method, arguing that even objective quantitative risk analyses are performed by someone and are therefore, to some extent, subjective. And as the purpose of their analyses is to understand complex events, a multidisciplinary approach is essential, as the events will impact across sectors and need cross-sectoral responses. Similarly, DSB also describes different types of uncertainties in their report and the differences between them to explain how some are method-depending while other are natural variations. None of the other reports or guides read as part of this review have explained methodological concepts or defended the methodolgical decisions in the same manner. Though it is only briefly described in chapter 2 of the national risk assessment (DSB, 2014a), it strengthens the work and makes it understandableto non-professionals.

[15] http://www.risckit.eu/

Recommendations for further development

As mentioned above and by Preston et al. (2011), before performing a vulnerability analysis, it is important to first set up a framework for the analysis to set the direction of the work. The same is true for defining where to improve or further develop vulnerability assessments, as it all depends on the purpose of the work. This is important to remember when reading the last part of this review, as it contains recommendations for further development within vulnerability assessements.

The recommendations are made based on my own experiences working with flood risk analyses and management, as well as from knowledge gained through literature. Some of the recommendations will be on increasing our knowledge but most of the recommendations will focus on how we perform vulnerability and risk assessments for risk management, as I am a practitioner and thus my main focus is to help manange flood risk and increase resilience, not on research.

Tangible damage models

As mentioned, tangible vulnerability analysis is the most widely investigated field, and thus it is easy to start there. Similarly, a tangible analysis may be used both locally and nationally, as it was in Denmark, and thus benefitting the risk analyses on several levels. However, performing damage calculations on different scales depend on the data availability and the models.

With this in mind, one first simple task for improving vulnerability analyses could be to go through the tangible damage models to identify which could be added and which could do with an update. Beside using this review for inspiration, many countries have developed damage models, which could be reviewed for inspiration, as well. For example, all EU member states are required to perform some sort of flood risk analysis as part of the Floods Directive. However, it is important to remember that it is not necessarily possible to use a damage model developed for one country in another (Merz, et al., 2010). Additionally, Merz et al. (2010) also mentions that damage models should be quality controlled, which is not the case for all models, hence they can be quite misleading. Several studies and projects have worked with flood risk and damage assessments, e.g. FLOODsite[16], but Merz et al. (2010) give a quick overview of potential tangible damage models for inspiration.

Intangible consequences

Beside improving/updating the tangible damage models, one other important aspect is to improve the intangible and indirect consequence analyses. I cannot say, if there is a better way to do this, as it will depend on the scope and frame of the analysis and preferences within the specific organisation or country. But including intangible and indirect consequences may change the geographical distribtution of the risk in an area compared to an all tangible assessment. And similar including intangible and/or indirect consequences of flooding and managing measures may result in a different cost-benefit or multi criteria analysis doing risk management compared to an all economic analysis.

It may be that risk assessments can be performed including both tangible and intangible consequences in the same integrated risk map, as DCA has done for Denmark (KDI, 2018), but such integrated risk analyses may also need further research and broader cross-sectoral analyses, for instance by doing a multidisciplinary proces as Norway has done for the comprehensive risk assessment (DSB, 2014a).

Going through literature, analysing intangible vulnerabilities has been performed using one of two methods. Either by economising the intangible values e.g. as done by Brouwer & van Ek (2004) for decision-support and by Norway in the cost-benefit tool (NVE, 2021), or by indexing the intangible values e.g. as done by Holand et al. (2011), Kazmierczak (2015), Martínez-Gomariz et al. (2019) and Tascón-González et al. (2020).

Resilience and vulnerability

One of my experiences working with flood risk management over the recent years is the increasing focus on multi-layered safety, dynamic adaptation planning and resilience. Though different concepts, they have one thing in common, namely that in many cases it is not the best and only solution to reduce flood risk only by

[16] https://www.floodsite.net/default.htm

protecting ourselves against flooding. We cannot prevent flooding completely, as more extremes will happen and we must expect floods to increase in frequency and size due to climate change. Therefore, we have to adjust our societies to floods and be flexible in our planning, as we cannot predict the future. This is supported by some of the literature reviewed as part of this study e.g. Aven (2011), Joakim et al. (2015), Hegger et al. (2016), and Jurgilevich (2021).

There is a strong connection between flood risk management, flood-related climate adaptation, vulnerability analysis and resilience (Aven, (2011), Joakim et al. (2015), Hegger et al. (2016), Jurgilevich (2021). Thus, connections between how we manage the risk and how we assess it are important. We cannot evaluate the effect of our measures, if, for instance, they focus on increasing social resilience and we only measure the risk through tangible consequences. Likewise, in order to increase e.g. social resilience towards flooding, we need to know more about how society and people react to flooding, as well as how social vulnerabilities vary in society and the reasons behind them.

There are lots of literature on both resilience and social vulnerability[17] and as practitioners it is our task to include that in our risk analyses and risk management. By applying a broad and cross-sectoral approach for both flood risk assessments and flood risk management we are more likely to reduce the flood risk and increase resilience.

This is not to neglect the quantitative and tangible risk assessments, as they are important for risk understanding and risk management. This is just to point out the importance of both aspects of risk assessments and risk management, as they are equally important.

If the purpose of an assessment is to get an overview of a larger area, e.g. a country, and see how the risk varies across the country, perhaps to identify high-risk areas for further investigation, it may currently not be possible to do this as a qualitative cross-sectoral analysis, in which case the appropriate approach should be used for that. However, if the purpose of an analysis is to get more indepth information about a geographically smaller area for planning risk management or resilience increasing measures, a comprehensive multidisciplinary analysis might improve the quality of the decision-making. This is why these methods are highly suited for such specific cases. This could be done using several different methodologies, for instance

(1) the Dynamic planning approach as used by Danicsh DCA in collaboration with two municipalities (DCA, 2020a & 2020b),
(2) the comprehensive risk and vulnerability analysis as used and recommended by Norwegian DSB (DSB, 2014a & b), or
(3) by using the Resilience Matrix approach as described by Linkov et al. (2013) and used on a case in USA (Fox-Lent, et al., 2015) and by Finnish SYKE for reservoir operations (Mustajoki & Marttunen, 2019).

Of course, the choise of method should reflect the scope of the analysis. As Preston et al. (2011) write, it is important to know the scope of the analysis in order to define which aspects need further investigation.

Changes in vulnerability

In conclusion, including work on how society, vulnerability and risk may or can change in the future is important for risk management. Not only changes in risk due to climate change but also changes in vulnerabilites. This part is two-fold, as projecting vulnerability, damage and risk by scenarios is one option and working with scenarios of how we should develop the vulnerability is another, each with different benefits.

If changes in vulnerability are not included in the risk analyses, using the SSPs in future risk projections, as Finland does (Parjanne, et al., 2018), is a good starting point. This may increase the awareness and understanding of the importance of vulnerabilities in risk and risk development, as focus historically has been on the hazard (Merz, et al., 2010). The work on the SSPs and SSP-RCP connections continues, so more knowledge will be available in this area. Some new knowledge on SSP-RCP connections has been done since

[17] Only a portion is included in this work but is shown in the reference list

Finland performed their risk projections in 2018 as described by Hausfather (2018). This method will be effective for quantitaive risk analyses.

When there is a possibility to do a more indepth analysis, developing site-specific scenarios of how the vulnerability could change and how we can influence it, may improve decision-making and future risk management, as described by Jurgilevich (2021), and could be an interesting concept to try out together with local flood risk management authorities.

Final remarks

In the end, as practiotioners in the field of flood risk assessments and management we have to be pragmatic. It is our task to find the right balance between what would be interesting and scientifically exciting to analyse and examine more in depth, and what is truly necessary and makes a difference in managing the flood risk holsitically and in balance with (and hopefully to the benefit of) other interest such as environment, societal development, etc.

This includes focusing broadly on communication as part of the task. All the in depth knowledge in the world will make no difference, if we cannot communicate challenges and options and create discussions regarding flood risk. Thus investing in different communication methods, e.g. through comprehensive workshops, are equally important to improving both tangible and intangible vulnerability and risk assessments.

6 Abbreviations

APSFR	Areas of Potential Significant Flood Risk identified according to Article 5 in the Floods Directive
DCA / KDI	Danish Coastal Authority / Kystdirektoratet[18]
DSB	Norwegian Directorate for Civil Protection / Direktoratet for samfunnssikkerhet og beredskap[19]
EAD	Expected Annual Damage
FD	EU Floods Directive, Directive 2007/60/EC[20]
FHRM	Flood Hazard and Risk Maps according to Article 6 in the Floods Directive
GDP	Gross domestic product
IIASA	International Institute for Applied System Analysis[21]
IPCC	Intergovernmental Panel on Climate Change[22]
NVE	Norwegian Energy Regulatory Authority / Norges vassdrags- og energidirektorat[23]
PFRA	Preliminary Flood Risk Assessment according to Article 4 in the Floods Directive
RCP	Representative Concentration Pathways describing different possible developments of radiative forcing in the atmosphere
SSP	Shared Socioeconomic Pathways describing the possible development of different socioeconomic factors across the globe
SYKE	Finnish Environment Institute / Suomen ympäristökeskus[24]

[18] https://kyst.dk/
[19] https://www.dsb.no/
[20] https://eur-lex.europa.eu/eli/dir/2007/60/oj
[21] https://iiasa.ac.at/
[22] https://www.ipcc.ch/
[23] https://www.nve.no/
[24] https://www.syke.fi/

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Appendix A: Overview of damage models

Overview of the flood damage models used in Denmark, Finland, and Norway as described in Sections 2.2, 3, and 4.1.

Category	Denmark	Finland	Norway
Buildings	Depth-damage model from insurance pay-outs. House value as input.	Depth-damage model determining structural damage from square meter price of similar new building. Age- and region-adjustments can be made.	Depth-damage model depending on building type and material using standard area prices.
Movables	Percentage of building damage.	Depth-damage model depending on building damage.	Depth-damage model using standard movables prices per area flooded.
People affected	No economic calculations. Number of affected inhabitants shown.	No economic calculations. Number of affected inhabitants shown.	Determined on expected number of people in building, building vulnerability factor, and the statistical value of a life.
Business	Depth-damage model for three business categories and based on number of employees. Damage to movable and unmovable goods. Also includes cost of business interruption.	Not included	Included in building damage.
Infrastructure	Cleaning costs	Repair costs determined from a depth-damage model using construction costs as input	Factor of rebuilding costs for similar infrastructure depending on how vulnerable the infrastructure is to floods.
Additional travel cost	Not included	Calculated for cars and railway based on assumed extra distance, and number of flooded sections as well as travel costs, traffic volume and flood duration.	Distinguishes between passenger cars and heavy traffic. Calculated based on expected hours of closed road, additional travel time, car density and number of vehicles.
Vehicles	Not included	Depth-damage model including calculation of expected number of vehicles in flooded are and an average price. Effect of early warning included in damage calculations.	Calculated from average number of cars in flooded parking lots, average car value and a hazard-factor.
Public areas	Not included	Not included	Damage corresponding to rebuilding prices.
Agriculture	Assume winter flood by saltwater. Loss of crops and delayed spring crops.	Not included	Determined based on type of crops in two categories, damage to crops and total damage of agricultural land.
Life stock	Includes pigs and cattle. Assume loss of production and expenses for new life stock at certain water depths	Not included	Not included.
Rescue costs	Not included	Determined as a percentage of building damage with relative lower costs in populated areas compared to more rural areas.	A set percentage of material damage.
Cleaning, renovation, and rehousing	Not included	Cleaning of houses included in the building damage calculation. Based on the square meter price of building.	Cleaning a set price per house. Renovation/rebuilding and rehousing costs depend on building material and flood depth.
Critical infrastructure	Not economic calculations, but potential households affected determined	No economic calculations. Affected critical infrastructure shown in online map-service.	Electric network included in infrastructure damage calculations.
Indirect damage	Not specifically included but represented in e.g. business disruption	Not specifically included but represented in additional travel, cleaning of buildings, and rescue costs	Calculated as a percentage of tangible damage, distinguishing between dense areas and more rural areas.
Intangible damage	No economic calculations. Shown on map	No economic calculations. Shown on map.	Intangible damage can be determined using a point-system including range and effect. Additionally, the feeling of safety is included in the cost-benefit analysis.
Future costs	Determined only caused by changes in hazard	Determined for six scenarios combining climate change and socio-economic change scenarios. Future damage is calculated by projected change in population and GDP.	Not included, but costs are scenario based, so using the tool, calculations can be made for future scenarios.