Risk analysis project within the Norwegian HYDRA flood research programme

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Abstract

Some central issues from the flood risk project in the Norwegian flood research programme HYDRA, presently in its final year, are presented. One sub-project has addressed the establishment of loss functions (typically damage as function of water level) for objects such as detached houses, roads and railroads, and cultivated land. Another project studied cost efficient methods for flood mapping. Together with regional flood frequency analysis, the result from these projects have provided the basis for economic risk analysis for floods. In addition some verification and uncertainty analysis have been carried out.

Most of the work is finished and is now under reporting, except a pilot study on local decision support systems, including public and expert perception of risk. This project starts these days and will be finished by September 1999.

1. The HYDRA Programme

HYDRA is a research programme on flood initiated by the Norwegian Water Resources and Energy Directorate (NVE) in 1995. The large floods in Asia, North America and Europe during the 1990s form the background for the programme. The major flood in south-eastern Norway in the spring of 1995 made the programme particularly relevant.

The working hypothesis is that the sum of all human impacts in the form of land use, regulation, flood-protection etc., may have increased the risk of floods. The programme will provide the basis for testing this hypothesis.

HYDRA is aimed at developing knowledge, information and methodology to support state and municipal authorities, insurance companies and other organisations in their work and decision making. The work is carried out at Norwegian research institutions and universities, the Norwegian Water Resources and Energy Directorate, and one river authority.

HYDRA has a time frame of 3 years, terminating in 1999 and with an economic framework of NOK 18 million - largely financed by the Ministry of Petroleum and Energy. The programme consists of the following projects:

- Natural resources and land use.
- Flood impacts in urban areas.
- Flood reduction, flood protection and flood management.
- Risk analysis.
- Environmental consequences of floods and flood prevention measures.
- Databases and Geographical Information Systems.

The programme is in its reporting phase, a series of reports are published or will be published during 1999. Unfortunately, most of the reports are in Norwegian, but with English summaries. A general report in English will be published next year. Information on the project can be found on the web server of the Norwegian Water Resources and Energy Directorate, at http://www.nve.no/prosjekter/hydra.htm
2. The Risk Analysis Project

The main objective for the risk analysis project has been to improve the methodology for flood mapping and loss assessments. Principal uses of this methodology is in land use planning and cost/benefit analysis of flood mitigation measures. Central components have been:

- establish standardised loss functions for various objects, with special emphasis on buildings and cultivated land, based on assessments and inventories after the 1995 flood;
- improving flood zoning methodology, including testing of various base map types and laser scanning;
- identification of exposed objects and areas by use of GIS and digital property registers;
- improved regional flood frequency analysis;
- economic loss risk analysis;
- test and verification of loss curves.
- decision support for "front line" action, i.e. decisions taken locally on incomplete information

The focus has been to utilise and combine different information sources, especially digital ones, with state-of-art methods. The main project report is Berg et al (1999), but there are also reports from the sub-projects.

Environmental considerations, and impacts of point source pollution has been covered by other HYDRA projects, especially the Mi Project. Some issues that have relevance for risk analysis and extended cost/benefit analysis are:

- Flood impacts on water quality (Faafeng m.fl. 1999);
- Floods and aquatic life (Brabrand m.fl. 1999);
- Erosion and sediment transport (Bogen 1999);
- Environmental effects of flood mitigation structure, and environment-friendly mitigation activities and designs Østdahl et al (1999), Østdahl and Taugbøl (1999);
- Flood protection and environment conflicts (Sælthun 1999);
- Flood and pollution (1999);

![Figure 1 Damage to detached houses in Åsnes as function of water level](image)

*Figure 1 Damage to detached houses in Åsnes as function of water level*
2.1 Loss functions

Standardised loss functions have been established for a number of typical objects, mainly based on the damage registered after the flood in Eastern Norway in 1995. Economic losses have been classified as follows:

- Direct losses. These are expenses required to reinstate objects to the state they were in before the flood.
- Indirect losses. Losses and costs that are not directly connected to flood water impacts - typically interruption and stoppage losses.
- Mitigation cost. Cost connected to mitigation and salvage activities during the flood.

Loss functions has been established for buildings, roads and infrastructure, and agricultural areas (Wathne & Alfredsen 1999).

2.1.1 Buildings

The most important class of objects is buildings. The loss estimates are based on the damage assessments by independent insurance assessors - these registrations also include the inundation level, allowing the damage to be related to water level. The results for residential houses are summarised in Figure 1. It is possible to relate damage to water level, a regression line gives a loss increase of 1240 NOK per cm over house foundations, but the variability is very large. It is somewhat reduced if age of the house is considered, but for significant improvement of the estimate the total value of the house is needed. This information is not available in the data obtained from the assessors. For the typical Norwegian residential house, which is a wood structure with extensive use of insulation mats (rock/glass wool), the damage seems to approach the full value when the water stage reaches one meter above ground floor level.

For outbuildings, garages etc. the average damage is 50000 NOK per building. Industrial buildings, shops, public buildings etc. do not lend themselves to generalised loss functions.

2.1.2 Roads and other infrastructure

The damage on public roads (county and national routes) are on the average 360 000 NOK per km inundated road. The damage on railroads are dependent on whether the water reaches only reaches the formation layer or the crushed stone sleeper foundations. In the former case, the average damage is 35 000 NOK per km, in the latter case the extra costs vary from 45 000 NOK to 250 000 per km, depending on the degree of siltation and erosion.

The indirect costs are very difficult to estimate, and to a large extent depending on the degree of interruption of inter-regional and national transport, but seem to be of the same order of magnitude as the direct costs.

2.1.3 Agricultural areas

The main losses in agriculture, beside the damage on buildings and infrastructure, are:

- harvest losses;
- damage on agricultural areas due to erosion and sedimentation.

The erosion damage is not evenly distributed, but concentrated to local hollow erosion. The damage after the flood in 1995 has been registered.
(Øygarden et al, 1996), and analysed for dependence on physical factors. The main predictors are:

- water velocity (calculated from river slope and depth by the Manning formula);
- proportion cultivated area of total flooded area;
- width of flooded area.

Figure 2 shows the regression line of estimated vs observed eroded mass (per unit area) for the investigated areas.

Season is also important - naturally the largest damages are experienced if a flood hits shortly after soil preparation and sowing.

### 2.2 Water surface profiles and flood maps

Different approaches for flood water surface estimation and flood map construction have been assessed. For surface water profiles, hydraulic modelling produces the best results, followed by parallel shift of historical flood lines. Parallel shift of water surfaces from normal runoff conditions can give large errors.

Several data sources for producing flood maps have been tested, standard ordnance maps (20 m equidistance), economic maps (5 m equidistance), detailed surveys and airborne laser scanning. As a general rule, 20 m equidistance maps will not give satisfactory results, while 5 m gives varying results, dependent on the whether the critical levels are close to an contour line or not. The errors are greatest for moderate floods with limited inundation - on the other hand these floods usually give moderate damage and are of less significance in economic risk analysis and cost-benefit analysis for flood protection measures. Generally flood maps based on economic maps will be satisfactory for statistical purposes and cost-benefit analysis, but not for detailed flood zoning. Figure 3 shows an example of maps and flood plain profiles for one of the nine test areas. Full description of the methodology and analyses is given in Kristensen and Voksø (1998).

### 2.3 Flood frequency analysis

A central element in economic risk assessments is frequency analysis. Norway has a well developed network of hydrometric stations with observation series of up to 120 years, but even then estimates of return periods for extreme floods have large uncertainties. This is further accentuated by the fact that many of the rivers are regulated for hydropower, creating non-stationarity in the runoff time series. The project has developed improved regional flood frequency methodology, and addressed the uncertainty in

![Profiles, Heradsbygd](image)

**Figure 3** Example of map and river/floodplain profiles produced on different data sources.
the estimates, including the influence of this uncertainty on economic risk assessments (Gottschalk & Krasovskiaia 1999).

Norway has traditionally applied regional flood frequency analysis based on the index flood approach, without connected uncertainty estimates (Wingård et al, 1978; Tveito 1993). The present study utilises a methodology developed by Gottschalk and Weingartner (1999). It demonstrates a clear connection between catchment area and flood distribution skewness. The regional analysis for the Glomma River (35 stations with catchment areas from 40 to 40 000 km²), indicates that the 1000 year flood is five times the average flood for a catchment of 10 km², and three times the average flood for a catchment of 50 000 km². Figure 4 shows the variation of the 10, 50, 100, 500 and 1000 year flood scaled on average flood, as function or area. The uncertainty of the regional analyses is greatly reduced when some local observations are available.

Another important aspect is the synchronicity of the floods. Correlation studies indicate that in the hydrological regime of eastern Norway, extreme floods tend to have a large spatial scale and affect large areas.

Figure 4. Regional flood frequency analysis for River Glomma, 10, 50, 100, 500 and 1000 year flood scaled on average flood, as function or area (scale parameter). The scale parameter is the catchment area in 100 km². The markers show observed floods.
2.4 Economic risk analysis

As a demonstration of risk analysis, damage/stage relationships for buildings has been established for a test area, with connected uncertainty analysis. Damage/stage curves for the situation with and without flood levees give the basis for flood cost-benefit analysis of flood protection measures.

The analysis is carried out based on the following information:

1. Simplified loss functions for individual buildings are constructed, based on the loss functions presented in Figure 1. Only two classes have been used: Low damage: only basement inundation - average damage 48 000 NOK per building. High damage: First floor inundated - average damage 410 000 NOK per building.
2. Elevation distribution of houses has been established through digital map analysis.
3. Stage/discharge curve from the lower end of the 32 km long river reach is known.
4. Water surface variations for the reach is established through an empirical function of discharge.
5. Top levee elevations have been established along the reach.

Damage/stage relationships can thus be established for the situation with and without levees. The presence of levees nominally reduced the expected annual damage by a factor of 10 for the test area. This is however somewhat misleading, as the utilisation of the flood plains would hardly be the same without the levees. It could be argued that as the presence of levees increases the economic value and the economic activities of the protected areas, the end result may not necessarily be reduced expected annual damage.

Comparison with the actual damage paid by the insurance companies in 1995 for the test areas shows good correspondence with the estimates from the risk analysis - with one major reservation: According to design (which is reflected in the risk analysis) the levees should have broken *en masse* during the 1995 flood. Due to massive public participation, most levees were heightened enough to withstand overtopping.

Uncertainties are known for all factors, and the uncertainty analysis show that the uncertainty in the flood frequency analysis dominates, especially in the lack of local information. The second most important contribution to uncertainty is from the stage/discharge relationship.

2.5 "Front line" decision support

This activity, that just has been started, aims at testing out methodologies for establishing simple decision rules for local activities under critical flood situations. These situations are characterised by incomplete information availability, high stress and decision makers that have not been exposed to such events before. The timing of the decisions are critical, the public response often unknown *a priori*, and there is often a trade-off between public safety and flood damage.

The main issues addressed by the project are:

**Risks:**

What are the risks and what kind of objects are they connected to?

- economic loss risks
- risk for loss of life
- environmental risks

**Actions and effects:**

- What are the available actions, and what are the expected effects?
- What is the response time (necessary lead time) for the different actions?
- What is the probability for an action to fail?
Information:

What is the optimal information requirements?

- Static variables (information that can be established *a priori*)
- Dynamic variables (variables that change during a flood event)

What is the probability that information is incorrect?

What is the probability that the information is not available?

Decision rules:

- What is the set of information that releases an action?
- How are actions released when information is missing?

A pilot study will be carried out during 1999. Central elements will be collection and analysis of the local experiences from recent floods and the use of expert panels. Quantification will primarily be based on fuzzy set logic. Public perception of risk will be assessed through polls.

References


