The Interreg IVB North Sea Region Programme

SAWA

NVE

Preliminary Flood Risk Assessment in Norway

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REPORT

Preliminary Flood Risk Assessment in Norway

An example of a methodology based on a GIS-approach

Norwegian Water Resources and Energy Directorate
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Preliminary Flood Risk Assessment in Norway

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Abstract: A preliminary flood risk assessment can be carried out by making susceptibility maps that aim to identify potential high risk areas for more detailed hazard and risk mapping. This method is based on a GIS-analysis and simple hydrological parameters. By undertaking a simple consequence analysis and aggregating the results to areas with a significant risk, maps showing the potential spatial distribution of high risk areas can be created to aid the decision making process of pointing out the areas vulnerable to significant flood risk.

Key words: Susceptibility mapping, application of GIS, Flood Directive, PFRA, SAWA

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Preface

This report is a contribution to the Strategic Alliance for Integrated Water Management Actions (SAWA) project. SAWA is an EU Interreg IVB North Sea Regional Development project concerned with reducing the risk of flooding in vulnerable areas. An intermediate target of this project is to exchange experiences on how to meet the demands of the European Flood Directive (Directive 2007/60/EC). The purpose of the Flood Directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community.

The first step of the directive is to conduct a preliminary flood risk assessment in order to identify areas with potential significant flood risk. This report describes a method that is meant to be a tool for a first approximate estimate of areas of significant flood risk in Norway. Within the SAWA project, this task contributes to Work Package 1 – Adaptive Flood Risk Management, activity 1.8 (phase 2).

The method was developed by Ivar. O. Peereboom. Oddrun S. Waagø and Marianne Myhre have contributed to the report. All are employed at NVE.

Oslo, oktober 2011

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1 Introduction

According to the European Flood Directive, (article 4.1) all member states and members of the EEA Agreement are committed to undertake a preliminary flood risk assessment for all river basin districts. The nationwide preliminary flood risk assessment for Norway will be conducted by the Norwegian Water Resources and Energy Directorate (NVE). NVE is subordinate to the Ministry of Petroleum and Energy (OED) and is responsible for administration of the nation's water and energy resources. NVE plays a central role in preventing and mitigating damages from floods and other natural hazards. NVE has been given a central role in the implementation of the Flood Directive (FD) in Norway.

This report describes a method for conducting a preliminary flood risk assessment developed for use in Norway. It describes the methods benefits, disadvantages and uncertainties.

Most Norwegian river basins are relatively small by European standards, and the topography of Norway is mountainous in many areas. These two factors make it feasible to conduct a preliminary analysis of susceptibility to flood hazard based on topography and hydrology alone, thus postponing hydraulic analyses to subsequent, more detailed mapping.

1.1 Previous flood risk management in Norway

Norway experienced a widespread and damaging flood in 1995. An Official Norwegian Report (NoU 1996:16), followed by a government White Paper (no. 42 1996-1997 – Measures against floods) was produced as a result of this flood. The White Paper no. 42 has come to be regarded as a national action plan for Norway with respect to flood mitigation.

The White paper no. 42 led to a focus on land use planning as a measure for better flood risk management. The White paper states that *'the most important measure to reduce flood damage in the future is to improve land use planning in flood prone areas*'. In response to this, NVE developed guidelines for land use planning in areas at risk of flooding. The following assessments are now recommended for different aspects of planning:

- Municipal plan: potential hazard should be identified
- Zoning plan: the actual hazard should be described and the risk quantified
- Building case: a satisfactory level of safety must be documented

To support municipalities in implementing these guidelines, detailed flood inundation maps have been produced for more than 150 areas with the highest assumed flood risk. The prioritizing of the mapped areas is based on suggestions from municipalities, expert judgement combined with recordings of historical damaging floods.

The detailed flood inundation maps show inundated areas for floods with different return periods. The discharge for different return periods is calculated by means of frequency analysis based on data from existing stream flow gauging stations. Water levels are subsequently calculated by means of hydraulic modelling. Historical knowledge from e.g. water lines is used to calibrate the models. GIS is used to calculate the flood extent. The flood inundation maps provide detailed information to be used in both land use planning, applications for building permits and prioritizing protection measures. In other words, the flood inundation maps meet the requirements for flood hazard maps (art. 6) in the Flood Directive.

1.2 Requirements of the Flood Directive

According to the Flood Directive, a preliminary flood risk assessment should be based on available or readily derivable information and include climate change impacts on flood occurrences. The assessment shall, according to article 4 paragraph 2, include at least:

- Maps of the river basin district at the appropriate scale including the borders of the river basins, sub-basin and, where existing, coastal areas, showing topography and land use.
- A description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity and for which the likelihood of similar future events is still relevant, including their flood extent and conveyance routes and an assessment of the adverse impacts they have entailed;
- A description of the significant floods which have occurred in the past, where significant adverse consequences of similar future events might be envisaged.

Depending on the specific need of the member state, more information can be included according to article 4.2.d. For international basins, the necessary information should be exchanged between the countries. The preliminary flood risk assessment should be completed by the 22nd of December 2011.

1.3 Relevant conditions in Norway

In addition to being a very mountainous country with rather small river basins, Norway is sparsely populated. Making flood inundation maps covering all the flood prone areas regardless of population density will be both time and money consuming without giving much benefit. To identify a useful threshold of significant potential flood risk will therefore be of interest.

Another characteristic is that a great number of the rivers and creeks are regulated for hydro power purposes. Regulation often decreases the occurrence of floods up to a certain volume. Taking into account that observations of floods cover only the last 50-150 hundred years and that land use along many rivers has turned from agriculture to developed areas more vulnerable to water, floods exceeding the regulation storage capacity may cause damages in areas that previously were unaffected. These factors suggest that historical floods alone will not be a good indicator for assessing future flood risks. We therefore decided to approach the task by a more predictive model.

2 Components of a preliminary flood risk assessment

2.1 Preliminary risk methodology

For this preliminary risk assessment we consider the potential maximum risk, which is represented by the worst case scenario leading to maximum negative consequences. Risk normally combines the probability of an event and the consequences of it, i.e. probability multiplied by consequence. In this worst case scenario approach, the probability is considered to be the same everywhere, independent of spatial location. It is therefore removed from the equation. The potential risk is evaluated directly as a function of the consequences of an event.

The basic principle behind a preliminary risk assessment is that areas with the highest potential consequence need to be identified so that measures taken to prevent and mitigate the risk are of most benefit. This is in contrast to a standard risk analysis, where probability plays an important role in assessing risk.

The disadvantage of not taking the probability into consideration is that two incidents with the same consequence would be judged as having the same risk, even if one incident statistically happens every year, while the other incident happens every 100th year. This means that this assessment will not consider floods with small impacts happening often.

2.2 Criteria for a preliminary risk assessment method

The method used in the preliminary risk assessment should ideally fulfil the following criteria:

- Be simple
- Be reusable
- Be scalable
- Be spatial

These premises are mostly set because the method should be convertible to be used for mapping of other natural hazard

Simplicity is requested in order to minimise the costs, taking into account that more detailed (and expensive) hazard and risk mapping should only be worked out for prioritized areas with significant potential risk. The method should be simple enough for both decision makers and stakeholders to be able to understand the method with its weaknesses and limitations and to verify the method and thus take the most appropriate actions.

The method should be reusable and applicable for creating different susceptibility maps, so as to maximise the benefit from the effort invested in creating the tool. This will also ensure the use of similar procedures for different natural hazards and thereby contribute to a better understanding of such methods for decision makers and people living in the areas prone to natural hazards.

The method should also be scalable in order to make it easier to change the weighting of consequences to produce various risk scenarios. The effect of various types of natural hazards can differ, and thus the perceived risk will also differ depending on the hazard analyzed. The majority of river floods leading to inundation in Norway can be anticipated hours or days in advance, so that people usually are warned in advance (for example through the national flood warning service). Consequently, river floods in Norway very rarely results in fatalities. This is in contrast with, for example, snow avalanches, which occur very rapidly and are more difficult to anticipate. This is also the case for flash floods and debris flows. Such differences may result in the use of different threshold values to quantify risk for different hazards.

Risk areas or areas for which events produce potentially large consequences should be spatially delineated. The boundaries of these areas should be based on the potential consequences and not on administrative borders (for example, municipal boundaries). For example, if spatial statistics describing the consequences of an event are summarised or averaged on a municipal-wide basis, the results may give a false impression as to the actual consequences for those affected by an event.

2.3 Flood types

The preliminary flood risk assessment should take all relevant flood types into consideration, and estimate the risk for the indicators regarded as relevant. In Norway, four flood types are considered relevant for significant flood risk:

- Fluvial floods (river floods)
- Flash flood (for example, rapid flooding possibly occurring outside of the established river channel network)
- Storm water flood (urban floods)
- Storm surge and increase in sea level.

In this preliminary flood risk assessment for Norway, floods in rivers and storm surge are included in the quantitative assessment. The effects of climate change are included implicitly as the overestimation of the model covers the expected increase in discharge from the climate change. For most rivers that drain large catchments, it is expected that future floods will decrease in size and frequency, partly because of expected decrease in snowfall and increased temperature leading to decreased snow cover.

Smaller watercourses will be more vulnerable for floods due to local rain events, which are expected to be more frequent in the future. These events are also associated with sediment transport. In steep catchments both flash floods and debris floods are dangerous. These flood types are included in the assessment, but for many catchments, especially the steep ones, the water level and its conveyance route in a flood situation is difficult to foresee, and consequently the predicted water covered area would be inaccurate.

Storm water floods are not included due to their limited extent and volume and the difficulties associated with mapping this hazard at a national scale. There is also a lack of available and readily derivable information for this flood type. Nevertheless, small scale storm water floods appear occasionally in many different areas each year causing damage. A single event would not be worth mentioning, but the total cost over years would be significant. Floods from sewerage systems (waste water) will be excluded from the Norwegian preliminary flood risk assessment, as is allowed under article 2.1 of the Flood Directive.

While storm surges are included in the model, the expected sea level rise due to climate change is not.

2.4 Risk indicators

According to the Flood Directive, "*a description of floods which have occurred in the past and which have led to significant adverse impacts on human health, the environment, cultural heritage and economic activity*" should be included in the preliminary flood risk assessment. Where the probability for similar future events is still relevant flood extent, conveyance routes and an assessment of the adverse impacts they have entailed should be described. An assessment of potential adverse consequences for future floods could be included if needed.

The GIS-method described in this report use a set of risk indicators to assess adverse consequences. These risk indicators must in some way be measurable so they can be used to identify risk areas. The parameters and their corresponding datasets that are used to assess the consequences for the receptor groups are described in the following sections.

2.4.1 Human health

With respect to the risk to human health, different factors could be included. In addition to the cost associated with the loss of human lives, the effects on physical, psychological and emotional health can be taken into account.

A possible way to quantify the risk to human health using already accessible data is to estimate the number of people resident at a site potentially subject to flooding. The use of a population density raster with a minimum cell size of 250*250 m was rejected as an option, as the topography raster is 25*25 m and information on inhabitants is required at a similar spatial resolution. The national database of Statistics Norway contains address points with the number of inhabitants per address and is used to provide data covering residential buildings.

To include the fact that people are not at home all the time, but spend much of their day at work, schools, hospitals, sport facilities and at other locations, other building types than homes are included in the risk assessment as well. The national building database is used for this purpose. The database contains point locations of all buildings classified into different building types. For each type, the number of people which may be present at these locations is estimated. The estimates are presented in Table 1. In reality the 150 separate building types were classified, this table can be viewed in appendix A. Table 1 shows the building groups.

Table 1: Estimated number of people present in different types of buildings. The table with the complete classification can be found in appendix 6 A.

BUILDING GROUP	GROUPNAME	CRITICAL INFRA WEIGTH
0	Other	0
1	House (Residence)*	0
2	Cabin	1
3	Industrial	10
4	Agricultural	0
5	Barn / Silo	0
6	Power supply	0
7	Communication	0
8	Healthcare	200
9	Civil protection	20
10	Sports facilities and assembly buildings	20
11	School and Daycare	200
12	Tourist center	20
13	Public transport	10

*Residential houses should not be weighed in this table because they are already included by using the database of address points).

The point dataset with the number of people per address and the one with the number of people present at critical infrastructure sites are converted to raster (similar to the susceptibility maps as described in chapter 3), and the number of people per cell is calculated. When these data are combined with the susceptibility maps, both the location and the number of people potentially at risk can be estimated.

The suggested weighting is not final and may be changed. Sensitivity analyses by changing weights, and thereafter assess the different results, will be useful in order to get the most likely results.

2.4.2 Economic activity

Assessing the economic consequences of a natural hazard can potentially entail a complex and extensive analysis. There are many economic parameters that can be considered, such as the immediate damages to properties, loss of production time or lost earnings because of downtime of communication systems, for example. However, the preliminary risk analysis should be based on available or readily derivable information, which limits the options available for an analysis at a national scale.

In this method we have used the national building database to estimate the economic value of residential dwellings and other buildings. A previous study of flood damages (Sælthun et al, 1999) indicates an average loss of 124.000 NOK per meter flood water level for residential buildings. This amount is increased by 3.1 to take into account the current property values (SSB, 2009), which gives an estimate of 400.000 NOK per meter flood water level. This is chosen as a benchmark and other building types are assigned damages based on the classification of building types from the national building database (GAB, 2009). The values of the different building groups are then assigned relative weightings, as given in Table 2. The economic value is based on damages due to a flood event and not on the actual economic value of a property. The damages to a house are considered to be the same as the damages done to an apartment block which means that the economic value of an apartment block is considered to be the same as the value of a house. This will lead to underestimating the damages since more households are affected in an apartment block than in a house. We lack however information on the layout of an apartment block (amount of apartments per floor) to do a proper correction.

Table 2: Weighted economic value of the residential dwellings and other buildings.

BUILDING GROUP	GROUPNAME	ECONOMIC WEIGHT
0	Other	0,1
1	House	1
2	Cabin	0,2
3	Industrial	2
4	Agricultural	1,5
5	Barn / Silo	0,5
6	Power supply	0,5
7	Communication	0,5
8	Healthcare	5
9	Civil Protection	5
10	Society	2
11	School and Daycare	5
12	Touristic	1,5
13	Public transport	0,3

The total cost of repairing and replacing infrastructure following a flood is also considered. From the same study (Sælthun et al, 1999), costs for damages to infrastructure came to 360000 NOK per km for a four-lane road. This was indexed by 1.36 (SSB, 2009) and then rounded to 480.000 NOK. For a single lane, the cost within a 25 m cell then comes to 500.000 / 4/ 40 = 3000 NOK. To differentiate between the costs of various types of roads, different cost factors are assigned to road types (Table 3), such that the 3000 NOK is multiplied by the cost factor for a given road type.

Table 3: Roads in Norway differentiated according to the type of road.

Road code	Road type	Cost factor
E	**European road**	**5**
R	**State road**	**4**
F	**County road**	**3**
K	**Municipal road**	**2**
P	**Private road**	**1**

The values describing damages are chosen for the purpose of summarising the consequences to both buildings and infrastructure, and are a useful simplification of a much more complex reality. For the purposes of a preliminary risk assessment, it is more important to see the spatial distribution of the economic consequences than it is to estimate the actual damages in detail. If the same criteria are used everywhere in the analysis, the spatial distribution of risk will be the same, independent of the actual numerical values underlying the analysis.

2.4.3 The environment

The environment is one of the factors for which the adverse consequences of flooding should be minimised. For the preliminary flood risk assessment, it is assumed that the level of threat to the environment is not significant at this mapping scale. Such risks, however, will be considered in more detailed mapping and in the flood risk management plan. For example, one of the most important measures is to locate structures with potential pollution risk outside flood inundation areas. Additionally, measures to reduce flood risk as described in flood risk management plans should not interfere with the aims of the Water Framework Directive. These sets of measures are more appropriately handled at the more detailed mapping and planning stages.

2.4.4 Cultural heritage

As for the environment, cultural heritage is not a factor that points out sites of significant flood risk during the preliminary flood risk mapping phase. Cultural heritage sites that are of significant value will be identified in the more detailed flood hazard and flood risk maps.

3 Preliminary flood risk assessment

3.1 Methodology for flood susceptibility mapping

Norway has a large number of rivers and lakes. Because of the mountainous landscape and the long coastline, many of the rivers are streams with small upstream catchments, with torrents in the steepest areas. The larger rivers tend to be located in deep valleys where the active flood plain can cover the entire bottom of the valley.

The total area of Norway is 324,220 km², and the estimated number of lakes and watercourse lengths, based on the 1:50000 topographic maps from the Norwegian Mapping Authority, are as follows:

Lakes: 968 444

Lakes larger than 2500 m^2: 250 000 (covering 17869 km^2).

Length of rivers and streams: 410 000 km

Given this amount of data, modeling the watercourses in a traditional manner (for example, with the use of hydraulic models) is not feasible for a PFRA. To meet the demands for a method based on easily accessible information we have developed a simplified GIS based method for flood susceptibility mapping.

In the preparation of the susceptibility mapping a statistical analysis of hydrologic data is conducted using data from more than 300 gauging stations from the national hydrologic database (HYDRA) and data from more than 125 detailed flood map projects. The method is based on the assumption that the water level can be derived without the use of detailed hydrological or hydraulic calculations. For approximately 150 river stretches in Norway hydraulic calculations have been made to produce detailed flood inundation maps. The rise of water levels from 125 of these rivers is correlated with discharge and catchment characteristics. For gauging stations outside of the flood inundation map areas, rise in water level can be established based on flood frequency analysis and the discharge rating curve.

A precondition is to use relative simple parameters that can be used for different kinds of rivers, both small and big, steep and flat, etc. Different catchment characteristics e.g. the area of lakes in the catchment and discharge are considered, but to keep the assessment simple, the catchment size is chosen as the only parameter to estimate maximum water level. Regression analyses are done with rise in water level for a 500 year flood, both at gauging stations and river stretches with flood inundation maps. In Figure 1 the catchment size is plotted against the maximum water level showing the correlation between these two parameters.

The results show a moderate relation with a R^2 value between 0,3 and 0,5. The regression residual is between 2 and 4 m, depending on catchment area. About the same values are found when using the rise in water level from both gauging stations and flood inundation maps.

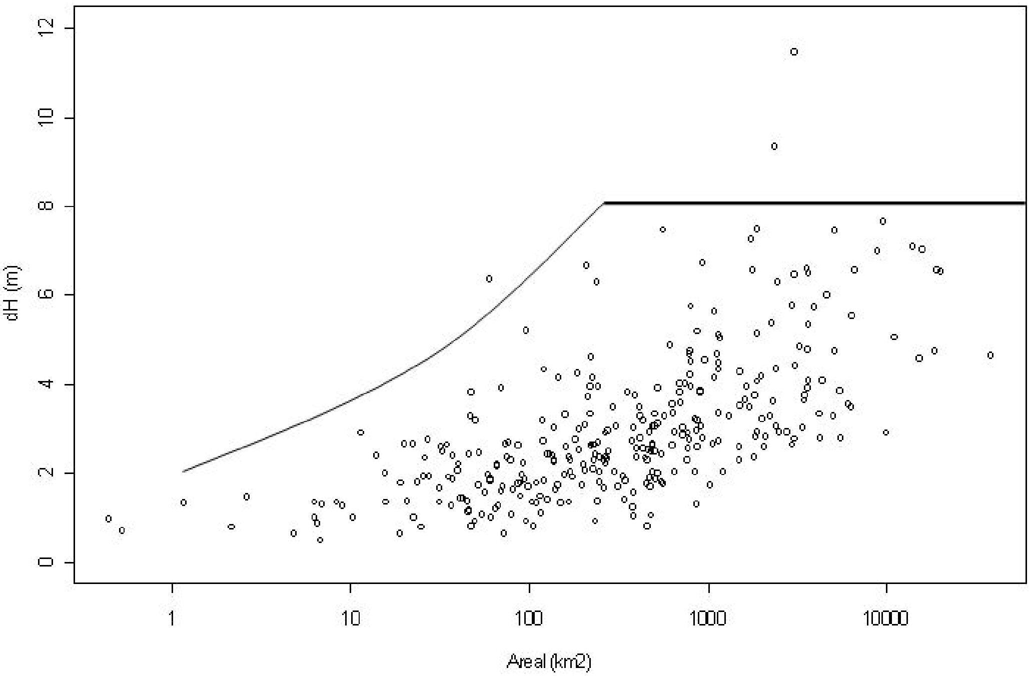

Figure 1: Correlation between maximum water rise and catchment area

A regression formula that covers 98% of all events is set up. This will of course give a general overestimation of maximum water level rise. Considering the aim of the project this is regarded as an advantage rather than a disadvantage. For all catchment areas less than 1 km^2, the maximum water level rise is set to 2 m, and for catchments larger than 500 km^2, maximum water level rise is set to 8 m. For the catchments larger than 1 km^2 but smaller than 500 km^2, maximum water level rise (dH) is given in equation 1:

$$dH = 0{,}965\ ln(Area) + 2 \qquad (1)$$

By using this equation, maximum water level rise is estimated for catchments lacking hydrological data.

Within GIS the catchment areas for all raster cells in the Digital Terrain Model (DTM 25 * 25m) are calculated. Smaller rivers in steep terrain vulnerable to flash floods will not necessarily be identified using the national DTM. All rivers and streams from the national river network database are therefore added to the DTM to create a hydraulically-corrected DTM. The statistical relation is then applied to calculate maximum water level rise for raster cells in the DTM that represent water courses. To calculate the flood level the maximum water level rise is added to the water levels, these are simply derived from the DTM. For all catchments the flood levels are calculated using a special technique, where cross sections are simulated by calculating a runoff pattern on a virtual terrain model based on the buffer distance along the river. Inundated areas are calculated by overlaying the flood level plane with the DTM.

Using this method, flood susceptibility areas are calculated for all river reaches with a catchment larger than 1 km^2. To include floods from the sea, flood susceptibility areas are also calculated along the coast for storm surge levels with a 1000 year return period. The national mapping authority, coastal department provided long term sea water level measurements from 22 gauging stations along the Norwegian coastline which are used in a frequency analysis to calculate storm surge levels at different return periods. They also provided the distribution of the tide in both space and time allowing us to calculate storm surge levels covering the whole Norwegian coastline.

Furthermore, a slope-dependent correction is used to prevent an overestimation of the flood plain, especially in steeper areas. By applying these techniques, flash floods are also considered to be included in this analysis. However, situations where a river changes its course during a flooding event through erosion cannot be predicted or identified using the topography-based analysis applied here.

The correlation between catchment area and maximum water level rise is quite poor. The equation chosen will overestimate the maximum water level rise in 98% of all cases. We assume that this overestimation will cover an increase in runoff due to climate change.

3.2 Preliminary risk analysis

Using the methods described in chapter 3.1, a preliminary risk can be calculated for each river reach. Due to the combination of overestimation of the method and the large number of river stretches in Norway, this assessment will result in large inundated areas, but most of these areas are scarcely or not populated. Because the aim is to identify areas with potential significant risk, the number of indicative inhabitants in each flood prone area must be found. We decided not to classify whole catchments or sub-catchments as having a potential significant risk, but rather to limit the areas as much as possible to the actual objects at risk. In order to find areas with potential significant risk the "Risk Square" method (Sane, 2007) is used.

Figure 2: Flood susceptibility (in grey) for Kirkenær. The grey areas indicate the possible flooded area in the worst case scenario.

In the risk square method, the consequences are first calculated at the most accurate spatial scale available (which depends on the input data used). For the Norwegian flood susceptibility maps (see figure 2) a raster of 25*25 m based on the national terrain model is used. The risk indicators are combined with the flood susceptibility map, and the result is an indication for every square where people are at risk of flooding. In figure 3 the home addresses (residences) and other buildings are marked in respectively black and red.

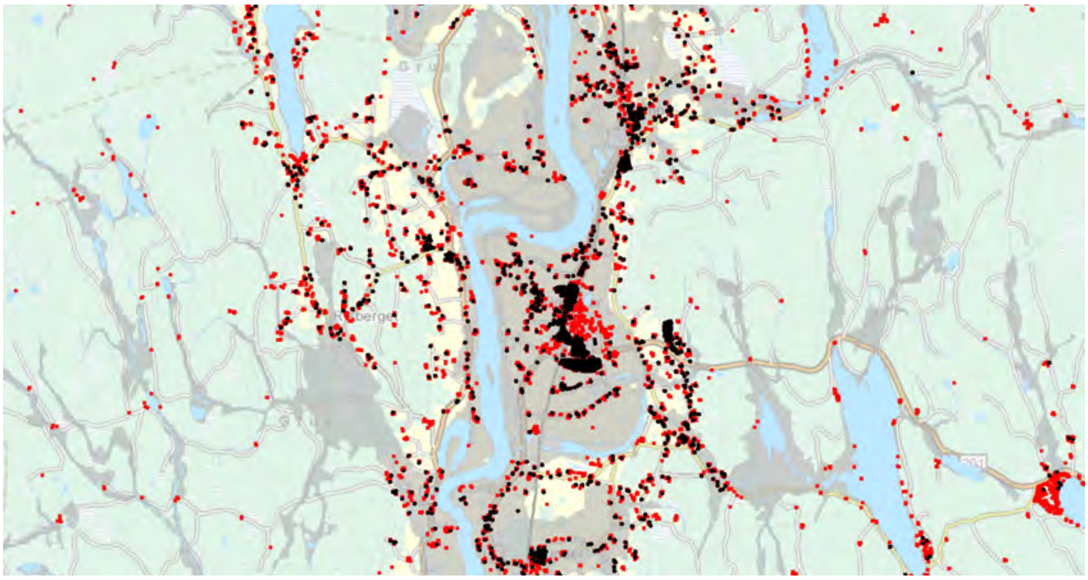

Figure 3: Flood susceptibility maps combined with addresses (black) and buildings (red) at 25 * 25 m at Kirkenær.

Scaling: Figure 3 shows each home address (residence) and other buildings affected by a possible flood. To smooth out the excessive detail obtained from an analysis based on individual buildings and addresses, the results are scaled up to a level appropriate for a regional assessment. The results are scaled up to cells of 250 * 250 m. The resulting effect is that "risk" cells at 250*250 m are now lying as connected neighbours, and these connected cells can easily be visually discriminated as areas.

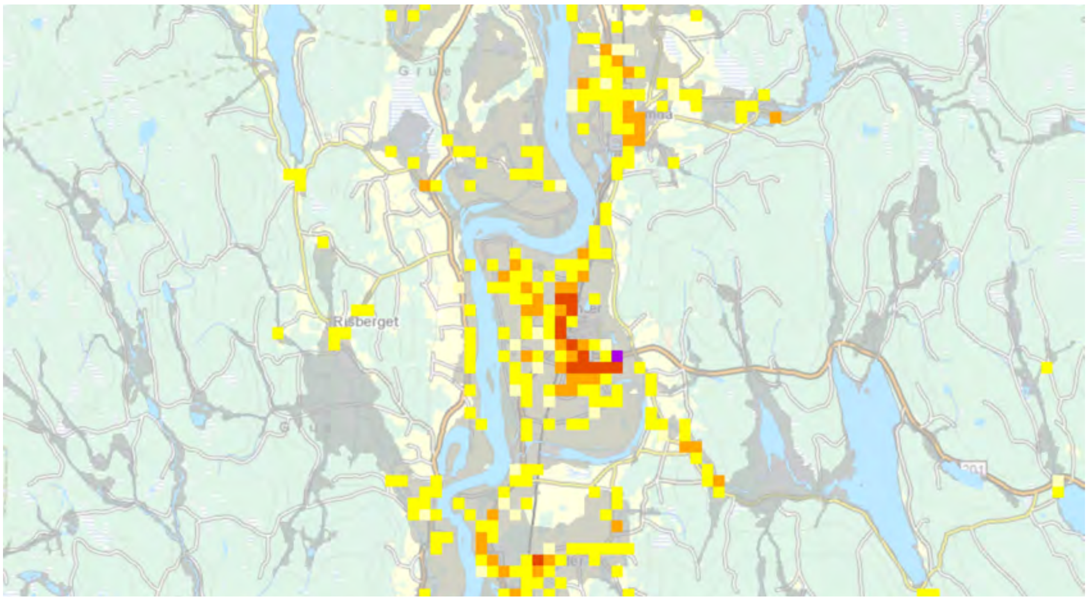

Figure 4: Risk classes (classified and scaled up)

Classifying: By classifying results into 5 classes (as shown in table 4) the level of detail is even further reduced, which makes it easier to interpret the results and to make decisions based on them. Different classifications and categories are used, which aids in the process of finding a threshold above which an area is considered to be at significant risk.

Table 4: Example of the thresholds between risk classes

Risk Class	Flood Inhabitants I	Flood Inhabitants II	Flood Inhabitants III
1	> 250	> 500	> 1000
2	51 – 250	100 – 500	250 – 1000
3	11 – 50	50 – 100	100 – 250
4	2 – 10	11 - 50	25 – 100
5	1	< 10	< 25

To identify areas of potential significant risk, three different risk maps are produced using the three different risk classes. The different maps are first used to visually pinpoint areas of "significant risk". The intervals of the number of affected people were classified with three different threshold numbers in each class. Figures 5 to 7 illustrate the effect of using different classifications for selecting areas of significant risk in the Lillestrøm area.

The different thresholds between risk classes can easily be seen on the map. Figure 5 shows the most sensitive threshold values corresponding to colonna I in table 4, where every person at risk will show as a cream-coloured square, two to ten persons will show as a yellow square, 11-50 as an orange square, 51-250 as a red square and 250 persons or more will be indicated by a purple square.

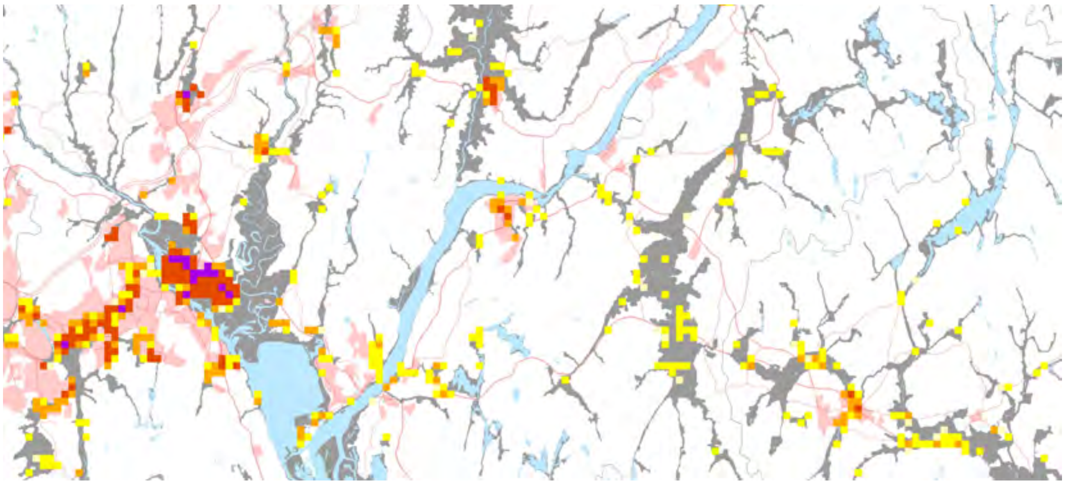

Figure 5: Risk areas with class intervals 1, 2-10, 11-50, 51-250, >250.

For a less detailed map, the threshold values were adjusted. Figure 6 corresponds to colonna II in table 4. Less than ten persons at risk will be indicated by cream-coloured squares, 11-50 by yellow squares, 51-100 by orange squares, 101-500 by red squares and more than 500 will be indicated by purple squares

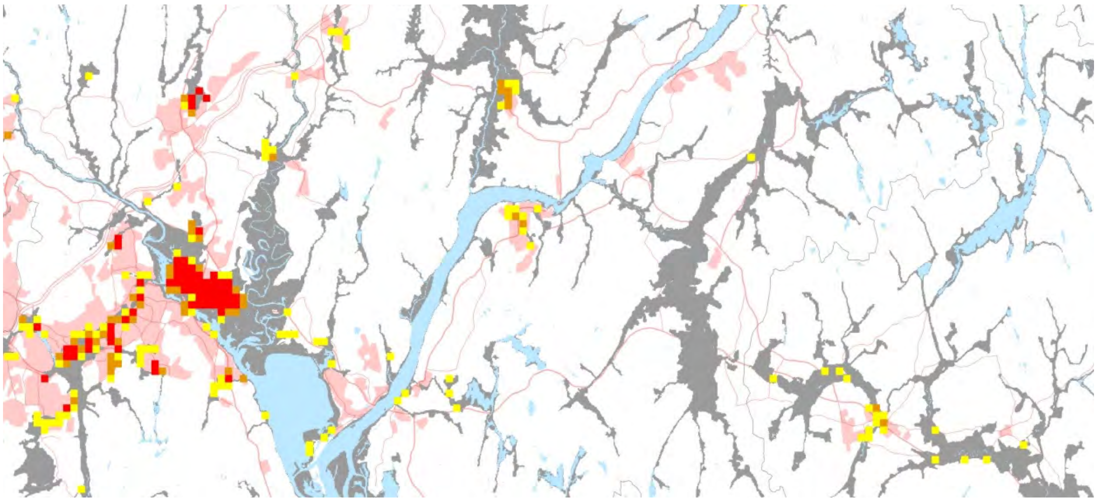

Figure 6: Risk areas with class intervals < 10, 11-50, 51-100, 101-500, >501

For a less detailed map, the threshold values were adjusted. In figure 7, squares has to contain more than 26 persons to be yellow, orange squares means 101-250 persons at risk, red squares means 250-1000 persons at risk, and more than 1000 persons at risk are indicated by a purple square. Figure 7 corresponds to colonna III in table 4.

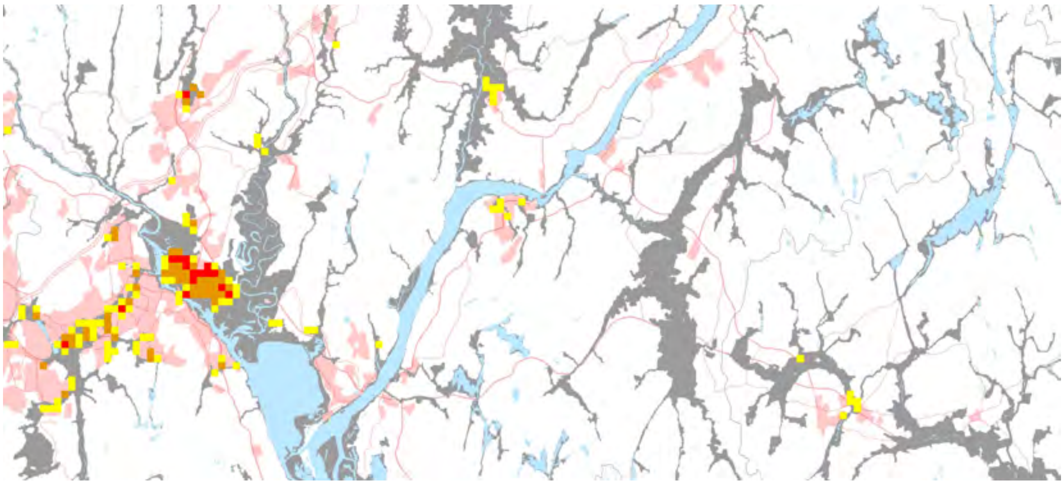

Figure 7: Risk areas with class intervals <25, 25-100, 100-250, 250-1000, >1000

Figure 7 appears more clean and structured than the more detailed figure 5 and 6, but it might be too sketchy and leave out too much information.

Scaling and classifying the results has various advantages. The values related to single addresses can not be seen, and privacy legislation will not be breached. The amount of data is decreased with a factor 100 which makes it easier to interpret. Furthermore spread values are being connected and thus creating areas in stead of a scatter pattern.

Aggregation: As shown above, the combination of scaling and classification of data can be used to visually determine areas of potential significant risk. Another way to identify areas with significant potential risk is to aggregate the up scaled risk cells by clustering neighbouring cells. The values of all the cells that connect are summarized thus creating risk areas, see figure 8.

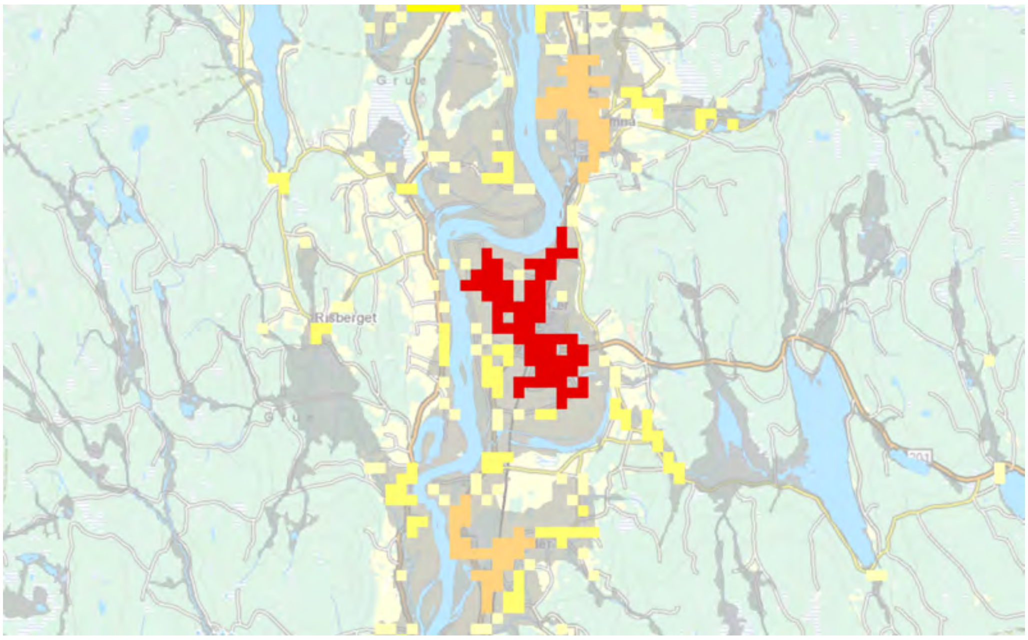

Figure 8: Aggregated risk areas, classified from low (yellow) to high (red) risk.

A significant advantage of this method is that statistics can be calculated for these risk areas, providing additional information for establishing criteria for identifying areas of significant flood risk.

The results from the GIS based Preliminary Risk Analysis are compared with the sketch map of the detailed flood maps produced within the Norwegian National Flood Mapping program. There is a clear correlation between the preliminary risk zones and the flood prone areas identified in the flood zone mapping project, illustrating that the susceptibility method is generally successful in identifying potential risk areas.

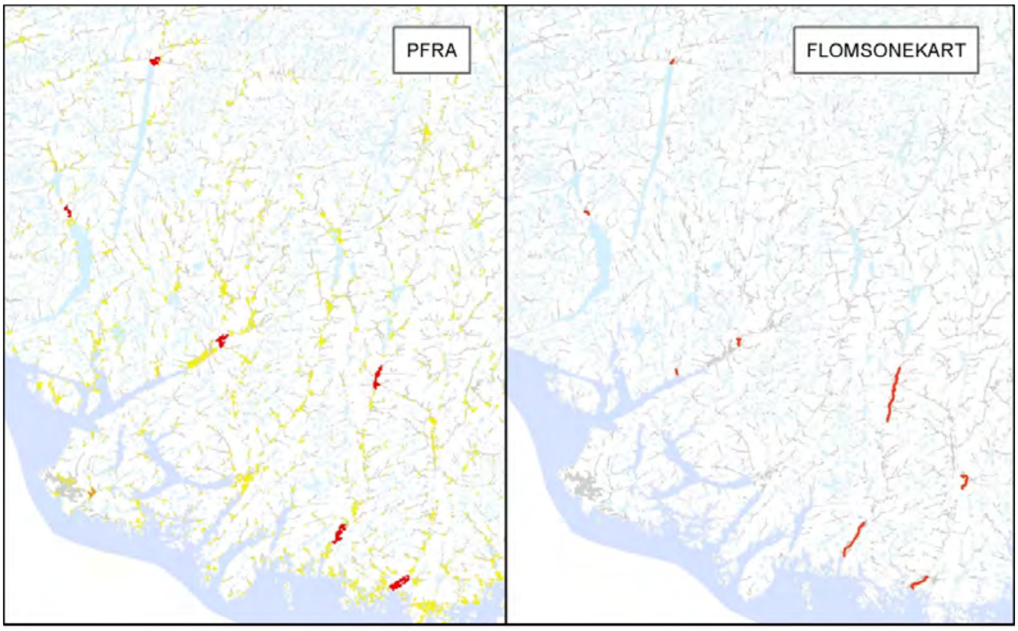

Figure 9: Results from the preliminary flood risk assessment compared to the flood mapping program. The map shows the south west part of Norway.

4 Results

4.1 Significant flood risk in sparsely populated countries

According to the Flood Directive each member state has the authority to define the level of significant risk. Due to geographical, topographical, meteorological and demographical differences flood risk and flood risk mitigation can vary between member states. Norway has neither large river systems nor densely populated floodplains as is often the case in central Europe. In parts of Norway, floods can happen within a few hours, and even though a flood will not affect many people, the situation can be very dangerous for those involved

With nearly five million inhabitants of which more than one million live in Norway's four major cities. The remaining four million are spread over an area of more than 324,000 km². The mountainous terrain is drained by 263 river catchments with a total length of rivers and streams of more than 400,000 km. Historically, settlements arose along rivers and lakes because of the favourable terrain for agriculture and accessibility, and many people still find it agreeable to live close to rivers and lakes.

4.2 Threshold for risk of significance

The flood directive comments that assessment, maps and plans should be based on best practice and that one should avoid excessive cost in the field of flood risk management. Because of the dispersed settlement in Norway, it is important to find a threshold that will include the highest risk areas that affects a large amount of people. For areas with minor risks it might be better to use funds and resources to take measures to mitigate flood risk directly rather than initiating a procedure of elaborate plans that cost both time and money.

The results from the GIS method show a very large number of potential flood risk areas. The number of inhabited flood prone areas is 6 777. The large number of areas is due to the way the risk areas are identified. An area at risk is formed more by the extent of the actual objects at risk than by the borders of the catchment, in order to limit the size of each area to obtain suitable unities for risk management planning. We underline that minimizing the areas at risk is not limiting any preventing or mitigating measures in other parts of the catchment areas, outside the limited risk areas.

Table 5 shows the statistics of different number of areas and the corresponding number of people living in risk areas, dependent of which threshold is chosen.

Table 5: Statistics for residential houses and other buildings.

Classification of indicative number of people	Number of risk areas	Cumulative number of people at risk	Cumulative % number of people at risk
<500	6 777	545 414	100
500	320	273 424	50
1 000	58	153 127	28
1 500	34	124 272	23
2 000	24	106 876	20
2 500	15	86 888	16
5 000	6	56321	11

Choosing a threshold of 1000 indicative persons will include more than a quarter of all people presumably at risk. There are however some uncertainties in the input data and the GIS method that should be addressed before defining a certain threshold in order to appoint the preliminary, significant flood risk areas.

For the other criteria (environment, culture heritage), we assume they will not reveal new risk areas, and thus there is no need to find an explicit threshold for them. The economic factor is assessed in a similar way as the risk of human health and the results shows a high correlation between the risk of damage to economical values and the risk of human health. Figure 10 shows an example of the correlation between the two risk indicators.

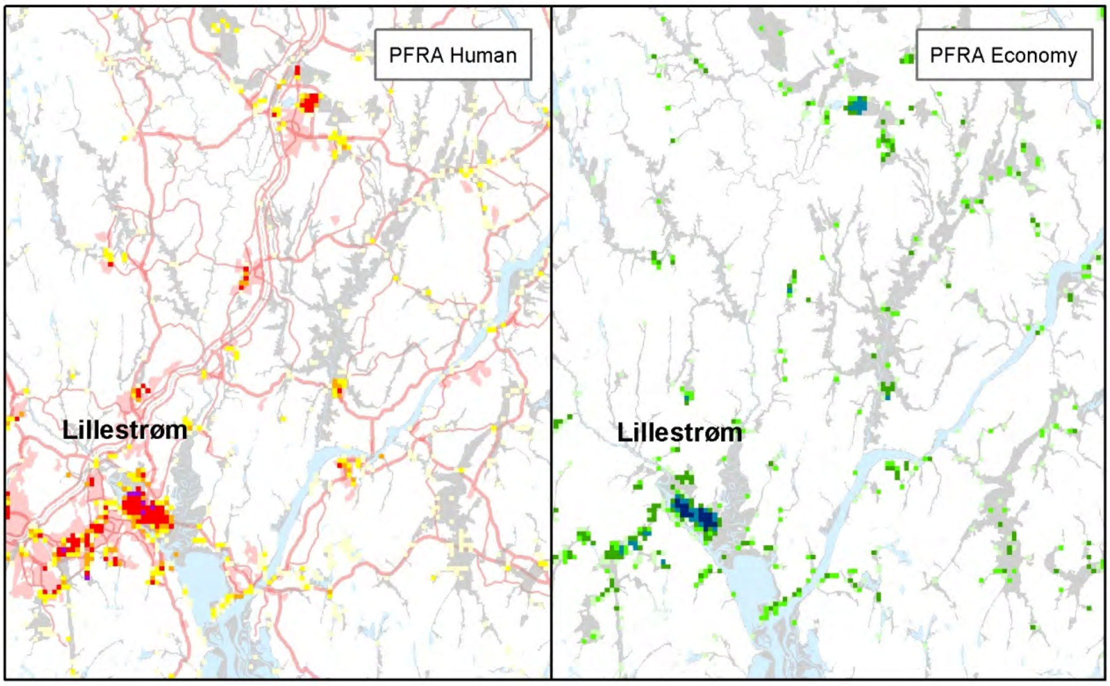

Figure 10: a) The area of Lillestrøm showing the possible risk of human health. b) The area of Lillestrøm showing the possible risk of economic values.

Because of the strong correlation between the risk areas to human health and the risk areas to economic factors, we propose not to take economic results into account, as the economic assessment is not expected to give any new information. By choosing a threshold of 1000 indicated individuals at risk, there will be 58 potential flood risk areas. The areas are distributed all over Norway (figure 11), though the flood risk areas are more concentrated in the south part at spots where the population density is high. The red spots are potentially affecting more people than the orange and the light orange spots.

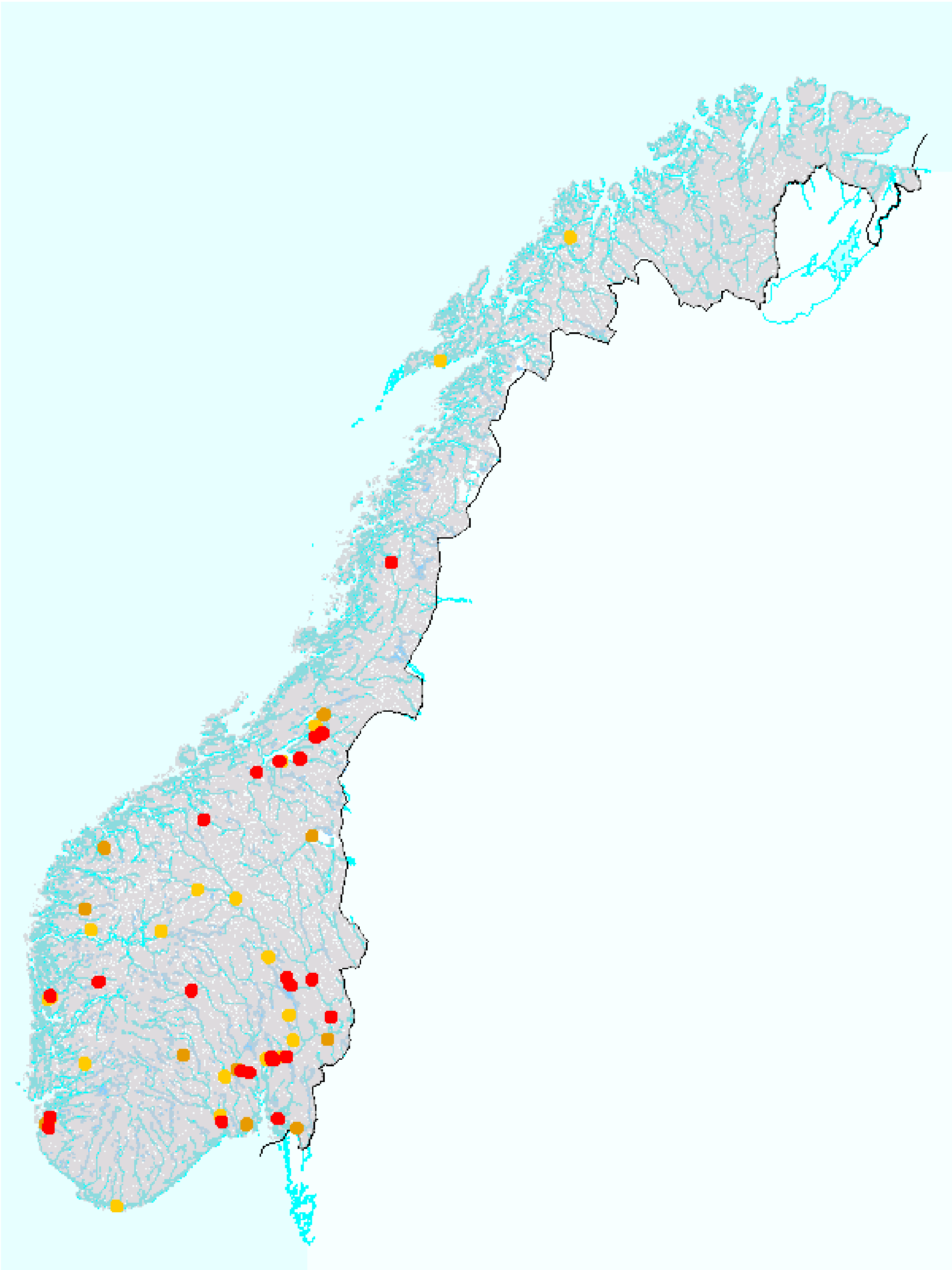

Figure 11: Possible flood risk spots before evaluating the uncertainties.

4.3 Uncertainties

Though the GIS-analysis gives an interesting overview of the potential flood risk in Norway, it seems to be some limitations. The overestimation of the potential rise of water levels (figure 1) can lead to possible flooded areas where inundation is not possible in reality. On the other hand areas actually exposed to flood can be left out, though this error occurs less frequently. To ensure that the method includes areas that actually are exposed to floods and exclude areas where flooding is impossible, it is necessary to judge the validity of the flood extension.

Uncertainties within the GIS tool can lead to the same overestimation of flood extension, as the DTM of 25 m * 25 m might be too coarse to represent the details needed for a useful preliminary flood risk assessment. An example is small creeks in deep canyons, where the modelled water will flow on a flat virtual plain with an infinite extent instead of finding the real waterway through the canyon.

For the flood prone areas where flood hazard maps have been produced, it is possible to compare these with our susceptibility maps for flood (see chapter 3.1). The susceptibility areas identified in the GIS-analysis seem to be coinciding with the same areas as investigated in the flood hazard map project (figure 9). The susceptibility maps are expected to show a larger flood extent than the flood hazard maps because the GIS-method shows extreme floods, with a return period higher than the return periods for the flood hazard maps. The flood hazard maps are also produced with a higher level of accuracy than the susceptibility maps.

For the area of Lillestrøm, a comparison between the susceptibility map and the flood hazard map shows some differences (figure 12 and appendix C). The susceptibility map seems to overestimate flood in the developed area. If this area is not actually at risk, even in an extreme flood event, the number of affected people is most likely highly overestimated. The map shows that there is also a potential for underestimating the flood risk in some areas.

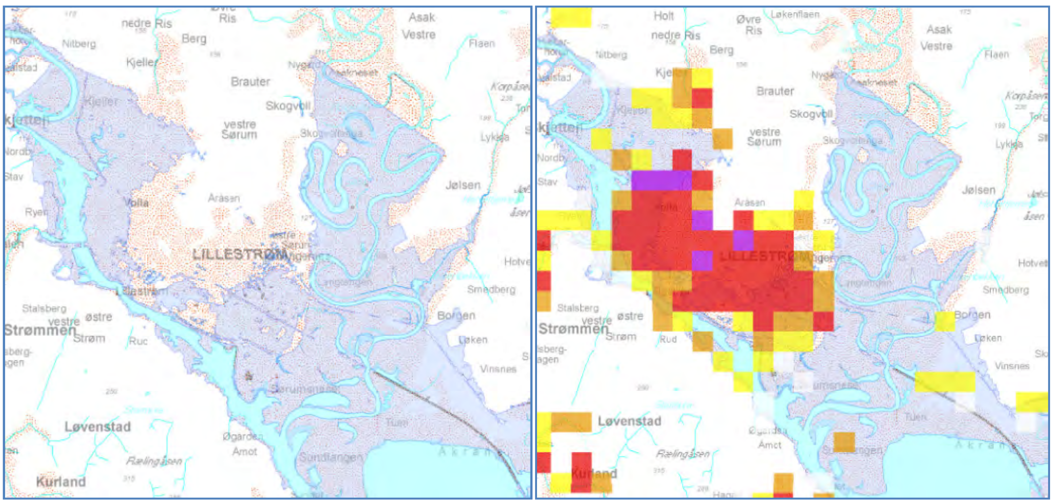

Figure 12: a) Flood susceptibility maps compared to flood hazard map for a 500 years flood. The flood hazard map is indicated by blue, and the susceptibility map is indicated by red dots. b) Flood susceptibility maps compared to flood hazard map for a 500 years flood included the indicated risk of human health

Apartment blocks could be a source of errors. Not necessarily all people living in an apartment block are in immediate danger during a flood. They are however affected and do certainly count when the building is being evacuated.

Another source of error is that the analysis depends on how many physical buildings an institution consists of. A school consisting of two buildings will be counted as having twice the risk of a school consisting of only one building, regardless of the actual number of people staying there. Many institutions are located near rivers and lakes, which could make this a serious error. This is a limitation of the program and the way the input data is represented

The input data is adjusted to meet the characteristics of river floods. The estimate of flooding in smaller rivers and areas where floods can happen very fast could be more correct by including more parameters, i.e. lake percentage, percentage of bare rock, swamp percentage, height above sea level, slope and distance to the coast. However, the terrain model used in this assessment is so coarse that improvement of other input data will not give better results unless the terrain model is improved. The most beneficial improvement would therefore be to use 10 * 10 m cells for the DTM instead of 25 * 25 m cells. When using a more fine-grained terrain model, it would most likely be beneficial to include more hydrological parameters.

The GIS-analysis can be improved by improving the quality of the input data. An alternative is to evaluate the results in order to improve the accuracy. In either way the results should be inspected, but the more inaccurate the input data used, the more a careful quality-control is needed. The presentation of the results from the method described here will therefore not be presented as finite results, as the purpose of the PFRA is to indicate potential risk areas.

4.4 Historical floods

The results from this GIS-method are compared with data from historical floods and damages. Some of the areas that have experienced damaging floods during the last century are not among top 25 of the highest risk areas found by the GIS-method, while for some areas pointed out by the GIS-method there are no records of damaging floods in the past. The reason for this is presumably that the areas where floods have happened in the past are less populated than the areas pointed out in the GIS-analysis. There could also be other explanations:

- The weighting of consequences in the GIS-analysis leaves out some areas where floods have happened in the past.
- The GIS-analysis does not summarize the people from different potential risk areas within the same river basin affected by the same flood event.

For approximately one third of the areas at highest risk pointed out in this analysis, NVE have not done any flood risk mapping because there has been no records of damaging floods in these areas. It is necessary to assess these areas more closely. Also areas where floods in the past have caused considerable damage should be included in the assessment.

5 Discussion

The results from the GIS-analysis could be useful as a basis for the preliminary flood risk assessment in order to prioritize significant flood risk areas in Norway.

The first generation results from the GIS-analysis are however rough. The susceptibility maps show large areas possibly prone to flood, with large uncertainties. The method's uncertainties should be evaluated and considered in a proper way.

To give priority to the areas with the highest risk that should be included in the PFRA, the potential risk areas pointed out in the GIS-analysis should be evaluated by verified criteria. For an efficient updating of the PFRA every 6th year, the process should be transparent and possible to verify. The flood prone areas should be described by given parameters including a description of the area and the land use, the indicative number of the people affected by a possible flood, and an evaluation of whether the estimated number is realistic. The precision of the estimated inundated areas should also be assessed and compared to descriptions of historical floods.

Three areas were picked out to show examples of how the results could be evaluated further: Lillestrøm, Orkdal and Torpomoen (maps are available in appendix B).

Lillestrøm is situated in the eastern part of Norway, east of Oslo, between the two rivers Nitelva and Leira where they run into the northern bay of lake Øyeren, Svelle,. The water level of lake Øyeren is influenced of the river Glomma. Approximately 1/3 of the catchment of Glomma is regulated for hydroelectric power. Floods that hit Lillestrøm are mostly caused by the natural rise of water levels in Svelle and Øyeren due to rain and snowmelt. Lillestrøm has experienced damaging floods in the past and measures to prevent flood damages have been taken. Flood hazard maps for the area are available.

Orkanger is situated by the river Orkla's outlet in the fjord. The river was regulated in 1985 for hydroelectric power. This is expected to have influence on floods with a small return period (i. e. 5, 10, 20 years). The regulation will have little effect on larger floods. Flood hazard maps for the area are available.

The third location, Torpomoen has been a former military camp. After the camp closed down, the buildings are used for different purposes, including hotel, catering, rescue service and business activity. The river Hallingdøla which runs through the valley is regulated for hydro power and the occurrence of floods in the area has been reduces as a consequence of this. Torpomoen is an example of the systematic error described in paragraph 4.3. Many of the buildings are classified as school buildings which all are weighted as 200 thus overestimating the risk.

To get a picture of the flood risk in each area, the following points were considered:

- The area at risk was described by the potential hazard and whether the actual river is regulated or not.
- The indicative number of people affected was listed.
- If the area had been subject to flood zone mapping this was mentioned with reference to the project report number.
- In areas where there are produced flood hazard maps, the inundated areas generated in the GIS-analysis was compared to these in order to assess the reliability of the flood extent.
- Existing flood protection.
- Threat to residents, service and facilities: The number of institutions, services and facilities within the possible inundated areas was compared to the number of institutional houses in order to keep or reduce the estimated consequence to the actual value. Schools and other public buildings with many users and employers can cause a great effect on the preliminary map if they are located in many small buildings near a river, lake or sea.
- Threat to infrastructure and economic activities: Economic values located within the flooded area, such as infrastructure or industry, other businesses, office buildings or other activities or assets to which a flood will cause damage or loss of value are to be mentioned as far as the information was easily accessible.
- Assessment of the number of affected people due to the GIS-analysis: As the most urbanised areas are more likely to be classified as having a significant risk than less urbanised areas, the potential risk areas should be evaluated with respect to the occurrence of high-rise buildings and other factors that could possibly increase the gap between the number of people actually at risk and the estimated number.
- Historical floods should be described with respect to significant adverse impacts on human health, the environment, cultural heritage and economic activity. It should be mentioned if a similar event is likely to happen in the future.
- The assessments of the real risk were summed up and should lead to a conclusion of the preliminary flood risk assessment of the actual area.

Table 6 on the next page shows an example on how the result from the GIS analysis can be assessed.

Table 6: Example of further evaluation of the results from the GIS-analysis (Naserzadeh, 2005, Sæther, 2005)

Area	2 Lillestrøm	15 Orkanger/Fannrem	20 Torpomoen
Description of area	Lake inundation and river Glomma. Small rivers	River Orkla, regulated by hydro power (built 1981-1985), storm water surge	River Hallingdals-elva, (hydro power regulated river)
Indicative number of people affected	24,009	5,061	4,256
Flood zone map	Sub-project Lillestrøm (NVE 13-2005)	Sub-project Orkdal (NVE 15-2005)	None
The result from the GIS- analysis compared to flood zone map project	The GIS-analysis shows larger flooded area than 500 years flood estimation	The GIS-analysis shows larger flooded area	-
Threat to existing flood protection measures in a 500 year flood	Water level will most likely exceed the flood protection	-	-
Threat to residents, services and facilities	Nursery, sports facilities, secondary school, residential houses and large areas at risk	Residental areas at risk. Hospital barely at risk	Center for rescue training Hotel/overnight stop
Threat to infrastructure and economic activities	Urban settlement, infrastructure, roads railway, petrol station, Industry area at Nesa	Harbour, industry, bridges, infrastructure	Road and railway
Assessment of the number of affected people due to the GIS-analysis	Some potential for overestimation	Some overestimation	More than 10 buildings classified as school. Highly overestimated
Records of floods in the past	1860, 1789, 1910, 1916, 1927 1967, (1995)	1944, 1940, 1967, 1934	none
Real risk compared to estimated risk by the GIS-analysis	Less than estimated, but still flood risk. Estimated risk by the GIS-analysis is acceptable	Approximately the same	Real risk is less than estimated by the GIS-analysis
Conclusion	Significant area	No conclusion	Not significant area

This evaluation indicates that the area of Lillestrøm should be included as an area with significant flood risk according to PFRA, and that the area of Torpomoen should be excluded. The conclusion for the area of Orkanger depends on the chosen threshold of significance. If the threshold is chosen to be 1000 inhabitants at risk, as stipulated in part 4.2, the flood risk at Orkanger would most likely be of significance.

By evaluating the results qualitatively, one could hopefully eliminate those risk areas from the GIS-analysis (figure 11) that in reality have no real significant flood risk. Rural areas with flood hazard but very few inhabitants should not be pointed out as significant risk areas.

Other possible methods to improve the results would be to improve the quality of the hydrological input data. The input data in the described analysis is considering the size of the catchment area to be the only variable influencing the water level rise. The water level rise is however dependent on many factors as well, but these factors would of course make the assessment more complex. In addition, the information for the assessment would be less readily derivable. Including more input data could make the assessment so detailed that it will be difficult to conduct the analysis for the whole country.

The quality of the DTM has a big impact on the quality of the results. By using the 10 *10 DTM the landscape would be represented in the model thereby giving more valid results especially for steep and small catchments. The 10*10 DTM was however not yet available when the GIS method was developed. Improving the model will also require a lot more computer performance.

Further improvement of the GIS-analysis could be to include urban floods and flash floods in the assessment.

6 Conclusions

Considering the premises of doing a preliminary flood risk assessment based on already available or readily derivable information, the results from the GIS-analysis are acceptable as a first approximate estimate of areas of significant flood risk. A quality control of the GIS-derived risk areas, including a sensitivity analysis where the factors in the GIS-analysis are given different weights, can improve the results and be a helpful tool in the process of pointing out areas with potential flood risk. The evaluation process should be transparent and possible to verify.

Both the hydrological input data and the digital terrain model can be improved. More detailed input data would require more computer performance, and the benefit of the improvement should be considered and weighted against the costs and inconvenience of using more resources and time. Improvement of the quality of the input data would make the result from this GIS-method more reliable.

Improvements would make susceptibility maps more accurate. It is however important to underline that the purpose of the PFRA is not to present the inundated areas in detail, but to find the areas with the highest risk of flood. This means that a susceptibility map will never be able to predict the risk areas in detail. The possible inundated areas should therefore not be presented by accurate limitations of the flood extent which could mislead the reader to believe that the inundation is accurate. A index map or a map showing the preliminary results as transparent areas with blurry edges could be an alternative.

A way of including urban floods and flash floods in the PFRA would also be an improvement of the flood management.

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Appendix

Appendix A Number of people estimated present at different locations in different types of buildings (residential houses are counted separately and are therefore not present in this table).

Appendix B Preliminary flood risk assessment maps.

- Lillestrøm
- Torpomoen
- Orkanger

Appendix C: Comparison of result from PFRA and flood hazard maps.

- Lillestrøm
- Orkanger

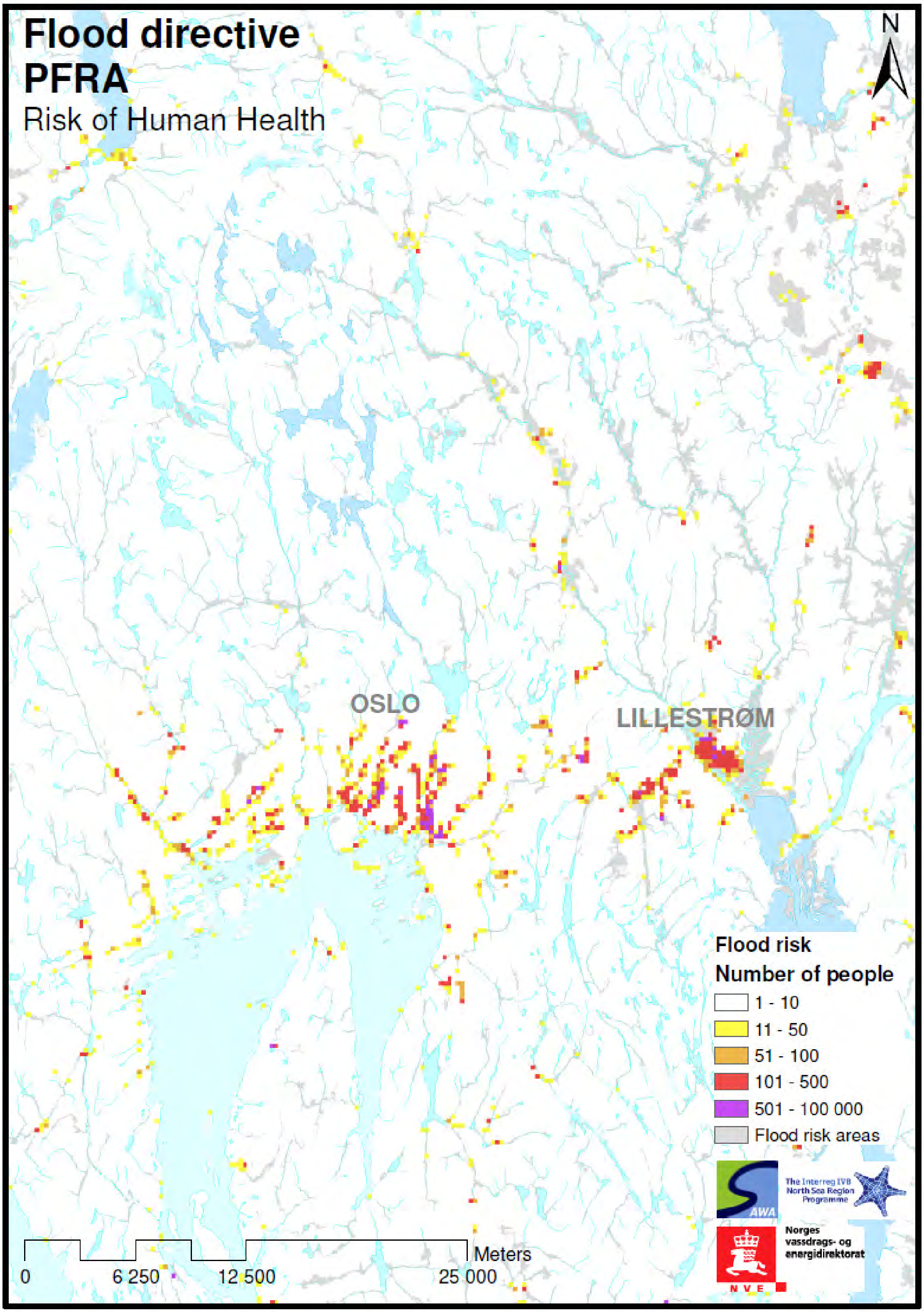
Appendix A:

SOSI		GAB		
Type	Builing type	BUIL_CAT	BUIL_GROUP	CRITICAL_INFRA_WEIGHT
161	Holiday cottage	161	2	1
162	Recidence used as leisure home	162	2	1
163	Farmhouse used as leisure home	163	2	1
171	Pasture, fishing hut and others	171	2	1
172	Hut, turf hut	172	2	1
181	Garage, outhouse	181	2	1
311	Office building, city hall	311	3	10
312	Bank and post office	312	3	10
313	Radio and TV-building	313	3	10
319	Other office building	319	3	10
321	Shopping centre, warehouse	321	3	50
322	Shops and commercial building	322	3	10
323	Petrol station	323	3	10
329	Other commercial building	329	3	10
413	Bus station/terminal/shed	413	13	10
414	Ferry terminal	416	13	10
432	Bus, tram and engine shed	432	13	10
433	Aircraft hangar	439	13	10
511	Hotel	511	12	20
512	Motor hotel	512	12	20
519	Other hotel building	519	12	20
521	Hostel, pension	521	12	20
522	Youth hostel, lodges	522	12	20
524	Camping (cabin)	524	2	1
529	Other lodging building	529	12	20
531	Restaurant, cafe builing	531	3	10
533	Snack bar, kiosk	533	3	10
539	Other restaurant building	539	3	10
590	Other hotel/restaurant building	590	3	20
611	Childrens park	611	11	50
612	Nursery, kindergaten	612	11	100
613	Primary school	613	11	100
614	Lower secondary school	614	11	200
615	Primary lowe secondary school	615	11	200
616	Upper secondary school	616	11	200
619	Other school building	619	11	200
622	Spesialbygning	622	11	10
641	Museum, art gallery	641	10	20
649	Other museum, art gallery	649	10	20

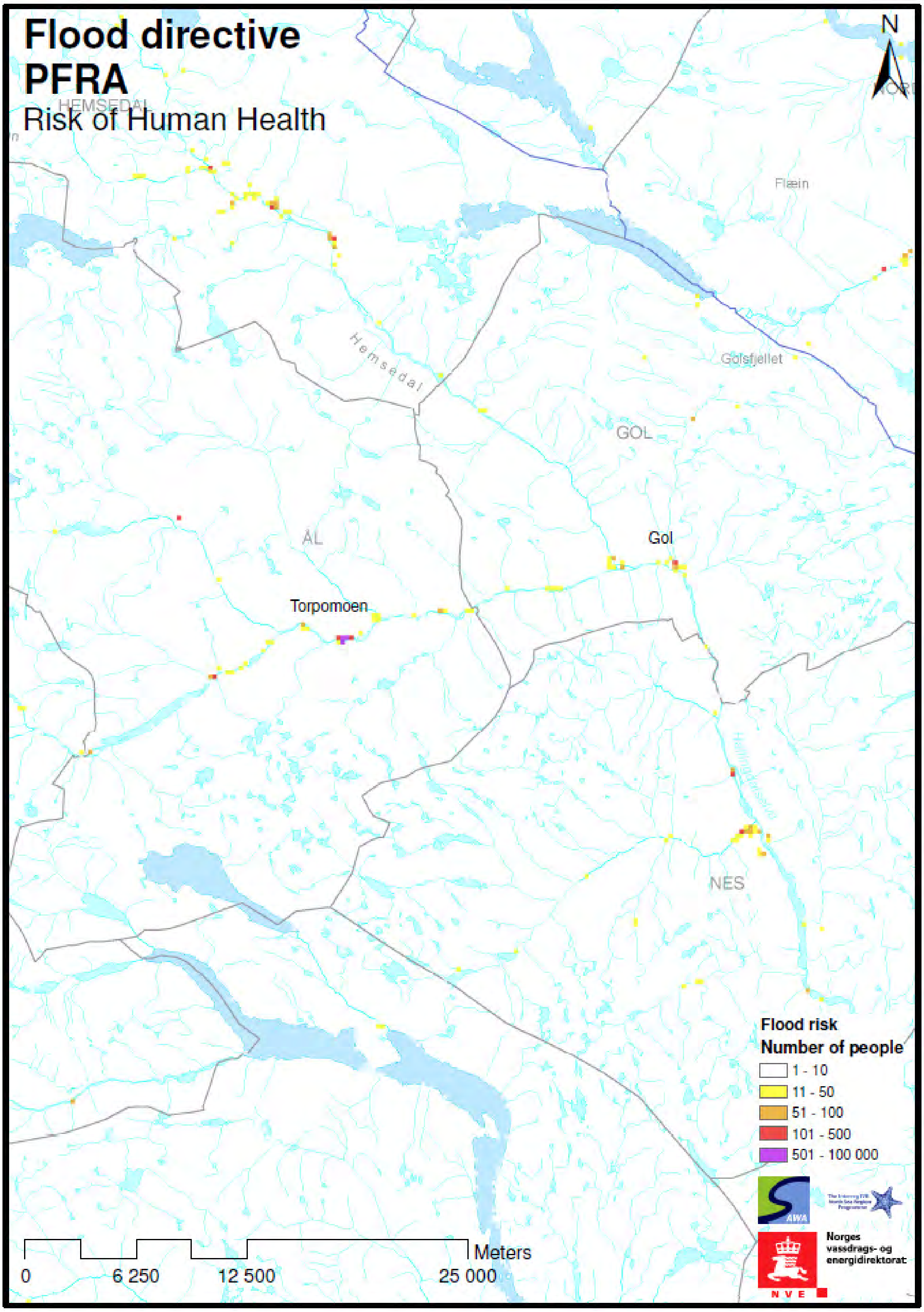
651	Sport centre	651	10	20
652	Ice skating facility	655	10	20
659	Other sport facility	659	10	20
662	Community center	662	10	20
669	Other arts centre	669	10	20
671	Church, chapel	671	10	20
672	Bethel, parish house	672	10	20
712	District general hospital	711	8	200
721	Nursing home	721	8	200
722	Treatment centre, retirement home	722	8	20
723	Rehabilitation centre, spa	723	8	50
731	Clinic, health senter, medical office	731	8	20
732	Health- and socialservices,	732	8	20
739	Other primary health care center	739	8	20
790	Other health care buidling	790	8	20
822	Fire station, emergency unit	822	9	20
829	Other emergency building	829	9	20

Appendix B.

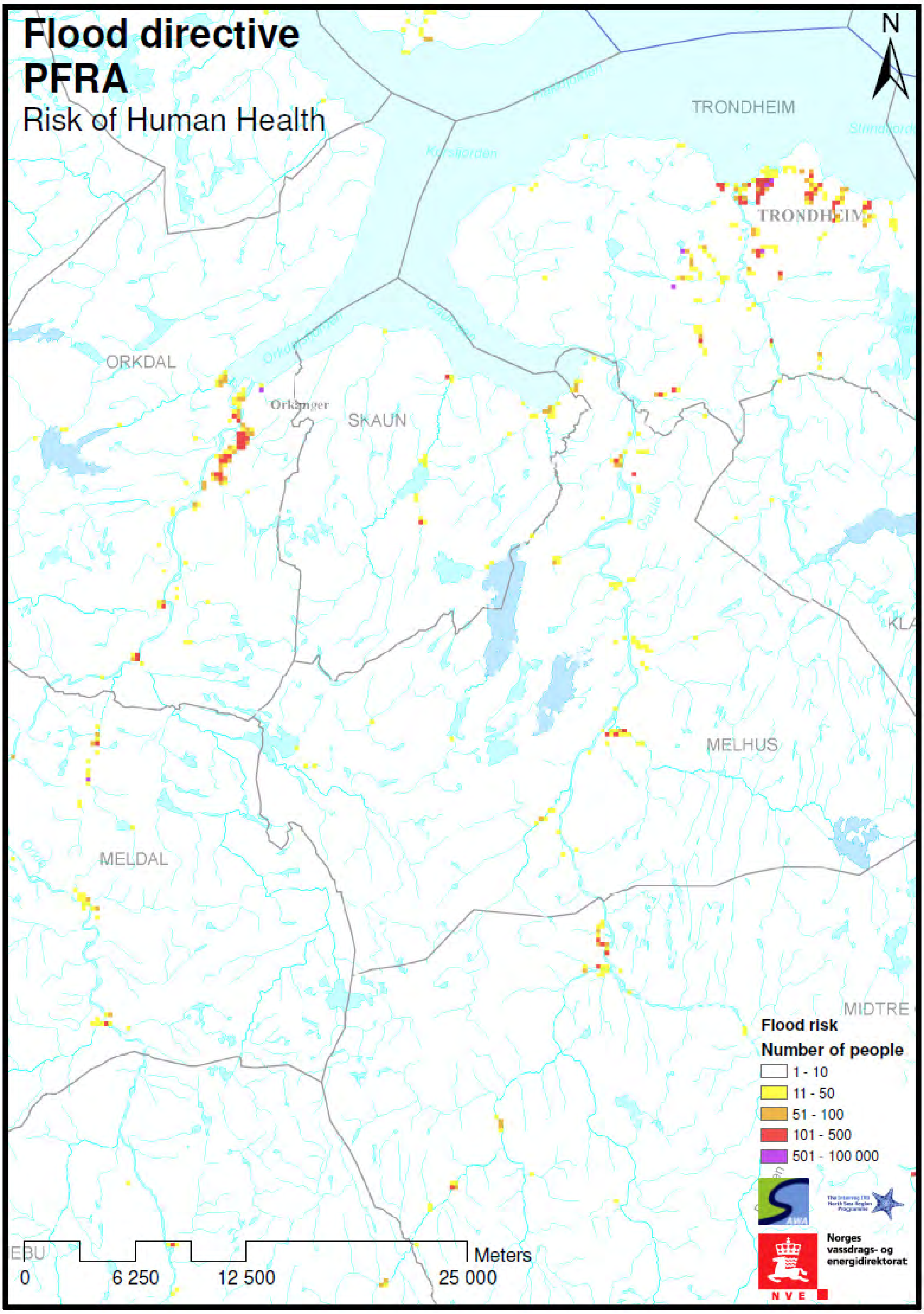
Lillestrøm



Torpomoen

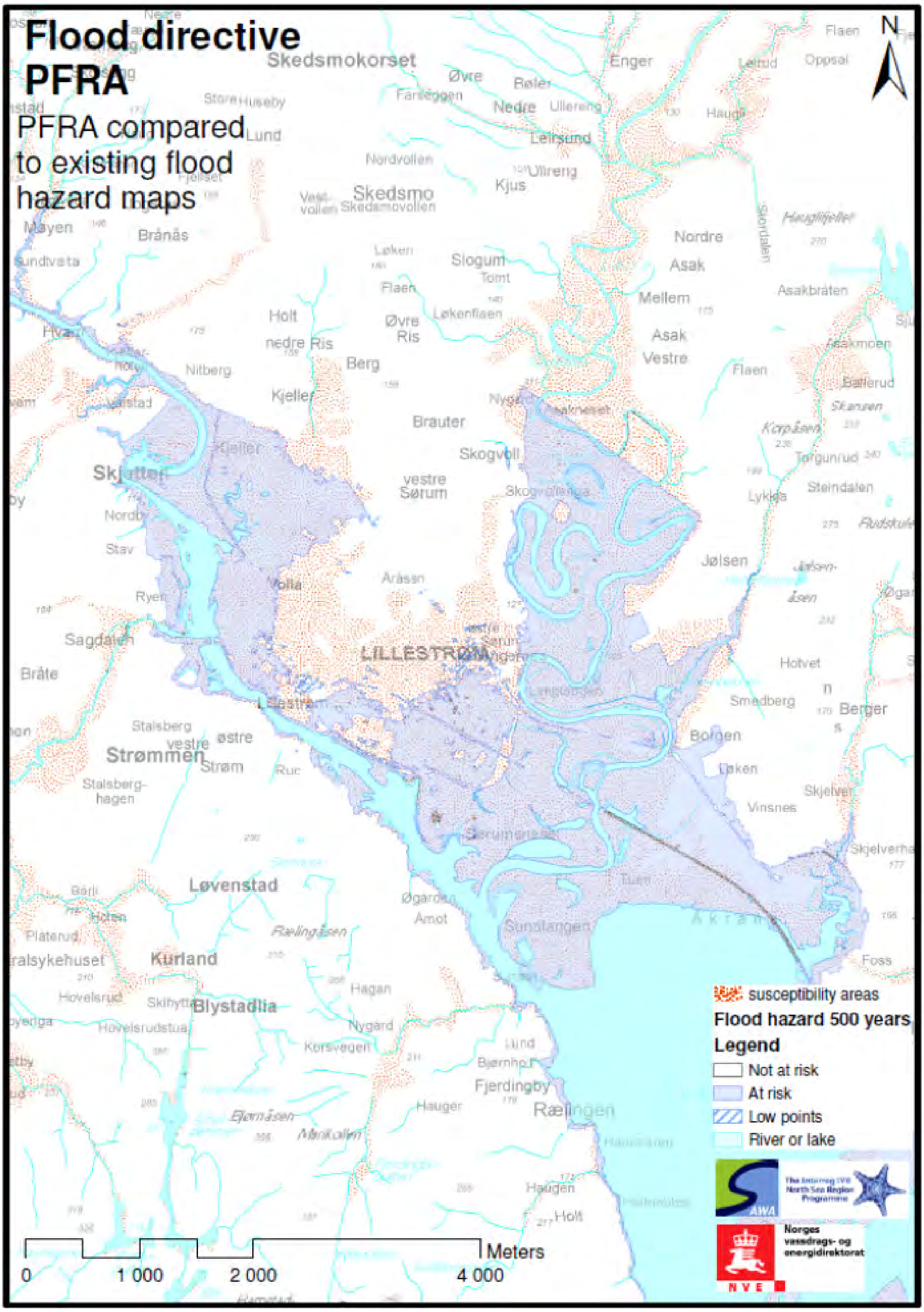

Flood directive
PFRA
Risk of Human Health
HEMSEDAL
N
Flæin
Hemsedal
Golsfjellet
GOL
ÅL
Gol
Torpomoen
NES
Flood risk
Number of people
1 - 10
11 - 50
51 - 100
101 - 500
501 - 100 000
Norges vassdrags- og energidirektorat
NVE
0
6 250
12 500
25 000
Meters

Orkanger

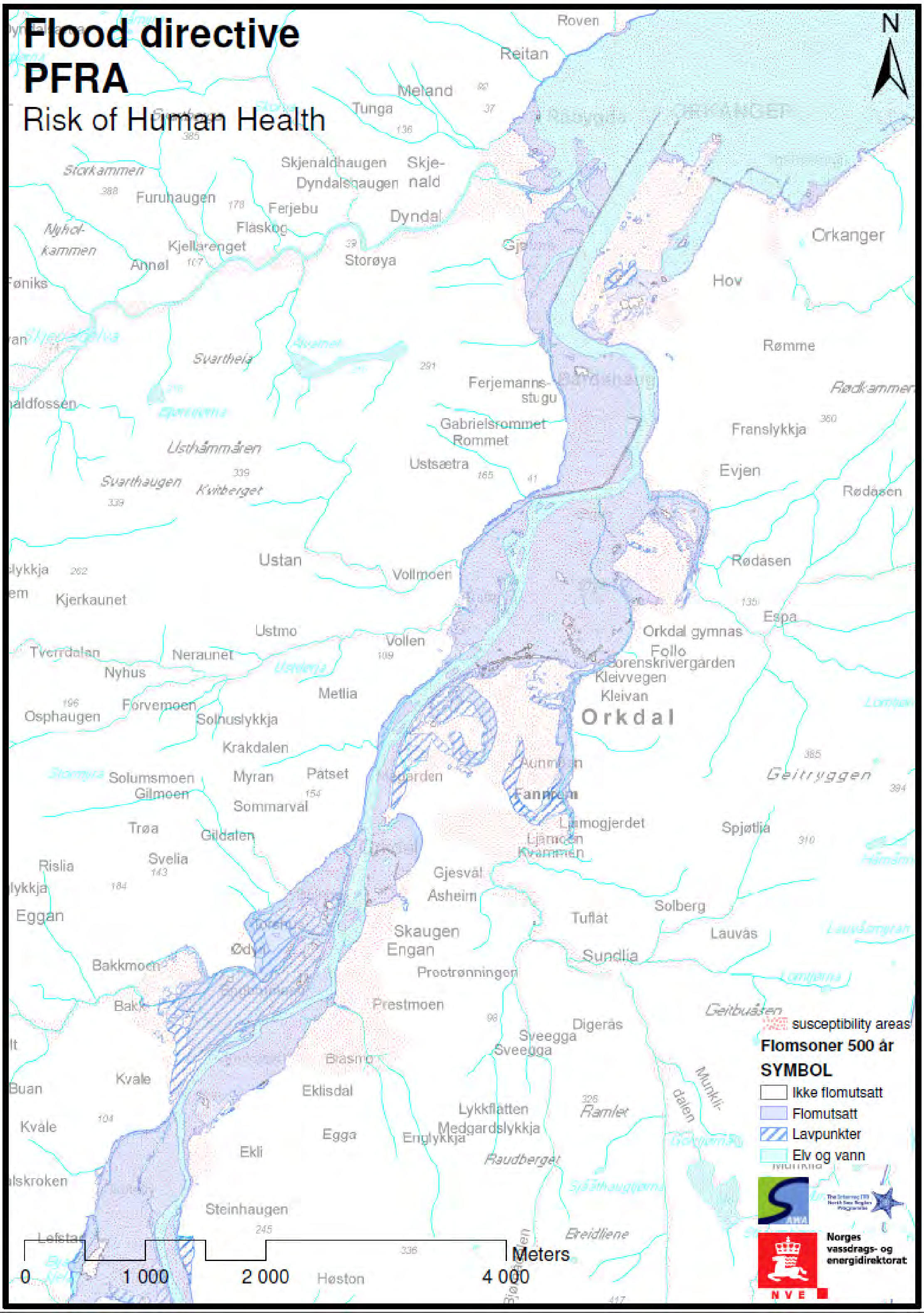

Flood directive
PFRA
Risk of Human Health
N
TRONDHEIM
TRONDHEIM
ORKDAL
Orkanger
SKAUN
MELHUS
MELDAL
MIDTRE
Flood risk
Number of people
1 - 10
11 - 50
51 - 100
101 - 500
501 - 100 000
Norges vassdrags- og energidirektorat
NVE
0
6 250
12 500
25 000
Meters

Appendix C:

Lillestrøm



Orkdal



Flood directive
PFRA
Risk of Human Health
N
susceptibility areas
Flomsoner 500 år
SYMBOL
Ikke flomutsatt
Flomutsatt
Lavpunkter
Elv og vann
0
1 000
2 000
4 000
Meters
Norges vassdrags- og energidirektorat
NVE
Orkanger
Orkdal
Hov
Rømme
Evjen
Fanrem
Solberg
Lauvås

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