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FLOOD RISK MANAGEMENT POLICY FROM AN INSURANCE PERSPECTIVE

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Flood Risk Management Policy from an Insurance Perspective

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Abstract

My work within a research project studying flood-risk management in Hungary is described, with special attention on loss-spreading instruments, mainly insurance. I argue that computer simulation tools are useful in catastrophe policy making. Computer simulation provides a method for estimating the consequences of different potential policy strategies. In decision making processes it also forces the involved parties to maintain a holistic perspective. My research contribution is twofold. I first structured and implemented a flood risk management policy model, capable of estimating the consequences of different insurance strategies for various stakeholders. I then incorporated a micro-level perspective in the flood risk management policy model.

Contents

1 Introduction

I argue that computer simulation tools are useful in catastrophe policy making. For problems that are hard to solve analytically due to inherent uncertainties and complex relationships between interacting subsystems, computer simulation provides a method for estimating the consequences of different potential policy strategies. A second advantage of using a multi-purpose computer tool in a decision making process, is that it forces the involved parties to maintain a holistic perspective, from the identification of the problem, throughout the analysis, to the final communication of alternative solutions.

Background

For almost two years, I have been involved in a research project studying flood-risk management in Hungary [23]. Special attention has been on loss-spreading instruments, mainly insurance. The Palad-Csecsei basin of the Upper Tisza river has been investigated as a case. The project is an ongoing joint research project between IIASA (International Institute of Applied Systems Analysis), Austria, The Hungarian Academy of Sciences, and DSV (Department of Computer and Systems Sciences, Stockholm University/KTH), Sweden. It ends in September 2002, when a final stakeholder workshop will take place in the Upper Tisza.

I was accepted to the Young Scientists Summer Program (YSSP) at IIASA, in Laxenburg for the summer of 2000. In the YSSP, I worked in the Risk, Modelling and Society (RMS) project, a project with an interdisciplinary research tradition, led by Joanne Linnerooth-Bayer. I was fortunate to find an interesting and applied research problem already in the first year of my graduate studies. A work that initially was supposed to be a 13-week summer task, expanded into an active participation in the flood-management research project: “Flood Risk Management Policy in the Upper Tisza Basin: A System Analytical Approach”. The project, funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), sought to investigate the flood risk management policy situation in Hungary including a field study in the Upper Tisza basin.

During the YSSP, I worked at IIASA. I shared an office with my fellow graduate student at DSV, Karin Hansson why a close cooperation was natural. The vicinity of other project members also made an intense exchange of ideas and information possible. After the YSSP, the work continued back in my home institution in Stockholm. Direct communication with most project partners was limited during this stage, but I was able to make two visits to IIASA for project meetings in 2001. Intense mail communication took place, mostly with István Galambos who shared data regarding the hydrologic models, and with Tatiana Ermolieva who gave advise on modelling issues. The model was iteratively refined, and an intense period of modelling took place in the shift 2001/2002. This was a phase of frequent communication between me and Karin Hansson, Anna Vári (representing the Hungarian Academy of Sciences), Joanne Linnerooth-Bayer, and Galambos regarding the size of different parameters in the model, such as premium sizes. The modelling period concluded with a journey to the Upper Tisza and Budapest on February 25th to March 3rd, where the model was presented to different stakeholders, and interviews were performed to extract the stakeholders' opinions on different policy scenarios, and on the model in general.

Research Contribution

My first research contribution was to structure a flood risk management policy model capable of estimating the consequences of different insurance strategies for various stakeholders. The integration of data from different systems into one model has been done earlier, in the area of corporate and insurance disaster management [21, 31]. The difference is the incorporation of geographically explicit data, coupled with an analysis of the dynamic economical consequences from a specified and adjustable policy strategy. Dynamic should here be understood as involving a stochastic element, or being variable, as opposed to fixed or static, thus reflecting the uncertainty involved in future outcomes.

A second research contribution was the incorporation of a micro-level perspective in the flood risk management policy model. This inclusion is a first step towards more realistic catastrophe policy models in which the actions of one individual impacts other individuals, the insurance companies, and the government, who in turn influence the individual. A fine-grained model also gives the possibility to inspect the consequences of a certain policy strategy for a specific individual. An aggregated outcome can hide much information, a policy strategy that seems reasonable on the average might hide unfair distributions [22, 24].

Division of Work

The first prototype model, implemented by myself and Hansson, built heavily on an earthquake simulation model by Ermolieva, see [1]. Later simulation models were inspired by the work of Ermolieva, but the design and implementation of them was entirely the responsibility of me and Hansson.

It is hard to divide the contribution between me and Hansson, since we worked in close cooperation with the models. However, the following division is reasonable: I am responsible for the bulk of the Matlab code, i.e., I am the one to blame if the model is not running satisfactorily, while Hansson's responsibility is the identification and formulation of most of the functions within the model; the goal functions and the wealth transformation functions.

A computer model is merely one of many possible ways to represent a problem. In a multi-disciplinary project, the model becomes a synthesis of the different perspectives of the involved researchers; a common platform for future work. The simulation model seeks to represent the involved experts from different scientific disciplines. These are the main contributions to the model:

- Hydrology: a flow model of the Upper Tisza river and an inundation model for the Palad-Csecsei basin was made by István Galambos
- Catastrophe theory: Yuri Ermoliev and Tatiana Ermolieva contributed their expertise in the fields of mathematics and statistics for disaster management
- Sociology: Anna Vári and Joanne Linnerooth-Bayer shared the results of initial surveys and interviews with stakeholders in the region
- Economy: Linnerooth-Bayer designed the different policy scenarios that were used in the simulation model
- Insurance theory: Ermolieva incorporated stochastic optimisation techniques in the model, and Linnerooth-Bayer contributed with information on the Hungarian insurance market

Outside the project, the Hungarian flood management issue has been used as a case to investigate the micro-macro linkage in multi-agent simulation models. Some of the experiments were made together with Hansson, and some with Harko Verhagen. In the work with Verhagen, the modelling was my responsibility while he contributed to the design of the agents with his sociological expertise. For these experiments, the flood simulation model was extended: all property owners were provided with decision making capabilities. A decision problem for a property owner could be to decide if he or she should buy insurance or not, and from what insurance company, and also how much coverage the insurance contract should have.

2 Research Method

The research presented in this thesis has been explorative, and given the constraints provided by the project, I have applied a system-theoretic perspective throughout.

Choice of Research Method

Being trained at a computer and systems sciences department, a natural perspective to adopt is the systems perspective. In this tradition, a system is considered as an organised, integrated whole made up of diverse but interrelated and interdependent units, not reducible to its parts. To analyse a system means from this perspective to establish a definition of the functions of the system and to identify and quantify the internal and external relationships. Decision analysis in the systems tradition, is the explicit formal inquiry carried out with the purpose to help a decision maker to make a better decision. A problem situation where decision analysis is called upon can be characterized by the:

- complexity of the issue
- uncertainty of the outcome of any course of action

These characteristics are indeed attributes of the Hungarian flood risk management problem, where a number of different systems are linked together, for instance the hydrological, the economical, and the social systems. The relationship between these systems contain much uncertainty, especially when future flood risk managements policies are investigated.

The research method often used in decision analysis consists of a combination of the following steps:

1. identification and re-identification of
   objectives, constraints, and alternative courses of action
2. investigation of the probable consequences of the alternatives,
   in terms of costs, benefits, and risks
3. presentation of the results in a comparative framework

This research method corresponds well to the method used in the RMS project, with its roots in complex systems modelling and with a special attention to the social and institutional aspects of risk policy issues. According to the view of the RMS project, research dealing with catastrophic risks and social risks requires a thorough understanding of the diverse public concerns and the complex institutional processes and cultural settings, as well as modelling and decision frameworks for incorporating the scientific and normative aspects of risk management. The RMS project has a tradition of combining social and economic aspects of risk management with the modelling and computational challenges presented by complex problems.

An explicitly stated goal for the Upper Tisza flood risk management policy project was to adopt an integrated participatory approach: the different stakeholders should be actively involved in the project already from the beginning. The method for fulfilling this goal was:

1. extraction of mental models of organisations, institutions, and the public, as input to the catastrophe simulation model
    - An investigation of the flood risk conditions and existing mitigation and loss-sharing alternatives was made [22, 25, 19]
    - A public survey was conducted to investigate public opinion on flood risk policy management issues, see [27, 28, 29]
2. communication and development of the model with the stakeholders:
    - Interviews with stakeholders in Hungary
    - Presentation of the model with three different policy scenarios, see [14] and its appendix [9]
3. validate the model structure and simulation results with the stakeholders
    - This will be done at the final stakeholder workshop

Application of Research Method

During the the first phase of my participation in the research project, in the YSSP year 2000, a broad understanding of the policy problem was gained through literature studies and discussions with the experts in the project as mentioned in Section 1.3, from different disciplines; economy, mathematics, sociology, hydrology, and insurance experts. After this wide approach to the problem, a second phase of abstraction took place when the most important features of the problem were identified and represented in the prototype model that was implemented by myself and Hansson. The prototype model was built in the mathematical programming language Matlab, and was based on earlier catastrophe simulation models made by Ermolieva [16, 1]. The prototype model integrated data from the different systems that were considered relevant to the problem: the hydrological system, the geographical system, the social system, and the economical system.

In the third phase, the prototype model was refined and made more complex as more real data was incorporated: the prototype was turned into a sharp model. Different experiments were performed on the model, where financial policy parameters were optimised, mainly insurance premiums and coverages. To represent the stakeholders, different agents were included in the model: the government, the insurance companies, and the individual property owners. Simple goal functions and wealth transformation functions for these agents were included. Some separate research experiments, outside the project, were performed. The aim of these experiments was to represent the effects of social interaction between the agents in the model: how the micro-level decisions and interactions affect the macro-level outcome.

The goal of the fourth phase was to communicate three different policy strategies to the stakeholders in Hungary. To be able to this, the model was modified and all data, relations, and assumptions in the model were checked and updated.

During a one-week long journey in Hungary together with Vári, Ekenberg, and his graduate student Ari Riabacke, the model was presented and thoroughly discussed with seven stakeholders in Budapest and in Upper Tisza. Three different policy scenarios had been simulated, and the economical outcomes of the simulations were presented from three different perspectives; the government, the insurance companies, and the house-owners (aggregated for the entire Palad-Csecsei basin), cf. [14].

On location in Hungary, modifications of the model had to be done as it became clear that some assumptions were false. The model must be very easy to to understand, since if the stakeholders fail to see how the model works they will not trust the outcome from it. This was a lesson learned during the session with the seven stakeholders. The simulation model was therefore modified to present output that could easily be transformed into decision trees, a modification that made it easier for the stakeholders to interpret and compare the results of the three policy scenarios. The time-critical changes and extensions of the model were not only my efforts, I had much assistance from Ekenberg on these tasks.

3 Research Objective

The research objective for this thesis is to investigate how computer simulation models should be structured to support flood risk policy making. Due to infrequency of disasters and the large space of possible outcomes, simulation models are normally used to analyse potential policy strategies, see, e.g., [13]. To ensure that a strategy is stable in the long term, the policy makers must include matters related to economical fairness and ecological sustainability. Models that can support policy makers in their tasks must be integrated; natural systems and socio-economical systems must be interconnected.

My underlying, long-term, research interests concern multi-agent systems and decision theory. During the initial six months of my graduate studies, these issues were highlighted. The main focus was on issues of rational decision making in groups. For instance, what would a formal decision rule look like to ensure that the interests of an individual agent are taken into consideration while the interest of the group is also considered? In the article “Artificial Agent Action in Markets” [3], I contributed ideas on the importance of trust in agent markets. I presented the results of some experiments where simulated agents used different decision-rules in the article “A Collective Level of Social Concern”[5]. In some of these experiments, the agents weighted their own interest higher than the interest of the group, and in other experiments the group was considered more important, and the outcomes were then analysed and discussed. These research questions on social rationality and decision making in groups were temporally put aside when I was enrolled in the flood risk project.

An intention has been to link the flood management research to multi-agent research. By introducing individual agents in the catastrophe models, a first step was made in this direction. The field of agent-based social simulation (ABSS) uses simulations as a means to investigate social mechanisms, see for instance [2, 15, 4] for the fundamentals. Within this field, the use of ABSS for policy making has been given special attention by a number of researchers, i.e. [12, 20, 26, 18, 17]. The majority of these models investigate policy issues related to climate change and sustainable development. I presented the article “Agent Models in Catastrophe Management” [30], by Harko Verhagen and myself, at the CEEMAS 2001 Workshop in Krakow, Poland. In the article, we argued that catastrophe management can gain from incorporating ideas from ABSS. The article “Scenario Simulations: Modelling of Flood Management Strategies” [8], accepted for publication in the journal *Computers, Environment, and Urban Systems*, describes how simulation of alternative policy scenarios can be used in catastrophe management, and the Upper Tisza flood management problem was used as a case.

4 Future Work

Within the immediate future, the final use for the model will be as a tool for joint scenario analyses during the stakeholder workshop in Upper Tisza in September 2002. A graphical user interface (GUI) will be added to the simulation model to allow for interactive testing of different policy strategies among the stakeholders. The GUI is currently being implemented by master students Mona Pahlman and Eva Wilberg. This test session would be a (weak) validation of the model. Ways to further validate the model could be through studies in which the intended users interact with the model. A possible extension of the research in this direction is to refine the model in accordance with the lessons (that will be) learned at the stakeholder workshop. A better GUI and extended possibilities for the users to interactively change parameters and assumptions are possible changes to the model. As a next step, initial tests with users could be performed in Sweden, followed by a brief ethnological study (or a number of interviews) with the real users in Hungary.

Extensions to the simulation model were made for two reasons, the first was to make the model more realistic, the second was a way to combine research interests: agent-based simulations and catastrophe modelling. All agents were de-aggregated and provided with decision making capabilities. Choices made by individuals were influenced by a number of factors, economical and social. Even though these academical experiments were interesting and showed promising results, the applicability of the experiments was limited. Interviews with stakeholders in the region showed that the decision-situation modelled in the extended agent-models, was unrealistic. Property owners are not in the situation to choose whether they want to buy insurance or not, they are too poor to afford insurance.

There are several possible paths for me to follow in the future:

- validate the simulation model by performing realistic user studies
- continue the efforts in combining agent-based simulations with catastrophe simulations
- find a new case, but still in the area of agent-based catastrophe models
- leave the catastrophe modelling and focus on different agent-based simulation approaches
- combine two or more of these possible tracks

5 Structure of Thesis

The first article included in the thesis is: “Spatial and Temporal Modelling of Flood Management Policies in the Upper Tisza Basin” [6]. It is my YSSP report to IIASA, in which I describe the research activities I engaged in during the YSSP in the summer of 2000. In the article, the insurance policy issue in Hungary is framed in the context of flood risk policy issues more generally. The overall policy issue was to find ways to shift parts of the economical responsibility for mitigation measures and compensation, from the government to the individuals, in a way that is acceptable to the stakeholders involved. The article further discusses how a flood risk management simulation model should appear; what data and relationships to include, and how uncertainty should be treated. An executable prototype model was implemented, and some initial experiments were performed.

The second article: “Simulation of Three Competing Flood Management Strategies—A Case Study” [10] has been accepted for presentation at the IASTED International Conference on Applied Simulation and Modelling (ASM 2002), which will be held on June 25-28, 2002, in Crete, Greece. It describes experiments performed on the real flood simulation model. From earlier work with the prototype model [6], we had identified what data and relations to include. The simulation model represented only a small land area, the Palad-Csecsei basin in the Szabolcs-Szatmár-Bereg County. There are 2508 private properties in the basin, these were all represented in the model. Three possible flood risk management policies were simulated in the model, and the economical consequences of them were presented and analysed from different perspectives.

The third article: “Agent Models of Catastrophic Events” [11] was presented as a poster at MAAMAW (Modelling Autonomous Agents in a Multi Agent World, the 10^{th} European Workshop on Multi-Agent Systems). The article describes a first attempt to include the micro-level perspective in form of individual agents in the flood simulation model. We conclude that the integration of multi-agent systems with policy modelling in the realm of catastrophic events is not only possible, but can result in novel observations important to a successful holistic approach.

The fourth article: “Micro Worlds as a Tool for Policy Making” [7] was presented at the International Workshop on Cognitive Research with Microworlds, held in Granada, Spain. In the article, initial experiments to test if agent based simulation models could support policy making are described.

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Spatial and Temporal Modelling of Flood Management Policies in the Upper Tisza Basin

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Abstract

Flood management policies is the subject of an international joint project with the Upper Tisza in Hungary as its pilot study area. Design specifications for a geographically explicit simulation model, based on surveys and interviews, are presented. Some experiments on an executable prototype of the model are also reported on. Besides more traditional evaluation of policy scenarios, the model incorporates adaptive optimisation functionality.

List of Figures

1 Introduction

The research project "Flood Risk Management Policy in the Upper Tisza Basin: A System Analytical Approach" is funded by FORMAS (the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning), see the project proposal and the progress report [28, 26] for more information. The partners in the project are (1) the International Institute for Applied Systems Analyses (IIASA) in Laxenburg, Austria, (2) the Department of Computer and Systems Sciences (DSV), Stockholm University/KTH, Sweden, and (3) the Hungarian Academy of Sciences. It is carried out within the Risk Modelling and Society (RMS) project at IIASA, and seeks to:

1. Prepare a case study of the 1998 floods in the Upper Tisza basin, Hungary.

2. Gather data and perform interviews on the interests, views of fairness and concerns of different stakeholders to use as a foundation when constructing policies for Hungarian national flood risk management program.

3. Implement and test a catastrophe model of the area, which includes hydrological models of the flood, and interdependencies between policy strategies and the distribution and frequency of risk, cost, losses, and benefits.

The work presented in this report is a summary of the work that I performed at the YSSP (Young Scientists Summer Program) 2000, at IIASA. A flood risk policy model was structured, capable of simulating flood failures in the Palad-Csecsei basin of the Upper Tisza and produce geographically explicit distributions of property losses. An additional requirement wasw that it should be possible to test different policy strategies on the model: the economical consequences should vary with the policy strategy. An executable prototype model was implemented, based on the identified model structure. Some experiments were performed to validate the structure of the model.

I would like to emphasize that the work presented in this report builds heavily on earlier work performed in the Risk, Modelling, and Society (RMS) project at the IIASA. Yuri Ermoliev and Tatiana Ermolieva have contributed with expertise in the fields of mathematics and statistics for disaster management, see [14, 8, 12, 13, 15]. István Galambos has provided detailed information on the hydrology of the Upper Tisza river. A flow model of parts the Upper Tisza river and an inundation model for the Palad-Csecsei basin was made [35, 15]. Surveys and interviews with the stakeholders in Upper Tisza were made by Anna Vári and Joanne Linnerooth-Bayer [38, 39, 40, 20, 28, 26]. Linnerooth-Bayer has also investigated catastrophe management globally, and the use of insurance [10, 9, 24, 25, 27]. External sources of information has mainly been a report on the Hungarian flood control development, by the World Bank [2], information and statistics on natural disasters from MunichRe [31], writings by Yevjevich [41] on flood control in Hungary, and by Reitano [32] about flood insurance programs.

1.1 Aim

The aim of this report is threefold. A justification for each aim is given in the bulleted list items:

1. To frame the insurance policy issue in Hungary in the context of flood risk policy issues more generally.
    - A broad background is needed to understand the policy problem of today
2. To structure a flood risk policy model that is capable of simulating the flood failures, and to estimate the consequences of different flood risk management strategies for different stakeholders.
    - Due to large uncertainties and many possible states, it is not possible to analytically estimate the consequences of a certain strategy; instead simulation can be used
    - It is important that the model can represent different perspectives; a strategy might be beneficial to one stakeholder and not to another
    - Scenario testing can lead into numerous iterations, with small changes of the parameters before next round, an automatic adaption of the parameter-values would be useful
3. To implement a prototype of the model and perform some policy experiments on it.
    - The prototype model should illustrate the important features, identified during the structuring, and by performing tests on the prototype model, the structure can be validated

A fourth goal, which points out the direction of future work, is to demonstrate how the model can be made useful in a participatory decision making process. The stakeholders could interact with the model by running scenarios and changing parameters. This fourth goal will not be addressed explicitly in this report, but in later stages of the project.

1.2 Methodology

I have used a system-theoretic perspective in this explorative research. Initially, a broad understanding of the Hungarian policy problem was gained through literature studies and discussions with Linnerooth-Bayer, Ermolieva, Ermoliev, and Galambos. After this initial wide approach to the problem, a second phase of abstraction took place when the most important features of the problem were identified and a structure of the flood risk management model was made; the different modules, the data requirements, and the relations, were identified.

The most important features of the structured model were represented in an executable prototype model, implemented by myself and Karin Hansson. The prototype model was built in the mathematical programming language Matlab, and was based on earlier catastrophe simulation models made by Ermolieva [14, 8]. The prototype model integrated data from the different systems that were considered relevant to the problem; the hydrological system, the geographical system, the social system, and the economical system. A series of experiments on different policy strategies was performed on the prototype model, to test if the model structure was realistic.

During these initial phases I worked at IIASA, located in Laxenburg, Austria. I shared an office with Hansson why a close cooperation was natural. The vicinity of other project members also made an intense exchange of ideas and information possible. It is difficult to divide the contributions between myself and Hansson, and the following is a simplification: my responsibilities have been to integrate all data and relations into one executable simulation model, while the responsibilities of Hansson have been to identify and implement the different goal functions and wealth transformation functions of the stakeholders.

1.3 Disposition

Chapter 2 discusses climate changes in general and the possible consequences to the hydrological system. An introduction to the conditions in Hungary and the specific river basin is also given in this chapter. Chapter 3 describes different flood management strategies. Chapter 4 gives a picture of the Hungarian policy problem, with focus on insurance issues. In Chapter 5, the problem is described in terms of interacting systems, and from this a rationale for the Tisza model is given, and the functions to be included in the model are listed. The use of computer models in participatory decision making is discussed in Chapter 6. Chapter 7 discusses conditions for it to be useful as a tool for policy-makers. The different proposed modules of the Tisza model are described in Chapter 8, and in Chapter 9 some experimental results from the executable prototype model are presented. Chapter 10 includes the conclusions, and a brief discussion on future extensions of the model.

2 Background

2.1 Climate Change

There are strong indications that humans are gradually but definitely changing the climate of the earth. Emissions from fossil fuels and greenhouse gases are altering the atmosphere, leading to an uncertain future of global warming, see, e.g., Jepma and Munasinghe [21]. The increased atmospheric concentrations of greenhouse gases lead to increases of global mean temperatures. The problem that usually is referred to as the"greenhouse effect" has developed since the Industrial Revolution. Emissions from the combustion of fossil fuels create a blanket of gases around the atmosphere of the earth. The heat of the earth does not escape properly through this layer of gas, with an increased temperature as result. Global surface temperatures have increased about 0.6°C since the late 19$^{\text{th}}$ century, and about 0.2 to 0.3°C over the past 25 years, according to data from U.S. National Climatic Data Center, 2001.

The global warming will affect the hydrological cycle. This occurs because a part of the heating will go into evaporating larger quantities of water from the surface of the earth. The atmosphere is also capable of supporting greater amounts of water vapour. In general, an increase in the proportion of extreme and heavy precipitation events would occur where there is enough atmospheric instability to trigger precipitation events. This intensification of the hydrological cycle means more flooding with an increase in extreme precipitation events (cf. [22]). In a report, following meteorological parameters were stated as being the most important for flooding (cf. [36]):

- Precipitation (type, intensity, and volume)
- Temperature
- Wind speed

- Season of year

Although the impacts of sea level rise and associated coastal flooding have been more widely discussed, global climate change could also change the frequency and severity of inland flooding, particularly along rivers. It is also possible that increased flooding could occur in areas that do not become wetter. This is illustrated by four examples:

1. Earlier snowmelt could intensify spring flooding.
2. The need to ensure summer/drought water supplies could lead water managers to keep reservoir levels higher and thereby limiting the capacity for additional water retention during unexpected wet spells.
3. Warm areas generally have a more intense hydrologic cycle and thus more rain in a severe storm.
4. Finally, many areas may receive more intense rainfall.

2.2 Natural Catastrophes

The number of great natural catastrophes has risen, by a factor of three in the time period 1950–2000, see Munich Re [31]. Economic losses, after being adjusted for inflation, have risen by a factor of nine. According to Loster [30], the three main reasons for this dramatic development are:

1. The concentration of population and values in high-risk zones.
2. The greater susceptibility of modern industrial societies to catastrophes.
3. The accelerating deterioration of natural environmental conditions.

There are also more and more indications of a climate-related accumulation of extreme weather events. In Figure 1, the number of great natural catastrophes is compared over the decades, and a dramatic increase is revealed. Munich Re [31] considers a natural catastrophe to be great if the ability of the region to help itself is insufficient, why interregional or international assistance proves to be necessary. When the number of catastrophes is increasing, the financial losses escalate as well, see Figure 2.

A key problem for policy makers is to find ways to improve resilience and to protect society effectively against the increasing risk [12]. Questions of accountability and liability for preventing and absorbing the financial losses are on the political agenda in most countries.

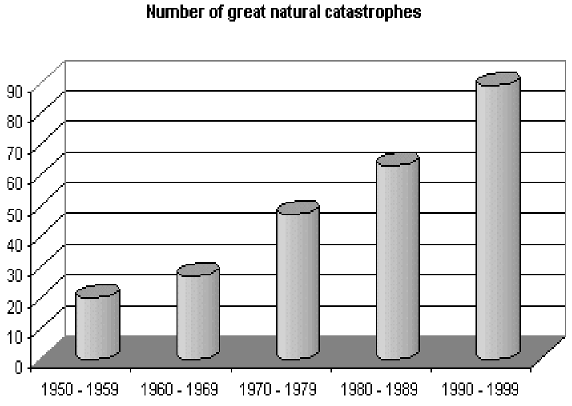

Figure 1: Number of great nature catastrophes 1950–2000, data from MunichRe.

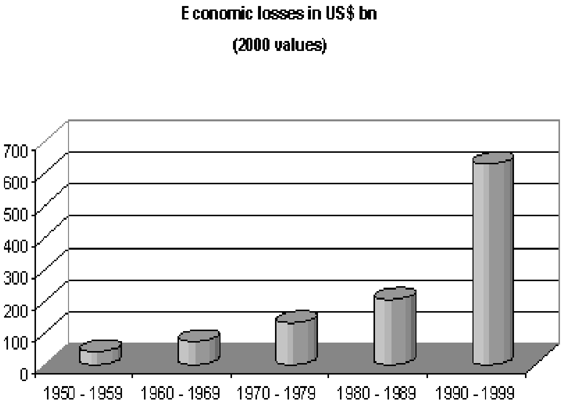

Figure 2: Economic losses from natural catastrophes world-wide, data from MunichRe.

2.3 Hungary in General

Hungary is a country where as much as 20 per cent of its 93 000 square metres of territory are at risk for flooding. The Upper Tisza region is one of the largest, natural riverside systems in Central Europe. A concentration of capital and people in risk prone areas result in increasing economical losses [24]. Due to agricultural activities and deforestation in the flood plains upstream, the water carrying capacity of the flood channels is deteriorating. Sedimentation also raises the terrain level of the unprotected flood plain. According to Kozak and Ratky [23], these factors result in ever-increasing flood levels.

2.4 The Tisza River and Upper Tisza Area

The Tisza is the second largest river in Hungary. It is a slowly flowing river with a gentle slope, famous for its beauty. Its water is a very important resource to Eastern Hungary. The entire stretches of the river Tisza is 800 km, the parts in Hungary sum up to 597 km. Through Upper Tisza, the river stretches for 235 km. It collects the waters of the Eastern half of the Carpathian basin. The source of the river is at the foot of the Magyar-Havasok Mountains, situated in Ukraine.

The study area for the Tisza project is Pilot Basin no 2.55, the Palad-Csecsei basin, see Figure 3. The basin lies on the eastern part of Hungary. Boundaries of the flood plain: from North and West the River Tisza, from East the Creek Batár and Creek Palád, from South the River Túr. The area of the pilot basin is 107 km^2, and it is located in the Szabolcs-Szatmár-Bereg County, see Figure 4. The number of persons living in the pilot basin accounts for only 2 per cent of all inhabitants in the County, an indication on how small the pilot basin is. The generality of the findings of this study can therefore be questioned. The reason for choosing such a small area for a case study was that we had detailed data available only for this area.

As much as 38 per cent of the land in the County is at flood risk. Because of few lakes in the Carpathian Mountains, the contrast between the maximum and minimum level of water is large; the level can increase by as much as 12 metres, see [37] for more information. When the flood waves arrive on the Tisza River, the speed can be extremely high, giving little time for preparation. The lack of lakes is also the explanation to the three annual floods. The first flood occurs in early spring, the second in early summer, and the third in the autumn. Apart from the minor or moderate annual floods, extreme floods occur every 10–12 years. During the last years the extreme floods appear to have become more frequent [40].

A 627-km long primary levee system protects the area from floods to-

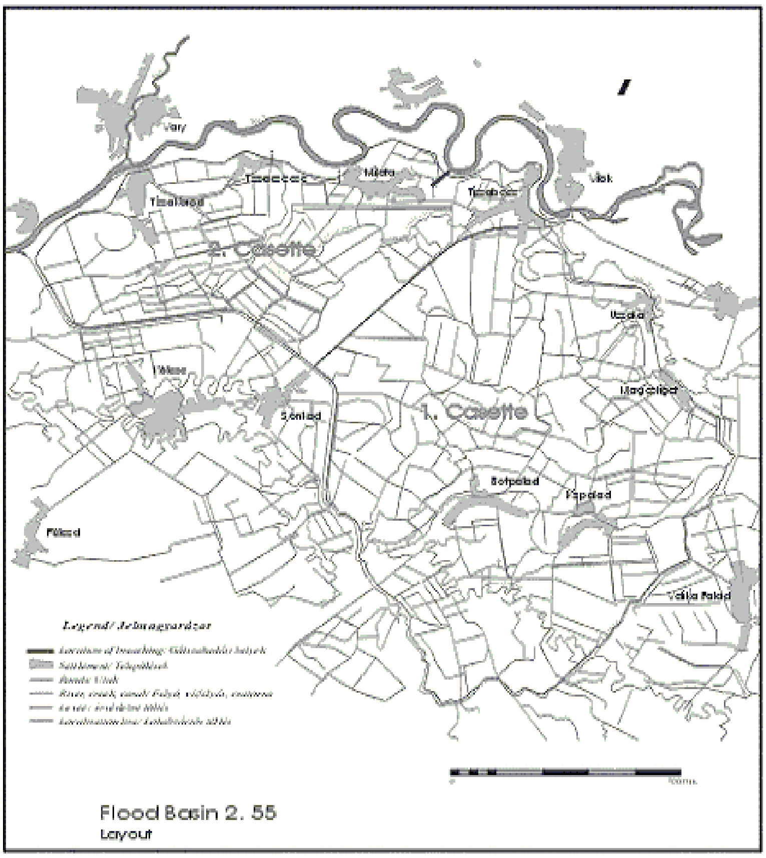

Figure 3: Basin 2.55, the study area for the Tisza Project.

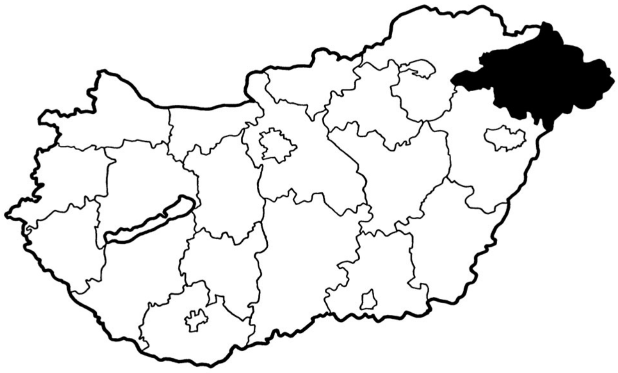

Figure 4: The County Szabolcs-Szatmár-Bereg, figure courtesy of VITUKI.

gether with a secondary line along 94 km of the river. The nature is to a large degree untouched, as much as 4.3 per cent of the county, 25 500 ha, is nature conservation area with rare fauna and flora. The region is also famous for its historic importance. Archaeological findings prove that the region was inhabited already in the Neolithic period.

It is a poor area, especially the rural areas along the river. Here, the population is very much dependent on the income from agriculture, which is not enough to support the local population. The distance between the small settlements and the cities is large, and the road connections are in a bad state. Many farmers are forced to sell their land, forests, and equipment due to economic difficulties. The situation is further aggravated by a number of severe floods in recent years. Since 1970, major floods have occurred in 1993, 1995, 1998, 1999, 2000, and in 2001 [20].

Statistics show that the region is one of the poorest in Hungary, and has a smaller agricultural production than most other regions. In 1998, the Szabolcs-Szatmár-Bereg region had the lowest average yield among Hungary's all 27 agricultural regions, for wheat, barley, as well as for potatoes, see Table 1.

Product	Position (27 regions)
Wheat	27
Rye	22
Barley	27
Maize	21
Sugar-beet	7
Potatoes	27
Grapes	23

Table 1: National rankings of the Szabolcs-Szatmár-Bereg region with respect to average yield, 1 means highest production among all regions and 27 means lowest. The figures were collected from the Hungarian Central Statistics Office [4], and reflect the year 1998.

About 200 000 people, located in 118 settlements, live in the Szabolcs-Szatmár-Bereg county. The gross domestic product per capita, expressed as percentage of the national average, was 57 in 1998. This county had the lowest GDP of all counties in Hungary, 567 000 HUF as compared to 1 858 000 HUF in Budapest, or 30.5 per cent of the GDP in Budapest. The number of unemployed was the highest in the country, 11 per cent. The beautiful areas along the Tisza would suggest a great potential for tourism and water sport activities, but this is not the case. Poor infrastructure is one explanation of why the tourism and recreation sectors are still weak here, and the cyanide spill in 2000 did not make the situation better for the young tourism industry. Greenpeace [5] among others has produced an in-depth report about the spill.

2.5 Hungarian Flood Risk Management

Flood risk management can be divided into pre-flood and post-flood actions. The pre-flood actions aim at reducing the risk for floods to occur, or to minimize the damages by moving houses out from the area for instance. Mitigation and response belong to this category. Post-flood actions include recovery and loss-sharing.

Flood protection in Hungary has a long history, and mitigation has been the dominating strategy. On January 1st, 1001 the Christian Hungarian Kingdom had already started regulating river flows and constructing protection structures against floods that endangered life and property. From documents dating back to the 13th century, it shows that it was the responsibility of the society to control floods and to minimize the risk of flooding. This view still holds, the interviews held in Upper Tisza [39] showed that most people feel that the government should compensate the victims if a levee fails. This has also been the policy, the government has a responsibility both to protect and compensate.

The technical and economical development in the 17th century made a more modern flood control approach possible. This was urgently needed as 4 000 000 ha (more than 40 per cent of the total territory of Hungary) used to be inundated when the Tisza flooded.

Before the regulations, it used to flow through the deeper parts of the Great Plains freely, causing severe damage to the arable-land agriculture. In order to increase the productivity in the region, the public appeal for river regulation grew. During the second half of the 18th century and the first half of the 19th century, activities like mapping, data gathering, planning, and designing provided the bases for flood control. The most urgent development goals for Hungary were formulated by count Istvan Széchenyi. Flood control and regulations of rivers were given top priority. Széchenyi started a national river regulation and flood control program on the Tisza River in August 1846. The plans designed within this program were almost entirely implemented during the last one and half century, as reported by Hankó [18]. During this time, Hungary became the scene of Europe's largest river controls. Large portions of land that earlier were flooded by the Tisza, were transformed into arable land. The result of these efforts is an extensive system of levees, controlling 3 860 km of the river.

3 Flood Management Strategies

Flood risk management strategies can be structured into pre-flood strategies and post-flood strategies, this is one of many possible categorisations of the different strategies:

1. Pre-flood strategies
    - Mitigation
        - Structural measures
            - Levees
            - Dikes
            - Reservoirs
        - Non-structural measures
            - Relocation
            - Coding, zoning, and proofing
            - Renaturalization
    - Response
        - Warning and forecast
        - Training and preparedness
2. Post-flood strategies
    - Recovery
        - Allocating funding
            - Government
            - Insurance
            - Charity
            - Self-help
    - Loss Sharing
        - Government compensation
        - Insurance
            - Public
            - Private
            - Public/private
        - Aid

Mitigation: Structural Measures

The most ambitious flood control measures within this group are levees, dikes, and flood-walls. Apart from assisting in flood control these structures also provide for irrigation, recreation, and hydroelectric power.

Levees are embankments along the course of a river. Many rivers produce levees naturally during floods when the overflowing river deposits debris along the bank. Gradually this builds up and contains the stream into the channel. Artificial levees are constructed in much the same manner. They may be temporary, as when sandbags are used during flooding, or permanent when the banks are raised to keep the river in its channel during times of increased water flow. Levees protect the surrounding countryside from floods by holding more water in the channel. They also aid in navigation by deepening the channel. A flood-wall is very much the same as a levee, but built out of concrete or masonry, instead of sand. Dikes are similar to flood-walls in all respects except that they usually refer to holding back large standing bodies of water, such as an ocean. A system of dikes prevents the North Atlantic Ocean from flooding the Netherlands.

Mitigation: Non-Structural Measures

The most typical feature of the measures belonging to the group of non-structural measures, is that they do not alter the physical characteristics of the river. These measures instead aim at changing the consequences of floods. For the last fifteen years, there has been a change in focus away from structural mitigation to non-structural mitigation measures. In industrialised countries, one possible non-structural solution is re-location. Families and businesses are moved out of the flood plain. This method is not commonly used, as there are many problems related to moving people. Even if such a policy would be economically rational, it is not often liked by the people living in the flood plain, why it is politically incorrect in most countries. In a land area with a given risk of inundation, regulations prescribe what can be done. It might for instance be forbidden to build certain types of industries in areas with a high risk of inundation. Because of the cost and environmental impacts of flood-protection structures, many parts of the United States rely on land-use regulations to prevent flood damages. This view is gaining popularity also in Hungary. Prime Minister Viktor Orban said in a radio interview that he would try to block local governments from issuing building permits in flood plains.[1]

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[1] He also said that he would see to it that a National Lands Foundation is set up to stop cultivation of farmlands that are frequently flooded, consult ReliefWeb [16] for more

Response and Recovery

Different concepts such as flood forecast, flood warning, and evacuation programs are grouped under this label. Awareness programs are tailored to fit the specific village or community at risk. The community engagement is very important for preventing a natural disaster or reducing the effects of a natural disaster. In very short time the event can occur, why external help may not reach its location in time. The organisation and education of local volunteers is more and more recognised as an important flood risk management strategy [1].

Loss Sharing

In most countries the government compensated victims from natural disasters to some extent. While British people get almost no compensation at all in case of a flood, Hungarian people are used to receiving full compensation. For large disasters, where the region lacks funds for recovery, aid from other regions or from other countries are quite common. In countries with restrictive government compensation, the individual can buy additional protection in form of insurance. Insurance is a way to distribute the losses over time and between policy holders. There are many different types of insurance, some are strictly commercial while others are fully or partly run by the government. A well functioning loss sharing mechanism is important for the recovery of a region or a country. The risk is often reflected in the size of the insurance premia, or no insurance is offered at that location. In either case, the property owner has to pay for choosing to live in a high-risk area. This could be considered fair, or unfair. The design and implementation of loss-sharing strategies in a country is tightly connected with political and ideological views. By implementing good loss-sharing strategies, the losses can be reduced. If a property owner has to take private precautions, in terms of proofing the cellar for instance, to be able to buy insurance, then the losses are likely to be lowered.

3.1 Approaches to flood risk management

Different stakeholders have expressed their opinions on flood risk management policies in interviews [38, 39]. Based on these opinions, the following categorisation has been made by Linnerooth-Bayer. It is strongly stylized, and tries to illuminate the differences in the approaches:

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information.

1. Hierarchical approach
   This approach promotes governmental responsibility, with no private responsibility. Large-scale structural measures are built and maintained by the government. If a levee fails, or if an unprotected area is flooded, the government compensates the victims.

2. Individualistic approach
   The responsibility lies on the individual, private responsibility is extensive. People should be relocated if they live in a high-risk area, but they should receive compensation for this. A system of private insurance is an ingredient, with a margin for private incentives; in order to get a reduced premium of the ground has to be waterproofed, for instance.

3. Naturalistic approach
   This approach considers floods as natural, it would be better to take down the levees and let the hydrological balance take over. The government should actively support sustainable development. An alternative non-profit insurance system could be a part of this picture.

In countries like Australia, USA, and the Netherlands, there has for the last fifteen years been a change in focus away from large-scale structural measures to non-structural mitigation measures. There is a growing recognition that the problem of flooding cannot be successfully managed by structural mitigation solutions as these deal with the symptoms of the problem, and not the problem itself.

The increasing concentration of people and property in flood-prone areas raises questions of responsibility and vulnerability. By building flood-walls and dams the frequency of floods in an area is reduced, allowing for changes in land use. The flood risk is not eliminated, however. The structures only give protection up to a certain flood level, and there is also a risk of failure of the structures. Large expensive structural measures initiated and supported by the government, seems to be very much off the current policy agenda, this view was put forward at the Australian Disaster Conference [1]. A new holistic view recognises the importance of working in harmony with nature and of approaching the problem of flooding in terms of responsible management and restoration of the natural function of rivers. Instead of spending public funds on flood mitigation structures, concrete channels are removed and the original meandering streams are restored. This new ecological approach has different names in different places, such as Total Catchment Management in Australia and Watershed Management in the United States.

4 The Hungarian Insurance Policy Problem

The cost for protection and loss reduction is peaking and the Hungarian government is considering a flood management program where private insurance plays an important role. One reason for such a program is that it is a fairer way of sharing the losses from flooding: people who choose to live in flood-prone areas should carry a larger financial responsibility. Another vital reason is said to be that private insurance would modify the population distribution so that fewer people would live in flood-prone areas. This is supposed to be the effect of reflecting the risk-proneness of a geographical location in the size of the insurance premium. The people who prefer to live in a flood-prone area must either be willing to pay high premiums or to bear the loss themselves in case of a flood. In Upper Tisza, few people would afford private insurance without subsidies from the government or cross-subsidation among the insurance takers, which raises questions on equity and fairness. Should poor people be forced to move from areas where their families might have lived for generations?

4.1 Distribution of the Economical Responsibility

In most countries, the government helps the victims of a natural catastrophe. This can be viewed as a public insurance method, as all taxpayers contribute to the governmental budget through their taxes. To date, this form of collective loss sharing, financed by the tax-payers of today and of tomorrow, plays the most important role in absorbing the financial losses from the victims of natural disasters [10]. In some countries, these premium funds are treated separately in a national disaster fund or a catastrophe pool, while in others the premiums are not separated from the state budget. Governmental insurance is a program where all property owners in flood prone areas are obliged to carry flood insurance. Instead of a private insurance company, the government institutes this insurance program. The rationale for this system is that private insurers would stand too high a risk of bankruptcy.

At the other end of the scale of responsibility lies private insurance. The private insurance can be combined with a public guarantee to assure that the insurers can rely on financial backing to avoid insolvency in case of exceptional floods. Private insurance is often restricted by many exceptions. In the Upper Tisza flood basin, insurance is only available for households in protected areas, and the insurance only cover inundation resulting from catastrophic failure of major levees.

4.2 Responsibility for Compensation of Losses

The Hungarian Prime Minister Viktor Orban declared that the state would compensate for most road damage, and was likely to decide in favour of assisting local governments in repairing damage to roads they own, from the flooding in spring 2000. He also said that the government would not categorically reject any claim related to flood damage, see ReliefWeb [16]. In Hungary there is no explicit duty of the government to compensate flood victims, but it is the policy followed in practice. Around the world different countries have implemented different strategies on how to carry the economic responsibility. In most countries, it is common to compensate flood victims except for a few countries like the UK and Australia; more information can be found in a World Bank report [2]. In Italy, the government used to compensate most of the losses for the victims. As they have to live up to the Maastricht restrictions on government deficit relative to GDP, they are now however looking for ways of passing a large part of the compensation to the private sector; for more thorough information, consult Mitchell [7].

4.3 International Implications

The most recent flooding has also highlighted the international implications of the problem, as reported in the Swedish newspaper DN [6]. The Hungarian part of the Upper Tisza region borders to Slovakia, the Ukraine, and to Romania. Prime Minister Orban accuses the neighbouring countries Romania and Ukraine for causing the flood by massive deforestation along the Tisza River. The effect of the cutting of trees is that the melt water from the snow in the Carpathian Mountains is not absorbed by the soil, but instead fills the river channel.

4.4 Current Flood Management Strategies in Hungary

The use of structural measures is still very much on the political agenda. In the spring of 2000, Hungary received a World Bank study free of charge that proposed to build dams at a length of 740 km over 10 years at an estimated cost of HUF 60 billion. The Hungarian government has allocated an equally large amount to reinforce dams during the same time period, according to the Hungarian American List [29].

There are also discussions on the possibilities of implementing a National Insurance system. The advocators of such a system stress the usefulness of an economical fund, or pool. Having the entire population contribute via an insurance channel would finance this pool. By spreading the contribution to the pool equally, the premiums in areas where the risk is high can be kept on an acceptable level. The pool would serve at least two purposes. First, to acr as capital buffer needed for insurance companies dealing with catastrophic risks. As the events are interdependent, the companies stand a high risk of insolvency if a large flood occurs. In Hungary, there are only 17 non-life insurers at work, as compared to 200 in Ukraine. A pool could play the role of a risk reserve for the insurers, making the difference between insolvency or survival and also a means to keep the premiums on an affordable level. The second purpose would be to minimize costs for the government in terms of economic compensation to the victims. At present only 60 per cent of the 3.8 million households are insured in Hungary and in the Upper Tisza region as few as 30 per cent carry property insurance. Possible explanations of this can be economic situation, as poor households cannot afford to pay the premiums, regardless of the size. The households with higher income feel they cannot afford insurance, as the premiums reflect the risk in the region. In some areas, insurance companies are not offering insurance due to high hazard potential possibly in combination with a history of high claims. Some of the buildings are considered uninsurable, as they do not meet the minimum construction standards stated by the insurers. When a catastrophe occurs, the joint efforts of the local inhabitants have proved to be the most efficient defence. For instance, in November 1998, the dikes failed in the Ukrainian section of the Tisza River and destroyed several communities. As a result of heroic flood-fighting efforts, the river did not overtop the dikes in the Hungarian section, but damages caused to levees, roads, and agricultural production in the flood plain were significant. The adoption of a stakeholder approach is one way of addressing the need for commitment among volunteers. In Hungary the participation of citizens is not yet developed. The local and regional defence and evacuation plans are not public, leaving the people at risk with insufficient knowledge for taking proper action in case of flooding [40]. The cyanide spill in the spring of 2000 brought with it raised voices for a new ecological approach to flood-plain management where the overall aim is restoration of the ecology in the region [5].

The effects of the withstanding regulations of the Tisza River are now being debated. The dams that were built during the regulation of the river cut off the flood plains and run-off areas from the riverbed, thus minimizing the flood-risk beyond the dams. At the same time, the dams caused severe losses to natural values and biodiversity. Environmental non-governmental organisations (NGOs) in Ukraine and in Hungary have suggested that all development is stopped in the flood prone area and that it be turned into a national park.

5 The Problem From a System-Analytic Perspective

5.1 Catastrophe Modeling

For complex problems, the use of a generalised representation, a model of the problem, is commonly used. The flood risk management problem in Upper Tisza is a complex policy problem due to the large degree of uncertainties, the many interdependencies, and the ambition to incorporate different stakeholders. As historical data on natural catastrophes normally is insufficient for predicting events at any particular locations, catastrophe modeling can to a certain extent compensate for this lack of historical data.

5.2 Flood Probabilities

The probability for a flood to occur during a certain year is normally expressed by its return period. Hydrologic frequency analysis is the evaluation of hydrologic records to estimate how often events of a given magnitude or greater will occur. A 100-year flood is a flood of such magnitude that over a long period the average time between floods of equal or greater size, is 100 years. The term return period is treacherous as it gives a false sense of security. It is often misinterpreted to be a statistical guarantee that hydrologic events of a given size will occur on a predictable, fixed time schedule. The probability concerns one single year and tells nothing about the accumulated risk during a longer period. The accumulated probability for a 100-year flood to occur during a time period of 50 years is 39 per cent. A 100-year event might happen once, twice, several times, or not at all during our lifetime. It is also important to remember that the calculated probabilities only are valid for a specific location in the river. As the conditions in regulated rivers often change, as new dams or reservoirs are built successively, it is very difficult to estimate the likelihood for flooding. For extreme floods, with a very long return-period, for instance a return-period of 10 000 years, the probabilities are very hard to calculate as there are few historical records to look at. In most cases there are not even 100 observations to ground statistics upon.

Severe flooding in regulated rivers occur less frequently than in unregulated rivers. Still, floods do occur in regulated rivers from time to time. When these events occur, they are unexpected and people are not prepared. For the flood managers and the policy-makers, it is important to remember that not all flood risk can be eliminated by protections. Whatever mitigation measures are taken, there is always the issue of "residual risk" and the rare event. The 1993 floods of the Mississippi/Missouri River in the USA, when 48 people were killed, is an illustrative example on how systems designed to prevent the relatively frequent, moderately destructive flood, are overwhelmed and almost completely ineffective against the more rare devastating flood. Occasionally even structures built to stand against large floods break, either from old age or from an abundance of water. In 1228, for instance, a major flood smashed through the first primitive dikes in Friesland, the Netherlands, killing at least 100 000 people, see Rekenthaler [33]. Even when levees do not break, floods can still occur. The rivers and their tributaries may for instance swell due to large spring rains. Eventually they overflow their banks and inundate the surrounding flood plains. The Yellow River in China is known for its tendency to overflow its banks. Soil carried by the Yellow River has been deposited in large amounts at the bottom of the river. Because of the soil deposits, the riverbed has been raised, increasing the risk of flooding. In the 1887 flood, nearly a million people died in China after the river overflowed its banks largely due to crop failures and famine that followed from the catastrophe, as reported by the LA Emergency Operations Bureau [3]. Seen from an economical perspective, it is impossible to build ever-larger structures to cope with events of extremely low probability. The cost for protection against very rare events grows exponentially. By building a new protection at a specific location along the river, the risk is modified. The variance and frequency of risk is transformed, but the risk is not eliminated. By building a dam upstream, the probabilities for a flood downstream will increase. If a levee is made higher, floods will be less frequent but the consequences more severe.

5.3 Rationale of the Tisza Model

The conditions in rivers are affected by many different systems, and the river system affects them. The probabilities for a flood to occur in a river and the consequences of a flood are related to systems of economy, ecology, meteorology, and hydrology. These systems are in turn influenced by the conditions in the river system. In all these systems, uncertainty is inherent. The dynamic interaction between humans, nature and technology makes the flooding problem even more multifaceted. Because of the inherent uncertainty and complexity, flooding different from anything experienced in the past might occur. Nature catastrophes do not repeat themselves. The uncertainty is further aggravated by the technological revolution: new flood protection policies make old knowledge about flood management unreliable.

The uncertainty and complexity of the flood management problem of Upper Tisza makes it very hard to use analytical methods to estimate the consequences of potential policy strategies. Due to the relative infrequency of catastrophes there is also a lack of historical data concerning major floods, and data on minor and moderate floods is of little help when assessing new policy decisions as the physical and economical landscape is constantly changing. New houses are built and assets are clustered in new locations. The methodology of “learning by doing” is not applicable when coping with rare events like natural disasters. The interval between two occurrences could be very long, and it is not morally defensible to experiment with the security of humans in order to find good protection strategies. By combining mathematical representations of the natural occurrence patterns and characteristics of a flood with information on property values, construction types, and compensation policies, a simulation model can generate loss estimates that aid the policy makers and the stakeholders in assessing different policy strategies.

5.4 Relations in the Tisza Model

A number of relations should be represented in the model. These are listed on a very abstract level here, and will be specified further.

- The cost function C determines the cost of mitigation for each agent.
- The flood function F determines the characteristics of the simulated flood.
- The inundation function I tells how the flood water overflows land.
- The vulnerability function V determines how vulnerable a building is.
- The damage function D determines how much damage the flood causes a certain asset.
- The loss function L determines how large the economical losses for an agent is, measured by the size of the replacement value.
- The wealth transformation function W determines how the wealth of each agent changes over time.

For the Tisza model to be useful it must illustrate the spatial and temporal dependencies, specific to the studied area, and specific to each stakeholder, or agent, represented in the model. As stated in the project description, the Tisza model is intended to play two roles:

1. To be used as a tool in integrated assessment.

2. To assist policy makers in identifying optimal, or at least robust, policy strategies.

The different roles pose different design requirements on the model, these are discussed and identified in the following two chapters.

6 Integrated Assessment

Integrated assessment (IA) can be defined as a structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders, in such a way that integrated insights are made available to decision makers [34]. There is a growing recognition that the participation of the public and other stakeholders is an important part of IA. This view is also recognised in the Tisza project, where it is stated explicitly as a goal to adopt an integrated participatory approach. The method for fulfilling this goal was:

1. Extraction of mental models of organisations, institutions, and the public, as input for the catastrophe simulation model.
    - An investigation of the flood risk conditions and existing mitigation and loss-sharing alternatives was made [25, 31, 17]
    - A public survey was conducted to investigate public opinion on flood risk policy management issues, see [38, 39]
2. Communication and development of the model, together with the stakeholders
    - Interviews with stakeholders in Upper Tisza
    - Presentation of the model simulations, with different policy scenarios
3. Validate the model structure and simulation results with the stakeholders
    - During the final stakeholder workshop

It is, however, not self-evident how to design a model to be useful in IA. The setting where a group of stakeholders and public participators use the model collaboratively is very different from more traditional use where an expert policy-maker consults the model to gain insight into specific issues. There is not much information on what methodological requirements to make on the design of the model for participatory IA to be found. One exception is [11], the Working Paper from the ULYSSES project. The ULYSSES project is a European research project on public participation in Integrated Assessment. The project has aimed at advancing IA methodologies by pursuing the following specific research goals:

1. Advancing IA methodology by integrating computer models with a monitored process of social learning.
2. Testing this methodology on problems of urban lifestyles and sustainability.
3. Tailoring this methodology to fit the cultural heterogeneity of the EU.

To fulfil the first objective, 52 so-called focus groups around the world were studied. In these groups, a number of citizens together with a session leader met approximately five times and debated climate change and different climate policies. The focus groups used one of six state-of-the-art computer models as help within the discussions, see Appendix B of the Working Paper [11] for a description of the different models. The six models used are different, ranging from complex and dynamic global models to simple accounting tools.

The results of this study are of high relevance to the design of the Tisza model, as one of the purposes of the Tisza model is that it should be used in a participatory setting where different policies are discussed and assessed by the stakeholders involved.

6.1 Spatial and Temporal Scales

The different spatial scales in the models used by the focus groups caused problems. While most participants considered global information as necessary for the discussion, they were more interested in regional and local aspects. Climate change as a global and long-term risk proved to lie beyond this horizon of "here and now" and to think about it was unusual and challenging for the participants.

Issues that need to be tested and evaluated before the Tisza model is used in a collaborative setting are what scales the model will use. The spatial data for a pilot basin is currently available in three different scales: aggregated for the entire basin, aggregated per municipality, and per individual cell (10×10 metres). Should only one of these scales be used or is it possible to combine two or more in the same model? The time scales are also difficult, and a short time interval is required when the catastrophes are simulated, e.g., one simulation round per month. As insurance is on the political agenda, it must be possible to evaluate different insurance schemes, for which a time steps of one year seems natural for testing premium sizes. As the floods are rare, the time period covered by the model must be quite long, say, 50 years per simulation.

6.2 Complexity

In the focus groups that used computer models with a large number of interacting variables and constants, the complexity was difficult to manage both for the participants and for the session leader. They felt that the level of complexity was too high for the little time available and the given scientific understanding. If the Tisza model is to be used in a stakeholder session, the complexity will have to be reduced as much as possible. Tests must be performed in advance to find the right balance between reduced complexity and remained usefulness. There is a risk that a simple model will convey simple insights, i.e. results that can be achieved without the use of a model. When the model is to be used in a participatory manner, the balance between complexity of the model and time available must be good.

6.3 Exploration of Policy Options

How useful the focus groups found the model to be for exploring different policy options depended on whether it was a global or a regional model, where the regional models proved to be more useful. This result is easily understood, as the consequences for local decisions are less uncertain than the consequences of global decisions. However, the regional models were criticised for not addressing the exploration of policy options in a convincing way. One of the groups complained that the model said nothing about feasibility; to what extent the measures suggested and tried were realistic, given economic, social and political constraints. It was left to the users of the model to critically evaluate their own selection of variables, which made the participants in the focus group feel abandoned.

In the Tisza model, the stakeholders must be given the opportunity to explore different policy options. An ideal situation would be if the policy variables could be changed interactively during the session without making the model too hard to understand.

6.4 User-Friendliness

The language used in the model proved to be a problem for many persons in the focus groups. Several of the terms used were unknown to the participants and the leader of the focus group had to translate into a less academic language. Regarding the graphical user interface (GUI) of the model, most groups found that the participants expected far more excitement in the form of fancy graphics and moving pictures, and that the participants wanted to see colourful maps and more vivid imagery. They felt that the graphical potential of modern PCs had not been fully utilised and would have appreciated sounds, video-clips, etc. This would have helped the understanding of the issues most difficult to grasp. The participants who were more familiar with computers typically asked for more interactivity, they said that the possibility to interactively change the values on a variable and to see the effect it caused would give the model higher believability. When designing the Tisza model, much effort should be put on the GUI. The users are likely to expect colours, sounds, and possibilities to interact with the model, and there is a risk that the users will feel disappointed if these features are left out.

7 The Tisza Model as a Tool for Policy Makers

On a very general level, the Tisza model will simulate a time period in the pilot basin, with regard to the occurrence of floods and the consequences of them. During the simulations there will be a flood when one of the following occurs:

- The water level (WL) exceeds the height of the levee (LH).
- The flow rate (FR) exceeds the resistance of the levee (LR).

The Tisza model is not only designed to be useful in a participatory setting, but for aiding policy makers in identifying good policy strategies. In a participatory setting the use of pre-compiled scenarios can be motivated, as the goal might be to reach consensus or to make clear where the different stakeholders disagree. A decision-maker needs help to identify the best policy strategy given a number of assumptions and constraints.

7.1 The Influence of Policy Strategies

The set X contains all relevant policy strategies. A specific policy strategy, x_i, is a combination of one or more policy alternatives with specified attribute values for each attribute.

A policy alternative can for instance be the strengthening of an existing levee, the implementation of a new flood tax, or a reduction in compensation from the government. The task of the policy maker is to design on a policy strategy x_i, this means to set the attribute values of all alternatives in X. To indicate that an alternative is not included in the strategy the attribute values of that alternative are simply assigned "nil". The consequences of a flood depend to a large degree on the current policy strategy. The height (LH) and resistance (LR) of a levee affect the frequency and size of floods. By adjusting the policy strategies, the overall outcome of the simulations will be affected, why many functions depend on the value of x:

- The cost function $C(x)$ determines the costs of mitigation for each agent. The cost is directly linked to the current policy strategy: the strengthening of a levee will affect the costs the government agent, for instance. The cost for a policy strategy might be shared by all agents, through taxes, or carried by a group of agents, the property owners for instance.

- The flood function $F(t, x, WL, FR)$ is dynamic and determines the water level and discharges in a number of initially specified cross sections the time $t + 1$, given the conditions at time $t0$. If the physical conditions in the river are altered, if the height of a levee is increased for example, the conditions will be affected. There is a flood whenever $WL > LH$ (height of levee) or $FR > LR$ (resistance of levee), if x comprises one or more levees. With or without a levee, a flood occurs whenever $WL > borderheight$.

- The inundation function $I(x, t, F(t, x, WL, FR))$ specifies the water levels at all geographical cells when there has been a flood. This function is also dynamic, the duration of an inundation can be obtained.

- The vulnerability function $V(x, SD)$ determines how vulnerable an asset is. The policy strategy can affect the vulnerability, if the policy includes proofing of all houses, then they will be less vulnerable to a flood. The specific soil type, and land-use at the location also affect the vulnerability. This information is gathered in the variable SD, for spatial data.

- The damage function $D(I(x, t, F(t, x, WL, FR)), V(x, SD))$ determines how much damage the flood causes a certain asset. The damage is a function of the inundation pattern, and of the vulnerability of the flooded asset.

- The loss function $L(x, D(I(x, t, F(t, x, WL, FR), V(x, SD))))$ determines the magnitude of the economical losses for an asset. The size of the losses depends on the damages and on the current policy strategy. If x incorporates a certain level of compensation from the government for instance, then the losses are reduced.
- The wealth transformation function $W(x, t)$ determines how the wealth of each agent is modified over time. The wealth of an agent is influenced by policy decisions, viz. the tax level.

7.2 The Objective Function

The objective function $f(x)$ measures the performance of a certain policy strategy at time t. Whether the objective function should be minimized or maximised is merely a design choice. A simple example of an objective function could be to minimize the costs and the economic losses is shown in equation 1:

$$z = f(x) = C(x) + L(x) \quad \text{should be minimized} \tag{1}$$

7.3 Constraints

Policy makers have to take different kinds of constraints into consideration when looking for the best policy strategies. These constraints might be logical, economical, or environmental. These constraints, $G(x)$, are expressed either as equations, or as linear inequalities. A linear inequality might for instance be that the compensation paid by the local government must not exceed its current wealth. The problem for the policy maker is to find the best policy strategy x with regard to the objective function without violating the constraints, see equation 2.

$$\begin{array}{rcl} \text{find} & x \in X & \\ \text{such that} & h_i(x) = 0, i = 1, \ldots, n & \text{and no constraints are violated} \\ \text{and} & z = f(x) & \text{is minimized} \end{array} \tag{2}$$

The different policy strategies are compared against the objective function, and the strategy that returns the smallest value of z without violating any constraints, is the best policy strategy.

7.4 The Influence of Uncertainty

Assessing the economical consequences of a certain policy strategy is difficult, especially when dealing with potential future policy strategies. Instead of assessing the experienced consequences of a policy, by looking back at the outcome, the consequences must first be estimated.

For the Upper Tisza flood management problem, several uncontrollable, or exogenous, parameters affect the consequences of a policy strategy. The consequences depend on the strength of a flood, the time when it happens, and the vulnerability of the inundated property, among other things. Because the occurrence of a flood, as well as the consequences of it, is probabilistic, the Upper Tisza model uses stochastic modelling techniques to generate simulated floods. A large number of conditions, or states of the river, are simulated in an iterative process. The stochastic variables are assigned random values from their probability distributions for each new simulation round. The set Ω contains all states the river system can be in. Each state ω_i consists of a vector of random variables. Each random variable is assigned a value from its corresponding probability distribution.

In flood simulation models, the random variables would typically include the discharge and river water level, as well as key meteorological parameters like precipitation, wind-speed, and temperature. Also other variables like inflation rate and unemployment rate could be included in Ω. It is important that the probability distributions are carefully selected, as they constitute a key assumption about the simulation model.

By randomly selecting a value for each variable from its distribution flood model simulates a time period, normally a month or a year, of flood activity. A large number of such simulations are performed to ensure that the estimated consequences of a policy strategy are representative. Many parts of the system are directly or indirectly affected by what state the river system is in. In the mathematical representation this is made explicit by letting the functions depend on ω, the randomly decided state.

- The cost function $C(x, \omega)$ is dependent on ω. The inflation rate and the weather conditions are likely to influence the cost for mitigation.

- The flood function $F(t, x, WL, FR)$ is affected by ω through the WL function and the flood rate (discharge) function.

- The inundation function $I(t, x, \omega, F)$ is influenced by the values of ω. The wind-speed and wind direction has impact on the inundation pattern.

- The vulnerability function $V(x, SD)$ is not a function of ω.

- The damage function $D(\omega, I, V)$ comprises uncertainty. The weather conditions have impact on the damages for instance.

- The loss function $L(x, D, V)$ is not directly affected by ω.
- The wealth transformation function $W(x, \omega, t)$ depends on the random outcome. The inflation rate affects the income and the expenditures.

By addressing uncertainty explicitly, the policy problem gets more complicated. If the constraints and the objective function are affected by ω, then E, the estimated values of the objective function and the constraints must be considered. The equation 3 describes the task of finding a policy strategy that minimizes the objective functions without violating any constraints, when uncertainty is taken into consideration.

$$\begin{array}{rcl} \text{find} & x \in X & \\ \text{such that} & Eh_i(x) = 0,\ i = 1, \ldots, n & \\ & Eg_i(x, \omega) \leq 0, i = 1, \ldots, n & \text{no constraints are violated} \\ \text{and} & z = Ef(x, \omega) & \text{is minimized} \end{array} \tag{3}$$

Policy makers dealing with catastrophic events must specify what risk means in their specific policy setting, and to what extent risk should be avoided. For a flood management problem at an abstract level, the risk function could be the probability of a flood. When reducing risk is the single goal of a policy maker, then the objective function consists only of a risk function. In most real situations the decision-maker has to take other things into consideration as well. A flood management policy strategy that suits a local government would have the risk of insolvency as a part of the objective function, together with the objective to maximise the wealth, or budget. An objective function can consist of one objective function combined with one or more risk functions.

7.5 Adaptive Stochastic Simulations

When X and Ω contain more than a few items, the number of possible policy strategies to evaluate becomes unmanageable. The objective function in a catastrophe model can be non-smooth or even discontinuous. A local government would normally include the wish to maximise wealth, or maybe rather to minimize the deficits in the objective function. A stylized trajectory of the wealth transformation would look like an irregular stair. Simplifications of the problem, by substituting the random vector Ω by the expected values of the variables according to their distributions may lead to sub-optimal decisions. The Expected Wealth would grow linearly and insolvency would not occur at event number three, see Figure 5. The mean value hides the extreme values, and these need to be investigated when looking at catastrophic risks, characterised by having low probabilities and severe consequences. By running Monte Carlo simulations, it is possible to estimate the consequences of a policy strategy in domains including uncertainty.

A problem with traditional simulations is that it might lead the decision-maker into an endless number of time-consuming 'if—then' scenarios. Such runs start with an initial design of the policy strategy x, with which a large number of simulations are run. If the outcome of the simulation proves unsatisfactory, then the policy strategy is modified. For decisions with a large amount of alternative policy strategies, this method is highly inefficient.

To aid policy makers in identifying robust policy strategies within reasonable time limits, the Tisza model instead uses adaptive stochastic optimisation techniques. This means that several simulations are run in a series. After the first simulation the values of X are slightly changed, according to the optimisation algorithm. By running a series of simulations with an automated adaption of the policy strategy after each round, the search space is reduced, only the paths that showed promise in earlier rounds will be further explored, see Ermolieva [12] for more detailed information.

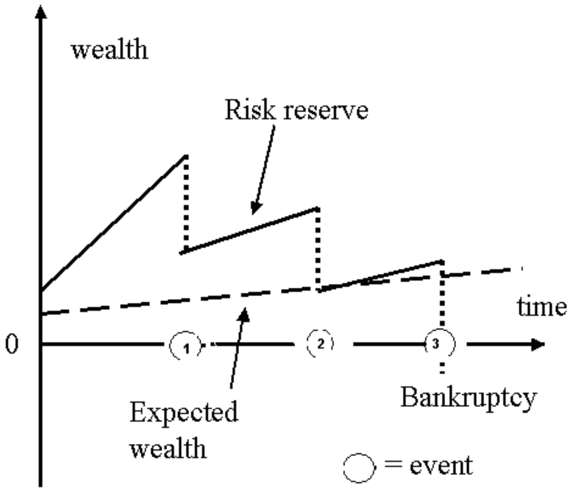

Figure 5: A stylized trajectory of the wealth of an insurance company, three events occur.

8 Executable Modules

The Tisza model will consist of a number of executable modules. The ones identified so far are the Stochastic module, the Catastrophe module, the Spatial module, the Agent module, the Consequence module, and finally the Policy and Optimisation module.

8.1 Stochastic Module

The purpose of this module is to address the uncertainty inherent in the policy problem. As the model will be used to assess different potential policy strategies, the model has to deal with the uncertainty of the future. The variables, for which we can not predict the value, are referred to as random variables in this model. The most important variables to include in Ω are:

1. The water level (WL) at all specified cross sections
2. The flow rate (WF) at all specified cross sections
3. Amount of precipitation (APR)
4. Intensity of precipitation (IPR)
5. Outdoor temperature ($TEMP$)
6. Wind speed (WS)
7. Inflation rate (IR)
8. Unemployment rate (UR)

For each variable the probability distributions must be provided. During each simulation round new values for the variables in Ω are randomly picked according to their specified distributions.

- Input (initialisation):
  - The set Ω containing the random variables, and their corresponding distributions
- Output (each round):
  - A random outcome, ω_i

8.2 Catastrophe Module

In the Tisza model, the catastrophes simulated are floods, but in other applications they might be earthquakes or cyclones. The Tisza model builds upon a catastrophe model made by Ermolieva [14] for simulating cyclones in Italy. Hydrological experts designed and built the catastrophe module. The Hungarian project partners possess expert knowledge in this field and they contributed two computer models, a hydrological model and an inundation model. The two models together constitute the catastrophe module. They are quite complex, for a more thorough description refer to documentation [35]. However, a brief explanation of the two models will be given here, in order to make the understanding of the data flow in the Tisza model easier.

In the hydrological model, the river channel of the pilot basin is represented as a network of connected hydrological units. The units are of the type cross-sections, nodes, branches, or levees. Each type has specific characteristics in terms of water resistance, etc. The hydrological model calculates the river water level (WL), and the flow rate (FR) at a number of cross sections in the network. This is done each time step, given the conditions last time step as input data. The hydrological model corresponds to the flood function $F(x, \omega)$.

Model number two, the inundation model, specifies how the water overflows the land neighbouring the river. Data collected from geographical information systems (GIS) has been used to produce inundation maps. The inundation model is represented by the inundation function $I(x, \omega)$.

- Input to the Hydrological Model (initialisation):
  - Descriptive data on the hydrological units (cross-sections, nodes, and branches)
- Input to the Hydrological Model (each round):
  - Current policy strategy, x
  - The random outcome, ω, specifically WL and FR
- Output from the Hydrological Model:
  - Water characteristics, new WL and FR, at selected cross sections
- Input to the Inundation Model (initialisation)
  - Digital Elevation Map (DEM) of the pilot basin
- Input to the Inundation Model (each round)

  - Current policy strategy, x
  - The random outcome, ω
  - Water characteristics, new WL and FR, at selected cross sections
- Output from the Inundation Model
  - Vector of inundated cells
  - Information for each inundated cell:
    - Duration of the inundation (number of days)
    - Depth of water level

8.3 Spatial Module

The spatial features of the pilot basin are represented in three different scales. As an aggregate of the entire pilot basin, on a municipality level where the eleven municipalities in the basin form the units, and on a very fine-grained level where 1551 × 1551 equally large cells (10 × 10 metres) form a grid. The use of GIS data makes it possible to use distributed asset data rather than data aggregated on a municipality level or aggregated for the entire flood basin. Due to this distribution, the model can be used to estimate the

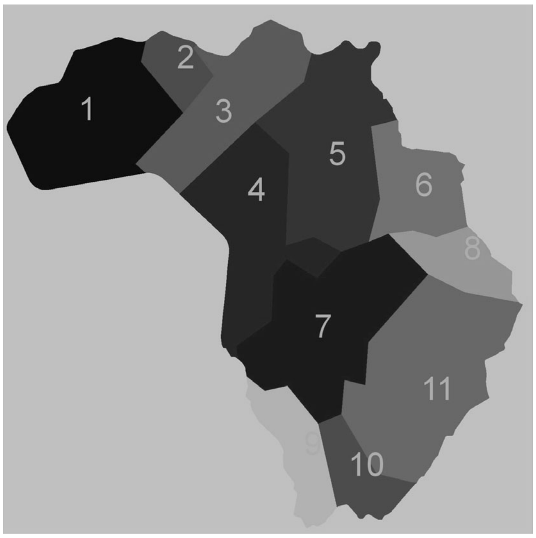

Figure 6: A map of the pilot basin with the eleven municipalities (listed in numerical order): Tiszakorod, Tiszacsecse, Milota, Sonkad, Tiszabecs, Uszka, Botpalad, Magosliget, Tiszaberek, Kishodos, and Kispalad.

consequences of a policy strategy on the cell-level as well as on an aggregated level, for the entire municipality.

- Input to the Spatial Module (initialisation):
  - The Grid, a grid with n cells
  - Spatial data (SD) for each cell:
  - Municipality code 1-11, (see Figure 6) or 0 which indicates that the cell is outside the pilot basin
  - Asset value
  - Owner ID of each asset
  - Current land-use (code)
  - Digital elevation (metres above Baltic see level)
  - Input to the Spatial Module (each round)
  - Vector of inundated cells
  - For each inundated cell:
    - Duration of the inundation (number of days)
    - Depth of water level
- Output
  - For each inundated cell:
    - SD, spatial data

8.4 Agent Module

To be useful in participatory settings it is crucial that the model can estimate the effects of a policy strategy for different stakeholders or interest groups. The term agent here means stakeholder or interest group as an aggregate, it does not imply that the agent has the ability to communicate or act autonomously. It is stated in the project description that the different stakeholders should be represented and involved in the policy process. Many different kinds of agents can be identified as relevant to the flood management problem, e.g, the central government, the local government, the water bureau, the insurance companies, environmentalists groups, farmers, and property owners.

The interests of the agents in the model are characterised by their objective functions. Note that the objectives of the different agents could be conflicting. A specific policy strategy might be advantageous to one agent, while devastating to another; it is not sure that a strategy that maximizes the insurer's profit is popular with the individual property owner. The variable z is assigned a value from the objective function each round of the simulation. Assessing a policy strategy includes analysing how z changes over time for the different agents. In many cases the economic wealth is part of the objective function for the agents, and in these cases a wealth transformation function is required.

- Input to the Agent Module (initialisation)
    - For each type of agent (aggregate)
        - Objective function, $f(x, \omega)$
        - Wealth transformation function, $W(t, x, \omega)$
        - Initial wealth at time = t_0.

8.5 Consequence Module

For each round in the simulation when there has been a flood, the consequences must be calculated for all affected agents. The consequences from a flood vary with the location why spatial data is used in this module. Inundation information is received from the Catastrophe Module and additional data on each inundated cell is received from the Spatial Module. The damage function estimates the degree of destruction for an asset, by looking at how vulnerable the asset is among other things. A typical damage function for property would take into account the depth of the inundation, the duration of it, how vulnerable the building is, and the current weather conditions. A flood will have economic consequences for different agents in the model, the owner of a flooded asset will have its wealth updated. The wealth of other agents than the owner of an asset can also be affected; i.e., if the asset was insured the insurer will have to pay compensation.

- Input to the Consequence Module (initialisation)
    - For each type of asset
        - Vulnerability function $V(x, SD)$
        - Damage function $D(\omega, I, V)$
- Input to the Consequence Module (each round)
    - Vector of inundated cells

  - Information for each inundated cell:
    - Duration of the inundation (number of days)
    - Depth of water level
    - Spatial Data, SD, from the Spatial Module
- Output from the Consequence Module
  - Updated value of damaged assets
  - Updated wealth for affected agents

8.6 Policy and Optimisation Module

If the model is used for running scenarios, this module will not be turned on. If the simulation involves optimisation of policy options, then this module is consulted each round as the policy strategy x is shaped here. The initial strategy x is adaptively altered to fit the overall objective function, which might be the objective function of one of the agents or a compound function for different agents.

- Input to the Policy and Optimisation Module (initialisation):
  - The set X
  - Initial policy strategy, x
  - Optimisation algorithm
  - Overall objective function $f(x, \omega)$
  - Constraints $G(x, \omega)$
- Output from the Policy and Optimisation Module (each round):
  - New policy strategy $x\prime$

9 Experiments

An executable prototype catastrophe model was implemented at an early stage and refined when more relations and data were identified. All described modules were present in the prototype, but they were simplified to allow quick implementation and testing. The experiments consisted of simulating a number of different financial strategies including the optimisation of a policy variable. Two different agents were incorporated, the property agent, and the insurer agent. The property agent was modelled as a conceptual fusion of the physical property (the house) and the owner of that property. The property value represented the wealth of the owner besides how much the building was worth. The time-period simulated was 50 years, and every simulation-year consisted of 12 simulation-months.

In the Stochastic Module it was randomly decided whether the levee in the prototype model would be overtopped, break, or hold back the water. The variable $flood$ was assigned a random value between 0 and 1 from a uniform distribution with equal probability for all values in the range, every simulation-month. If the value was higher than a specified limit (representing the height of the levee border/the resistance capacity), the flood broke through, or over-topped, the levee and flooded a number of cells. As we did not have real hydrological or geographical data at that time, the following variables were assigned values randomly:

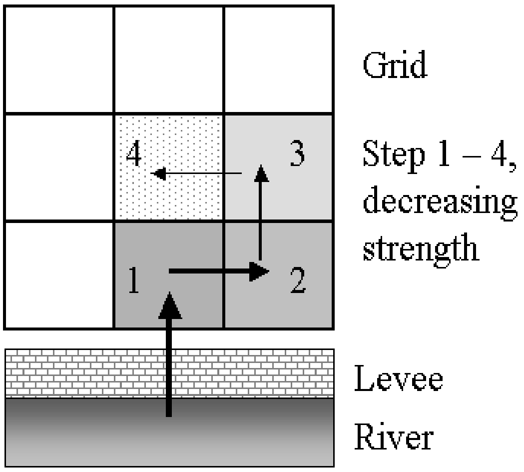

Figure 7: The flood inundates a number of cells in the grid.

- Location of the initial levee burst/overtopping,
  one of the cells bordering the levee (equal probability).

- Initial strength of flood = $\gamma^{stepNo} \times r$,
  γ and r were random variables with values between 0 and 1, stepNo denoted the order in the inundation walk, see Figure 7 where number 1 to 4 denotes the order in which the cells are flooded. The earlier they are inundated, the larger amount of water will cover the land.

In the experiments, the inundation walk, i.e., how the water flooded the land, was represented by a random walk of five steps. For each step of the random walk, a new cell was flooded, and the flood moved randomly to one of the neighbouring cells. The strength of the variable $flood$ was reduced for each step. The wealth transformation functions for the property agents and the insurer agents were described in the Agent Module. Each agent was assigned an initial wealth: for the property agents this equalled the property value and for the insurer agents it was the risk reserve. The wealth of all agents was updated every simulation-year.

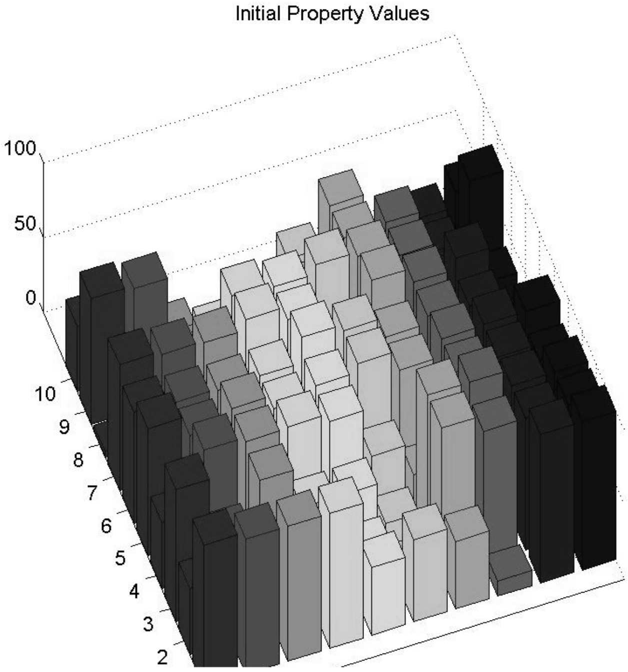

Figure 8: A landscape of initial property values.

$$\begin{aligned} WT_{t+1} = PropVal_t - D_t + \sum_{j=1}^{noIns} H_t^j(x, D_t) + \\ GovComp_t(x, D_t) - \sum_{j=1}^{noIns} Prem_t(x, PropVal_t) \end{aligned} \tag{4}$$

The wealth transformation function, see equation 4, of property agents describes how the wealth (property value) is decreased with possible damages

D, and increased with possible compensations H from all insurance companies the property agent has contracts with. The size of the compensation depended on the coverage, a variable in the policy vector x, and on the extent of the damage that has occurred during the year. The premiums paid to the insurance companies were deducted from the wealth (property value).

$$WT_{t+1} = RR_t - \sum_{j=1}^{noProp} H_t(x, D_t) + \sum_{j=1}^{noProp} Prem_t(x, PropVal_t) \tag{5}$$

Equation 5 describes the wealth transformation function for insurer agents. The risk reserve, RR, of the insurance company was reduced with the sum of H, all compensations paid during the simulation-year. The size of the compensation was a function of the coverage offered (in x) and the size of the damage, D. The premiums from all clients, $Prem$, were added to the risk reserve, the size of the premiums was a function of x and the property value, $PropVal$.

Every simulation-month, when a flood occurred, the economical damages were estimated by the Consequence Module.

$$Damage_t = PropVal_t - (\gamma^{StepNo} \times r) \tag{6}$$

How much the value of a property was reduced after a flood, was decided by the damage function, see equation 6. $PropVal$ denoted the economical value of the building, γ was a random variable in the range 01 which decided the strength of the flood, represented by the variable $flood$. The value of $flood$ was reduced stepwise, for each new cell that was inundated. $StepNo$ stated the position of the step in the inundation walk. The random variable r, also in the range 01, was added to tune the size of the damages.

Different policy strategies regarding insurance were investigated in the experiments. The variables looked at were the premium size, and the pattern of coverage. Each insurer agent was assigned a number of contracts, or cells, initially. The insurance companies offered contracts where only a part of the property value was covered, or the entire property value. For instance, when coverage was set to 0.5 of the property in a cell, it meant that that insurance company insured 50 per cent of the total property value. If the building was worth 100 000 HUF and a flood destroyed 20 per cent of the property value, the insurance company would pay 10 000 HUF (50 per cent of the damaged value) to the property agent. A coverage set to 0, constituted that the building was uninsured and a coverage set to 1 meant that the building was fully insured. The coverage patterns for each insurer agent were defined in the policy vector x.

An insurer agent could have contracts with different coverage in different cells and different insurer agents could provide insurance to the same cell, see table 2.

In a cell, the summed coverage from the different insurer agents was not allowed to exceed 1, the building could not be insured to more than 100 per cent of its value. The pattern of coverage was optimised in the Policy and Optimisation Module in the end of each simulation-year.

The three insurer agents were given identical goal functions.

$$Goal = \prod_{i=1}^{noClients} (Prem_i(x) \times Cov_i(x)) + Risk \times min[0, RR_t] \qquad (7)$$

should be maximized

In equation 7 the goal function for the Insurer agents is described. The goal function was invoked for each cell and for each insurer. If the risk reserve was negative that year, then the deficit was multiplied by the variable $Risk$. The size of $Risk$ stated the risk profile of the insurance company. A high value indicated a risk-avoiding insurer. For each insurer the pattern of coverage was optimised each year. A quadratic programming algorithm was used, looking at the derivatives, the risk reserve, and the value of z (returned from the goal function), see Ermolieva [14] for details.

9.1 Results

In the first experiment the pattern of coverage was optimised, with only one insurer agent operating in the region. The experiments showed that a single insurer in the area would go insolvent rather fast, unless the premiums were very high and/or the coverage reflected the risk of the cell. The optimised coverage offered by the insurer approached zero for high-risk cells and one for low-risk cells, see Figure 9 and figure 10. In a real situation this would mean that no insurance would be offered to households located close to a river. The economic losses for the property agents were severe as the ones who needed insurance the most could not buy it.

Insurer Agent	Cell 1	Cell 2	Cell 3	Cell 100
1	0.0	0.5	0.3	0.0
2	0.1	0.2	0.3	0.0
3	0.2	0.3	0.2	0.0

Table 2: Example patterns of coverage for three insurers.

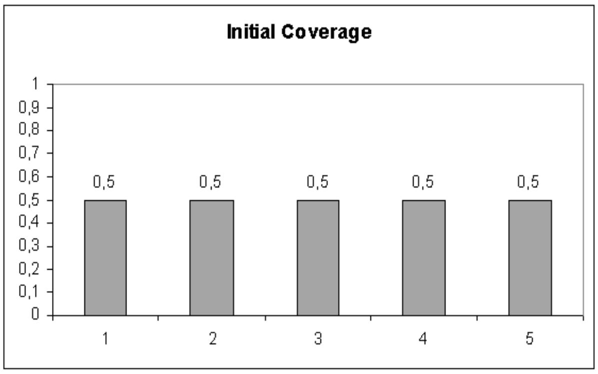

Figure 9: Initial coverage offered to five locations.

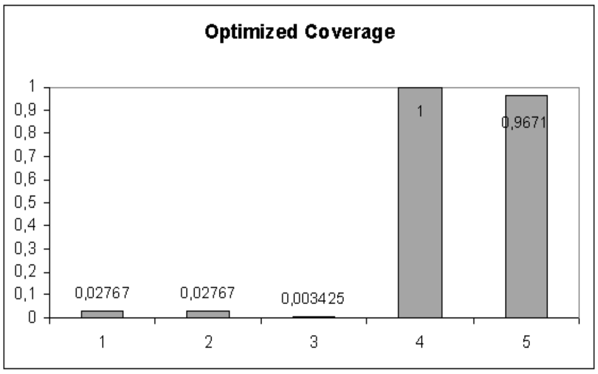

Figure 10: Optimised coverage offered to five locations.

We introduced an additional insurance company for the next series of experiments. The insurance contracts were evenly shared between the two insurers. One cell could be insured by both insurance companies, as long as the total coverage of the cell did not exceed one (100 per cent).

By spreading the risks this way, the insurer agents managed to avoid insolvency as well as offer coverage also to high-risk locations. More information on the results from the experiments can be found in [19].

10 Conclusions and Future Work

The use of models to simulate catastrophic events is very much in demand, and the insurance industry are more and more using computer models to quantify risk, instead of relying on traditional actuarial techniques for deciding levels of premium and coverage. For such models to be useful it is necessary that they are geographically explicit.

The experiments performed on the prototype model shows that an integrated approach to modelling of policy decisions is successful. During the iterative design process relevant and realistic data has been identified, and will be included in the real model. The implementation of the prototype model and the experiments performed gave clear indications that geographically explicit catastrophe models are useful to investigate policy strategies.

For optimisation of a single policy variable, the current optimisation algorithm worked fine. Other optimisation algorithms must be implemented in order to deal with multiple policy variables.

Much work remains until the model can be used as a tool in integrated assessment. The major challenge is to find the balance where the model is easy to learn and use, without becoming simplistic and naive. A number of scenarios are under construction, describing different insurance strategies. These scenarios will be tested on the model, in a stakeholder workshop, which will take place in the spring of 2002. Real GIS data has recently become available, and is now incorporated in the model. Different experiments are being performed, where miscellaneous insurance schemes are investigated. To make it possible to explore the consequences for individuals as well as for aggregates, the agents are being extended with the abilities of communication and decision making.

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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.

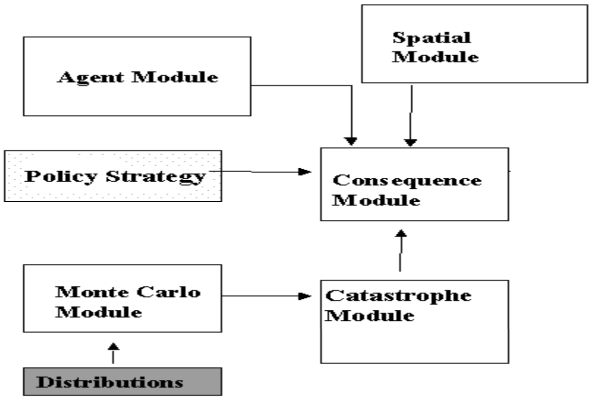

Figure 1. Modules in the flood model

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.

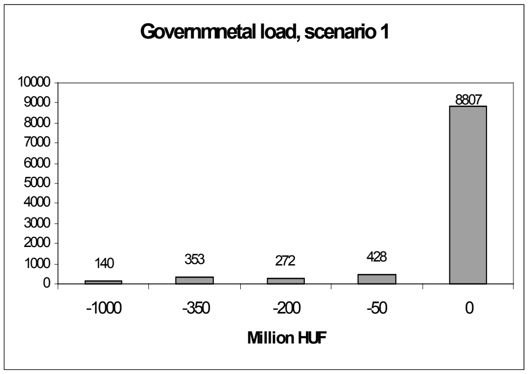

Figure 2. Histogram showing the governmental load, scenario 3.

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.

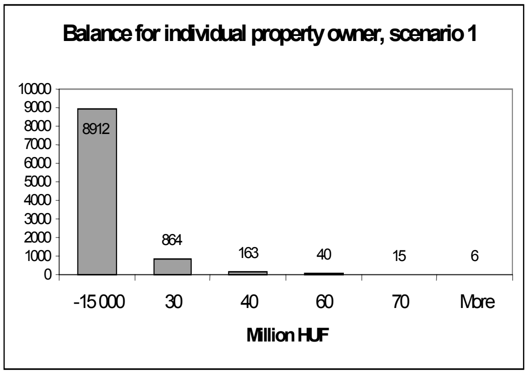

Figure 3. Histogram showing the balance for an individual property owner, scenario 1.

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.

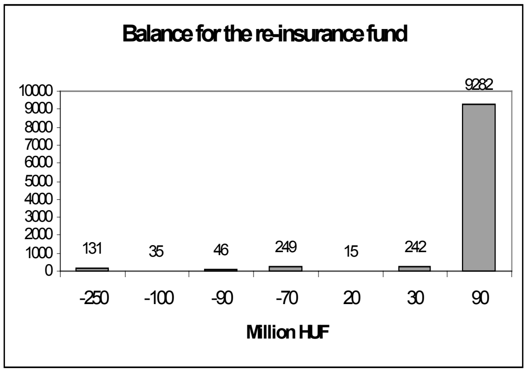

Figure 4. A histogram showing the balance for the re-insurance fund, scenario 3.

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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Agent Models of Catastrophic Events

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Abstract

We argue that complex policy modelling and complex models involving several stakeholders require an integration platform in order to be able to take full advantage of a multi-agent system representation. We present a basic model allowing for integrated assessment. A flooding policy problem with many exogenous variables and non-linear dynamics is investigated as a case in point. We conclude that the integration of multi-agent systems with policy modelling in the realm of catastrophic events is not only possible, but can result in novel observations important to a successful holistic approach.

Keywords: catastrophic modelling, integrated assessment, multi-agent simulation, fairness

1. Introduction

The number of natural disasters was five times greater in the decade 1988-1997 than in 1960-1969. As the number of catastrophes increases, human and financial losses are escalating, and in the period 1988-1997, major natural disasters cost US$700 billion (MunichRe 1998). The increased concentration of populations and vulnerable assets in high-risk areas are the main reasons for the increase (Loster, 1999). The key problem for policy makers is to find ways to improve resilience and to protect society effectively against increasing risk (Ermoliev *et al.*, 2000). For instance, more efficient land-use can be achieved by using flexible insurance conditions as an incitement to make people choose safe areas for their homes. A problem with using a financial instrument such as insurance is that flooding is by the insurance industry often considered uninsurable. Moreover, with escalating losses, many insurers are reducing their catastrophic cover. Recent advances in computer modelling of catastrophic events have increased interest in insurance policies, however (Evans *et al*., 2000). As analytical solutions producing optimal allocations are impossible, due to the complexity of the policy problem, and the large amount of stochastic variables in particular, the hope is instead turned to simulations. In our own work, we have used methods of adaptively improving the values of the policy variables according to the goal function, in combination with Monte-Carlo simulations, as advocated in (Ermolieva, *et al.*, 1997). An example goal function is for an insurer to maximise the risk reserve.

By explicit modelling of all involved individuals, a level of granularity that is out of reach for mathematical modelling can be obtained. The possibility to model interactions between individuals, their environment, and feedback of the resulting macro-structures to the micro level of the individual decision-makers, are key advantages of an agent-based approach to simulations. This makes agent-based modelling suited as an inductive analysis tool for understanding fundamental processes across a variety of applications (Axelrod, 1997). In our model, the agents represent some of the stakeholders in a policy problem pertaining to the Tisza region in Hungary, a relatively poor part of Europe, often hit by floods. The latest flood, in March 2001, was the worst in 100 years, and killed seven people. We had the hypothesis that multi-agent systems research can be useful for catastrophic modelling in the Tisza region, as explained in Section 2. In section 3, the basic simulation model is presented. In section 4, results obtained without individual agents are presented, and in section 5, these results are compared to those obtained with an individual agent representation. Because this is work in progress, we close with indications of further research necessary.

2. Integrated Systems

Fairness and other social issues must be included in the decision framework: If the initial wealth distribution is considered unjust or undesirable, efficient policies may instead escalate inequalities (Linneroth-Bayer & Amendola 2000). The process of involving different stakeholders and experts from different scientific disciplines is generally referred to as *integrated assessment*. This participatory approach to policy making stresses the importance of involving all concerned interest groups already from the beginning (Rotmans et al, 1998). The question of ensuring that policy insights from modelling are robust can be considered the main strategic challenge in integrated assessment (Downing, Moss & Pahl-Wostl, 2000). From a systems analysis perspective, disastrous events are usually seen as resulting from complex interactions between different systems, such as physical, social, economic, etc. For instance, the probabilities for a flood to occur in a river, as well as the consequences of that same flood, are related to systems of economy, ecology, meteorology, and hydrology. These systems are in turn influenced by the conditions in the river system, and uncertainty is inherent, requiring explicit modelling. It is impossible to predict the amount of precipitation, the humidity of the soil, the level of inflation, etc. These stochastic variables can at best be represented as exogenous parameters in the model, and their dependencies investigated. For instance, rain data from the meteorological system affects soil absorption, measures that are important to the hydrological system. Even though there is sufficient data on a regional level, this is insufficient for *ex ante* loss estimations, pertaining to particular locations. However, a wealth of geographical data on climate, soils, land cover, and groundwater flow is available through remote sensing, incorporated in geographical information systems (GIS). GIS tools can produce highly detailed maps. Taken alone, such tools are insufficient for complex decision support, as the GIS models typically do not account for spatial interdependencies (Keyzer & Ermoliev, 1998). The integration of data acquired from a GIS system with a simulation tool makes dynamic simulations possible, however, and we will exploit this fact in a MAS setting. Our hypothesis is that our simple models of interaction on the individual level through simulations will provide important information on the stability and flexibility of our earlier obtained solutions.

3. The Basic Model

We developed a geographically explicit dynamic model, the chief purpose of which was to investigate the possibilities for a national Hungarian insurance program. The model contained the information in Table1.[1] For the sake of brevity, we do not go into detail on methodological aspects, but refer the interested reader to earlier reports (Brouwers, 2000; Ermolieva, 1997; Hansson 2000). The model was implemented in Matlab, and all simulations were executed on a single personal computer. Detailed simulation data and colour graphics can be found at `www.dsv.su.se/~lisa`.

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[1] Discretionary income is disposable income less essential purchases for food, clothing, shelter, and transportation. Basically it is the money you have after paying your living expenditures to either save or blow. Payments on credit card bills for vacations, and consumption other than living expenditures are paid for out of discretionary income.

Agents

- Individual Agent (Aggregated)

Wealth (discretionary incomes[mean value] + savings[mean value] + compensation - premiums)
Wealth transformation function
Goal function

- Insurer Agent

Wealth (Risk reserve + premiums – compensations)
Pattern of coverage, and premium size
Wealth transformation function
Goal function

- Governmental Agent

Expenditures (Compensation of uninsured losses + flood mitigation)
Compensation level
Goal function

Data

- Property data (per grid square)

Monetary value
Vulnerability

- Land data (per grid square)

Land use
Slopes

- Flood data

Strength of flood (exogenous)
Height of water level (exogenous)
Duration of flood (exogenous)

- Meteorological data

Precipitation (exogenous)
Humidity of soil (exogenous)
Wind (exogenous)
Temperature (exogenous)

Structural Measures

- Levees

Height, location, material, and age

Interdependencies

How the flood is affected by the levee
How the flood is affected by land properties
How the property values are affected by the flood

General Functions

Cost function with levee
Benefit function with levee

Table1: Information represented in the basic model.

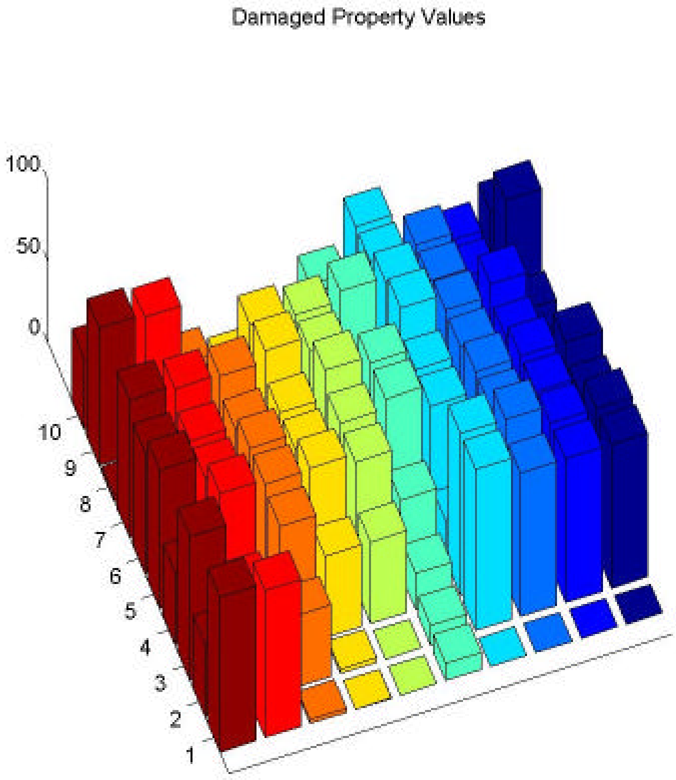

Fig-1: Damaged property values in a particular region, as represented in the simulation tool.

As an example, a snapshot of a simulation on damages on property values is shown in Fig-1. The model consists of different systems or modules, as shown in Fig-2. A detailed description is given in (Brouwers, 2000). The catastrophe generator represents the hydrological system and carries information on the conditions in the river. The loss estimator calculates the economical losses in each flooded square of the grid. Each round of simulation represents one month, so twelve rounds represent one year. For each round, the Monte-Carlo simulator picks new random values for the exogenous variables. The last module, the optimiser, refines the value of the policy variables according to the specified goal function. This can be seen as a directed search towards the optimal setting of policy parameters.

In this basic model, the agents are used as aggregates, each agent representing one stakeholder. We looked specifically at the government, the insurers, and the individuals, leaving out, e.g., non-governmental organisations. Our agents have different preferences and goals, which had to be taken into consideration in the model. Numerous interdependencies occur when modelling the agent views. For instance, insurance is available to those living in flood basins only if the area is protected. The role of insurance is a complement to structural measures. There is an economic optimum to the degree of protection available from structural measures, where the cost of building more (greater protection) is higher than the additional benefits. Here insurance covers the residual risk. In general, a mix of the structural and non-structural mitigation measures is required for an optimal solution (Retiano, 1995).

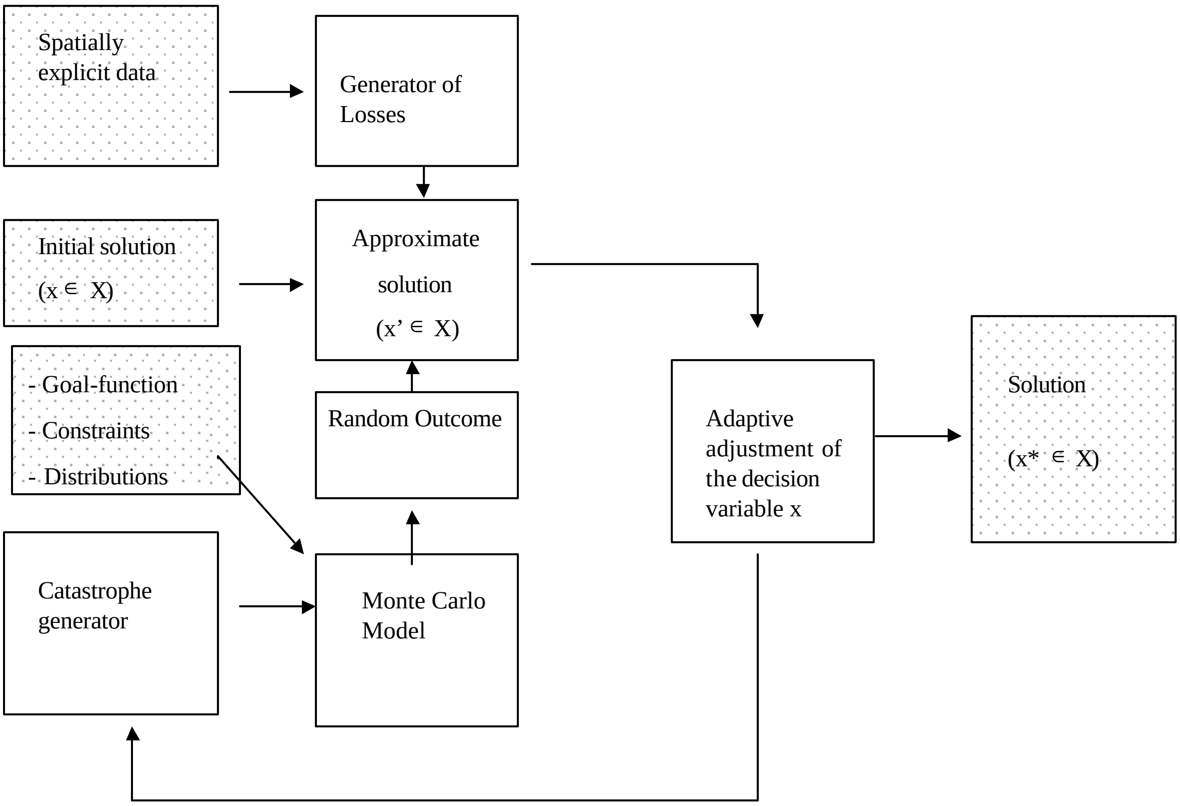

Fig-2: Modules in the basic model.

The goal for the individual agent as well as for the insurance agent is to maximise wealth. The governmental agent strives to minimise expenditures. The wealth is transformed by actions of the other agents, by policy decisions, and by the flood conditions (Hansson, 2000). In our simulations, the wealth of all agents was updated every month depending on losses and compensations from flooding. Each year, premiums updated the wealth and expenditures of the insurer agent and the individual agent accordingly. Costs and benefits from structural measures were also updated. The different goal functions are not independent, and each agent action affects all other functions in the model, resulting in complex reduction and loss-spreading problems.

4. Simulation without Individual Agents

In our first set of simulations, the policy variable optimised was the 'pattern of coverage' over a time period of 50 years. Coverage is defined as the insured percentage of the property, and is measured in each square of the grid. The optimisation was directed by a combined goal function of the governmental agent, the insurer agent, and the individual agent. The following assumptions were made.

- The initial coverage pattern was 50 per cent for each contract
- The size of the premium was 1 per cent of the property value covered, each year
- The government compensated uninsured losses to 70 per cent
- The individual agent always bought maximum level of insurance offered

The results showed that both the insurer agent and the aggregated individual agent avoided insolvency. The expenditures for the government were high, due to large compensation of uninsured losses. The optimised pattern of coverage reflected the level of flood risk directly. In safe squares, 100 per cent coverage was offered while the coverage for riverside squares approached 0. We also performed a number of simulations where different heights of the levee were tested. A high levee is expensive to build and maintain for the government, however the increased protection was reflected in the optimised pattern of coverage. When extreme floods occurred, and the high levee was destroyed, the insurer went insolvent, as the claims were too high. Contracts were not treated separately for each individual customer, but were aggregated, and as a result no consideration was taken to the vulnerability of each individual customer agent.

5. Simulations with Individual Agents

We next extended the model to include individual agents in order to test if the increased granularity brought more insight. In each square of the geographical grid, we introduced 0 to 100 agents. The following information was given about each individual agent.

- Individual Agent

Wealth (discretionary income + savings + compensation - premiums)
Property assets (percentage of the property value of that grid square)
Risk profile (0 or 1, 0 = no insurance and 1 = insurance)

The insurance agent and the governmental agent had the same properties as described above. The policy variable optimised was again ‘pattern of coverage’. We also kept the time period of 50 years. The goal functions of all individual agents were represented by the aggregate goal function used earlier. This simplification was necessary as interpersonal utility comparisons proved to be too complex to be included in these experiments. All individual agents were annually given the offer of buying property insurance. Whether they accepted or not depended on the value of their attribute ‘risk profile’. For reasons of commensurability, we started out with parameter settings similar to those used earlier. The following assumptions were made:

- All individual agents were assigned value 1 in their risk profile
- The risk proneness of the individual was unchanged throughout the simulation
- The initial coverage pattern was set to 50 per cent
- The size of the premium was set to 1 per cent
- The government compensated uninsured losses to a 70 per cent extent

The first set of simulations with these parameters showed that even though most individual agents avoided insolvency, a small group of agents experienced severe economical losses. The individuals most vulnerable were those living in flood prone areas, with low wealth; some were extremely vulnerable, viz. those that could not afford to buy insurance. The insurer agent performed well and avoided insolvency. The expenditures for the governmental agent were slightly higher than in the previous experiments, because of the increased compensation paid out to the agents with low wealth. The optimised pattern of coverage was similar to our earlier result.

In Hungary, only 60 per cent of the households are insured against flooding. To reflect this distribution of the willingness to buy insurance, we introduced noise, represented as irrational rejection of insurance offers. This time the first of the assumptions above was changed to:

- 60 per cent of the individual agents were assigned value 1 in their risk profile

The decreased number of insurance contracts in the region led to increased expenditure for the government agent since there were more individual agents to compensate. Not only the government and the individuals were struck in this simulation round, the insurance agents’ wealth was diminished due to less income of premium. Considering individual agent wealth transformations separately, we could see that some individuals were hit extremely hard, even though the aggregated result did not indicate this. The government's policy could here be deemed unsuccessful with respect to the fairness issue. To the individual agents, we could issue the following warning to those residing in risky areas. An agent is vulnerable to a flood if one or more of the below conditions is true:

- Wealth is low or average, and the insurance company offers a low coverage
- Wealth is low or average, and the individual chooses not to buy insurance
- Wealth is low and the individual cannot afford to buy insurance

6. Conclusions and Further Research

The system dynamics have been modelled in a simple fashion. Diversity among agents has not been analysed, other than with respect to geographical distributions. Asynchronous message passing has not been implemented, and flocking behaviours and mutual mimetic contagion have therefore not been studied.

That said, the above shortcomings should be seen as directions for future research. We have presented certain aspects of an ambitious case study, involving dozens of researchers (in Hungary, Sweden, and Austria), working in an interdisciplinary fashion over a three-year period. We have here given some evidence for our hypothesis that multi-agent simulations could be useful also for extremely complex policy problems. We were through such simulations able to shed light upon some analytically intractable aspects of our optimisation problems, and we could also make non-trivial observations related to fairness issues.

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LIENHYPERTEXTE

MicroWorlds as a Tool for Policy Making

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2001-10-17

Abstract

The Hungarian government is experiencing escalating costs for flood mitigation measures and for economical compensation to victims. In a joint research project between the International Institute of Applied System Analysis (IIASA) in Austria, Computer and System Science Department (DSV) in Sweden, and the Hungarian Academy of Science, the flooding problem of Upper Tisza in Hungary is investigated. A catastrophe simulation model has been implemented, where different policy options are tested and evaluated. We investigate how the willingness to buy insurance affects the results on the macro-level and on the micro-level.

1 Introduction

The economic losses from floods are escalating. One reason is that the severity and frequency of floods are increasing. Climate change may be one of the explanations of this phenomenon; a warmer atmosphere absorbs more moisture, which leads to increased precipitation as a part of the heating will go into evaporating larger quantities of water from the surface of the earth. The atmosphere is also capable of supporting greater amounts of water vapour. In general, an increase in the proportion of extreme and heavy precipitation events would occur where there is enough atmospheric instability to trigger precipitation events. This intensification of the hydrological cycle means more flooding with an increase in extreme precipitation events according to [4]. Another reason has to do with land-use changes; there has been a concentration of people and vulnerable assets in flood-prone areas during the last years.

In Hungary, the costs for protection of flood and compensation to victims are by tradition considered the responsibility of the government [6]. The Hungarian government is looking for new loss-sharing mechanisms. The government is investigating the possibilities to transfer part of the economic responsibility from the government to the individuals. A reason for this intension is that the government is under press to lower its expenditures in order to pass the economical requirements in order to be accepted as a new member of the European Union. Another motive is that the government has a desire to implement a system that is fairer, a system where the flood risk of the geographical locations affects the degree of responsibility. A person living in a flood prone area should contribute more than a person living in a safe area should. The current situation is that all taxpayers contribute equally and share the majority of the cost trough their income tax. A financial mechanism, like private insurance is one possible method for better reflecting the risk level of a certain area. The size of the premiums may reflect the flood risk of a location. Differentiated premiums can besides giving a fairer distribution of the economical responsibility also be seen as an incitement for a sounder land-use.

The implementation of a National Insurance system is a complicated policy problem. It is vital that the different stakeholders support the policy before it is implemented. One of the important stakeholders is the insurance industry. Insurers normally regard flooding as uninsurable. With escalating losses, many insurers are reducing their catastrophic cover. In Hungary, only a few companies offer insurance against floods. Moreover, the insurance contracts that are offered are connected with a number of limiting conditions; ground water related floods are for instance excluded. Many times it is difficult to tell if the flood is caused by intense precipitation, by a failure of some flood protection, by ground water elevation, or if it is caused by a combination of these factors.

The relative infrequency of catastrophe events and the resulting scarcity of historical loss data make it nearly impossible to reliably estimate catastrophe losses using standard actuarial techniques. However, recent advances in computer modelling of catastrophic events have increased the interest to offer flood insurance. By combining mathematical representations of the flood occurrence, with information on property values, construction types etc., simulation models that generate loss estimates can guide insurers and other policy makers. For such a catastrophe simulation model to be useful, it must demonstrate the spatial and temporal dependencies specific to the studied area, and specific to each stakeholder in the region. In order to investigate

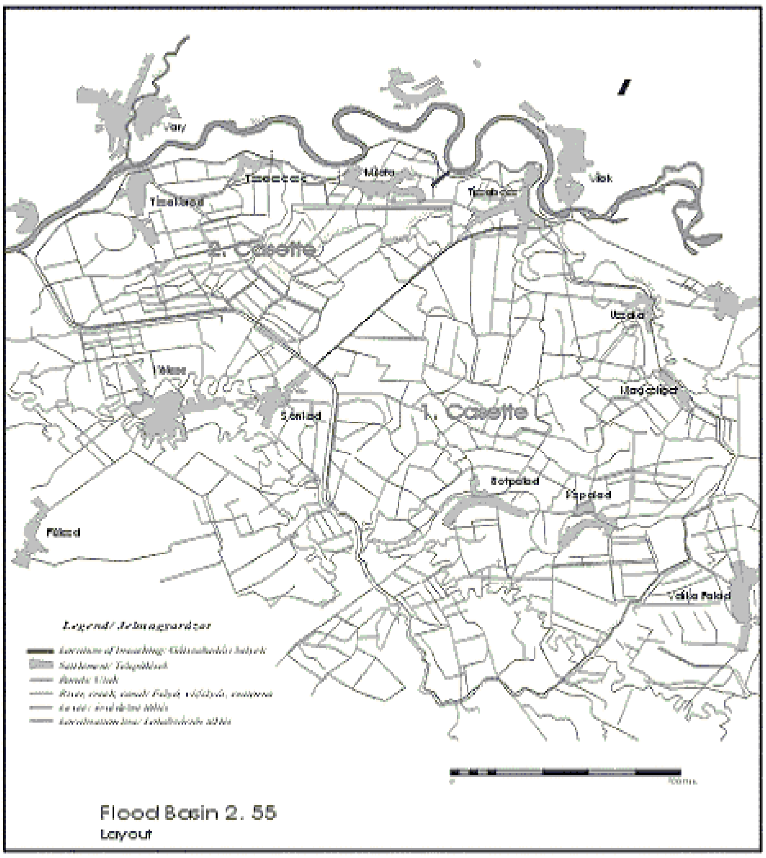

Figure 1: Basin 2.55, the study area for the Tisza Project.

the effects of different flood management strategies for Upper Tisza in Hungary, an executable simulation model of the river basin has been built. In Figure 1 the basin investigated is presented. Before real data from the basin was available, a prototype model was used to perform initial experiments, see [1, 3]. These experiments indicated what features to improve or leave out in the real simulation model, which is described in next chapter.

2 Simulation Model

A river is affected by many systems, and the river affects these systems. The probabilities for a flood to occur in a river, and the economic consequences from a flood are strongly connected with systems of economy, ecology, meteorology, and hydrology. In all these systems, uncertainty is inherent. For complex problems, the use of a generalised representation, a model of the problem, is commonly used. The problem of investigating different policy strategies for flood mitigation is indeed complex as it is impossible to predict what state the system will be in at a certain time. By simulating the change of states, different policy strategies can be tested and evaluated on the model. A policy strategy is here a combination of one or more policy alternatives. An example strategy is *"Levee height at location 1: 5 metres, levee height at location 2: 3 metres, levee height at location 3: 2 metres, Compensation level from the government: 30 per cent, Premium levels: 3 per cent of property value"*. The catastrophe simulation model consists of several modules; see Figure 2. The stochastic variables (i.e., water-level, precipitation, discharge) are assigned new random values from the specified distributions in the Monte Carlo module each round of the simulation. The

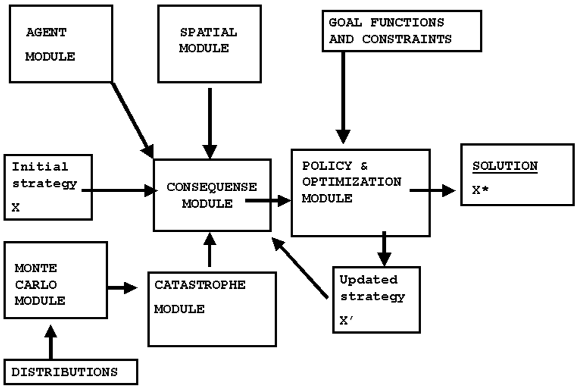

Figure 2: Modules in the system.

random outcome, the values of the stochastic variables telling what state the system is in, is passed to the Catastrophe module. This module contains a hydrological model and an inundation model, both developed in Hungary by Vituki Consulting [7]. The Catastrophe module calculates how the water overflows the levees in case of a flood, what land areas are inundated, and by how deep water. The Consequence module consults the Spatial Module for information on property values for the inundated cells. For each cell where there is flooded property, the economic consequences for all concerned agents are calculated and their wealth is updated accordingly. The different agents represented in the model are the property agent, the insurer agent, and the governmental agent. For a more exhaustive description of the agents, see [2]. The economic consequences depend on the current policy strategy. For each year (here represented as one simulation round) the Policy and Optimisation module evaluates the success of the current policy strategy with regard to the stated goal function. If the optimisation feature is turned on during the simulations, the policy strategy is slightly altered, in the direction that seems most promising trough an automated dynamic adaption. The search space can be further delimited by different constraints; and violations against these are checked before a new policy strategy is generated. This process of adaptive Monte Carlo simulation is described in detail by [4].

3 Mathematical Representation

Let X be the set of all possible policy strategies, then x_i is one specific policy strategy. The strategy described earlier is an example of such a strategy. The set Ω contains all states the system can be in, each state is described by the values of the stochastic variables. A certain state is for instance, ω_7 a vector with the following values of the stochastic variables, *"Amount of precipitation: 37 mm, Water level: 7 m, Discharge: 12"*. During our simulations, the vector (contains only one variable, $flood$. The hydrological relationship between water-speed, temperature, wind-speed and the flood conditions is not yet fully determined. Instead, we use nine scenarios of levee failures. Each scenario describes the structural damages for each cell.

When the economic consequences are calculated in the Consequence module, the wealth transformation function of each agent is consulted. These functions are described in the following sections.

3.1 Wealth transformation function for each Property agent

$$W_{t+1}^{prA}(x,\omega) = W_t + \sum_{1}^{n} H_t(x, g_i^t, \omega) + G_t(x, c^t, \omega) -$$

$$D_t(x,\omega) - \sum_{1}^{n}(\pi_t(x, g_i^t, \omega)) + I_t(x,\omega) - T_t(x,\omega) - E_t(x,\omega) \tag{1}$$

Let W_1 be the initial amount of wealth of the property agent, given initially as a constant. The wealth is transformed over time as a function on the size of compensation H received from one or more insurer agents i, at time t. The amount of compensation also depends on the coverage g for each insurer agent, where n represents number of insurer agents. Coverage might be a percentage of the property value or a more complicated function with thresholds. Compensation from the local government G is added to the wealth, where c is the compensation level. Cost for damages D on property is deducted. Premiums π are deducted from the wealth according to each insurer agent policy and coverage. The wealth is increased with the income I and decreased with the Catastrophe taxes to the Local Government T and the expenditures E, which contains all other expenses.

3.2 Wealth transformation function for Local government agent

$$W_{t+1}^{Gov}(x,\omega) = W_t + \sum_{1}^{n} T_t(x,\omega) - \sum_{1}^{n} G_t(x, c_t, \omega) - M(x,\omega) \tag{2}$$

The wealth of the local government is increased by the tax T, received from n property agents. The wealth W is reduced by flood compensation G paid to the property agents, and c is the compensation level. M represents the costs for flood mitigation; cost for maintenance of the three levees.

3.3 Wealth transformation function for each Insurer agent

$$W_{i=1}^{Ins}(x,\omega) = W_t + \sum_{1}^{n} \pi_t(x, g_t, \omega) - \sum_{1}^{n} H_t(x, g_t, \omega) \tag{3}$$

The initial wealth of the insurer agents, wealth at $t = 1$, is transformed by their income in form of premiums π minus compensation H according to size of coverage g.

4 Policy Simulations

In the simulations, we use nine pre-compiled scenarios of levee failures. For each scenario Vituki Consulting [5], has estimated the pattern of inundation and the amount of economic damages for each cell. We have the following probability distribution for the nine scenarios, also provided by Vituki:

Location.:	1	2	3
100-year flood	0,0012	0,0020	0,0028
150-year flood	0,0012	0,0015	0,0027
1000-year flood	0,00019	0,00033	0,00045

Table 1: Probabilities for flood failures at three locations, from floods of three magnitudes.

The value of the random variable $flood$ is determined in the Monte Carlo module and checked in the Catastrophe module. If it is less than 0.01238 an event has occurred. The variable $flood$ is assigned either the value of the scenario that has occurred according to the scenario distribution, or zero. The geographical information data at hand were at a very fine-grained resolution, the size of each cell measuring 10 m^2, forming a grid of 1551 × 1551 cells. As the focus of our simulations is to investigate the economical consequences of different financial policy measures, we filtered out all cells that did not contain property and use only the remaining 2508 cells.

Depending on the desired scale of granularity in a model, an agent can represent either an individual or an aggregate. For a realistic modelling of the flood management problem of Upper Tisza, the ideal would be to model each individual property owner as an agent with capabilities to reason and act autonomously and with the ability to communicate with other agents. Our agents lack the ability of communication, however they can reason about the choice to buy insurance or not.

5 Results of the Simulations

We present the results of four policy simulations, where insurance was used as the policy strategy of which the parameters were altered. In the first rounds of simulations, we used the settings described in Table 2. We found that the local government went insolvent at the first flood event, see Figure 3. This indicates that such a policy strategy is very costly for the local government. For the second simulation, we increased the tax level to 10 per

Compensation level from local government	100 per cent of damages
Catastrophe tax level	2 per cent
Number of insurer agents	0
Number of simulations	50 × 12
Income of property agents	Randomly generated Normal distribution, mean = 33690 Standard deviation 10000)

Table 2: Settings for the first rounds of simulations.

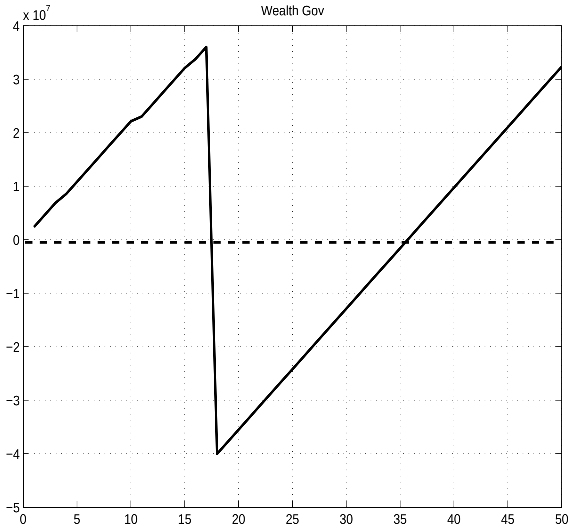

Figure 3: Dynamic wealth of government (tax 2 per cent).

cent, all other parameters stayed the same. We found that even though the government avoided insolvency, some of the property agents became very poor, see Figure 4. We investigated a different approach by introducing two insurer agents the next simulation. Tax level was lowered to 2 per cent, and compensation level from the local government was reduced to 40 per cent. The coverage level of the insurers was set to 70 per cent of the property value. The assumption that all property agents would buy insurance was made. Premium size was set to 3 per cent of covered property value.

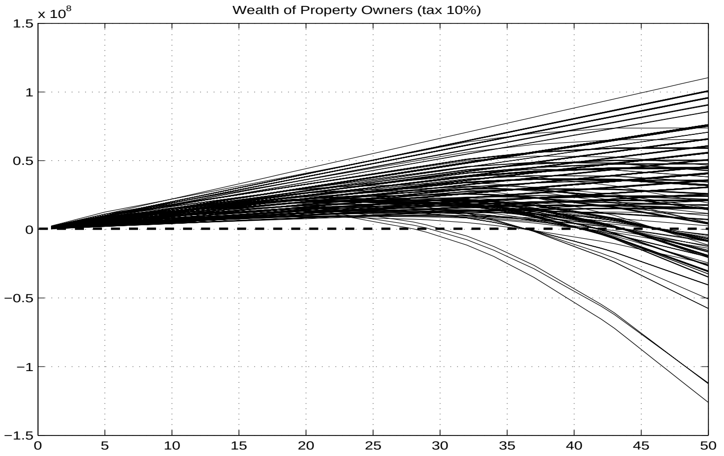

Figure 4: Property agents go bankrupt.

The overall results from this policy simulation looked good. However, the assumption made is not realistic. In Hungary only 40 per cent of the house owners buy insurance. Therefore, we performed a last round of simulations where property agents were given the choice of buying insurance or not.

The decision function $DF = N + AW + H + RW$ consisted of the following four parts:

1. N (neighbours): A function of the number of neighbours (the four closest), who have insurance
   0 returns - 5, 1 returns - 3, 2 returns 0, 3 returns 3, and 4 returns 5.
   Range: [-5 , -3 , 0 , 3 , 5]

2. AW (available wealth): Returns 1 if current wealth minus premium ≥ 0
   otherwise -10 is returned
   Range: [-10 , 1]

3. H (history): Returns -5 if the sum of $flood$ for $cell_i$ from the first round to current round = 0
   (in that case no flood failure has occurred)
   otherwise the sum is returned
   Range: [-5 , 1 ... $9^{CurrRoundNo}$].

4. RW (risk willingness): Returns a random value
   Range: [-5 ... 5]

In the initialisation of this simulation, 40 per cent of the property agents were randomly picked to have insurance. The proportion was chosen as it corresponds to the real situation, as much as 60 per cent of the people in flood risk areas in Hungary has no flood insurance for their homes [6]. All other parameters where unchanged. The decision function was consulted for each property agent for each round (each year) and if the value was 0 or below the agent did not buy insurance.

The results showed that the insurer agents went insolvent after a few events, since the wealth was reduced with the number of property agents who declined the offer. The government stayed solvent, as their wealth was not affected since a large proportion of the responsibility had been transferred to the property agents. On the surface the property agents appeared to be solvent, but when investigating the micro level we found that insolvency did occur, see Figure 5.

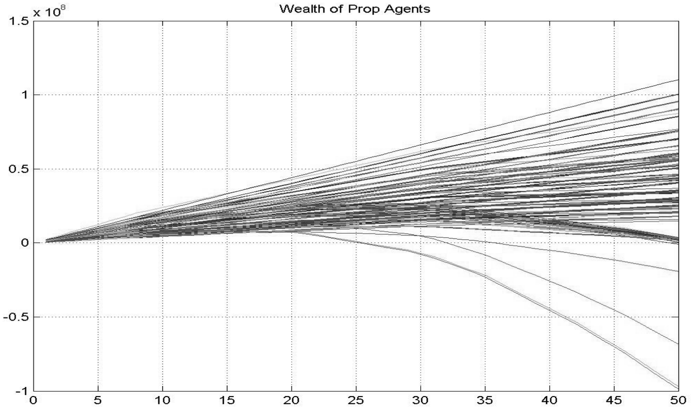

Figure 5: Wealth of property agents, when risk-willingness is introduced.

Most vulnerable were the poor property agents in risk-prone location who could not afford insurance. Risk-willing property agents in safe areas, decided not to buy insurance, as history indicated that it was unnecessary. When a rare disaster (scenario 7 or higher) occurred, these property agents were severely affected.

6 Conclusions

When modelling policy problems it is important to take the linkage between the micro and the macro level into consideration. Traditional catastrophe models neglect this aspect, by using aggregates and average values instead of distributions. Our simulations of the flood management problem of the Upper Tisza basin show the need for catastrophe models with the ability to represent agents at different levels of granularity and with the possibility to include social patterns. We have made a first step in this direction by letting the overall outcome be affected by the decisions of the individuals. The individual decision-maker is in turn affected by other agents, forming a social network of decision-makers.

The model is currently being extended and provided with a graphical user interface, in order to use it interactively at a stakeholder workshop.

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