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Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza

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Abstract

Flood management policy has been the subject of an international joint research project with the Upper Tisza in Hungary as its pilot study area. Design specifications for a geographically explicit simulation model are presented. Potential flood management policies, based on surveys and interviews with stakeholders, are presented. Some experiments on an executable prototype of the simulation model are also reported on, where the consequences of flood management policies are investigated. Focus has been on financial policy measures, mainly insurance. Besides more traditional evaluation of policy scenarios, the model incorporates adaptive optimisation functionality. The report incorporates three contributions:

1. the insurance policy issue in Hungary is framed in the broader context of flood management
2. the structuring of a flood risk policy model, capable of simulating flood failures and estimating the economic consequences
3. reports from policy experiments performed on the implemented prototype flood risk policy model

Acknowledgments

I would like to thank Professor Yuri Ermoliev from IIASA's Risk, Modelling and Society Project, and Dr Tatiana Ermolieva from IIASA's Social Security Reform, for helpful advices and guidance during the Young Scientists Summer Program (YSSP) 2000. I am also grateful to Dr Joanne Linnerooth-Bayer for her inspiration and support during and beyond the YSSP. Finally I would like to thank Dr Marek Makowski for his kind assistance.

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Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza

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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 [27, 25] 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

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IIASA. Yuri Ermoliev and Tatiana Ermolieva have contributed with expertise in the fields of mathematics and statistics for disaster management, see [10, 2, 8, 9, 11]. 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 [34, 11]. Surveys and interviews with the stakeholders in Upper Tisza were made by Anna Vári and Joanne Linnerooth-Bayer [38, 39, 40, 18, 27, 25]. Linnerooth-Bayer has also investigated catastrophe management globally, and the use of insurance [4, 3, 23, 24, 26]. External sources of information has mainly been a report on the Hungarian flood control development, by the World Bank [37], information and statistics on natural disasters from MunichRe [30], writings by Yevjevich [41] on flood control in Hungary, and by Reitano [31] 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 [10, 2]. 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 [19]. 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^{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. [20]). In a report, following meteorological parameters were stated as being the most important for flooding (cf. [35]):

- 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 [30]. Economic losses, after being adjusted for inflation, have risen by a factor of nine. According to Loster [28], 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

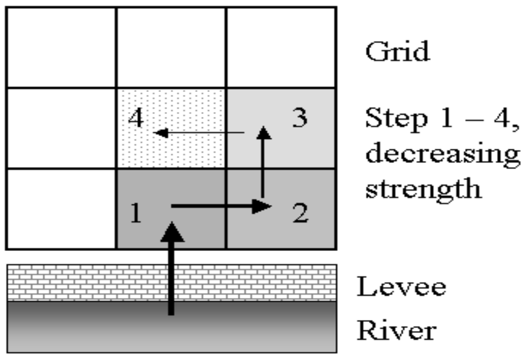

Figure 1: Number of great nature catastrophes 1950–2000,data from MunichRe.

compared over the decades, and a dramatic increase is revealed. Munich Re [30] 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.

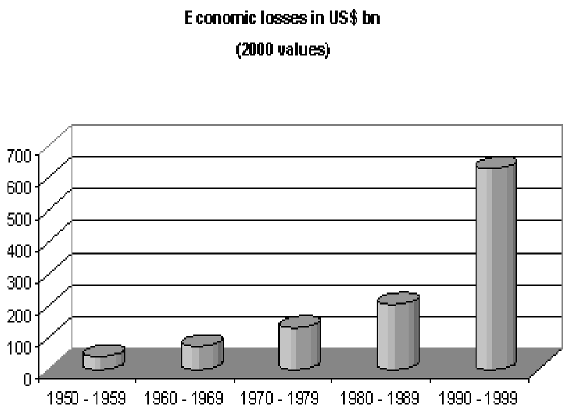

Figure 2: Economic losses from natural catastrophes world-wide, data from MunichRe.

A key problem for policy makers is to find ways to improve resilience and to protect society effectively against the increasing risk [8]. Questions of accountability and liability for preventing and absorbing the financial losses are on the political agenda in most countries.

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 [23]. 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 [21], 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 [36] 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 together 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.

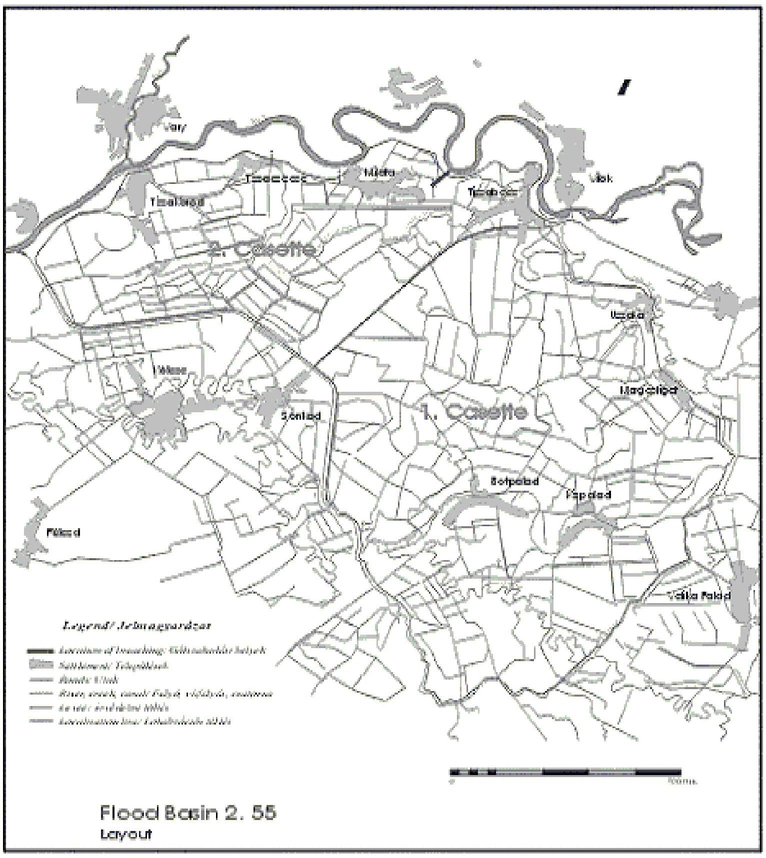

Figure 3: Basin 2.55, the study area for the Tisza Project, figure courtesy of VITUKI

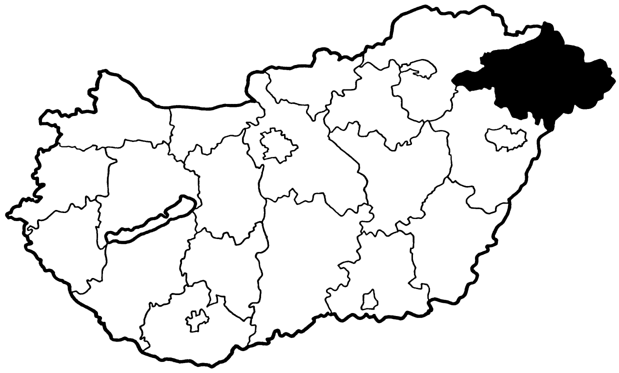

Figure 4: The County Szabolcs-Szatmár-Bereg.

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 [18].

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 [22], 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 [14] 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 [16]. 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, dams, and reservoirs
        - Non-structural measures
            * Change location: relocate properties to less vulnerable places
            * Change land use: coding, zoning, proofing, and re-naturalisation
    - Adaptation
        - Loss Sharing
            * Flood insurance: Public, Private, and mixed (public/private)
    - Response
        - Preparedness (early warning)
        - Awareness and training
2. Post-flood strategies (recovery)
    - Bear losses (self-help)
    - Share losses
        - Governmental funds
        - Insurance
        - Charity
    - External aid (international)

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]

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

[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 [12].

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:

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 [4]. 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. Instead of a private insurance company, the government institutes this insurance program. The National Flood Insurance Program in the US is an example on a governmental insurance, insurance is not mandatory, but it is a pre-requisite for being allowed a loan where the property is the security (a mortgage). 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 [12]. 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 [37]. 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 [29].

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 [15].

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 [14].

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 [32]. 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 [7]. 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 [33]. 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 [24, 30, 13]
    - 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 [5], 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 [5] 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.

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

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.

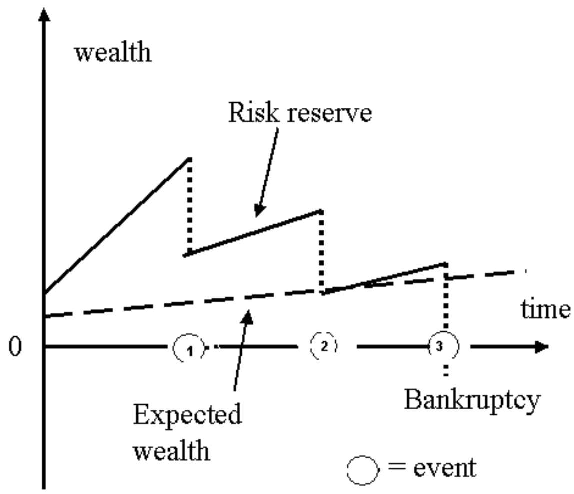

Figure 5: A stylized trajectory of the wealth of an insurance company, three events occur.

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 [8] for more detailed information.

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 [10] 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 [34]. 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

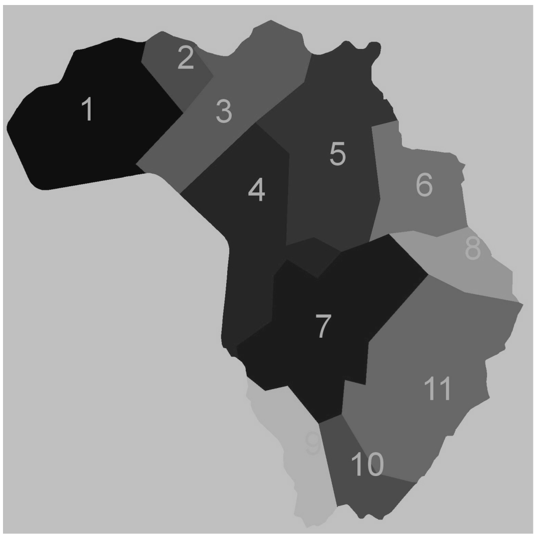

Figure 6: A map of the pilot basin with the eleven municipalities (listed in numerical order): Tiszakorod, Tiszacsecse, Milota, Sonkad, Tiszabecs, Uszka, Botpalad, Magosliget, Tiszaberek, Kishodos, and Kispalad.
Figure courtesy of VITUKI.

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 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:

- 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.

$$WT_{t+1} = PropVal_t - D_t + \sum_{j=1}^{noIns} H_t^j(x, D_t) +$$

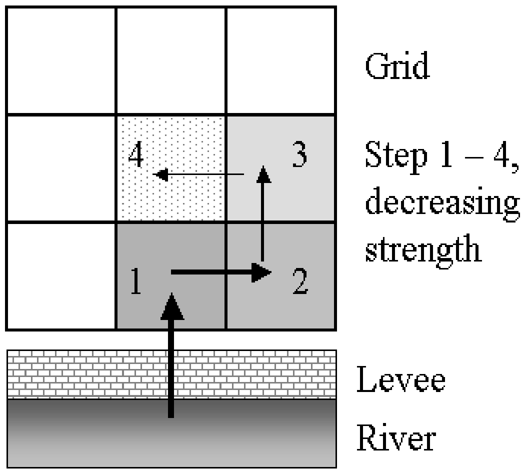

Figure 7: The flood inundates a number of cells in the grid.
Figure courtesy of VITUKI.

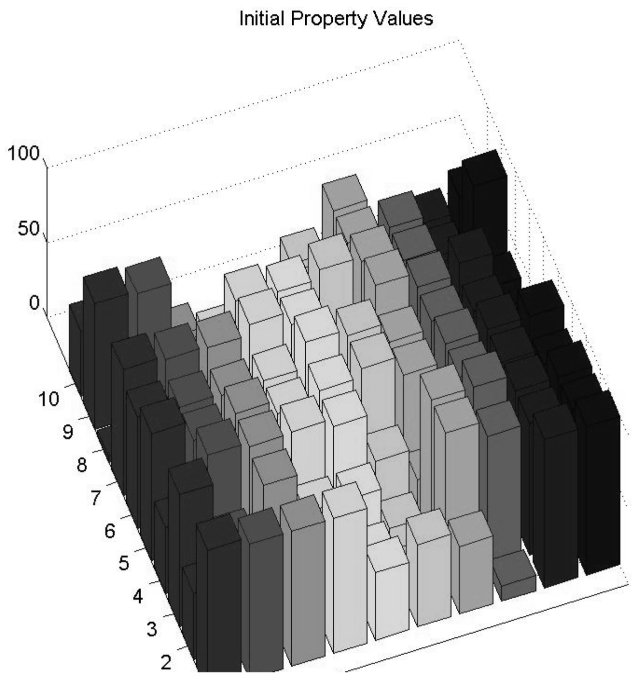

Figure 8: A landscape of initial property values.

$$GovComp_t(x, D_t) - \sum_{j=1}^{noIns} Prem_t(x, PropVal_t) \quad (4)$$

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).

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

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.

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

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.

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

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 [10] 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

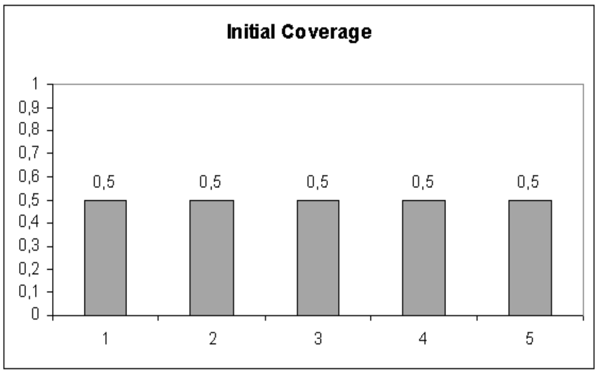

Figure 9: Initial coverage offered to five locations.

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.

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.

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 [17].

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 autumn of 2002. Real GIS data has recently become available, and is now incorporated in the

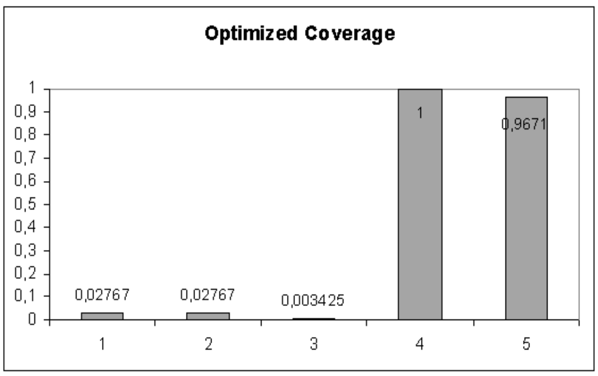

Figure 10: Optimised coverage offered to five locations.

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 ability of making decisions.

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