SIMULATION OF THREE COMPETING FLOOD MANAGEMENT STRATEGIES - A CASE STUDY

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ABSTRACT

We argue that integrated catastrophe models are useful for policy decisions, for which a large degree of uncertainty is a natural ingredient. Recently, much attention has been given to the financial management of natural disasters. This article describes the results of a case study performed in northeastern Hungary where different flood management strategies have been explored and compared using an integrated catastrophe model. The area used for the pilot study is the Palad-Csecsei basin (the Pilot basin) where 4 621 persons live. The Pilot basin is located in the Upper Tisza region. An executable and geographically explicit model has been developed, linking hydrological, geographical, financial, and social data. The outcomes of the policy simulations are represented at different granularity-levels; the individual, the aggregated (entire basin), and the governmental.

KEYWORDS

flood-management, catastrophe, simulation, insurance, integrated models, risk.

1. INTRODUCTION

Natural disasters and especially floods are increasing in frequency and magnitude. Hence, costs for mitigation and compensation are rising [1].

Hungary is a country where as much as 20 per cent of its 93 000 square meters of territory are at risk for flooding. During the past decades, the central government has spent huge sums on building and maintaining extensive levee systems along the main rivers to protect the endangered land and communities. The government has not only taken the pre-flood responsibility, but also the post-flood responsibility. If a flood occurs in a protected area, this is considered to be the responsibility of the government, and the government has by tradition compensated the victims. After the recent devastating floods of the river Tisza, in 2001 and 2002, the government paid full compensation for all damaged private properties.

In Hungary, as in other countries, the government is looking for alternative flood management strategies, where part of the economic responsibility is transferred from the public to the private. In the design of different flood management strategies, a key interest for the Hungarian government has been to find the balance between social solidarity and private responsibility.

In this document, the consequences of imposing three different policy strategies are investigated. The studied flood management strategies are not necessarily optimal in any respect, but are constructed for the purpose of illuminating significant effects of adopting different insurance policies. Therefore, a main focus in this investigation has been placed on insurance schemes in combination with level of governmental compensation. In particular, the degree of solidarity, i.e., the subsidiary level has been studied, that is, how much money is transferred from low-risk areas to high-risk areas, and from richer property owners to poorer. A case study has been performed in the Palad-Csecsei basin (the Pilot basin), situated in the Szabolcs-Szatmár-Bereg County in northeastern Hungary. The second largest river in Hungary, the Tisza River flows trough the County. This is one of the poorest agricultural regions of Europe, and floods repeatedly strike large areas. The Pilot basin consists of 11 municipalities, of which primarily two experience flood damages.

The work presented in this article is part of an ongoing research project between IIASA (International Institute of Applied Systems Analysis), the Hungarian Academy of Sciences, and the Department of Computer and Systems Sciences in Sweden [2]. Interviews with stakeholders in the Upper Tisza region were also performed [3]. The purpose of these was to identify flood management strategies that are realistic and considered 'fair' by the public. Based on the interviews, three alternative flood management strategies were produced.

2. SIMULATING FLOOD FAILURE

It is impossible to predict the time, the location and the magnitude of a flood, due to the inherent infrequency of natural disasters. The shortcoming of statistical methods emphasises the role of models for evaluating new policies in presence of dependencies and lack of data c.f. [4]. Simulation models are also increasingly used for flood inundation and damage assessment, see for instance [5, 6].

The uncertainty can be treated in different ways, we have chosen to make the uncertainty explicit by considering the flood-related variables as stochastic variables. The catastrophes that are simulated in the geographical model are of the type 'flood failures'. A flood failure occurs when the flood overtops a structural flood mitigation measure, for instance a levee, or if the levee breaks. The reason for restricting the simulations to only flood failures is that insurance companies only compensate damages caused by failures, not damages caused by ground water related floods.

Nine different flood failure scenarios are implemented in the model; the flood can be of three different magnitudes, and the failure can occur at three different locations. The financial damages are estimated for all flooded properties for the nine failure scenarios. The size of the damages is directly affected by the imposed flood management strategy. The effects of these are investigated in a time-horizon of ten years. The simulation is iterated 10 000 times in order to get a statistically reliable result.

The individual property owner can choose to buy insurance or not, this choice affects the outcome both for the individual and for the insurance company. Computer based simulations are increasingly used to understand how micro order actions affect the macro order outcome, see for instance [7, 8, 9]. Simulations are a most convenient approach in this case, since it would be very hard to determine an analytical solution to this problem. In the present version of the model, we use ten different possible scenarios (nine with flood failures and one without), simulated over a period of ten years, i.e., we have $\frac{19!}{10!*9!}$ different possible outcomes for each of the three different flood management strategies.

3. THE FLOOD MODEL

The flood model consists of five modules, see figure 1. For each simulated year, the financial consequences for the different stakeholders are compiled and saved in the Consequence Module. A brief description of the functionality of the different modules is given in the following sections.

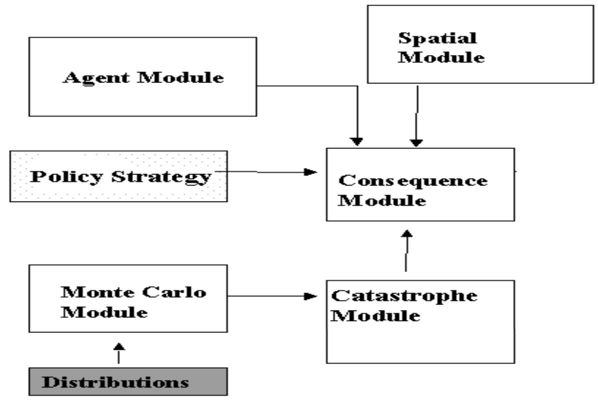

Figure 1. Modules in the flood model

3.1 THE MONTE CARLO MODULE

Two stochastic variables are used to represent the uncertainty of floods. The first variable *Magnitude* tells if there will be a 100-year flood, a 150-year flood, a 1000-year flood, or no flood at all this simulation-year. The probabilities are: 1/100, 1/150, 1/ 1000, and 1 - (1/100 + 1/150 + 1/1000). The second variable *Failure* tells if the flood will cause a levee failure at one of the three locations. The following probability distribution is used, provided by Vituki Consult Rt. [10]:

100-year flood	Location 1:	0,12
100-year flood	Location 2:	0,20
100-year flood	Location 3:	0,28
150-year flood	Location 1:	0,18
150-year flood	Location 2:	0,22
150-year flood	Location 3:	0,40
1000-year flood	Location 1:	0,19
1000-year flood	Location 2:	0,33
1000-year flood	Location 3:	0,45
no flood	Location 1-3:	0,0

For each new simulation-year, the stochastic variables are assigned random values. The random outcome is passed to the Catastrophe module.

3.2 THE CATASTROPHE MODULE

The value of the stochastic variable *Failure* is checked. For each of the nine failure scenarios, the Catastrophe module calculates what land areas are inundated, and by how deep water.

3.3 THE SPATIAL MODULE

The Pilot basin is geographically represented in form of a grid, in which every cell represents an area of 10 square meters. There are 1551*1551 cells in the grid. For each cell there is a rich amount of data, e.g., soil type, land-use pattern, digital elevation, and property value. In the simulations, only structural flood losses are considered, why agricultural data is omitted.

3.4 THE CONSEQUENCE MODULE

Only the simulation-years when a flood failure has occurred, this module is consulted. The financial consequences are calculated for each inundated cell. Data on property values and vulnerability for all inundated cells are collected from the Spatial Module. The structural losses are estimated by a loss-function, which considers initial property value, vulnerability, and depth and duration of inundating water.

3.5 THE AGENT MODULE

The various stakeholders represented in the flood model are; the individual property owner, the insurance companies, and the central government. In the end of each simulated year, the economical situation for all agents is updated. See [11]. If there has been a failure during the year, the property-value is reduced for the affected cells. Premiums are paid annually. The financial consequences also depend highly on the current flood management strategy, i.e., how much the government and the insurance companies compensates. For more detailed information on the flood model and the settings see [12, 13].

4. SIMULATIONS

This section describes the settings for the simulations, and a description of the financial indicators that are being examined.

The indicators that are outputted from the simulations and analysed, are:

- **Governmental load**: Compensation from government (plus subsidies and contribution to re-insurance fund in Scenario 3).
- **Balance for the insurance companies**: Income in form of premiums to flood insurance, minus compensation paid to property owners.
- **Balance for individual property owners**: Compensation from government plus compensation from insurance companies minus property damages and premiums.
- **Balance per municipality**: Compensation from government plus compensation from insurance companies minus property damages and premiums, the individual balances are aggregated per municipality.
- **Balance for entire Pilot basin**: Compensation from government plus compensation from insurance companies minus property damages and premiums, the individual balances are aggregated for the entire Pilot basin (all municipalities).

In this article, only the results concerning the individuals, the insurance companies and the central government are presented. For those interested, full simulation results can be collected at: http://www.dsv.su.se/~karinh/simResults0202.zip

The results of the simulations of the different flood management strategies are described in terms of financial consequences; the indicators are examined using statistical methods. When the results are presented in form of histograms, the different intervals, or bins, should be understood the following way: *–100* under a bin means that it represents the results with values less than or equal to –100. That is, the bin label always states the upper limit of the range. The lower limit should be clear from the context.

4.1 POLICY SCENARIO 1: "BUSINESS AS USUAL"

This scenario is a continuation of the current policy strategy in Hungary, where the government is the main bearer of the economical responsibility. The assumptions for this scenario are the following:

- The government compensates 100 per cent of property damages.
- 30 per cent of the households have private property insurance, a bundled insurance in which 2 per cent of the total premium accounts for flood insurance.
- Holders of private (bundled) insurance are compensated by 80 per cent by the insurance company.
- The insurance premium is not risk-based. It is based on the property-value (2 per cent of the property-value per year).

Governmental Load

The costs for the government equal zero in most 10-year periods (in 88 per cent of the periods), see figure 2.

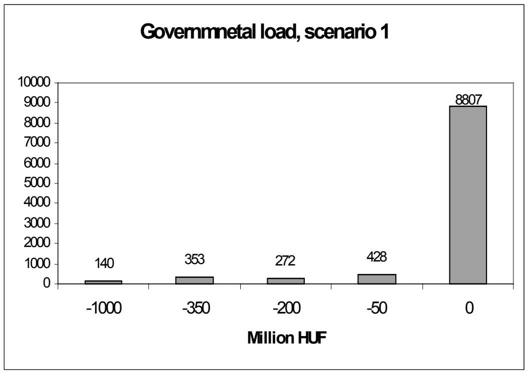

Figure 2. Histogram showing the governmental load, scenario 3.

In these decades no flood failures occurred. However, out of 10 000 simulations, 428 times the costs were greater than zero, but less than (or equal to) 50 million HUF. In 272 times the costs were 200 millions. In the most extreme decade it amounted to 2.6 milliards HUF.

Balance for Insurance Companies

When the balance for the insurance companies was investigated, only premium incomes from the Pilot basin was considered. Note that only 30 per cent of the property owners in this region has property insurance as compared to 60 per cent in Hungary in total.

The simulations show that the insurance companies make a small profit in most decades, since they receive flood premiums (2 per cent of the bundled property insurance premium) while no compensations are paid. In decades with minor flood failures the balance is slightly negative, premiums are not sufficient to cover for compensations. In extreme decades the shortage is even larger, in 272 time-periods the deficit was greater than 25 million HUF. In the decade with most failures, the deficit amounted to 560 million HUF. One explanation to why the insurance companies have a negative result in many decades is the low fraction of households with insurance.

Balance for Individual Property Owner

The results for the individuals vary considerably, mostly depending on the location of the property. To exemplify the consequences for an individual, the outcomes for an insured property owner living in a high-risk area , are presented.

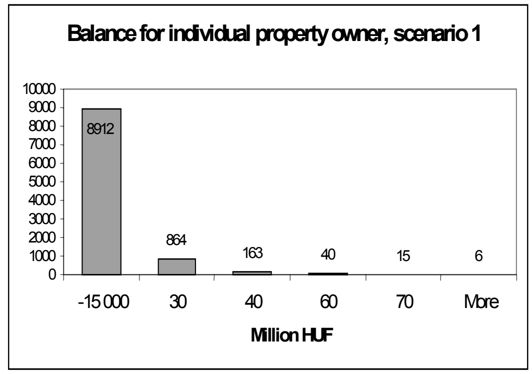

Figure 3. Histogram showing the balance for an individual property owner, scenario 1.

In most decades the property owner pays premiums without retrieving any compensation, since no flood failure occurs. When a failure occurs, the property owner is compensated by the government by 100 per cent of damages, and is also compensated by the insurance company by 80 per cent of the damages. Because of this double-compensation, the property owner gains economically if there is a flood failure. Since the premiums are based on the property value only, the risk of the location is not considered. Property owners with insurance in low-risk location subsidy the premiums for those living in high-risk locations. In 1088 decades the property owner profited largely, more than 25 million HUF.

Summary Scenario 1

1. The governmental load is extensive in this scenario, compensations to individual property owners are high, in extreme occasions more than 350 millions HUF.
2. Insurance companies in the pilot basin become insolvent when there is a flood failure. As only 30 per cent of the property owners are insured, the risk reserve is insufficient.
3. Property owners with insurance perform very well. They are double compensated; i.e. they are (highly) compensated by the government as well as by the insurance companies. The premiums are not risk based, why a person in a high-risk area pays a subsidised premium. Individuals in high-risk areas can gain economically from floods.
4. The pilot basin balance is negative in most decades, since costs for premiums are paid. Largest positive outcome was more than 500 million HUF; many households in the basin were double compensated from flood failures.

4.2 POLICY SCENARIO 2 "MORE PRIVATE INSURANCE"

In this scenario part of the responsibility is shifted from the government to the individual property owner. This is done by lowering the compensation from the government as well as the level of compensation from the subsidised property insurance, insurance 1. A new additional insurance, insurance 2, is introduced. This insurance has a risk-based premium. The assumptions are the following:

- The government compensates 30 per cent of property damages.
- 30 per cent of the households have a bundled insurance, in which 2 per cent of the total premium accounts for flood insurance. This is referred to as insurance 1.
- Holders of insurance 1 are compensated by 40 per cent by the insurance companies.
- The premium of insurance 1 is based on the property-value (1 per cent of the property-value per year).
- Holders of risk-based insurance 2 are compensated by 100 per cent.
- The premium of insurance 2 is risk-based. It is calculated from the expected damage per municipality divided by the number of properties in the municipality.

Governmental Load

As in the previous scenario, the majority of decades result in no flood failures, and no compensation is paid to the property owners. This occurs in 88 per cent of the decades. In 394 periods the losses were 2 million HUF or more. In 118 decades there compensations were large. The largest load for a 10-year period was 546 millions HUF, which is a considerably smaller load than in scenario 1.

Balance for Insurance Companies

The insurance companies receive premiums from two different insurances; one with subsidised premiums (30 per cent uptake rate in the pilot basin) and one with risk-based premiums (5 per cent uptake rate).

The balance for the insurance companies is calculated accordingly: income in form of premiums, both subsidised and risk-based, minus expenditures in form of compensation. The resulting balance is positive in most ten-year periods. In more than 8 900 simulations the balance is 15 millions HUF. The insurance companies manage to stay solvent even for minor flood failures; this can be contributed to the risk-based insurance. When flood failures occur, the insurance companies pay less compensation less than in scenario 1. The reason for this is the low compensation level for the subsidised insurance 1, in combination with the low uptake rate for the risk-based insurance 2. The most severe losses summed up to 303 million HUF.

Balance for Individual Property Owner

A property owner, who has both subsidised insurance 1 and risk-based insurance 2, pays large premiums if the property is located in a high-risk area. Premiums amount to almost 94 thousands HUF per decade for this example-individual, that is approximately 780 HUF per month. When floods occur the individual is compensated generously, from two insurance companies as well as from the government.

Summary Scenario 2

1. The governmental load is substantially smaller than in scenario 1. The largest loss was 546 millions HUF. The reason for this is that the compensation level was considerably lower.
2. The pilot basin balance shows a more negative result, since risk-based premiums are expensive for the property owner.
3. Insurance companies are showing a more balanced result than in scenario 1. The incomes are a bit lower and the expenditures are smaller. The major shortage is 303 million HUF.
4. Most property owners are worse off than in scenario 1, since only five per cent are assumed to have risk based insurance. Risk-based premiums are very expensive in municipalities 1 and 2. The example individual pays more than 9 thousands HUF per year in premiums for insurance 1 and 2. However, when floods strike highly insured households, they receive high compensation. This is because risk-based insurance compensates to 100 per cent and this is combined with compensation from government and insurance 1.

4.3 POLICY SCENARIO 3: "MANDATORY INSURANCE"

In this scenario, the government does not compensate the flood failure victims at all. Instead it is mandatory for the property owners to purchase insurance. The compensation for losses is 60 per cent. Premiums for the mandatory insurance are cross-subsidised in two ways; (1) as the premiums are not risk-based, property owners in high-risk locations are subsidised by property owners in low-risk locations, and (2) low-income households are subsidised by the government who pays the premium. The relatively low compensation is intended to stimulate property owners to take own mitigation precautions. A part of the premium income is transferred from the insurance companies to a governmental re-insurance fund. The government contributes to this fund with a small amount of the income taxes. If the insurance companies cannot cover the claims after a severe flood failure event with very high losses, the property owners will be compensated from the re-insurance fund. If the re-insurance fund would run out of money, the government would reimburse the re-insurance fund. The assumptions are the following:

- The insurance companies are re-insured by a governmentally run re-insurance fund.
- A mandatory subsidised insurance is introduced; a bundled property insurance in which 2 per cent of the total premium accounts for flood insurance.
- The premium for the mandatory insurance is 1.5 per cent of property value/year.
- Holders of mandatory (bundled) insurance are compensated by 60 per cent by the insurance company.
- The insurance companies pay 5 per cent of their premium incomes to the re-insurance fund.
- The government subsidises insurance premiums for low-income households, 60 per cent of the property owners in the pilot basin are considered to be low-income households.
- The government contributes with 0.5 per cent of the income taxes (in the Pilot basin) to the re-insurance fund.

Balance for Re-Insurance Fund

If the insurance company can not cover the claims, the re-insurance fund contributes with the deficit.

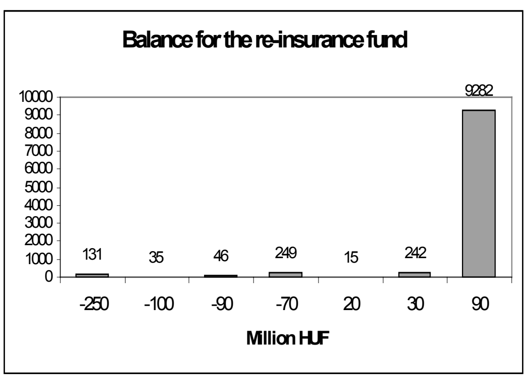

Figure 4. A histogram showing the balance for the re-insurance fund, scenario 3.

The balance for the re-insurance fund is positive in most of the 10-year periods, see figure 4. In fact, the surplus reaches 90 millions HUF in more than 92 per cent of the decades. In these time-periods, the insurance companies do not need support from the re-insurance fund (since no or only small failure occurs). However, in 461 ten-year periods, the fund has a negative balance. In 131 of the decades, the deficit is approximately 250 millions HUF. These losses occur when the re-insurance fund must support the insurance companies. The worst case scenario is a deficit of 1.4 billions HUF.

Governmental Load

The governmental load in scenario 3 consists of the money that is transferred from the government to the re-insurance fund when the balance of the fund is negative, plus the premium subsidies for the low-income households. Furthermore, tax contribution (0.05 per cent of income for individuals) to the re-insurance fund is added as a load for the government.

The load of the government is in most cases 120 millions HUF; this value consists of the subsidisation of the premiums for low-income households (60 per cent of the property owners) in the pilot basin, in addition the government contributes to the re-insurance fund yearly by 0.5 per cent of the income taxes. When the re-insurance fund is unable to cover the claims, the government reimburses these deficits. It occurs in 461 of the 10 000 simulations. However, when it does occur, the magnitude of the loss is at 249 occasions more than 190 millions HUF. In the most extreme decade, the load amounted to 1.5 billions HUF.

No description of the balance for the insurance companies is included, since insures are re-insured by the fund, and the balance for the insurance company is consequently always positive.

Balance for Property Owner

The balance for the individual property owners consists of compensation from the insurance company minus property damages and premiums.

The balance never becomes positive. This is due to the low compensation level (60 per cent). The premium costs are 20 000 HUF for each time-period. For a low-income household, the government would however subsidise the premiums.

Summary Scenario 3

1. The balance for the re-insurance fund is rather positive. In rare occasions the fund suffers high losses.
2. The costs for the government are higher than in the other scenarios, due to the cost for contribution to re-insurance fund, and aid to low-income households.
3. The insurance companies suffer no losses whatsoever, since the re-insurance fund compensates in case of insolvency.
4. The individual property owner shows a negative balance. The flood compensation is low. In the

scenario there are no possibilities for the individuals to buy extra insurance.

5. CONCLUSIONS AND FUTURE WORK

The analysis of different policy strategies would have been very hard to conduct without a geographically explicit model where the flood failures are simulated. The use of an integrated model, i.e., a model in which geographical, hydrological, social, and institutional data is represented, has been very successful in this study. By calculating the financial consequences for the most important stakeholders in the model, it is fairly easy to produce interesting results for all involved parties. It is not straightforward to conclude which of the three policy scenarios is the best, the preferences concerning level of solidarity/private responsibility have affect on this choice.

The results from these simulations will be used for exploring how suitable the three described policy strategies are for nation-wide implementation. In a first step, early March 2002, interviews will be performed with the different stakeholders in the region. They will be presented the results from the simulations and their views on the outcomes will be elicited. In the next step a stakeholder workshop will be conducted where the stakeholders can debate and promote the different policy strategies. The stakeholder workshop will take place in the late spring of 2002.

Other activities within the research project are to scale up the results of the Pilot basin to the entire County. More policy strategies are also being identified and implemented, for instance re-naturalisation; by taking down sections of the levee upstream the villages. This step is quite controversial, as much arable land would be sacrificed to save the villages. It can also be seen as a more holistic flood management strategy; floods are a natural part of the riverine system, the problem occurs when people build houses in flood basins.

It is worth mentioning that the frequency of floods and levee failures used in the described simulations are based on historical data. That is, they do not reflect recent years flood increase at all. For a number of years, the flood peaks have constantly increased. This may be accounted for by the change in the land use, for instance forest cutting, urbanization, asphalting and other changes of land use, or it could be contributed to climate changes, c.f. [14]. Further experiments with increased probabilities would in all circumstances be most interesting.

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