Special Issue on Flood Risks in Europe

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Introduction to Special Issue on Flood Risks in Europe

Joanne Linnerooth-Bayer[1]* and Aniello Amendola[1]

1. INTRODUCTION

Flooding in Germany, Austria, Hungary, the Czech Republic, and Russia in August 2002 may result in the highest flood damages ever recorded in Europe. An independent commission has announced a loss estimate of over U.S. $16 billion solely for the German state of Saxon.(1) Even before these flood disasters, the risks from floods of all types, including flash floods, river floods, and sea surges, were high on the political agendas of almost all European governments.

In comparison with many developing countries, the fatalities from floods in Europe are low, approximately 500 in the past decade, and the death toll is decreasing due to improved forecasting and early warning technologies. At the same time, economic losses appear to be soaring. There are no reliable estimates of the full direct and indirect damages from European floods, but many of the over 20 major flood events in Europe in the 1990s are unprecedented in terms of economic damage. For example, loss estimates from the Italian floods of 1994 were over U.S.$9 billion, which came close to the U.S.$11 billion estimated losses from the inundation of nine U.S. states in the midwest in 1993.(2) Particularly for the transition countries of central and eastern Europe, floods pose a significant risk to economic development and can be devastating to the usually uninsured victims and to governments that are ill prepared to provide flood relief and recovery. For example, economic damages from the 1997 floods in Poland and the Czech Republic were U.S.$3.7 billion and 1.5 billion, respectively, which is 2.9 and 3.5% of their respective GDPs.(3,4) To put these losses into perspective, the U.S.$110 billion loss from the 1995 earthquake in Kobe resulted in a nearly equivalent 3.2% of Japan's GDP.

Europe is not alone in its recent experience of large economic losses from flood disasters. Worldwide, floods are responsible for a greater number of economic damages than any other type of natural event. Although loss estimates from natural disasters must be viewed with great caution, in the period 1985 to 1999 Munich Re estimates total global losses from all natural disasters to be U.S.$896 billion. As shown in Fig. 1, Europe's approximate share of these losses is 13%, or U.S.$116 billion. At least one-third of these losses is roughly estimated to be from flooding,(5) and this proportion is higher in Europe. More disturbing than the absolute value of the losses is their increase in the last decades. Again according to Munich Re, economic losses from floods, storms, and other disasters have increased about 14-fold from the decade of the 1950s; however, the number of flood events has not risen significantly, indicating that the main culprit for rising losses is increased vulnerability of people and capital.(6) Global social and environmental changes, such as shifts in land use, population and migration, energy use, and climate warming, will likely increase the costs of natural disasters and raise the potential for more severe catastrophes.

Attribution of blame for the escalating flood losses to human activities has generated a wide debate on issues of responsibility and liability, as well as on the appropriate measures for mitigating losses and providing relief to victims. Throughout Europe, governments have traditionally spent large sums on protective levees and other structural mitigation measures. These measures have recently come under attack from environmentalists and others, who argue that they are costly and detrimental to local ecosystems, that they often displace the flood risk from upstream to downstream countries, and that they

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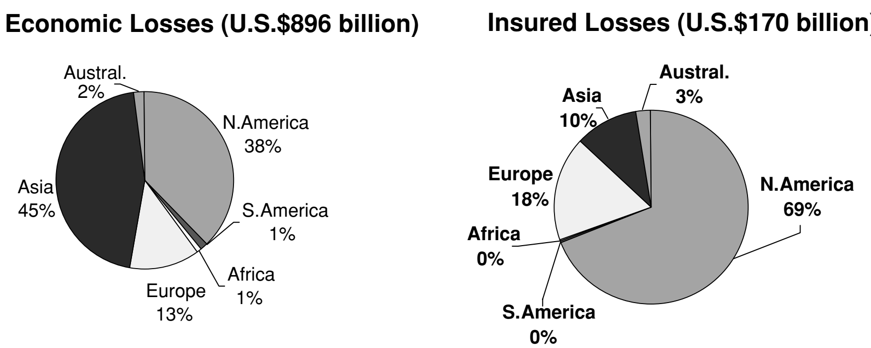

Fig. 1. The global distribution of natural catastrophe losses and insured losses (1985–1999).

Source: Munich Re.[5]

encourage more development in flood-prone areas. With important exceptions, for instance, the United Kingdom and Germany, governments also assume major responsibility for losses to private individuals, in addition to their post-disaster expenses for repairing public infrastructure. In some countries, notably Hungary and Italy, the central government compensates up to 100% of private structural losses. Compensating flood victims is discouraging local efforts to reduce flood losses and is also causing serious problems for many governments, especially those striving to meet the Maastrich conditions for EU membership. These governments would welcome more private responsibility and insurance.

In Europe, and worldwide, the proportion of disaster losses covered by insurance and reinsurance is relatively small in comparison with that reimbursed by governments.[7] As shown in Fig. 1, only about 18% of European disaster losses are insured, which, however, is above the global average. In the past, insurers have been reluctant to enter many catastrophic markets, but this is changing with improved computer modeling for estimating the risks. The potential for catastrophe insurance is enormous, especially as insurance markets become more international, but this market is constrained by the large capital requirements on the part of insurers. A unique feature of catastrophe insurance is that spreading risk cannot be achieved just by having a pool of premium payers. The problem is the timing, since a rare catastrophic event can occur before enough premium income has accumulated to cover the claims. Therefore, insurance companies rely on both reinsurance and capital reserves to meet very large, dependent claims. To overcome the finite nature of insurance capital, recent attention has been given to novel risk-transfer or hedging instruments, including catastrophe bonds that transfer the risks to the global capital markets.[8,9] There is also interest in exploring whether governments could insure their infrastructure with the use of these instruments.

The policy debate on issues of responsibility and liability for flood losses, as well as on the appropriate measures for mitigating losses and providing relief to victims, raises an important set of research questions: What is the role of anthropogenic phenomena on current and potential future losses from flood events? How should governments, businesses, and the public manage or cope with their increasing risks of flood damages? What are cost-effective and socially acceptable mitigation strategies, and how should the remaining losses be shared or pooled? How can governments cooperate with insurance companies, other private entities, and NGOs in mitigating flood damage, providing relief to the victims, and ensuring economic recovery? What is the potential role of novel financial instruments, such as catastrophe bonds, for transferring risks? What types of democratic institutions can cope effectively with the escalating risks?

These questions have motivated the selection of articles presented in this special issue. The articles originate from two conferences held at IIASA in Laxenburg, Austria in 1999 and 2001: Global Change and Catastrophe Risk Management: Flood Risks in Europe, sponsored by the European Commission, and Integrated Disaster Risk Management, jointly sponsored by IIASA and the Disaster Prevention Research Institute (DPRI) of Kyoto University. The selected articles focus on three highly topical and largely unexplored issues raised by European flood risks. The first is the respective roles of climate change and human interventions in hydrological and economic systems on flood risks in Europe. Armed with information on the causes of the damages, European governments and publics can better proceed in reducing and coping with the losses. This raises a second important issue on public participation and democratization of flood risk management processes. There are no singular solutions to managing flood risks, but many different paths for reducing losses, providing relief to victims, and restoring public and private infrastructure. Because of the different views and values of the stakeholders, a challenge is to design trustworthy risk management institutions and processes. A third and very new issue is the financial management of disaster risks by public or sovereign entities. Especially in the case of Europe's transition countries, governments often have difficulty raising sufficient funds after a disaster to finance their obligations of providing relief and repairing public infrastructure. A question addressed in this volume is whether the public authorities of transition and poor countries should hedge their risks from floods and other extreme events with insurance or insurance-related, risk-transfer instruments.

These questions and issues are not unique to Europe. By addressing the underlying causes and policy responses to escalating flood damages in Europe, this collection of articles will be of interest to a broad audience of policymakers, practitioners, consultants, and academics who are concerned about the rising global economic toll from flood disasters.

2. THE ROLE OF CLIMATE CHANGE ON EUROPEAN FLOOD RISKS

The UN's International Panel on Climate Change recently concluded that, while there are uncertainties, some extreme events, such as droughts, floods, heat waves, avalanches, and windstorms, are projected to increase in frequency and/or severity due to changes in the mean and/or variability of climate.[10] A question addressed in this volume is what this means for Europe *today*? To what extent, if any, can the recent flood losses in Europe be attributed to climate change?

Two authors in this volume, Axel Bronstert and Zdzislaw Kazmarek, investigate this question. In his article on "Floods and Climate Change: Interactions and Impacts," Bronstert discusses the difficulties and uncertainties in separating the effects of global warming from the many other human-induced factors influencing the frequency and intensity of flood events and the resulting losses. He refers to the interdependency of the flood risk components as the "cascade of flood risk," which includes changes in land use and land cover, modifications to the river morphology and the channel system, the increase in human settlements and capital in flood risk areas, in addition to the possible effects of a changed climate. These components affect the risk of catastrophic flood losses in many different ways, for example, by altering the retention capacity of river basins and by increasing the vulnerability of people and property in flood-endangered areas. Climate change can also affect the frequency and intensity of floods in different and sometimes subtle ways. A warmer climate will likely increase precipitation,[11,12] where the distribution of rainfall in addition to the average plays an important role with regard to flood risks. It is not only precipitation that translates into flood losses. As Bronstert points out, climate warming can alter vegetation and affect water absorption and flooding.

Bronstert's review of research on climate change and European flood risks shows evidence of a correlation between climate warming and more intensive and frequent flooding in some European regions and no correlation in other regions. He is not surprised by the conflicting evidence and cautions about the uncertainties and unknowns inherent in the scientific investigations. The knowledge of climate change and its effects on systems and cycles of the earth is still very limited. Much of the research relies on the results of large global climate models, but the spatial scale of these models is too large for simulating anthropogenic climate change on a regional level. Moreover, most of the investigations of changing flood risks do not adequately take into account the full range of human influences. Bronstert concludes that an integrated analysis of the human-induced affects on the whole chain of causes and effects, including precipitation, runoff generation and concentration, flood wave propagation, and inundation and flood damage, is needed to determine the effects of climate change on flood risks.

The conclusion Bronstert draws for Europe has been reaffirmed by recent research investigating the relationship between global warming and riverine flooding.[13–15] These authors present results indicating that global warming may have increased the risk of flooding in selected, very large river basins; however, they also point to the limitations of available climate models, which do not have a fine enough resolution for an accurate application at the river-basin level, and to the large and inherent uncertainties.

Whereas the causal link between global warming and flooding is still speculative, an important part of this link in Europe may be the relationship between the temperature cycles of the North Atlantic Ocean, the North Atlantic Oscillation (NAO), and European weather. To explain the variations observed in snowmelt-induced floods in Polish rivers, Zdzislaw Kaczmarek investigated the correlation of European precipitation and snow cover with the NAO index of temperature variations. Applying a simple model of snow cover and its changes in selected Polish river basins, he concludes that as the NAO has increased, snow cover has decreased significantly. This means that the spring floods resulting from the combination of melting snow and precipitation[2] may be linked to the stochastic properties of the NAO index.[3] This result is of substantial interest for assessing the risks of European flood events associated with precipitation and snow melt.

Kaczmarek does not address the question of whether there is a link between the NAO index and climate change and thus does not suggest that springtime flooding is resulting from a warmer climate. Despite the IPCC's warning that climate warming will likely increase the extremes in weather events on a global scale, there is still scant evidence that climate warming is contributing to flood losses in Europe today. Alternatively, the escalation in European flood losses are convincingly linked to other anthropogenic causes. In his article on "European River Floods in a Changing World," Ken Mitchell argues that the main driving forces of flood losses are the movements of population and capital into harm's way and human-driven transformations of hydrological systems. Population and capital are concentrating in flood-prone areas; land-use practices are increasing the runoff from precipitation; and private construction and public infrastructure continue to be vulnerable to flood damage. This conclusion applies beyond Europe and beyond flooding. Normalizing the trend in losses from major natural disasters across the globe over the last decade to account for population and wealth increases, Mileti[18] concludes that increased disaster losses can almost be fully explained by increasing population and capital.

3. INSTITUTIONAL CHANGE AND THE DEMOCRATIZATION OF FLOOD RISK MANAGEMENT

The conclusion that climate change is playing a role in Europe's increasing flood damages is premature; however, the IPCC suggests that such a role is likely in the future. In countries like the Netherlands, which have a large geographic exposure to the risks of flooding, a small increase in flood probability and intensity can translate into large losses. In their article on "Adapting to Climate Change: A Case Study on Riverine Flood Risks in the Netherlands," Richard Tol, Nicolien van der Grijp, Alexander Olsthoor, and Peter van der Werff ask whether institutions like the water-management authorities and their likely successors will learn and adapt to the increasing flood risks posed by climate change and also by interventions in the system by the authorities themselves.

This question cannot be addressed without taking into account the full institutional setting surrounding river-basin management. In the Netherlands, more so than in most other European countries, the public and NGOs have become influential, especially in protesting the extent of flood protection by dikes and other structural measures in favor of more naturalistic policies like "letting the river be the river." Public interventions have constrained the water authorities in providing engineered flood protection. The authors argue that the increasing demands of the public to participate and influence flood risk management poses an added difficulty with regard to the institutional response to climate change. Based on a study of the Rhine and the Meuse Rivers over the past 50 years and a scenario study looking into the future, they show that new and major infrastructure is needed to maintain flood risks at their current level. They give particular attention to a Dutch proposal to construct bypass channels as an alternative to building stronger dikes. The authors are pessimistic, however, that there will be sufficient political will or needed institutional reform to meet this challenge.

Hungary ranks only behind the Netherlands with respect to flood exposure. In contrast to the Netherlands, participatory institutions and processes with regard to flood risk management in Hungary are at an early stage; yet, in all areas of environmental policy the public is becoming increasingly involved. In their article on "Stakeholder Views on Flood Risk Management in Hungary's Upper Tisza Basin," Anna Vari, Joanne Linnerooth-Bayer, and Zoltan Ferencz report on the results of a public survey to elicit views on the appropriate means of reducing the high flood losses in the Upper Tisza area and for transferring the residual losses from the direct victims, who are mainly very poor farmers, to taxpayers or an insurance pool. These issues are especially topical for the Hungarian government, which has spent large sums on protective

[2] By downscaling GCM models for Alpine catchment areas, Nachtnebel[16] also argues that an increase of flooding probability may depend on simultaneous precipitation events and snow melting due to warmer spring temperatures.

[3] A further correlation between sea temperature and precipitation has been found by Maracchi,[17] who shows that the triggering of convective storms in Tuscany, Italy has been enhanced by warm moist air from the Mediterranean due to increased sea surface temperature.

levees and has a traditional obligation to provide substantial relief to private victims (following recent devastating floods the government fully repaired or rebuilt all damaged homes and buildings). Although many view government support as fair for this destitute region, there are mounting concerns that it is unsustainable. Levees inevitably increase flood risks further downstream, and compensating flood victims is not only discouraging local efforts to reduce flood losses but is also causing serious problems for the Hungarian government, which intends to meet the Maastrich conditions as a new EU member. The government would welcome more private responsibility and insurance, a policy path that few in this region could afford and thus a path that would force many villagers to leave the area. Moving the villagers out and renaturalizing the river are measures many consider more sustainable and, at the same time, unfair. Hungary, like many countries, is thus asking how it can manage its flood risks in a more responsible, sustainable, and equitable way.

In contrast to the Netherlands, the Hungarian survey showed a great deal of public support for structural flood-protection measures. Another surprising result was that a large number of the survey respondents *including those facing no risks* thought the taxpayers should continue to aid Tisza victims on the grounds that the government—by not pursuing more sustainable policies in the region—is largely *responsible* for the flood damage. Yet, there was strong minority support for more ecological flood policies and more private insurance, which led the authors to conclude that a flood-risk management strategy in Hungary will likely not gain widespread support unless it combines elements of the business-as-usual path, that is, the path characterized by central government protection and relief, with more market-based and ecological policy paths.

The hierarchical policy response to flooding in Hungary is typical of central and eastern European governments but contrasts sharply with, for example, the United Kingdom, which has traditionally placed far greater responsibility on individuals and households. Fig. 2 shows the relative proportions of state aid and insurance in the cases of four recent floods in Europe and the United States (the 1998 Easter floods in the United Kingdom, the 1993 German Rhine floods, the 1997 Polish flood, and the 1993 midwest floods in the United States). Although the United Kingdom and Germany stand out as having practically no or very little government aid to victims, respectively, the Polish government (like Hungary) is very generous in compensating victims after a disaster. Interestingly, the United States, with its extensive National Flood Insurance Program, is closer to the Polish case. Many observers point out the drawbacks of relying heavily on government post-disaster relief, which encourages more development in flood plains,[19] but as the Hungarian case demonstrates, many citizens value social solidarity.

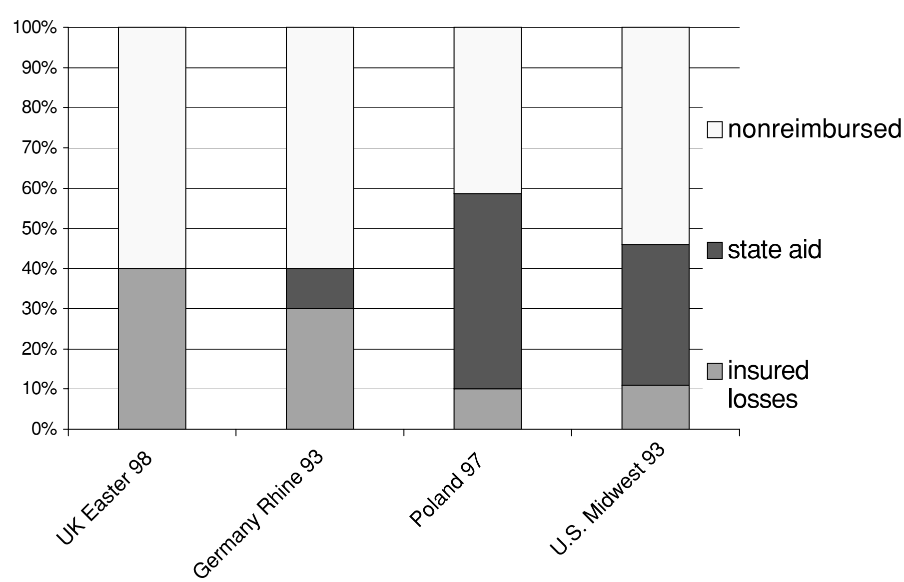

Fig. 2. Percentage of losses reimbursed by insurance and state aid in recent European and U.S. floods.

Source: Linnerooth-Bayer and Quijano.[20]

4. THE FINANCIAL MANAGEMENT OF DISASTER RISKS BY PUBLIC AUTHORITIES

Social solidarity, however, is creating a dilemma for the Hungarian and many transition governments in Europe. With escalating flood losses, transition countries may have great difficulty in financing disaster relief and recovery. This is especially true in the developing world, where very poor and very disaster-prone countries, for example, Honduras, the Philippines, and China, face such enormous risks that they can be set back years in their development. The question addressed by three articles in this volume is whether these governments could potentially benefit from insurance or insurance-related financial instruments, like catastrophe bonds, that are put into place before the disaster occurs.

Keeping in mind that the purchase of insurance or related financial instruments raises the average costs of disasters to governments in the long run, the question is whether the benefits justify the costs. This is the question posed by Paul Freeman and Georg Pflug in their article on "Infrastructure in Developing and Transition Countries: Risk and Protection." The theory of insurance suggests that private individuals will purchase insurance only if they are averse to large losses. If these losses are spread across taxpayers, is there a reason for governments to purchase protection? Freeman and Pflug point out that insurance has added value in assuring a country's solvency and stability, especially if the government authorities have a difficult time borrowing, diverting funds from other budget items, or otherwise raising funds after a major disaster. Therefore, the cost-benefit tradeoff is one between economic growth through infrastructure investment and added solvency and stability for the economy, and the authors develop a model to show this tradeoff. The model provides a basis for evaluating alternative financing options based on a country's objectives in terms of growth, solvency, and stability.

In their article on "Sovereign CAT Bonds and Infrastructure Project Financing," David Croson and Andreas Richter examine this tradeoff more specifically by exploring the opportunities for using insurance and other catastrophe-linked securities to reduce the total costs of funding public infrastructure projects in emerging economies. This question is of particular interest to countries that fund infrastructure projects with loans from international financial institutions, such as the World Bank. The reason is that funding for infrastructure projects in vulnerable countries is often rerouted as relief for natural disasters, for example, almost 40% of World Bank funds to Mexico are diverted for this purpose.[21] The authors address three key questions: Can catastrophe-linked securities be useful to a sovereign nation? Why are such financial instruments ideally suited for protecting public infrastructure projects sponsored by third parties (for example, the World Bank)? How can the benefits of a government or external project sponsor, who values timely completion of the projects, be estimated? To address these questions, the authors develop a model to calculate the overall cost reductions possible with the use of insurance-linked financial instruments based on the costs of capital, the risks of disasters, the feasibility of strategies for mid-stage project abandonment, and the timing of capital commitments to the infrastructure investment. With this model, they can identify the set of circumstances under which governments or lenders might be advised to pay the costs of these instruments.

This research shows that governments can potentially benefit from insurance or insurance-related financial instruments that are put into place before a flood or other disaster occurs. This is not the case for governments of wealthy countries, since they usually have ample opportunities to raise needed capital after a disaster occurs, usually by issuing highly rated government bonds. This raises a dilemma: those countries or governments that can benefit most from insurance-linked instruments can least afford them. Are there ways that private "charitable" investors or international financial institutions could play a role in enabling poor countries to purchase pre-disaster financing instruments?

Howard Kunreuther and Joanne Linnerooth-Bayer in their paper on "The Financial Management of Catastrophic Flood Risks in Emerging-Economy Countries" address this question and suggest that international lending institutions, like the World Bank, consider innovations for subsidizing insurance-related instruments for poor countries. These authors also examine another important consideration with regard to sovereign insurance. Since governments, like individuals, may invest less in mitigation measures if they have insurance, the so-called moral hazard, these authors suggest alternatives for linking insurance-linked instruments with incentives for mitigation. As a concrete case, they discuss the financial arrangements for disaster recovery after the 1997 flood disaster in Poland, which caused losses of approximately 3% of Poland's GDP. They examine the full range of pre-disaster financing or hedging instruments and compare them with those available after the disaster. They also show how pre-disaster instruments can be designed to create incentives for the Polish authorities to invest in flood-proofing a water-treatment plant.

5. CONCLUDING REMARKS

Research investigating the relationship of climate change to the intensity and frequency of flooding at a regional level will be indispensable if countries over the globe are to adapt to a warming climate. Indeed, weather-related extreme events may be one of the costliest consequences of climate change. Even without climate change, Europe and the world will likely face a dramatic rise in weather-related damages. Our knowledge about climate change and other factors contributing to extreme events and their consequences is improving, but this knowledge will prove insufficient if institutions and democratic procedures are not in place to respond to the risks.

Stakeholder involvement in policies for the mitigation of flood losses and the design of a public-private insurance system in Hungary is a step in this direction. Yet, the pessimistic outlook for institutional adaptation to increasing flood risks in the Netherlands, which has a strong democratic tradition of stakeholder involvement, is sobering and suggests that we need new, innovative ideas for adapting to the challenges of floods and other extreme events. A recent innovation for the financial management of extreme events stems from the financial markets and includes a range of insurance-related, risk-transfer instruments, such as catastrophe bonds, to hedge the risks of disasters. These instruments have proven useful to insurance companies with high exposure to catastrophes, and they could potentially support poor governments facing the potential of very large disaster losses. However, those governments most in need of pre-disaster financial arrangements are usually those that can least afford them. This may call for rethinking the way governments provide aid to poor countries, in effect switching from post-disaster relief to aid in the form of pre-disaster insurance instruments.

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Floods and Climate Change: Interactions and Impacts

Axel Bronstert*

Whether the floods experienced during the last decade in Germany and in other European countries are triggered or worsened by human activities has been the subject of a great deal of debate. Possible anthropogenic activities leading to increased flood risk include river regulation measures, intensified land use and forestry, and emissions of greenhouse gases causing a change in the global climate. This article discusses the latter by reviewing the existing knowledge on the subject. First, the relevance, capabilities, and limitations of climate models for the simulation and analysis of flood risk under aspects of the anthropogenic climate change are described. Special consideration is given here to differences between the "typical" spatial scale of climate models and hydrological flood models. Second, observations of trends in climate variables relevant for river flooding issues are summarized. Special emphasis is put on the Rhine and other German catchment areas. Third, the possibilities of modeling the different parts of the "cascade of flood risk" are summarized, introducing the special features of meteorological, hydrological, and river hydraulic models.

KEY WORDS: River flooding; flood risk; climate change; hydrological modeling; climate downscaling

1. INTRODUCTION

Whether the floods experienced in recent years in Germany and in other European countries are triggered or worsened by human activities has been the subject of a great deal of debate.[1–5] Possible anthropogenic activities leading to increased flood risk include river regulation measures, intensified land use and forestry, and emissions of greenhouse gases causing a change in the global climate. This article discusses the latter by reviewing the existing knowledge on the subject.

In recent years, rising water levels, floods, and landslides following heavy precipitation have occurred with increasing frequency in many European countries. Table I gives a still not complete overview of severe river floods in the European Union and neighboring countries and their direct effects on the population of the affected areas between 1991 and 2000.

In 1990, the Intergovernmental Panel on Climate Change (IPCC) confirmed the increase of greenhouse gases in the atmosphere and the resulting global warming of the earth.[6] The second technical report[7] concluded, *inter alia*, that the mean summer temperatures in the northern hemisphere in the last decade have been the highest experienced since the beginning of the 15th century. On the basis of a wide array of proxy sources, such as ice cores, tree rings, corals, and lake sediments, it has been concluded that the 20th century is at least as warm or even warmer than any century of the last millennium. Accordingly, for some places of the earth, especially for high mountain regions, the 20th century seems to be the warmest century in several thousand years. These findings are supported on a even wider basis by a variety of temperature measurements over the globe as reported in the IPCC third assessment report.[8]

In the 20th century warming took place basically during two periods: from about 1910 to 1940 and from

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Region	Year	Fatalities	Evacuations
Wallis (Switzerland); Northern Italy	2000	36	?
England and Wales	2000	?	?
Eastern Spain	2000	?	?
Hungary and Romania	2000	11	?
Bavaria (Germany); Austria; Switzerland	1999	12	?
Southwest France	1999	?	?
Portugal; Western Spain; Italy	1998	31	?
Belgium; Netherlands	1998	2	?
Slovakia, Czech Republic, Poland	1998	ca. 100	?
Eastern Germany; Czech Republic; Western Poland	1997	114	195,000
Southern Spain	1996	25	200
Southern, western, and northern Germany; Belgium; Luxembourg; Netherlands; eastern and northern France	1995	27	300,000
Piemonte and Liguria (Italy)	1994	73	3,400
Greater Athens (Greece)	1994	12	2,500
Southwest Germany; Belgium; Luxembourg; southern Netherlands; eastern and northern France	1993–1994	17	18,000
Piemonte and Liguria (Italy); southeast France	1993	13	2,000
Essex and Devon (UK); Ireland	1993	4	1,500
Vaucluse (France)	1992	42	8,000
Sicily (Italy)	1991	16	2,000

Table I. Heavy Floods in the EU and Neighboring Countries, 1991–2000, and Their Effects on the Population

the middle of the 1970s to the present.[8] The seven warmest years occurred during the last 10 years of the 20th century (see Fig. 1). A similar trend of temperature increase, as well as an accumulation of warmer years during the last 10 years, was not only observed worldwide, but also in Germany.

The decisive questions for evaluating the effects of climate warming on the risk of flooding in Europe are the following:

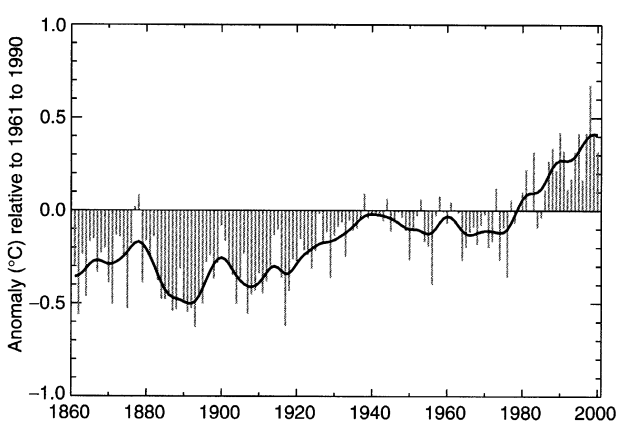

Fig. 1. Mean annual values of air temperature over the land areas of the earth (°C) 1861–2000 in relation to the average of 1961–1990.[8]

- Is the observed temperature increase accompanied by an increase in precipitation as well as by an increasing number and/or severity of floods?
- Is there any change in the characteristics (quantity, intensity, extension) and frequency of extreme precipitation events causing floods?
- What are the effects of climate change on flooding in comparison to other anthropogenic impacts and in comparison to the "normal" natural variability?

At present, large scientific uncertainties are associated with these questions. However, some conclusions with regard to the possible effects of global warming on the risk of flooding may be drawn on the basis of the knowledge available today. For this purpose it is advisable to differentiate between two categories of floods according to the size of the affected area and the duration of precipitation (spatial and temporal scale of the flood events). *Extensive, long-lasting floods* (*plain floods*) describe the flooding of larger areas that is almost invariably caused by rainfalls lasting several days or weeks in connection with high antecedent soil saturation. Flooding caused by extensive and long-lasting rainfalls, partly connected with the melting of snow and ice, occurs mostly in

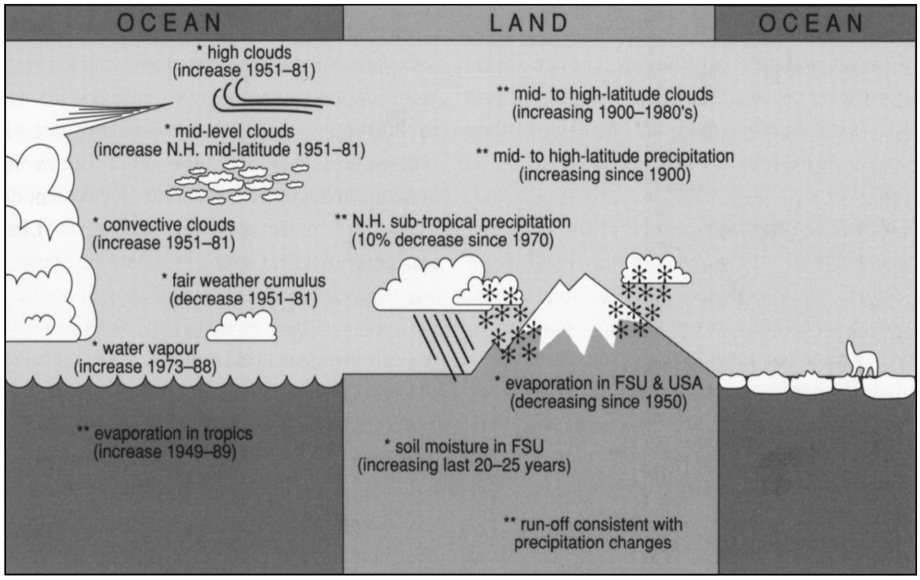

Fig. 2. Overview of observed trends in global hydrology.[7]

plain areas when the dikes along the big rivers can no longer contain the flood discharges. This can lead to flooding of wide areas, as, for example, during the flooding of the Rhine/Maas rivers in December 1993 and in January/February 1995. *Local, sudden floods* (*flash floods*) describe flooding in small catchments that is mainly caused by short and highly intensive precipitation (e.g., thunderstorms). Flash floods occur primarily in hilly or mountainous areas due to prevailing convective rainfall mechanisms, thin soils, and high runoff velocities. The warning time for these events is short. In general, the duration of the flood event is also short, but this flood type is also frequently connected with severe damages.

2. CLIMATE MODELING AND ITS RELEVANCE TO THE FLOODING ISSUE

The mean global temperature has risen by 0.3–0.6°C since the end of the 19th century, and 0.2–0.3°C of this increase occurred in the last 40 years. According to statistical analyses carried out by the German Center for Climatic Computations (DKRZ), the warming of the last 20 years can be attributed with 95% certainty to anthropogenic causes as opposed to natural climatic variability.[9] With regard to the question of flooding, the decisive factor is not the temperature, but rather the characteristics of precipitation. In this respect, long-term observations on a global to continental scale have, for instance, shown an increase in precipitation in higher latitudes of the northern hemisphere in winter and a certain decrease in precipitation over the subtropical areas from Africa to Indonesia. Fig. 2 illustrates the observed trends in global hydrology over the last 20–30 years.

Energy and water cycles are closely interrelated systems with mutual impacts. On the basis of thermodynamic principles, it can be stated that on the global scale a temperature increase will lead to a general intensification of the hydrological cycle. Assuming a global temperature increase between 2.8–5.2°C, Mitchell[10] estimates increased global evaporation and precipitation rates to be between 7–15%. This increase is similar to the calculations by Roth,[11] which showed an intensification of the global hydrological cycle by approximately 10%. Due to the shifting of climatic zones and an increasing intensity of convective processes, Berz[12] anticipates a future increase in the frequency and severity of windstorms, floods, and storm surges in many parts of the world.

An assessment of the change in the evolution (severity and intensity) of floods calls for analyses that are carried out on much smaller scales than that of the global or continental. For such an assessment it is necessary to analyze the change of hydrological conditions, and especially the characteristics of heavy precipitation, at the *regional to local hydrological scale*.

This requires the adaptation of existing regional, dynamic climate models and/or statistical downscaling of methods toward the requirements of regional hydrological models.

Dynamic climate models attempt to mathematically simulate, at various degrees of detail, the physics of the atmosphere, of the oceans, and the exchange processes between the earth's surface and/or the biosphere and the atmosphere. The most powerful climate models today are coupled global atmosphere-ocean circulation models (GCM), which carry out three-dimensional calculations of the equations for mass and energy transport, momentum, humidity of the atmosphere, and salt content of the ocean for the entire globe. For this purpose the atmosphere and the oceans are separately subdivided into a gridded system of vertical layers and horizontal sections so that an overall three-dimensional disaggregation is achieved. As the GCMs were originally conceived for the analysis of large-scale circulation systems, they are much too coarse in their spatial resolution to yield usable data for the analysis of floods.(13) Precipitation values for an area of 500 × 500 km, that is, one mean value for 250,000 km^2, cannot supply reliable information on the risk of heavy rainfall in a river basin covering an area of the order of 10,000 km^2.

Therefore, a variety of techniques have been developed to derive the climate forcing required for assessing the hydrological, basinwide impacts of climate change. The most important ones are the statistical downscaling and the regional climate models. Statistical downscaling bridges the two different scales by establishing empirical (statistical) relationships between large-scale features simulated reliably by the GCMs, such as geopotential height fields, and regional or local climate variables, such a temperature and precipitation at a certain location. Statistical downscaling techniques have been applied in a series of studies,(14) but few of these studies have been carried out in the context of climate change and flooding. A review of prospects and limitations of this approach for use in climate change impact studies focusing on extreme hydrological events is beyond the scope of this article.

The so-called regional climate models have been applied for some time. In contrast to the general circulation models, they cover only a section of the globe that can be modeled at a finer spatial resolution. At present, the grid widths used for regional climate models are approximately 50 km or less. The climatic conditions at the boundaries of the regional sections are predetermined by the results of the GCMs. Such a spatial resolution is considerably more adequate for the analysis of flood risks. However, these models cannot assess or project precipitation with the high degree of certainty necessary for the quantification of flooding risk for the following reasons.(15)

- The boundary conditions of the regional model are obtained from the GCM, and thus an error of atmospheric dynamics contained in the large-scale model is transferred to the respective region. Errors or shortcomings in the GCM thus directly limit the capacity of the regional climate model.
- The resolution of the regional climate models is sufficiently detailed to represent large-scale precipitation patterns. However, these models are not yet sufficient to cover small-scale, convective precipitation (e.g., thunderstorms) in the necessary detail. Though processes taking place at a smaller scale than represented by the grid box (subgrid-scale processes) can be parameterized by the subdivision of the grid boxes into a clouded and a cloud-free section, several convective systems cannot be localized within a grid square. With an increasing resolution, an increasing number of parameters would have to be isolated from the explicit modeling process, a problem that has not yet been resolved.
- Flooding is triggered by extreme precipitation. However, the climate models have not yet been sufficiently tested for their realistic representation of such extremes.
- The parameterization of important processes, such as the formation of clouds, soil moisture dynamics, or land surface interactions, has not yet been resolved in a way that allows for a definition of the natural variability under any weather condition or for the recognition of a possible signal of climate change.

An example of the effect of soil moisture dynamics on the generation of precipitation, that is, soil water being available for evapotranspiration, thus increasing atmospheric humidity and contributing to cloud formation, is given by Beljaars.(16) In an application of the weather forecast model of the European Center for Medium-Range Weather Forecast (ECMWF), the sensitivity to land surface parameterization in particular to the soil moisture module was analyzed. Two approaches (the at that time operational version "C47" and an extended and improved version "C48") were compared on the basis of their forecasts for the extreme precipitation in July 1993 in the midwestern states of the United States. One of the major differences between C47 and C48 is the representation of the soil water dynamics: the C47 version contained two prognostic soil layers (7- and 42-cm deep) and an additional 42-cm climatological layer as boundary condition, whereas the C48 version is built up by four soil layers (7-, 21-, 72-, and 189-cm deep) and free drainage as lower boundary condition. The results (Fig. 3a/b) show a rather different forecasted precipitation pattern, particularly over the central United States. It can be clearly seen that the amount of rain over the regions of Kansas, Nebraska, and Iowa, which was calculated using the former approach (CY 47) is almost zero (Figure 3a). In contrast, the precipitation calculated by means of the improved approach (CY 48) is considerably higher and of longer duration. The authors conclude that the extreme precipitation over the Mississippi area in summer 1993, which was mainly responsible for the extreme flooding at that time, could be estimated much more realistically by the new approach. This

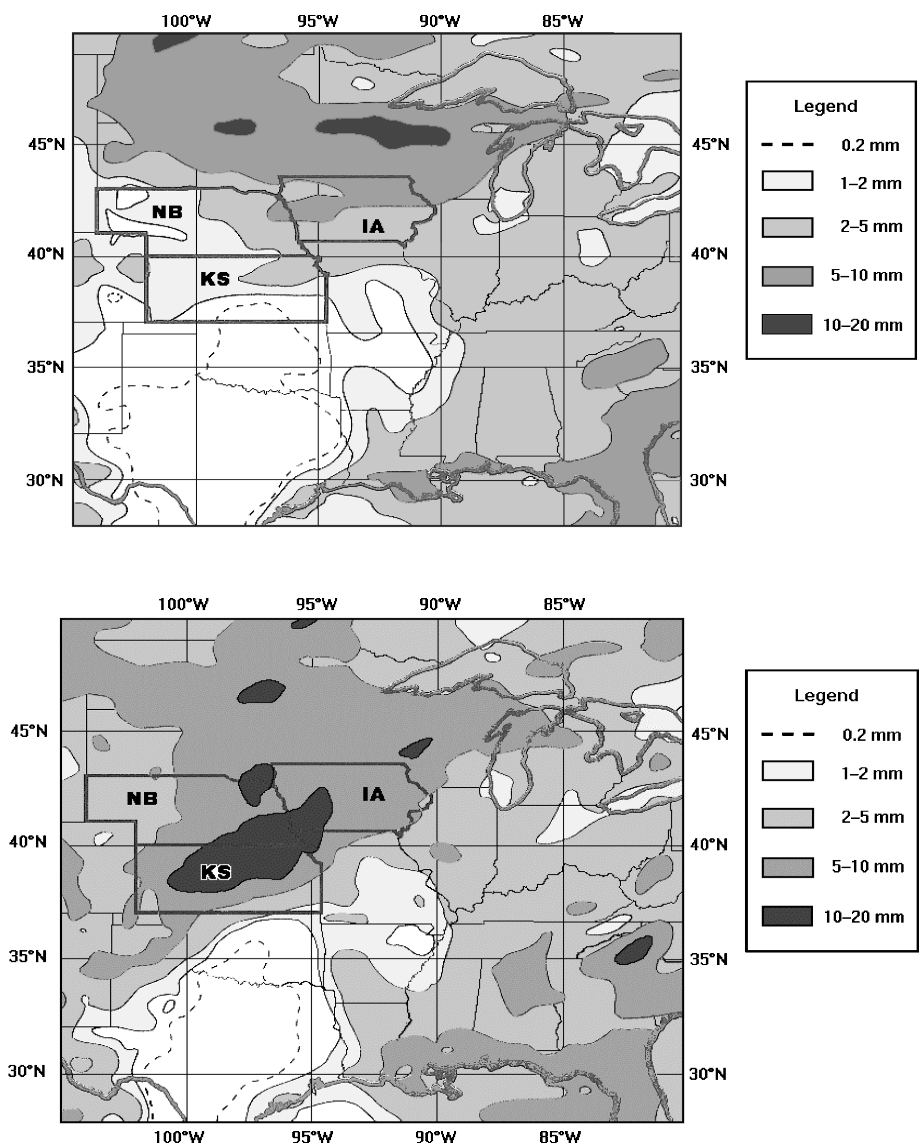

Fig. 3a/b. Mean precipitation forecast with an operational weather forecast model of the ECMWF for all 48–72-hour predictions between July 7–22, 1993 for the midwestern states of the United States. Fig. 3a (upper chart) and 3b (lower chart) present the results based on the former and the new land-surface parameterization (by personal communication of A. Betts, based on results from Beljaars[16]).

example illustrates the sensitivity of climate projections to the soil moisture module. However, this might not be an artifact of the climate model, because nature, itself, is probably not less sensitive. The water stored and evaporated from the soil has a decisive influence on the hydrological cycle, both on cloud and rainfall formation (recycling of precipitation) and on the generation of runoff.

Regional climate models can supply information necessary for the estimation of flood-relevant precipitation, particularly with regard to weather conditions connected with large-scale precipitation fields. However, for obtaining accurate information *on the location, quantity, and intensity of precipitation* (necessary for the analysis of the flooding process) as well as on *a change of the precipitation characteristics resulting from global climate change*, the models are not sufficiently accurate or spatially detailed.

Apart from the difficulties in climate modeling there are further unresolved problems with regard to flood modeling.

- The transformation of precipitation (and/or snow melting) into floods in a catchment area, that is, the basic hydrological modeling effort, frequently cannot be carried out with sufficient accuracy due to the high natural variability of the infiltration characteristics, insufficient knowledge of the processes involved during extreme precipitation periods, and insufficient data on the catchment areas.
- Measurements of extreme precipitation and runoff are frequently incorrect and not very numerous. However, such measurements are indispensable in order to standardize and improve climate as well as hydrological models.
- Any climate-induced trends in the runoff behavior of a river are often superimposed by the effects of changes in land use, river regulation measures, settlement expansion, and changes in the river morphology. Frequently, it is not possible to separate the effects of these changes.

3. EFFECTS OF CLIMATE CHANGE ON FLOOD CHARACTERISTICS

Flood generation and runoff is a highly nonlinear system, which is exposed to the natural and spatial/temporal variability of meteorology, topography, soil, vegetation, climate, groundwater conditions, and the channel drainage system. Therefore, quantitative statements, especially with regard to the effects of climate change on flooding and runoff processes, are highly uncertain.[17] A qualitative assessment of the situation can be based only on our present state of knowledge, summarized below, taking into account the underlying physical laws and the interpretation of a series of measurements.

In investigating the risks of flood losses, meteorological and hydrological conditions, river hydraulic characteristics, and land-use conditions must be considered and separately assessed. Each of these factors can contribute to an increased risk of flood damage, in particular if there are negative interrelationships and synergies. Of these flood-risk factors, the meteorological conditions are considered to be of primary importance with regard to climate change. Also, vegetation and soil conditions in the catchment area, which determine water retention and evaporation processes, can be affected by climate change and thus have a feedback effect on flood development.

3.1. Observations in Germany and Europe

3.1.1. Trends in Precipitation and River Discharge in the Rhine Area

An increase in mean precipitation, estimated on the global scale on the basis of theoretical considerations (see Section 2), has been confirmed on the regional scale in parts of Germany and neighboring areas by corresponding trends measured over approximately the last 100 years. According to Engel,[18] the annual precipitation over the Rhine area extending to Cologne has, since 1890, shown a rising overall tendency with distinctive periodical fluctuations. Apart from the increased amounts of annual precipitation, there is also a tendency of a seasonal shift from summer to winter. Combining both trends over the last 100 years, on average this results in a fairly constant summer precipitation (June–October) and a significantly increased winter precipitation (November–May). The statistical analysis of precipitation trends in Europe between 1891 and 1900 by Rapp[19] shows a significant increase in winter precipitation of central and northern Europe and a decrease in southern and southeastern Europe. These results are consistent with the rainfall trends observed in the Rhine basin.

Apart from the above-mentioned precipitation trends, corresponding tendencies were also noted for the mean discharge in the Rhine basin extending to Cologne. Engel[18] reports a rising tendency of the maximum annual discharge of the Rhine at Cologne over the last 100 years. However, the observed trend only applies to the maximum annual discharge derived from daily data and cannot be related to extreme discharges, that is, floods occurring less frequently, but involving heavier discharge. Grünewald[20] reports that the cause of the spectacular floods of the Rhine in the years 1993/1994 as well as in 1995 cannot be attributed to runoff from the Alps, but rather to the low retention capacity of the soils in the flood-relevant middle mountain range in Germany and France. The low infiltration rates can mainly be attributed to the spatially extensive periods of rainfall prior to the actual period of flooding, for example, December 7–18, 1993, and/or to the melting of the snow cover and the frozen soil in January 1995. These flood events showed how important the melting conditions of the snow cover can be for the development of floods. Thus, climate-induced changes in the quantity, frequency, and timing of melting of the snow cover may have an effect on the hydrological regime of a river and on flooding.

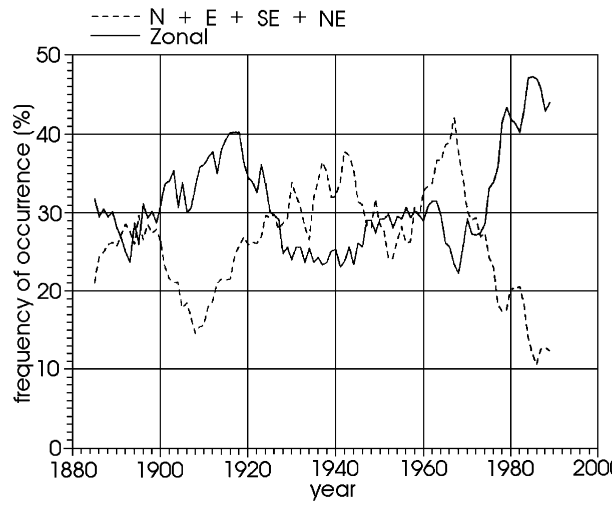

Fig. 4. Moving average frequencies (10-year window) of large-scale westerly zonal weather conditions and large-scale weather conditions north, east, northeast, and southeast (N+E+NE+SE) over Europe for the months of December and January from 1881 to 1989.[22]

3.1.2. Changes in Frequency of Weather Conditions in Europe

Under zonal atmospheric circulation conditions, in particular, a high correlation has been found between the large-scale weather type over Europe and the North Atlantic and the occurrence probability of regional or local precipitation in central Europe. For example, Bárdossy[21] reports a probability of 85.6% for daily precipitation occurrence at the climate station at Essen with regard to *cyclonal westerly* weather type and of 82.9% for *cyclonal southwesterly* weather type. Investigations at many other weather stations in western Europe have also confirmed the relationship between westerly/south-westerly zonal circulation conditions and heavy precipitation over parts of western Europe.

Bárdossy[22] and Gerstengarbe[23] have examined the frequency of weather conditions in Europe since 1891 by means of time series of daily weather maps (*Grosswetterlagen*). They found a significant increase in the frequency of west weather conditions, the statistical breaking point of the time series occurring in the middle of the 1970s. The time series of western weather conditions and complementary types of weather conditions for the months of December and January is shown in Fig. 4. The increase of western zonal conditions is evident. Since these weather conditions can be considered typical of long-term, large-scale precipitation patterns in central Europe (see above), for some catchment areas a correlation can be established between the increase of these weather conditions and an increased frequency of floods. In this connection, Caspary[24] draws the conclusion that for some catchment areas in the Black Forest the probability of flooding has dramatically increased. Due to the lack of earlier weather maps and records, however, it is not possible to state to what extent the observed trend of the 115-year time series is explained by longer-term, natural fluctuations.

3.1.3. Effects of Regional Warming in the Past Two Centuries

Burkhart[25] reports a decrease of the extreme floods of the Elbe river during the past 200 years. This decrease is probably due to a reduction of floods caused by ice jams and ice jam breaks. The reduction of ice jams resulted mainly from the regional warming that occurred after the end of the last little ice age (after 1800) and, to a smaller extent, from the increase of salt content and from the inflow of relatively warm waste and cooling water. The construction of numerous upland reservoirs is also a factor to be considered in assessing water levels in the Elbe over recent decades.

Table II compares the statistics of water-level time series for the 19th and 20th centuries at the Elbe gauges Dresden and Magdeburg. From this data, it

Table II. Discharge Rates (in m^3/s) for Elbe River Floods of Equal Recurrence Intervals Based on Time Series for the 19th and the 20th Centuries[25]

Period	Statistical Return Period (in Years)							
	2	5	10	20	25	50	100	200
				Gauge Dresden				
1806/1900	1,808	2,690	3,212	3,669	3,806	4,206	4,577	4,924
1900/1990	1,386	1,974	2,318	2,617	2,706	2,967	3,207	3,432
Difference	522	715	894	1,052	1,100	1,239	1,370	1,492
				Gauge Magdeburg				
1727/1890	2,280	3,200	3,730	4,310	4,180	4,700	5,050	5,370
1890/1975	1,720	2,430	2,830	3,220	3,330	3,650	3,950	4,240
Difference	560	770	880	960	980	1,050	1,100	1,130

is evident that the flood discharge rates for equal statistical recurrence intervals have decreased, that is, that the flooding risk of the Elbe is lower in the 20th century than it was in the previous century.

3.1.4. Changes of Characteristics of Debris Flow Events in Alpine Environment

If the permafrost borderline rises in the high mountain range due to a long-term mean temperature increase, this can lead to thawing and to a destabilization of the currently frozen glacial deposits. In this case, landslides and moraines with severe local damage are likely to increase over the next several decades. Whether the increased frequency of landslides and debris flows in Switzerland observed in the past years is related to the warming in the Alpine region observed since 1850 has not yet been clarified.[26]

3.1.5. Indirect Effects of Reduced Vegetation Densities and Degraded Soils

In the long term, climatic change also leads to a change in the natural vegetation cover. Soil degradation resulting from reduced vegetation, a reduced macro porosity, and increased crusting and siltation will decrease the infiltration capacity and enhance direct runoff in the case of heavy precipitation.

The effect of reduced vegetation density on flood development stems from a diminished interception storage capacity and, above all, in the reduced protection of the soil surface against the kinetic energy of precipitation. The latter may lead to the accumulation of silt and thus to a considerable decrease in infiltration potential, which may, in the case of highly intensive rainfall, trigger flooding. Problems of this kind are especially important in semi-arid areas (e.g., in the Mediterranean), but also in agricultural areas with temperate climate conditions. Changes in the natural composition of the vegetation cover and of the soil structure due to changed climatic conditions, however, only occur over longer periods. Therefore, they will only have a long-term impact on changes in flood patterns.

3.2. Modeling Possibilities

One important objective of modern flood risk management and modeling is to understand and predict the extent, location, duration, and timing of floods. Such forecasts must be based on complex and detailed mathematical modeling systems. To simulate a flood, basically three different modeling components are required.

3.2.1. The Meteorological Model

The quality of weather forecasting models has significantly improved during the last years. Today, such models can supply information on temperature, wind, and precipitation up to approximately one week in advance. However, forecasting cannot yet assess accurately the location and the extent of precipitation. In particular, information on the location and intensity of local convective heavy rainfall (thunderstorms) is still insufficient for the direct forecast of *flash floods*.

Weather forecasts must not be confused with climate projections. Dynamic climate models, which, from a physical point of view, are very similar to weather forecasting models, can supply information only on climatic trends and mean, longer-term changes. A concrete time- and location-specific forecast of the various weather data is impossible within the usual, necessarily long-term, time frame of climate models.

3.2.2. The Hydrological Model

Hydrological models, which simulate the transformation of precipitation into runoff, have progressed considerably as directed to different types of flood generation.[27–29] However, the transformation of precipitation into runoff is not always a routinely applied part of a real-time flood prediction modeling system. Especially under conditions of extreme rainfall, the hydrological models show deficiencies in the assessment of infiltration overland flow, that is, the share of the precipitation running off at the surface, and of the groundwater reaction to excessive rainfall. Furthermore, questions of *scaling* in the assessment of hydrological processes are still partly unclear. A third problem lies in the frequently insufficient requisite databases. Improvements in these models, however, can be expected, and this will reduce the gap between the forecast of precipitation and runoff within the catchment area, thus presenting a basis for flood projection.

3.2.3. The Hydraulic Model

Hydraulic models calculate the routing of the flood wave within the river channel. They are not concerned with the question of *how much* water is flowing *into* the river, but *how* the water moves *within* the river system. They require inflow data at the starting points of the system (usually measurements from a water gauge in the upper part of the river tributary, or supplied by a hydrological rainfall-runoff model, as explained above) to calculate water level, discharge rates, as well as extension of the flooded area for the channel system analyzed. These models are highly developed for many large river systems, and they have supplied flood-level projections for many years.[30–34] Since they require the input of inflow data into the respective water system, however, they only work for short early warning times (i.e., the time in which the inflow moves from the point of measurement to the point of calculation). For the Rhine in Cologne, for example, this early warning time is only slightly longer than two days. For smaller rivers, the early warning times are so short that hydraulic models are of little use for real-time projections of floods.

The challenge for the future lies in the improvement and coupling of the above model systems to allow for early warning times according to reliable weather forecasts. Such coupled systems would also permit the investigation of the longer-term effects of climate change in the form of *scenario* analyses. By means of such scenarios it will be possible to analyze the behavior of a catchment area in the event of flooding under selected, typical future climatic conditions in order to derive typical flood characteristics. These events can then be compared with present or past conditions in order to make qualitative estimates for the river system under consideration.

3.3. Changes of Extreme Weather Conditions in Relation to Changes of Sea Surface Temperature and Ocean Currents

In Section 3.1.2, the relationship between large-scale atmospheric circulation patterns and the intensity and frequency of rainfall events over parts of Europe was discussed. It was shown that the increase of westerly weather conditions over Europe has led to an increase of precipitation in certain European regions. In addition to the changes of atmospheric circulation conditions, the relationship between global warming, warming of the sea surface, changes of large-scale ocean currents, and an increasing frequency of weather anomalies are gaining increasing interest by hydrometeorological researchers. A similar important research topic concerns changes in the course, frequency, and intensity of cyclones and the relation to the formation and water content of clouds. It is beyond the scope of this article to review the recent research on sea surface temperature anomalies and heavy precipitation events leading to floods. However, a few examples from different climatic regions are given below.

Maracchi[35] examines the relationship between extreme convective events in Tuscany (Italy) and sea surface temperature anomalies in the Mediterranean Sea. Based on an analysis of a series of thunderstorm events, Maracchi concludes that the triggering of convective storms will be enhanced by an increased sea surface temperature due to the increased advection of warm moist air from the sea. Ali[36] investigates the trends in cyclone intensity and frequency due to a rise of sea surface temperature of 2 and 4°C by using a model for simulation of storm surges in the Bay of Bengal. Mason[37] discusses the possible changes of precipitation over Southern Africa by using a GCM, including the effects of an increasing sea surface temperature. Mason concludes that increases both in frequency and intensity of extreme rainfall events are simulated throughout the subcontinent. Kaczmarek[38] examines the relationship between the North Atlantic Oscillation (NAO) index and snowmelt-induced floods in Poland. He concludes that an increasing NAO index increases the risk of winter/early spring floods for selected rivers in Poland due to an earlier and more frequent appearance of snow-melt weather conditions.

3.4. Knowledge Gaps

It is apparent that there are numerous unresolved questions with regard to the relationship between climate change and flooding. The following overview of knowledge gaps is based on Bronstert[39] and Dooge.[40] Further information on the subject is given in the guidelines for future-oriented flood protection by the German Working Group on Water[41] and by Kundzewicz.[3]

3.4.1. Change in the Frequency of Heavy Local (Convective) Rainfall

For operational purposes, regional and local forecasts are particularly important. However, a quantitative prediction of the frequency, location, extent, and intensity of highly intensive local rainfall has so far only been possible to a very limited degree, even in short-term weather forecasting. Methods of analyzing spatial/temporal precipitation frequency on a small scale must be further developed, which applies to the linkage of weather-radar measurements and precipitation data as well as to the linkage of typical weather conditions and precipitation. Progress is urgently needed, especially with regard to local, highly erosive flash floods.

3.4.2. Significance of Changes in Weather Conditions for Long Time Series

The significance of the changes in the frequency of weather conditions in parts of Europe (see Section 3.1.2) over longer time periods is not yet known. In this respect it would be desirable to trace large-scale weather conditions well into the past and to correlate them with proxy sources, for example, biological indicators. This may provide information on how significant changes in the frequency of weather conditions coincide with long-term and spatially extensive statistical nonstationary behavior.

3.4.3. Risk Analysis: Natural Conditions Versus Anthropogenic Interference with Nature

Apart from individual cases, hydrologists have not yet been able to distinguish the influence of climate change on flooding in relation to other anthropogenic interferences or in relation to the natural variability of the meteorological and area-specific hydrological conditions. For such an analysis the further development of process-oriented hydrological models coupled with meteorological and hydraulic simulation tools is necessary. Such a model development could result in an operational tool for the quantification of the anthropogenic influences in relation to the natural fluctuations of the meteorological and hydrological conditions.

3.4.4. The Effect of Changes in Land Coverage

Changes in land surface and vegetation during the past decades are mainly due to human interference with the natural systems, such as agriculture, forestry, settlements, and road construction. Climatic change influences on land coverage play a secondary role compared to more severe, direct changes of land use, such as forest clearing or urbanization. Nevertheless, in the long term, climatic change influence on land coverage may become a more important factor influencing the frequency and severity of floods.

Direct anthropogenic interferences, such as wood clearing, extension or transformation of agricultural areas, and urbanization, or indirect anthropogenic influences, such as the consequences of forest damage or changes in water availability due to the enhanced greenhouse effect, may result in significant large-scale and long-term changes of the biosphere. In particular, the long-term effects on the vegetation cover and soil surface condition and consequently on the probability of flooding have not yet been adequately assessed.

4. CONCLUSIONS

This article has discussed various aspects and relations of flood risk. Stock[42] termed the interdependency of different flood risk components the "cascade of flood risk" (see Fig. 5). This cascade includes the flood-relevant aspects of global change: climate change, change in land use and land cover, modifications to the river morphology and the channel system, as well as the increase in human

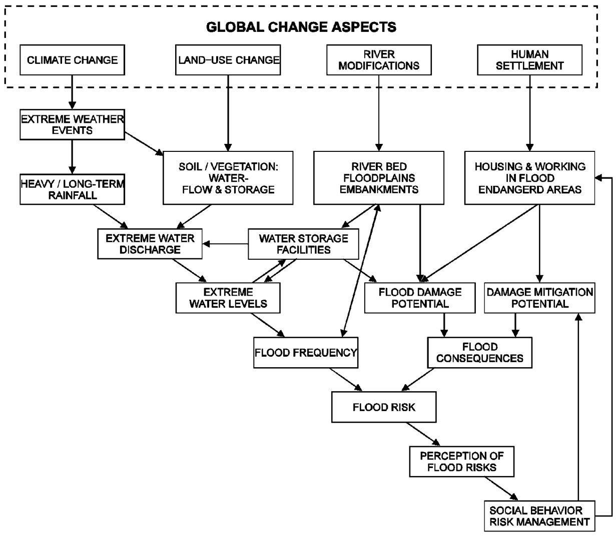

Fig. 5. Causes, effects, and consequences of floods: "Cascade of Flood Risk."[42]

settlements. These changes of environmental conditions affect the flood risk at different levels, for example, by altering the retention capacity of river basins, by changing both the retention capacity and the potential damage in floodplains adjacent the river, and by increasing the vulnerability due to settlement in flood endangered areas. Subsequently, flood risks are influenced by natural (climate; river basin morphology) and man-made (river channelization; urbanization) factors influencing the frequency of floods and social/economic factors influencing their consequences.

Our knowledge of climate change, its future development, and its effects on systems and cycles of the earth is still very limited. This discussion has shown that *in some areas there is evidence* of an increased risk of flooding from climate change. *In other areas there is no such evidence*. Most of the past investigations of flood development have been carried out from a mono-causal point of view, that is, from the view of the respective observer. An integrated analysis, covering the cause-effect chain of *precipitation—runoff generation—runoff concentration—flood wave propagation (routing)—inundation—flood damage*, would allow for a comparative assessment of the various flood-triggering and damage-causing factors. For this purpose the further development of complex hydrological catchment models and of statistical tools for incorporating the stochastic components of such models would be required.

Therefore, a state-of-the-art evaluation on flood risk should include all relevant levels of flood risk composition, both the aspects of naturally induced hazard and vulnerability due to the activity of humans.[43] One must keep in mind that only in exceptional cases will it be possible to quantify each of the factors involved in the composition of flood risk, and in many cases it will be difficult to separate climate from anthropogenic effects. However, an integrated management of flood risk will enhance our ability to mitigate the total damage caused by river floods and can result in an optimization and adaptation of flood protection measures, both structural and non-structural. As a "byproduct" of integrated flood risk management, one may also improve the quantification of climatic and other global change impacts on flood risk.

Since knowledge of climate change and its effects is still limited, population, industry, and governments should take cost-effective climate protection measures, for example, by reducing climate-relevant trace gases and protecting the vegetation cover of the earth. Climatic protection is also desirable from the point of view of flood protection. A concrete mitigation of floods at specific locations and times cannot be expected from climate protection measures; however, a long-term, generally positive reduction in flood risks can be anticipated.

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The Impact of Climate Variability on Flood Risk in Poland

Zdzislaw Kaczmarek*

This article examines the role of climatic and hydrological variability in assessing the cumulative risk of flood events in Poland over a T-year period. In a broad sense flood-risk estimation combines a frequency analysis of extreme hydrological phenomena with an evaluation of flood-induced damages. The damage from floods depends on the critical values of the river discharges. The probabilistic flood analysis usually includes an estimation of the expected annual probability of the critical discharge Q_{cr} being exceeded and the equivalent long-term risk of it being exceeded over the next T years. If, however, the process is nonstationary, the T-year risk of flood damage may depend importantly on the variation of hydrological processes. As a possible explanation for the variations observed in snowmelt-induced floods in Polish rivers, this article investigates the possible impact of the North Atlantic Oscillation (NAO) on surface air temperature T and precipitation P. The spatial distribution of the correlation coefficients between NAO and T, as well as NAO and P, show very significant differences in the NAO impact on meteorological variables in various parts of Europe. To assess the implications of NAO variations on spring flood discharges, a simple model of Snow Cover Water Equivalent (SCWE) was applied to selected Polish river catchments. The conclusion of this analysis is that the yearly maximum of SCWE values significantly decreases with increasing NAO. This leads to a temporal redistribution of winter and spring runoff. The question of spring flood characteristics being stationary or nonstationary may therefore be linked with stochastic properties of the NAO index time series.

KEY WORDS: Flood risks; snow cover; NAO index; climate variability

1. INTRODUCTION

Risk and uncertainty in water resources arise from the inherent variability of geophysical processes and changes in complex socioeconomic factors. As a decision tool, risk analysis is based on the quantification of the probabilities of floods occurring and their possible consequences. Uncertainty arises from the lack of exact knowledge regarding the probability distribution of floods, errors in estimated parameters of these distributions, and a number of factors having an impact on damages related to a given flood pattern.

In the recent decade, water managers have been alarmed by extreme floods in China, the Czech Republic, Germany, Poland, Sweden, and many other countries. Most of these catastrophic events were caused by unusually intense precipitation in mountainous areas or by the complex interaction of rainfall and snowmelt.(1) At the same time, since the 1980s a decrease of peak discharges during spring floods has been observed in most of the central European rivers. It is therefore difficult to generalize about flood hazards across Europe.

The aim of this article is to discuss the role of climatic and hydrological variability in assessing the cumulative risk of snowmelt-induced flood events over a T-year period. In a broad sense, flood-risk assessment combines a frequency analysis of extreme hydrological phenomena and an evaluation of the flood damages. In this article, I consider the physical (hydrological) aspects of flood risks and their relation

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to large-scale atmospheric processes. The potential linkages between changes in the statistical properties of snowmelt-induced floods and large-scale meteorological phenomena, like atmospheric circulation processes, are the main subjects of this analysis. In particular, the possible connection between snowmelt-induced floods and the North Atlantic Oscillation (NAO) is investigated.

Many authors link changes in the atmosphere's hemispheric meridional heat and moisture transport to the high variability of the North Atlantic Oscillation.[2,3] The NAO is a large-scale alternation of atmospheric mass with centers of action near the Icelandic Low and the Azores High.[4] There are several methods to describe the NAO phenomena by means of numerical indicators. In this article, I will apply the Hurrell NAO index,[5] defined as the normalized pressure difference between Lisbon in Portugal and Stykkisholmur/Reykjavik in Iceland. The time series of the winter (December to March) NAO index in the period 1901–2000 is shown in Fig. 1.

Shorthouse and Arnell[6] note that the winter river flows in northern Europe are positively correlated with the North Atlantic Oscillation, whereas rivers in southern Europe are negatively correlated with the NAO index. They explain this correlation by "enhanced rainfall over Northern Europe and Scandinavia whilst a significant reduction of the total atmospheric moisture occurs over parts of Central and Southern Europe, and the Mediterranean" in years exhibiting high NAO index. This interpretation

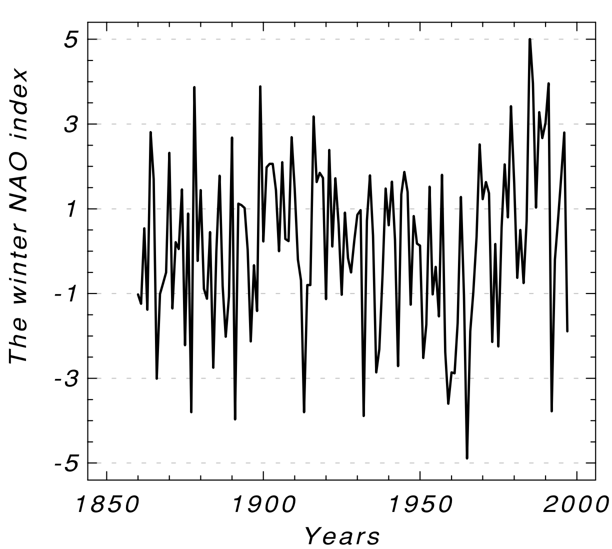

Fig. 1. Time series of winter NAO index (Source: Hurrell[5]).

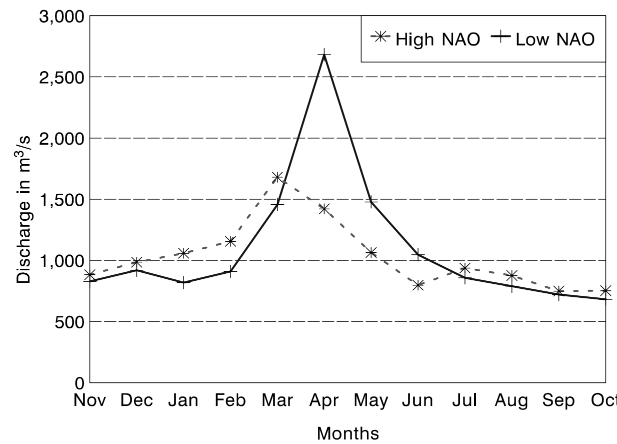

Fig. 2. Mean monthly discharges of the Vistula River in years with high and low NAO index.

of the recent changes in the winter/spring river discharges in central Europe is nonetheless disputable because of the very weak correlation between the NAO index and winter precipitation for most of the central European catchments (e.g., Rhine, Elbe, Odra, Vistula, and Nemunas) and the simultaneously significant changes in the temporal pattern of river flows.

As an example, the Vistula River hydrographs in years with high and low NAO index are shown in Fig. 2. An interesting picture of the correlation of the mean monthly river discharges (from January to June) on the winter NAO index is presented in Fig. 3. It can be seen that for high values of the NAO index, the river discharges slightly increase from January to March. This is probably due to a reduction of snow accumulation and the consequent decrease in river

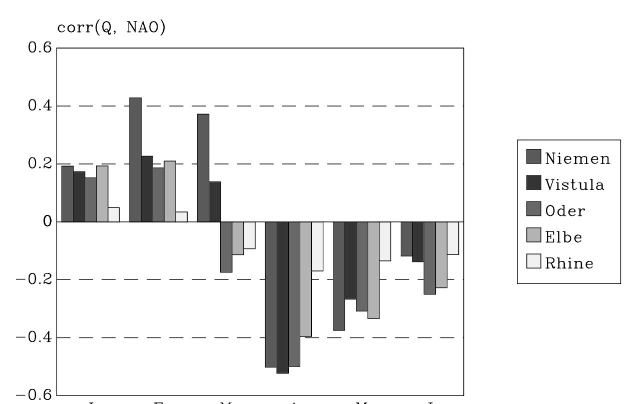

Fig. 3. Correlation of mean monthly discharges of selected European rivers with the winter NAO index.

discharges in April and May, which is a typical flood period in central Europe. This temporal pattern of correlation between the NAO index[5] and the water balance during the winter and spring seasons is particularly apparent in the eastern part of Poland, for example, for catchments of the Nemunas and Vistula Rivers. High values of the NAO index contribute to warm winters over much of Europe, which may highly influence snow accumulation and snow-melting processes, and can consequently have a significant impact on spring floods in central and eastern Europe. This hypothesis will be discussed below.

2. CUMULATIVE RISK OF FLOOD OCCURRENCE

Riverine flood losses depend on many factors: the critical values of river discharges, floodplain management, and the efficiency of warning and protection measures. In addition to the consequences, the assessment of flood risk requires an estimation of the frequency that the peak flood rate will be exceeded. Often, this assessment requires a subjective judgment on the mathematical form of the probability density function, making use of all the available information, including *in situ* stream-flow data, historic and paleoflood data, and information concerning atmospheric and catchments processes accompanying flood formation. Estimating probabilities of extreme floods will always require extrapolation beyond the data set, and procedures for doing this are controversial.

The performance of an engineered flood protection system must be evaluated over the system's lifetime. Consequently, the hydrologic conditions can be described as a function of time, particularly if the river environment changes over time due to the impact of land-use change or because of climate perturbations. The probabilistic risk analysis of floods should therefore include the statistical estimation of the expected annual probability of exceeding the critical discharge Q_c, as well as the long-term probability of exceeding the critical discharge over the next T years (e.g., $T = 10, 20, 50$, etc.). This T-year probability can be expressed as:

$$R_T(Q_{\max} \geq Q_{cr}) = 1 - \prod_{t=1}^{T} \int_0^{Q_{cr}} f(Q_{\max}, \Omega_t)\, dQ_{\max} \tag{1}$$

where Ωt is a vector of time-dependent parameters of the probability density function. In the case of a stationary hydrologic process $\Omega t = \Omega = \text{const}$. If, however, the conditions of runoff formation change over time, the T-year probability of a critical flood occurrence will depend on variations of meteorological and hydrologic variables. For example, as has been shown by Kaczmarek,[7] in the case of stationary conditions, the 50-year probability of exceeding the flow rate of 8,000 m^3/s on the Vistula River in Warsaw is approximately equal to R50 = 0.1. But if one assumes a linear increasing trend of mean maximum discharges by only 0.5% per year, the 50-year probability of exceeding the critical value at the Warsaw gauge station will increase to R50 = 0.334, that is, triple in relation to the stationary case. Alternatively, assuming a decreasing linear trend of the same magnitude, the R50 probability would be reduced to 0.035. In some cases the hydrological process may be stationary, but over decades it exhibits considerable variability with respect to concentrations of spectral power. Calculation of the T-year probability of flooding will thus depend on the time window in which it is assessed.

Several questions arise with regard to the possible nonstationarity of hydrologic processes. Does a change display a steady downward or upward trend, or is the process approximately periodic? Can the trends be estimated with reasonable accuracy? Would the change concern only the mean (central) value of the probability distribution, or would the variance or distribution asymmetry also change over time? Answering these questions based on a relatively short history of hydrologic data is difficult, if not impossible. An analysis of the interrelation between large-scale meteorological processes and the river hydrology may, however, add some clarity.

3. TRENDS IN SPRING FLOOD DISCHARGES IN SELECTED RIVERS IN POLAND

Changes in land-use patterns and in greenhouse gas concentrations may result in the nonstationarity of the hydrological regimes in many river catchments areas. Statistical tests applied to dozens of relatively long time series of river discharges in various parts of the world resulted in the rejection of the stationarity hypotheses for about 20% of the cases at a 5% significance level.[8,9] Some scientists claim that land-use and climate changes will result in an increase in the frequency of both high and low river flows. Others have expressed the opinion that if the climate changes and snowfall decreases, there could be a widespread shift from spring to winter runoff.[10,11] Such a shift may already be observed for some European rivers.[12]

A negative trend in the spring maximum discharges has been observed for the major Polish rivers—the Vistula, Odra, Warta, and Bug. The Vistula River system has a catchment area of about 194,000 km^2 and covers most of central and eastern Poland; the Warta River (54,000 km^2) is a tributary of the Odra River (109,730 km^2) and is located in the western part of the country; while the Bug River (20,140 km^2) is a tributary of the Vistula River on the border between Poland, Belarus, and Ukraine. The last two catchments have different climatic conditions. In particular, the average winter temperature in the Warta River basin is 1.9°C higher than in the Bug River basin. On average, the snow cover in the Bug catchment area lasts three to four weeks longer than in the Warta catchment area. Recently, a negative trend in the spring maximum discharges for most of Poland's rivers has been verified by time series of maximum discharges accompanying snowmelt-induced floods, a trend that has been notably visible for the Warta River since the middle of the last century (see Fig. 4).

A number of statistical tests can be applied to detect a trend in time series data on geophysical phenomena.[8] In what follows, an uncommon procedure is described that can be useful for testing changes in the *frequency* of hydrological and meteorological phenomena. Let us assume that a random sample of size N, which is drawn from an unknown continuous distribution of a stationary random process X, is divided into two independent samples of sizes n_1 and n_2. Let's further assume that in the first sample an event A $(X \geq X_A)$ has been observed K $(K = 0, \ldots n_1)$ times. The probability that in the second sample A will appear u times $(u = 0, \ldots n_2)$ can be calculated by means of the hyper-geometric distribution:

$$P_A(u) = \frac{K\binom{n_1}{K}\binom{n_2}{u}}{(n_1+n_2)\binom{n_1+n_2-1}{K+u-1}}, \quad (2)$$

where

$$\binom{a}{b} = \frac{a!}{b!(a-b)!} \quad (3)$$

denotes the total of possible *combinations* of b-element sets that can be obtained based on an a-element set $(b \leq a)$. If the probability in Equation (2) is small, the stationarity hypothesis of the investigated meteorological/hydrological process is not well founded. According to Gumbel and von Schelling:[13]

> These methods may be of interest for forecasting floods if, instead of the size of the flood, we are interested only in the frequency. The same procedure may also be applied to other meteorological phenomena, such as droughts, the extreme temperatures (the killing frost), the largest precipitation, etc. (p. 249)

To illustrate an application of the hypergeometric distribution, I analyze 176 years (1825–2000) of winter/spring floods of the Warta River as shown in Fig. 4. Let the random event be defined as $A(Q_{max} \geq 416)$, where $m(Q_{max}) = 416$ m^3/s is the average value of the maximum discharge series. In the years 1825–1980 ($n_1 = 156$), the event A was observed $K = 60$ times, while in the years 1981–2000 ($n_2 = 20$), the event A was observed only once ($u = 1$). The probability $P_A(u)$, which is calculated from Equation (2), is therefore equal to 0.0016. This probability is small enough to doubt the stationarity assumption of spring flood discharges in the Warta River. Similar results were obtained for other river basins in Poland and in some neighboring countries. Below I suggest that winter weather conditions and snow cover may help explain the nonstationarity of spring discharges, which, from Equation (1), has a significant impact on flood risk assessment.

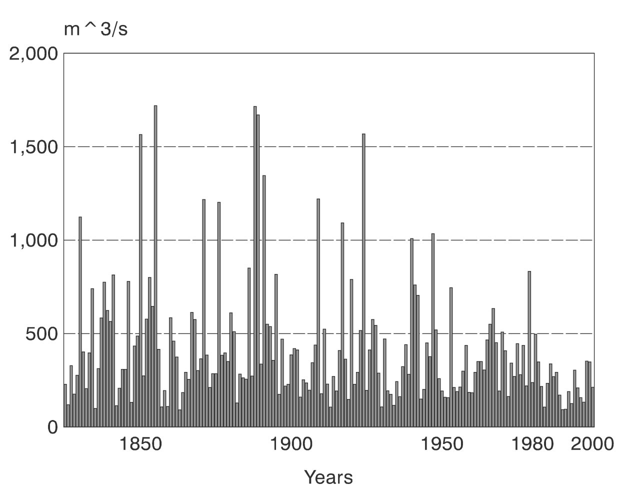

Fig. 4. Time series of the Warta River peak discharges during snowmelt-induced floods.

4. MODELING SNOW COVER WATER EQUIVALENT

To investigate the implications of winter weather conditions on spring flood discharges, a conceptual model of snow cover water equivalent (SCWE) as a function of air temperature T and precipitation P observed during winter months is described below.

Let the change of SCWE over time be described by means of the differential equation:

$$\frac{d(SCWE)}{dt} = \Pr(T^-)(1-K_S)\cdot P - \Pr(T^+) \cdot K_M \cdot \mu(T^+)(1-e^{-SCWE}). \quad (4)$$

The probability in a given month of the daily air temperature being below or above zero may be calculated as:

$$\Pr(T^-) = \frac{1}{\sigma(T)\cdot\sqrt{2\pi}} \int_{-\infty}^{0} \exp\left[-\frac{[T-\mu(T)]^2}{2\sigma^2(T)}\right] dT \quad (5)$$

and

$$\Pr(T^+) = 1 - \Pr(T^-), \quad (6)$$

where $\mu(T)$ and $\sigma(T)$ denote the mean value and standard deviation of air temperatures, respectively. The mean daily value $\mu(T^+)$ of air temperature calculated for a given month for days with $T > 0$ is:

$$T^+ = \frac{1}{\sigma(T)\cdot\sqrt{2\pi}} \int_{0}^{\infty} T\cdot\exp\left[-\frac{[T-\mu(T)]^2}{2\sigma^2(T)}\right] dT. \quad (7)$$

Let us further denote:

$$\frac{d(SCWE)}{dt} = a + b\cdot e^{-SCWE}, \quad (8)$$

where:

$$a = \Pr(T^-)(1-K_S) - \Pr(T^+)\cdot K_M\cdot\mu(T^+);$$
$$b = \Pr(T^+)\cdot K_M\cdot\mu(T^+).$$

Integration of Equation (5) yields:

$$SCWE_{(i+1)} - SCWE_i + LN\frac{a+b\cdot\exp(-SCWE_{i+1})}{a+b\cdot\exp(-SCWE_i)} - a\cdot\tau = 0. \quad (9)$$

Solving Equation (9), the snow cover water equivalent at the beginning of month $(i+1)$ can be estimated knowing the $SCWE$, the parameters a and b, and the monthly time interval τ (in days). The model depends on two parameters, K_S and K_M, which can be estimated (calibrated) based on results of snow measurements and on meteorological data. For river basins in central Europe, an approximation for the degree-day factor K_M can be taken as 4, while for K_S the following empirical relationships can be applied:

$$K_s = 0.05, \quad \text{if } [\mu(T)-\mu(T^+)] < -3.0$$
$$K_s = 1.0, \quad \text{if } [\mu(T)-\mu(T^+)] \geq +1.0$$
$$K_s = 0.762 + 0.238^*[\mu(T)-\mu(T^+)], \quad \text{if } -3.0 \leq [\mu(T)-\mu(T^+)] < +1.0.$$

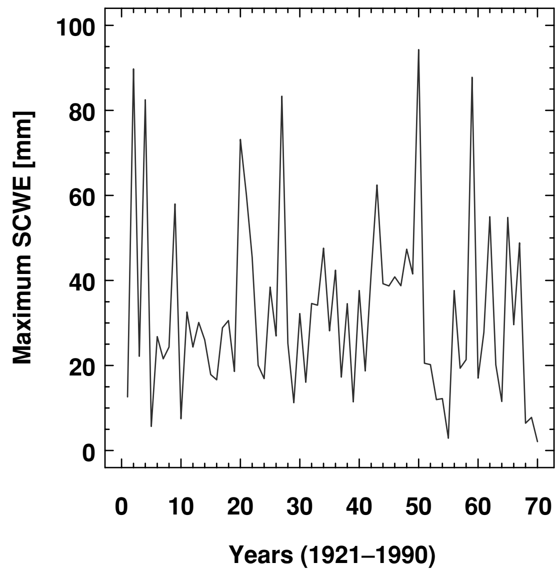

Fig. 5. Time series of maximum snow cover water equivalent (SCWE) in Poland's lowland.

Based on Equations (5)–(9), a time series (November to April) of the SCWE was calculated for a number of catchment areas in Poland's lowland. The time series of maximum winter/spring SCWE values, averaged for this region, are shown in Fig. 5. This figure shows a decreasing trend of about 0.9% per year, marked by the very high variability of accumulated snow. No statistically significant autocorrelation in the SCWE time series was detected.

5. SNOWMELT-INDUCED FLOODS IN POLAND AND THE NAO INDEX

Figs. 6 and 7 present the results of regressions of spring flood discharges of two Polish rivers with the North Atlantic Oscillation (NAO) winter index (December to March). Similar results were found for a number of other river catchment areas in central Europe. In an attempt to explain these correlations, an analysis was made of the possible impact of the NAO index on the winter air temperature T, winter precipitation P, and the SCWE. In the European region, Figs. 8 and 9 show the spatial distributions of the correlation coefficients between the NAO index and T, as well as between the NAO index and P, based on data taken from Table I.

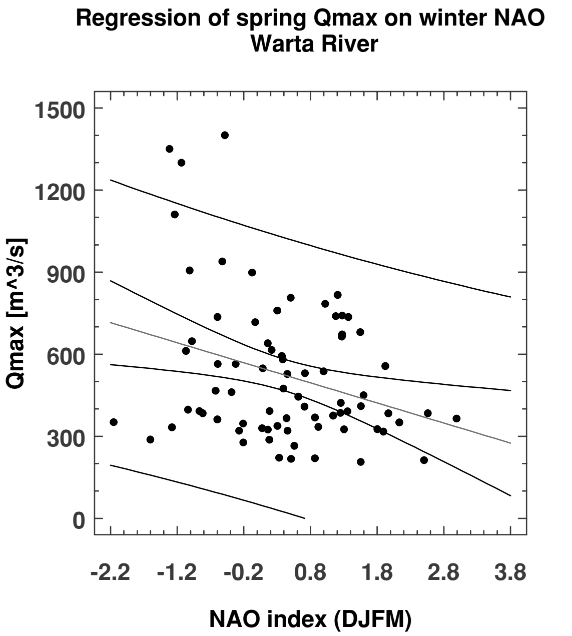

Fig. 6. Correlation of spring peak discharges of the Warta River with the winter NAO index.

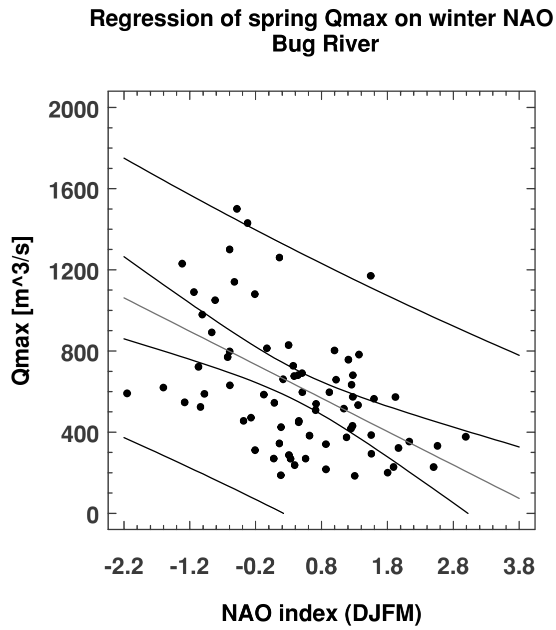

Fig. 7. Correlation of spring peak discharges of the Bug River with the winter NAO index.

It can be observed that the European regional differences in the NAO have an impact on the meteorological variables that is very significant. In northern Europe, temperature and precipitation increase with the increase of the NAO index, whereas the opposite is the case in southern Europe. From an application of the earlier described conceptual model (Equations (5)–(9)) of snow processes to selected Polish river catchments, we conclude (Fig. 10) that the yearly maximum of SCWE decreases with the increasing NAO index. This, in turn, could lead to a decrease in flood risk caused by snowmelt-induced floods in the years

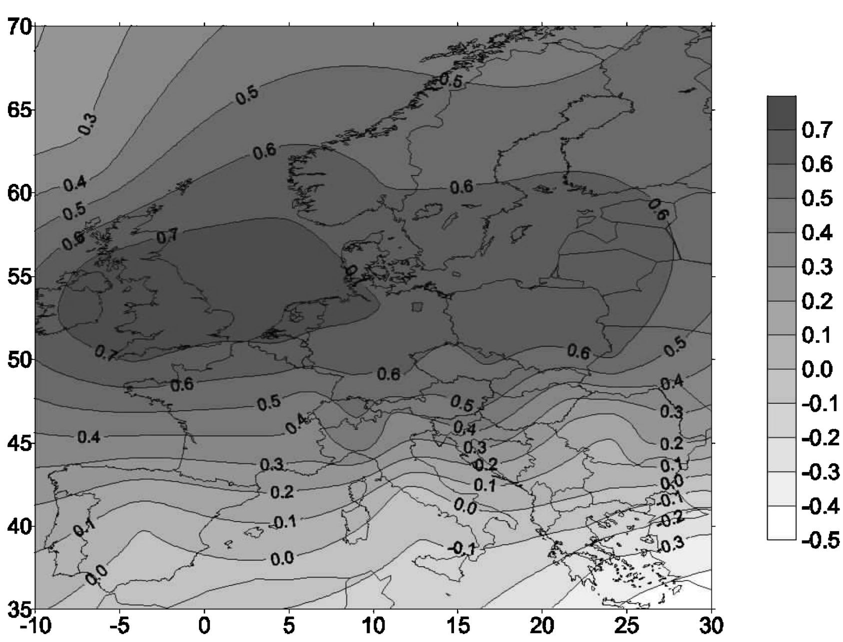

Fig. 8. Correlation of winter air temperature with the winter NAO index.

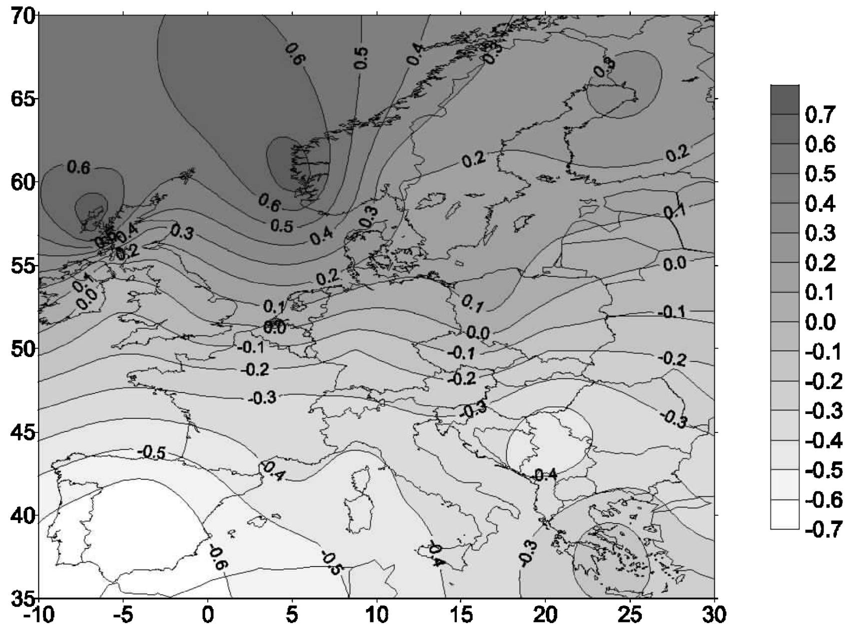

Fig. 9. Correlation of winter precipitation with the winter NAO index.

Table I. Correlation of Winter (DJFM) Precipitation and Temperature with the NAO Index

Station Name	Coordinates	*r* (NAO, *P*)[a]	*r*(NAO, *T*)[b]
Haparanda	65.8°N, 24.2°E	0.37	0.53
Angmagssalik	65.6°N, 37.6°W	−0.02	−0.18
Thorshavn	62.0°N, 6.8°W	0.53	0.32
Bergen	60.0°N, 5.3°E	0.77	0.67
Helsinki	60.3°N, 25.0°E	0.18	0.60
Oslo	59.9°N, 10.7°E	0.21	0.60
Stockholm	59.4°N, 18.1°E	0.14	0.62
Copenhagen	55.7°N, 12.6°E	0.14	0.64
Belfast	54.6°N, 6.2°W	0.01	0.78
Warsaw	52.1°N, 21.0°E	−0.05	0.66
De Bilt	52.1°N, 5.2°E	0.08	0.73
Valentia	51.9°N, 10.2°W	0.09	0.66
Wroclaw	51.1°N, 16.9°E	−0.09	0.65
Frankfurt	50.1°N, 8.7°E	−0.19	0.66
Krakow	50.1°N, 20.0°E	−0.17	0.56
Paris	49.0°N, 2.5°E	−0.19	0.60
Lyon	45.7°N, 4.9°E	−0.37	0.42
Milan	45.4°N, 9.3°E	−0.35	0.52
Rome	41.8°N, 12.2°E	−0.37	−0.08
Istanbul	41.0°N, 29.1°E	−0.36	−0.21
Madrid	40.4°N, 3.7°W	−0.69	0.02
Lisbon	38.7°N, 9.1°W	−0.64	0.10
Athens	38.0°N, 23.7°E	−0.11	−0.31
Ponta Delgado	37.7°N, 25.7°W	−0.49	0.12

[a]Hurrell and Van Loon (1997).
[b]Author's calculations based on data from the Carbon Dioxide Information Analysis Centre Data Package (Oak Ridge, TN).

characterized by high NAO. The question of stationarity or nonstationarity of snowmelt-induced floods is therefore partially linked with the statistical properties of atmospheric circulation.

The mechanisms responsible for long-term variations of the NAO are poorly understood. From both

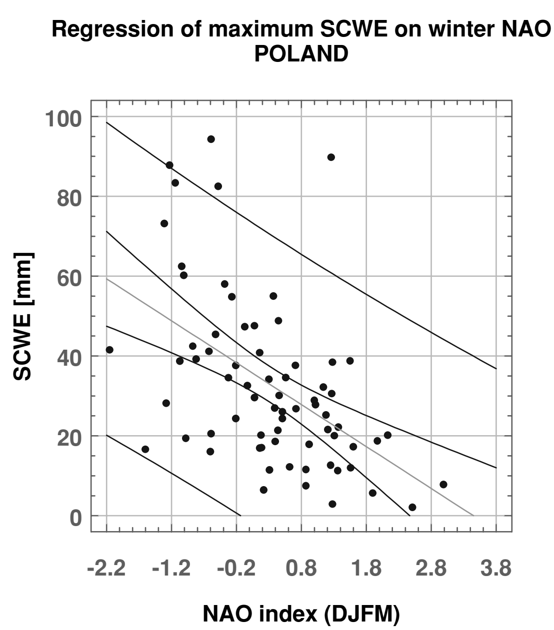

Fig. 10. Correlation of snow cover water equivalent with the winter NAO index.

proxy and observational data one can conclude that the multidecadal signal in the NAO index has been amplifying with time, with an accompanying tendency of the NAO spectrum to become redder.[4] However, it is difficult to judge whether the high values and positive trend of NAO index that has been observed over the last two decades will continue as a result of global warming. Investigations implemented within the World Climate Research Programme may be central to clarifying this unresolved question. Until this question is resolved, flood protection systems should not be designed with the assumption of reduced long-term risk of flood damages. Flood risk should also not be assessed on the basis of a relatively short series of peak discharges of snowmelt-induced floods, which are observed in a period characterized by the recent high values of the North Atlantic Oscillation.

6. CONCLUDING REMARKS

There are many approaches and models for assessing flood hazard and providing decisionmakers with the tools necessary for designing flood protection systems.[14,15] To assess flood risks, there is a need to combine the available meteorological information with an analysis of the hydrological processes. In the case of snowmelt-induced floods, the winter precipitation and air temperature conditions determine the intensity of runoff formation in the spring. Because the North Atlantic Oscillation is to a large extent responsible for the winter weather conditions over much of the Europe, it seems reasonable to investigate its impact on hydrology, in particular on snow processes and on related flood phenomena.

There is evidence that the amount of snow accumulated in central European lowlands decreases as the NAO index increases. This leads to a decrease of maximum spring river discharges in years characterized by high winter NAO. For this reason, hydrologists are interested in studying decadal variations of the NAO index, as well as its possible long-term change due to increased concentration of greenhouse gases. Much remains to be done, however, before the necessary level of understanding and predictability of large-scale atmospheric circulation is achieved for practical use for flood risk assessment. Unless more reliable information on the future stochastic properties of atmospheric processes becomes available, the long-term risk of flood damages should be assessed using relatively long series of hydrological observations, which should include years with high and low NAO characteristics. Another possibility is to apply a scenario approach, which is usually done in the climate impact assessment studies.[16]

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European River Floods in a Changing World

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Whereas the verdict is undecided about the effects of global warming on Europe's flood risks, it is clear that Europeans are becoming more exposed and vulnerable to floods. Losses are increasing dramatically, mainly because of population and capital moving into harm's way and also because of human-driven transformations of hydrological systems, including river basins and floodplains.

KEY WORDS: Risk; vulnerability; context; urbanization; flood policy; Europe

1. INTRODUCTION

Loss of life and injuries due to flooding have generally been declining in Europe[1] during the past two centuries but there is now renewed worry about this hazard. Unusually severe floods during the 1990s and early 2000s affected much of the continent and have been the most obvious spur to attention (e.g., western Russia, Ukraine, Poland, Czech Republic, Germany, the Netherlands, France, Switzerland, Spain, and the United Kingdom, among others). But the shift in opinion has also been propelled by many other factors. Prominent among these are concerns about possible atmospheric warming and marked changes in European land cover and land use.[(1,2)] Taken together, these semi-global processes may exacerbate future flooding by altering river regimes in the direction of larger runoff volumes and shorter low water to flood peak intervals.[(3–5)] In addition, there exist flood-forcing factors of more specific European provenance. Many of these are connected with powerful shifts in Europe's political-economic and sociocultural systems as well as the specifics of society-environment relations in different parts of the continent. Sorting out the relative contributions of these varied factors is an important scientific and public policy challenge for the new millennium.

2. HISTORIC TRENDS OF EUROPEAN FLOODING

Historic data on flood losses are neither comprehensive nor standardized throughout Europe and it is only in recent years that anything like a complete catalog of floods has begun to be maintained. But, for all its limitations, the available evidence permits drawing some conclusions about flood trends. Although annual numbers of flood disasters have shown no consistent trend during the most recent period (1987–1998),[(6)] throughout the 20th century as a whole flood-related deaths have been either stable or decreasing while economic burdens of flooding and related societal disruptions have become decidedly worse.

Large-scale loss of life from individual floods predate the 19th century (Table I). These have nearly always been associated with coastal storm surges, mostly around the North Sea littoral. Twentieth-century flood disaster death tolls have been much lower—typically averaging fewer than 250 per year during the 1940s, 1950s, 1960s, and 1970s. Although

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[1] Here Europe is interpreted broadly to include territory between the Ural Mountains in the east and the Atlantic Ocean in the west, and from the Arctic Ocean in the north to the Black Sea and the Mediterranean Sea in the south. Turkey (part of which falls within these boundaries) is also a potential member of the European Union.

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Table I. Flood Disaster Deaths in Europe 1099–1829 (730 years)*

Year	Location	Flood Type	Deaths
1099	East Anglia, UK	storm surge	100,000
1219	Jutland, Denmark	storm surge	"thousands"
1228	Netherlands	storm surge	100,000
1287	Waddenzee, Netherlands	storm surge	50,000
1362	Schleswig, Germany	storm surge	30,000
1421	Dort, Netherlands	storm surge	10,000
1530	Netherlands	rivers/storm surge	400,000
1570	Netherlands	river/storm surge	50,000
1634	Cuxhaven, Germany	storm surge	6,000
1717	The Hague, Netherlands	storm surge	11,000
1824	St. Petersburg, Russia	ice jam	10,000
1829	Gdansk, Poland	ice jam	1,200

*Deaths are reported for significant large floods only. Due to disputes among sources, the accuracy of these totals cannot be established. Especially before 1600 they are best regarded as approximate indicators of loss.
Sources: References 7–11.

there has been an upsurge of concern about flood deaths in Europe during the 1990s, available data suggest that the annual aggregate numbers have been significantly smaller than earlier in the century.

Economic losses associated with flooding are up sharply in recent years. By the end of the 1990s, many flood events were imposing multi-million U.S. dollar losses to structures and other property. The 1997 floods in Poland and the Czech Republic are believed to have inflicted losses on each country in excess of $1 billion.(11,12) Not all losses represent material impacts. Costs of disruption to farms, industries, and transportation systems are substantial and precautionary evacuations are also growing. Although the losses fall well short of those in the United States, they are unprecedented for European river floods. In a related trend, the geographical spread of disastrous flooding also appears to be increasing, though whether this is a function of fuller and more transparent reporting, including improved data from behind the former Iron Curtain, is difficult to gauge.

National-level flood data are informative, but they do not necessarily reflect trends in individual communities. This is especially true of large cities that have historically been disproportionately well protected against hazard as a function of their power to affect the political priorities of national governments. Typically, urban flood disasters had declined to low levels by the beginning of the Industrial Revolution. For example, all but two of the 56 major floods that affected Florence since 1177 occurred before 1844.(13) However, as urban areas have grown and become more complex during the 20th century, a gap has begun to appear between the capabilities of existing flood defenses and the potential for larger urban flood disasters.

3. CONCERNS ABOUT FLOODING IN EUROPE

In Europe, concern about flooding has grown rapidly in recent years and has resulted in significant public policy responses by transnational organizations as well as national ones. (See, e.g., the 20-year "Action Plan on Flood Defence" adopted in Rotterdam on January 22, 1998 by the 12th Conference of Rhine Ministers at a projected cost of 12 billion ECU.) These actions have been partly propelled by a general heightening of flood awareness that was facilitated by improved environmental surveillance and monitoring technologies, as well as by enhanced telecommunications systems. The European Space Agency(14) now supplies user groups with remotely sensed images of flooding in real time, and comprehensive data sets that record the location, extent, and duration of floods are beginning to become available on a global basis.(11) The result is quicker, more reliable, and more complete provision of data to flood scientists. At the same time, there has been an acceleration in natural science and social science research on European flooding, which has led to more informed public debates about flood issues.(15–19)

More effective and widespread reporting of events by the mass media have also contributed to growing awareness of floods. Newspapers, television, and radio have undergone their own transformations, both technologically and organizationally. The news horizons of Europeans have expanded in step with the increasing mobility of European populations and the evolving Euro-consciousness of institutions that were formerly focused on more parochial issues. As a result, Ukrainian and Iberian floods that might once have been obscure events for British and German audiences are now likely to feature on nightly news reports beamed throughout the continent to people whose jobs and vacations are increasingly part of a common European social space.

Moreover, the types of flood disasters that are featured in media reports often touch on deep-seated contemporary anxieties about human security: victims caught in unfamiliar surroundings; children and young people without experience of hazard; sites that were assumed to be protected but proved otherwise! Scenes of Mediterranean tourist towns and vacation campgrounds inundated by flash floods pose worrying questions about safety for northern European vacationers. Reports of young canyon-runners drowned in sudden Swiss thunderstorms tap the fears of parents and older family members. The occurrence of record-setting floods in cities like Lisbon and Cologne is unsettling for populations that have come to regard such places as well buffered against natural extremes. Water lapping at the tops of Rhine dikes that had been assumed to possess comfortable safety margins reinforces the notion that the floods themselves are becoming more extreme—although a more careful analysis suggests that the human component of the hazard is changing more dramatically.

Recent news reports tend to suggest that European flood problems are increasingly ubiquitous and that existing flood-management systems are operating close to their limits of effectiveness. These media judgments are reinforced by assessments of European-based reinsurance companies like Swiss Re (Geneva) and Munich Re, which have pointed out the growing toll of economic losses and issued cautions about overreliance on insurance as a tool for managing flood hazards.[20] Together with academic analysts, media and insurance sources have raised questions about the adequacy of European flood-warning systems, especially for flash flooding.[21,22] Unlike the United States, where forecasting and warning systems are highly important components of flood-mitigation strategies, they are less well developed in most parts of Europe, and public confidence in them is correspondingly weaker.[2] A series of well-publicized prediction failures has also highlighted both the technical difficulties of forecasting floods in Europe and the underdeveloped role of warnings in Europe's national hazard management systems.[23,24] Taken together, these factors convey the impression that floods are increasing objects of concern in Europe and that at least some of their effects are growing worse. A casual observer might be tempted to look to climate change for an explanation of these trends, and part of the answer may lie in that direction. Since there has not been a thorough investigation of climate change effects on European flooding (see Bromstedt, this issue), the question must remain open. But there is ample reason for concluding that other factors are of equal or greater importance than climate change. The next section takes up this theme.

4. DRIVING FORCES OF FLOOD HAZARD IN CONTEMPORARY EUROPE

Like other natural hazards, floods are not simply extreme physical events that inflict losses on unsuspecting human populations and their property. They are interactive processes that involve inputs from both nature and society. Some analysts have expressed the general relationship in terms of a simple formula: Hazard = Risk × Vulnerability, where Risk is roughly equal to the natural contributions and Vulnerability to the human ones.[25] That expression captures the interactive and uncertain character of hazard, but it also grossly oversimplifies the natural and human inputs, especially by conflating several distinctly different human dimensions, namely, exposure, resistance, and resilience. All these dimensions are also strongly contextual.[20,26] In particular, they are affected by the combined effects of powerful, pervasive, and often destabilizing forces, such as the burgeoning electronic information revolution; new technologies of environmental surveillance and transformation; widespread human modifications of river-basin landforms, land cover and land use; the globalization of economic relations; marked shifts in the composition and distribution of populations; rampant urbanization; and the restructuring of political ideologies or governmental systems as well as public reactions to those changes.

Findings from a recent study that focused on a wide range of natural hazards in 10 international mega cities[3] are also useful for understanding the changing human ecology of European floods.[27] Briefly stated, they suggest that changes in exposure and vulnerability are disproportionately important causes of increasing hazard losses in major cities. Though not unimportant, increasing natural physical risks are less significant contributors to the rising toll of losses. Existing responses to hazards are being pushed to their limits with consequent pressures not only to develop new alternatives but also to redefine acceptable thresholds of loss. Although only one European city (London) was included in the study, there is evidence that the findings also apply

[2] The Netherlands—which has had a long history of severe flooding up through the mid-20th century—is something of an exception. Large-scale evacuations continue to follow in the wake of flood warnings that forecast water heights above dike levels. For example, during one period of high water in 1995, a quarter of a million people were evacuated from the lower Rhine region (*The Times*, December 28, 1999).

[3] London, Lima, Mexico City, Miami, Los Angeles, San Francisco, Sydney, Tokyo, Seoul, and Dhaka.

to places like Florence, the interconnected Utrecht-Rotterdam-Hague-Amsterdam complex known as Randstad, and many other European cities.[28]

At the outset it is worth pointing out that absolute population growth is not usually a major contributor to the increasing flood disaster potential of Europe. Whereas invasion of floodplains by humans in search of new land for farming or homes is one of the most important drivers of flood losses in places like Bangladesh and throughout much of Africa or Latin America, Europe's total population is increasing only very slowly and in some states may actually be declining. More important is the concentration and redistribution of population that accompanies urbanization, although rates of urban expansion in Europe are again lower than in many developing countries. The spread of low-density suburbs and ex-urbs is a particularly significant factor in the conversion of rural lands near European cities, including floodplains. But far more important than any of these are shifts in the location of industries and homes impelled by economic factors and lifestyle choices.

The invasion of downstream floodplains by export-oriented businesses and industries, especially along navigable waterways that connect with deepwater international ports, is one example of increasing exposure to flood risks that reflects economic stimuli. This process is marked in London where there has been a decided shift of the locus of flood hazard during recent decades, as new investments crowd into the Thames estuary and the lower Thames valley seeking superior access to European and world markets. Similar processes can be observed in the lower Rhine valley (e.g., the massive Europort facility near Rotterdam and the Hague) and to a lesser extent along the lower Elbe and the lower Seine (e.g., Le Havre port complex). Even the outer fringes of Europe are not exempt from floodplain invasions by export-oriented businesses. Norwegian furniture manufacturers locate factories on flat sites beside fjords where they can import desirable cherry and maple woods from North America and reship the finished products to transatlantic consumers.

It has become conventional to apply the term "economic globalization" to the process driving these changes, but that simple label should not disguise the fact that many different interlocking—and sometimes countervailing—subsets of human activity are involved. For example, the burgeoning emphasis on port locations for industries is facilitated by changes in a complex web of factors that includes, among other things, marine transportation, navigation, and dredging technologies; shipboard labor practices; vessel registration and regulation rules; the acquisition of new electronic skills by mariners; the profitability of the shipping industry; and the state of competition between different transportation modes. In turn these components are embedded in a dominant consumer-oriented economy that is made possible by fluid supplies of investment capital and preferences for entrepreneurial risk-taking, coupled with precisely segmented and targeted marketing strategies that rely on vast quantities of timely and comprehensive information about consumer tastes and surplus income. The foregoing itemization only begins to scratch the surface of an economic process that is amplifying flood hazards in Europe and elsewhere, but it is sufficient to illustrate that hazards analysts and managers must look beyond the obvious elements of high water and unwise location decisions for effective responses to the flood-hazard conundrum.

The movement of exporting industries to waterside locations is one kind of regional shift that is affecting the distribution of flood-hazard potential in Europe. Another is the phenomenon of north to south industrial migration, which is occurring in countries like Britain, France, and Germany. Probably best seen in Germany, where it is described as a "descent to the south," this process is characterized by the relocation of high-technology, service-oriented industries from older decaying manufacturing cities in northern parts of the continent (that had been hearths of the Industrial Revolution), to small cities and villages with the kinds of climatic, recreational, and cultural amenities that are preferred by affluent business managers and highly mobile workforces. A byproduct of this movement is a net transfer of land-development pressures away from the big river systems of northern Europe to smaller upland watersheds on the fringes of the Alps, Apennines, and Massif Central or to maritime locations in France, northern Italy, and southern Portugal.[29] When the boom in vacationers, who frequent the mountains and coasts of southern Europe, is added to the influx of new industries, the aggregate southward shift in patterns of flood-hazard potential is clearly marked.

Meanwhile, the old river cities of northern Europe are experiencing their own changes in flood-hazard potential as a result of urban clearance and redevelopment projects that are designed to improve the attractiveness of waterfront areas to existing residents and new investors. Along the Thames in London, the Manchester Ship Canal, the Seine in Paris, the Rhine in Rotterdam, the Spree in Berlin, and the Elbe in Hamburg, old docks, crumbling warehouses, derelict train terminals, and outdated power stations are being replaced by new upscale apartments, cultural facilities, government offices, parks, shopping and entertainment complexes. Low-value investments at risk to flooding are disappearing and higher value ones are taking their place. This trend is not confined to old industrial Europe as growing European affluence is multiplying the value of buildings, infrastructures, services, and amenities all across the continent. In other words, the basis for even larger future flood disasters is being laid down.

In many places, transportation infrastructure, watershed protection and water supply, nature conservation, and recreation are becoming more important floodplain land uses than traditionally dominant agriculture. Historically, much riverside land in Europe has been used for agriculture, and demands for additional agricultural acreage frequently gave rise to large-scale wetland drainage and river-straightening schemes.[30,31] But now the need for locally produced farm goods is declining as cheaper substitutes become available from other continents, including North America. An early retreat from floodplain agriculture was sounded in the Netherlands during the 1960s and 1970s when Dutch officials cancelled plans for agricultural reclamation of new polders near the IJsselmeer and turned them over to water supply, forest park, and urban uses instead. Road, rail, and waterborne transportation routes now thread the floodplains of western European rivers to a remarkable degree. The redesign and extension of transportation infrastructures has already played a large part in the project for a single European market (e.g., tunnels under the English Channel and through the Alps; road bridges across the Kattegat/Ore Sund and the Bosporus; improved links between the Rhine and Danube waterways; high-speed intercity passenger trains; ongoing efforts to connect and pivot the continent's freight rail network around newly reunited Berlin). Even more so than inundation of fields and homes, the disruption of commuting and freight services for vast regions is often the economic impact that is most at stake during floods. It is too early to tell whether similar changes in flood exposure and vulnerability will occur in eastern Europe, but there the picture is complicated by possible regional shifts in agricultural production that may accompany expansion of membership in the European Union. We may see more investment in floodplain agriculture along the rivers of Poland, Romania, and the Ukraine rather than less. In any event, it is likely that Europe's flood-hazard patterns will be shaped by global as well as local forces.

One of those forces is the growing power of humans to shape natural landscapes and biogeophysical processes. By the beginning of the 20th century, the landscapes and ecosystems of Europe may have been more extensively modified by humans than those of any other continent, and the past 100 years have seen a further acceleration in these activities.[32] Although the clearance of forests and the conversion of wetlands for agricultural purposes are no longer major forces in much of Europe, they have been replaced and surpassed by other equally effective agents of environmental transformation. These include, among others, demands for tourism, recreation, and amenity services (ski slopes, marinas, resort developments); the degradation of natural ecosystems by air pollutants and other complex products of affluent societies (e.g., toxic contamination of wetlands by mine spoil and other wastes; so-called forest death, or *Waldsterben*); increased demands for water (e.g., supply reservoirs); and low-density residential sprawl. Many of these changes have direct implications for flooding. For example, throughout the Alpine regions environmentalists have argued in support of a connection between deforestation of mountain slopes, on the one hand, and increased runoff with shorter times to peak flows at downstream flood gauges, on the other.[33] But here a word of caution is in order. Although a general relationship between watershed conversion and increased flooding has been established in many parts of the world, the mix of contributory factors and the operating parameters seems to vary considerably from place to place. Thus the combined interaction of human and natural factors may have different flood-related consequences in, say, China, Great Britain, and the United States.[34–36] In summary, without a great deal of additional field data and analysis, it is premature to conclude that human-driven changes in river-basin landforms, land cover, and land uses are universally contributing to increased flood vulnerability in Europe but the possibilities are suggestive of such a connection.

Flood vulnerabilities are also changing in Europe. The continent's population is aging; almost 15% of Europe's citizens are now over 65 years old—up from 12% in 1980.[37] Since the aged tend to want—and need—more assistance during or after extreme events, this places a heavier burden on public services and raises anxiety levels among potential flood victims. Much of Europe's population is also becoming more affluent—though there are major contrasts between the richer states of the European Union and the poorer ones of the former USSR, which suffered grave economic crises during the collapse of Communist economies. Greater wealth confers some additional security on groups that might once have lived close to the margins of economic survival, but wealth also tends to drive up the economic costs of natural disasters because more people occupy larger and more costly houses and are often willing to sustain bigger disaster losses. Vulnerability is also increasing among Europe's recent immigrants. Newly arrived poor populations and local itinerant or homeless populations increasingly have begun to occupy marginal sites in and around major cities, including some river floodplains. Though the trend is detectable in places like Frankfurt am Main and some inner neighborhoods of London, it is nowhere as pronounced as in the third-world shantytowns of Latin American and Asia, nor even in the riverside embankments of Tokyo or certain districts of Los Angeles.[38,39] Given the fact that: (1) many of the most flood-prone parts of European cities lie close to their historic cores; (2) these places are valued for a mixture of tourism, amenity, and heritage reasons; and (3) the demand for inner-city residential properties is usually strong, it is unlikely that urban flood vulnerability differentials in Europe will be as wide as those of North America or elsewhere but the trend bears watching nonetheless.

Levels of urbanization vary widely among the states of Europe, but tend to be highest in northern countries and lowest in periphery states of the Balkans, Switzerland, Austria, Ireland, and Portugal.[29] Urban growth is disproportionately occurring in the hinterlands of existing large cities and in the medium-sized and smaller cities of the European "Sunbelt." These are the places where one would tend to expect additional flood problems in the future. But the relationship between urbanization and flood potential is by no means simple and is strongly affected by trends toward increasing functional specialization of cities. A recent study identified 11 different types of European urban units, ranging from global cities like London and Paris through specialized high-technology service centers, such as Bristol and Munich, to declining port cities (e.g., Genoa, Marseilles), planned new towns (e.g., Evry), monofunctional satellites (e.g., Roissy), and tourism centers (e.g., Salzburg, Venice).[29] The combination of economic and noneconomic forces that is driving flood potential affects these places differentially and in ways that call for careful assessment on a case-by-case basis.

It is important to note that flood-loss potential in Europe is affected by certain situational characteristics that influence vulnerability and complicate the task of choosing appropriate public policies. Among others, these include high population densities in most river basins and large numbers of historic buildings and culturally valued sites. For example, it can be argued that Europe's generally high population densities hamper the enactment of floodplain land-use controls, but this overlooks the fact that it is in (high density) urban areas where the demand for controls is greatest and where they have historically been most effective. Europe's generally long history of human occupancy also confers some distinctive emphases on flood policy. Simply because there are so many of them, the protection of historic communities and historic buildings looms disproportionately large as a European policy issue. Inasmuch as "zero damage" is an acceptable flood-protection criterion for historic buildings that are irreplaceable, thresholds of acceptable loss are often set quite low and are therefore highly sensitive to small-scale fluctuations of flood regimes.

Issues of flood protection for historic buildings are but one facet of a larger and more complex subject: European practices for assessing flood risks and for setting thresholds of acceptable risk as well as acceptable flood hazard management practices. Although the human dimensions of flood-risk assessment are attracting hazards researchers in Europe,[40–43] this subject has not yet received sufficient scrutiny. In the United States and Japan it has been observed that risks that were once tolerated under one set of socioeconomic conditions can become unacceptable when circumstances change. One of the best examples of this phenomenon is the shift in thresholds of acceptable natural risks that followed a substantial growth of national wealth in Japan during the decades after World War II. High death rates from floods, typhoons, and earthquakes that were tolerated during the 1930s, 1940s, and 1950s became unacceptable in a country that was rapidly moving into the upper echelons of developed states by the 1960s. A national commitment to reduce disaster deaths was accepted by the Japanese government after the Ise Bay (Nagoya) typhoon of 1959 and successfully implemented during the 1960s, 1970s, and 1980s. European parallels have not been so dramatic, but it is nonetheless clear that many people in Europe have become increasingly adverse to imposed risks. Though there have been few prominent European advocates of a "zero-risk society," public opinion seems to be shifting toward greater risk sensitivity. Hence, there may be less willingness to tolerate floods than previously.

In much the same manner, willingness to accept conventional engineering flood-management practices or technologies appears to be changing in Europe. Dikes, reservoirs, and concrete walls are increasingly viewed as ugly or environmentally damaging and sometimes—as in the case of large dam failures—a source of catastrophic hazard in their own right. Whereas the range of choice among adjustments to floods is relatively large in the United States, in Europe the dominant preference seems to be for fewer alternatives but more conservatively designed ones.

Various pieces of evidence support a judgment that Europeans and Americans may hold different perspectives on environmental risk. Differing design risk thresholds are one example. Flood-protection works in Europe are often designed to provide what American engineers would regard as very high thresholds of safety. Along the Rhine, many river works are designed to accommodate 1 in 1,250-year floods, whereas the typical standard on U.S. rivers is 100–200 years (http://www.sare.org/san/htdocs/hypermail/html-home/15-html/0424.html). Other engineering examples might be cited, such as the exacting construction standards for the Thames Flood Barrage or for European buildings in areas exposed to high winds. Sensitivity to catastrophic environmental risks was elevated in Europe by the experience of the Chernobyl nuclear disaster and by fears about the failure of similar power stations in eastern Europe. Perhaps because of this, Europeans have been quick to embrace social theories that privilege (environmental) risk as a fundamental new organizing concern of post-modern societies. (i.e., the so-called risk society paradigm).[44–46] Though not unreceptive to arguments that would elevate the social importance of risk, American hazards scholars have been more reluctant to endorse a similarly expansive view. Of course, countervailing notions have been voiced by some Europeans to the effect that Americans demand unrealistically high standards of safety against a vast range of risks. One of these is Alexander Solzhenitsyn—a shrewd judge of human foibles—who in a commencement address at Harvard University argued that Americans have an exaggerated sensitivity to what Russians would regard as minor environmental threats!

These observations are meant to remind readers about the complexities that attend environmental policy making at the beginning of the third millennium. To the age-old realities of a world where the assemblage of physical and biological factors that make up specific environments is immensely variable from place to place and subject to sharp temporal discontinuities, we must add the realization that humanity possesses both vastly expanded capabilities to modify environmental risks and rewards as well as a burgeoning propensity for fundamentally restructuring the institutions and practices of daily living. This is the thoroughly dynamic, uncertain, and ambiguous context within which the selection of appropriate European flood policies and programs will take place.

5. CONCLUSIONS

There is ample reason to be concerned about the growth of flood-disaster potential along the rivers of Europe even without taking climate change into account. Clearly, Europeans are facing a serious hazard challenge that is continentwide in scope. As inheritors of a long and complex history of flood experience—the lessons of which have too often been ignored—Europeans have the advantage of already knowing a good deal about environmentally sustainable flood management. As pioneers of new institutions of government and new systems of decision making that were shaped by the political fallout from wars both hot (1939–1945) and cold (1945–1989), they have faced—and will continue to face—a unique suite of flood-policy challenges. As citizens of governments that continue to pursue more interventionist public policies than their recent transatlantic counterparts, they may be able to "reinvent" government along somewhat different lines from the United States. And as members of societies whose perspectives on environmental risk may not be the same as those of the United States, Japan, and other places that have heretofore dominated much of the international discourse on hazards, they have the opportunity to fashion creative alternatives that will enrich the storehouse of techniques by which humans come to terms with uncertain and hazardous environments in ways that commend themselves to people in other parts of the world.

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Adapting to Climate: A Case Study on Riverine Flood Risks in the Netherlands

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Climate change may well lead to an increased risk of river floods in the Netherlands. However, the impacts of changes in water management on river floods are larger, either enhancing or reducing flood risks. Therefore, the abilities of water-management authorities to learn that climate and river flows are changing, and to recognize and act upon the implications, are of crucial importance. At the same time, water-management authorities respond to other trends, such as the democratization of decision making, which alter their ability to react to climate change. These complex interactions are illustrated with changes in river flood risk management for the Rhine and the Meuse in the Netherlands over the last 50 years. A scenario study is used to seek insight into the question of whether current water-management institutions and their likely successors are capable of dealing with plausible future flood risks. The scenarios show that new and major infrastructure is needed to keep flood risks at their current level. Such a structural solution to future flood risks is feasible, but requires considerable political will and institutional reform, both for planning and implementation. It is unlikely that reform will be fast enough or the will strong enough.

KEY WORDS: Adaptation; climate change; flood risks; institutions; Lower Rhine

1. INTRODUCTION

Studies of the impact of climate change often ignore adaptation,[4] and studies that include adaptation often follow first-order approaches under a *ceteris paribus* assumption.(2) This may well be inappropriate, because people's and systems' relations to climate tend to change due to many factors (technology, wealth, land use), the majority of which are not related to climate. So, to better understand reactions to climate change, we must study the institutions that channel people's perceptions and intentions into actual responses to expectations of climate change.

This raises questions such as: Do water managers realize that the climate is changing? Do they recognize the implications for their tasks and objectives? If so, are they able to react timely and adequately? What constitute institutional barriers to implement certain proposed flood risk mitigation schemes? And what, given current societal trends, are the prospects for adapting institutions to find better and feasible responses to climate change?

In this article, we focus on water management in the Netherlands, in particular management of flood risks posed by the large rivers (Meuse and Rhine). In this context, the questions of awareness of climate change and its implications are not particularly

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4 Adaptation is the knowing and unknowing response of actors and systems to climate change, either in anticipation of or reaction to, so as to mitigate the negative impacts of climate change and maximize its positive impacts, whether successful or not.(1)

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interesting, as everyone who has something to do with Dutch water management knows about climate change. We therefore largely restrict ourselves to the conflict between what should be done about increasing flood risks and what can be done in the current and expected future institutional context. The central question in this article is whether Dutch water-management authorities will be able to cope with a substantial increase in riverine flood risk. As our answer is no, this automatically leads us to propose institutional reform. Current decision making is too vulnerable to being hijacked by special and local interests, both in the planning and in the implementation phase. At the same time, local knowledge and interests are disregarded. The current separation of water management and land-use planning policies also creates unnecessary problems for adequate flood management.

The article has three building blocks. One is an analysis of trends in water-management institutions in the Netherlands.(3) The second building block is an engineering study of future flood risks.(4) The third building block consists of two case studies. The first is on the implementation of a current flood management project: the *Maaswerken*.(5) The second case study is on the public acceptability of a future flood management project: the *Rijn op Termijn*.(6) In this article, we bring the three elements together to study potential adaptation to flood risks in the Netherlands. Miller *et al.*(7) and Cohen *et al.*(8) also emphasize the importance of institutional arrangements for water-management issues in the United States and for flood management of the Columbia River, respectively. Kelly and Adger(9) similarly stress the social context of adaptation. Strzepek *et al.*(10) go a step further and build scenarios of future institutions and context as well, a more or less similar approach as the one taken here.

The article follows this route. We sketch the current developments in water management against the background of societal trends, and extrapolate these to the future (Section 2). Section 3 lays out solutions to current (*Maaswerken*) and anticipated (*Rijn op Termijn*) flood risks. The institutional responses to these initiatives are discussed in Section 4. Section 5 concludes.

2. FLOOD RISK MANAGEMENT AND TRENDS IN WATER MANAGEMENT

The Netherlands is densely populated with prosperous and well-educated people. Decisions are typically made through consensus. The country is formed by the deltas of the rivers Scheldt (a rain-fed river originating in southern Belgium), Meuse (a rain-fed river originating in northern France), and Rhine (a glacier- and rain-fed river originating in Switzerland). The Scheldt River connects Antwerp Harbor to the North Sea. The Rhine is the largest of the three rivers. Just after passing the Dutch-German border, it splits into three major branches (the IJssel, the Lek, and the Waal) and a number of smaller branches. The Waal branch connects Rotterdam Harbor to the German industrial heartland. The country is flat. Centuries of subsidence have left most of the country below mean sea and river level. Dikes and dunes are supposed to protect the country from floods from both sea and river. Centuries of floods have left the people rather nervous and inventive about flood risk management. Water flows are regulated through an elaborate system of canals, sluices, pumps, and so on. Dutch civil engineers are amongst the best in the world when it comes to engineering water works.

Flood risk management is only one part of water management, although it has top priority. Under current national law, flood risk, inland navigation, fisheries, leisure, rivers as a fresh water resource, and nature conservation must be managed in an integrated way. Recently, under the expectation of increasing flood risks, the water-management community advocated a more important position for water management in national spatial planning in the Netherlands. The possibilities for dealing with very high river discharges should become one of the guiding principles for national spatial planning.

Reflecting these multiple interests of rivers, water management is carried out by a complex array of authorities. An overview of the main players and their main responsibilities can be found in References 3, 11–14. Van der Grijp and Olsthoorn(3) identify four major trends in water management over the last 50 years. These trends may well continue to change institutions in the same direction for the next 50 years.

The first trend is *internationalization*, or the geographical extension of policy from the local scale to the watershed. Water-management policy, traditionally a matter of local and regional authorities, was first nationalized by Louis Napoleon, viceroy for his brother Bonaparte (see References 15 and 16 for a more extensive review of the history of flood management in the Netherlands). The responsibility of the central government for water issues was reconfirmed in the Constitution of 1848, and strengthened in the Constitution of 1983. Operational responsibility for flood safety rests with the water boards. The flood of 1953 led to a reorganization of the water boards. There were over 2,500 semi-professional water boards in 1950. There are less than 50 fully professional ones now.[11] Geographical upscaling of institutions continues at an international level. The 1986 Sandoz incident[5] gave teeth to the International Rhine Committee, though initially only to chew on water-quality and pollution issues. Since the floods of 1995, mostly in Germany, its mandate has included flood control.[3] The Helsinki Convention provided a framework for treaties on the Meuse.[17] The new EU Water Directive is likely to reinforce the trend of internationalization of river water management.

The second trend is *integration*. Water has many roles, and water management serves many purposes. These include drinking water, irrigation water, navigation, recreation, nature preservation, fisheries, and cooling water. Problems may arise because of floods, droughts, and contamination. All these roles and the associated management goals come together in one system, and pretending that interactions do not exist may be seriously misleading or counterproductive. Yet, different aspects of water are often still managed by different entities with different, occasionally conflicting, interests. Over the years, and particularly in the last decade, integration of water issues has been pushed by the central government.[18] However, operational reality lags behind.[19] It should be noted that, currently, integration more or less stops where the water ends. Land-use planning and water management remain largely separated, although there is considerable mutual consultation.[20]

The third trend is *democratization*. Engineers, bureaucrats, and politicians have less to say about water management than they used to. More stakeholders get increasingly involved. This is marked by the gradual extension of voting rights in water boards from large landowners to all inhabitants (completed in 1994).[19,21] More importantly, elaborate impact assessments of proposed projects are now required by law, media attention to planned infrastructure can be enormous, and public hearings are extensive.[3] Although this increases the democratic nature of decision making and thereby the quality of planning and implementation, it may also increase its costs and slow down the process considerably.

Note that in reaction to the (near) floods of 1995, the *Deltaplan Grote Rivieren* (Delta Plan for Large Rivers) was introduced. The accompanying law accelerates and streamlines decision-making procedures, partially reversing the democratization trend. This law applies also to infrastructure other than flood-safety-related investments.[22]

The fourth trend is *ecologicalization*. Water management used to be decided on a narrow economic and engineering calculus, and used to be biased by typical civil engineering thinking. The upsurge of the environmental movement in the 1970s, reinforcing the older movement for protecting landscape and cultural heritage, changed this. Notably, during that time, plans to impolder the IJssel Lake and the Waddensea were abandoned, and plans to close the Eastern Scheldt Estuary were changed, all in favour of nature preservation.[23] The thoughts behind these isolated decisions are now pervasive. Civil engineering has given way to ecological engineering. Rivers are no longer just transport channels and a resource of fresh water, but important recreation areas and part of the "ecological main structure." The current round of dike reinforcements is supposed to be the last one. After 2000, flood risk management should make use of natural dynamics, rather than concrete and steel.[12]

These trends both constrain and enable future management options. Together, they determine what options are feasible, and which one is likely to be adopted. Reactions to climate change should be placed against this background.

3. A RADICAL PLAN TO COPE WITH CLIMATE CHANGE

The implications of climate change may be quite severe for river deltas such as the Netherlands. The majority of general circulation models (GCMs) project winter precipitation to increase in the Rhine River basin.[6] This would increase the risk of river floods.[26–28][7] Earlier snowmelt in the Alps could further enhance river floods. Sea level rise would slow down the outflow of water. In the Netherlands, the impact of climate change on water resources and flood risks is clearly recognized. The works of the

5 A factory spilled large quantities of poisonous chemicals during a fire.

6 That is, GCMs that look at the effect of greenhouse gas emissions generally project the northern half of Europe to get wetter. GCMs that also include sulphate aerosols occasionally project a drying of northern Europe.[24] However, acidification policies in Europe rapidly decrease sulphur emissions.[25]

7 Note that sizeable rivers such as the Rhine react to above-average rainfall for an extended period (at least a month) over the whole watershed.[29,30] GCMs are more reliable for this type of floods than for flash floods and floods of small rivers, and the Rhine catchment is sizeable to be resolved in a GCM.

Table I. Annual Average Damage (in Million Guilder per Year) Due to River Floods in the Limburg Meuse Valley[a]

Policy Intervention	1995	2050[b]
Do nothing	9.9	21.8
Embankments	0.7	1.5
Nature development	0.6–3.3	1.4–7.3
Deepen summer bed[c]	3.5	7.4

[a]Average damage is estimated using a hydrological model of the Meuse, coupled to a GIS database of the stock at risk from flooding. Modeled flood damage is calibrated to the actual flood damage of 1995 (without policy intervention). Input comes from a stochastic weather generator, calibrated to current climate and a scenario of future climate.
[b]Winter temperatures 2°C higher than today, winter precipitation up 10%.
[c]The summer bed is that part of the riverbed that is permanently flooded. The winter bed is only flooded in winter and early spring.
Source: Schuurman.(32)

Committee Boertien is one example, but there are more.(3)

This committee studied flood risk management along the river Meuse. The Meuse is a medium-sized rain-fed river originating in the north of France, traversing Belgium and the Netherlands to mouth in the North Sea. The Limburg Meuse Valley is unique for the Netherlands[8] because it is hilly and there are no dikes because the soil is such that water would seep underneath the dike (if there were one). Severe floods in 1993 led the government to install Committee Boertien (officially: *Commissie Watersnood Maas*) with the assignment to assess what could be done to avoid flood damages in the future.(31) The findings of this committee with respect to the benefits of possible options to reduce flood risks with and without climate change (Table I) are interesting.

Table I shows the estimated annual average flood damage for various management scenarios. The Committee Boertien included robustness to climate change in their study, using a temperature and precipitation scenario for the year 2050 that is arbitrary but still well within the set of possibilities. Scenarios like this should be viewed as a sensitivity analysis rather than a forecast. A relatively modest change in climate (a 2°C temperature increase and a 10% precipitation increase in winter in 2050) would more than double the average annual damage. Medium-sized European rivers typically respond in this way.(33,34) But, under the studied management interventions (see Table I), average damage would be kept below the 1995 damage. However, the studied management interventions would reduce average damage by a factor of 3–16. Thus, in the Limburg Meuse Valley, the effect of management is much stronger than the effect of climate. That is, the impact of climate change is "noise" compared to the "signal" that management potentially effectuates. This is true for many impacts of climate change.(35)

The situation is completely different, however, for flood risks along the river Rhine. The flood risks posed by the Rhine and its branches are much larger than the flood risks of the Scheldt and the Meuse. This has to do with the large discharge of the Rhine, and the fact that the areas adjacent to the river are polders. Most polders are below mean river level, so if water gets in, it needs to be pumped out, which takes a long time. If a dike breaks, fast-flowing water would cause a lot of damage. The traditional first response to expectations of increased risk would be to raise dikes. However, this approach is widely rejected as not sustainable.

Unfortunately, no one has found a neat solution so far to the climate-change-induced increase of flood risks. A default solution would be to continue current and past practice of solving problems as they emerge (that is, after some harm is done), and picking a solution that does not upset the delicate balance of interests. This has proven to be quasi-successful, although problems were often shifted in place or time rather than solved.(15,16) It is doubtful whether this strategy will be of great help in dealing with climate change due to the scale of the problem and the state of the current water-management system. Works to improve the weakest dikes were accelerated in 1995. No definite plans have been decided upon for after 2000. Proposals, which focus on increasing the retention and recreational value of the flood plains, tweak the water-discharge system, but do not substantially alter it.

The alternative would be a radical redesign of the delta of the water-management system. In 1998, the research institute Delft Hydraulics(4) produced a blueprint *Rijn op Termijn*. This plan is not painless, but it could take away a number of current problems and prevent a number of future ones. The core element of the blueprint is to redistribute the water flow over the three branches of the Rhine, that is, the Waal, the Lek, and the IJssel (see Fig. 1). The Waal, which discharges most of the water, is the major shipping route from Rotterdam to Germany and back. The Lek and the IJssel are less important.

[8] Although more common in the rest of the world. Limburg is the southern-most province of the Netherlands, squeezed in between Belgium and Germany. The Meuse is on the Dutch-Belgian border, the Limburg Meuse Valley is shared by the two countries.

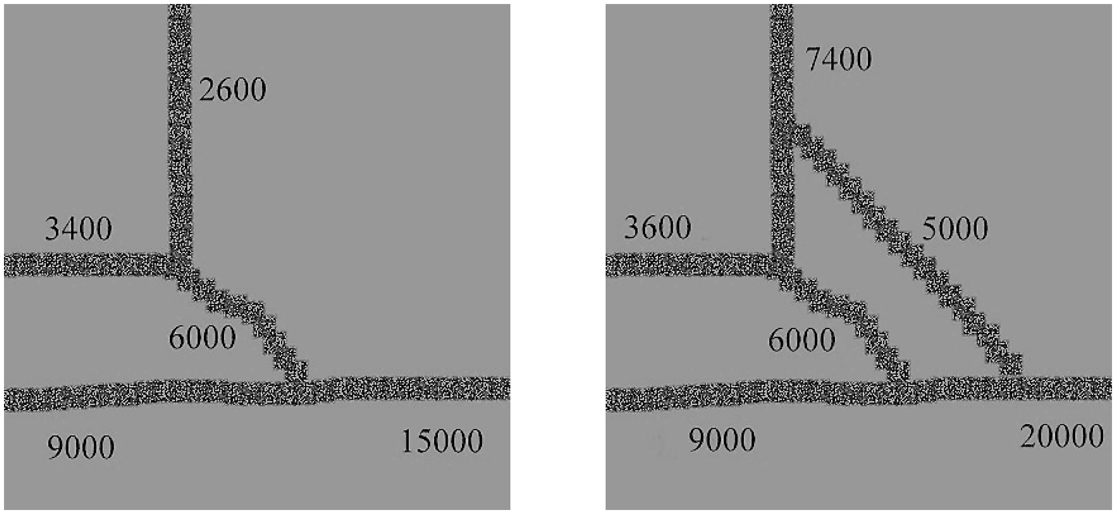

Fig. 1. Current (left panel) and proposed future (right panel) distribution of the Rhine's peak flow over its branches. The 5,000 m^3/s branch is additional and only used in times of high water. It involves digging a new canal but largely relies on an earlier branch of the river.[4]

Climate change is likely to increase the peak flow. In the study by Delft Hydraulics, the design peak discharge is assumed to increase from 15,000 m^3/s to 20,000 m^3/s. This is an arbitrary but not implausible scenario. The design peak discharge is the maximum river flow—as measured at Lobith where the Rhine enters the Netherlands—that occurs without causing severe floods downstream. The design peak discharge constitutes the first element of the guidelines for flood protection. The second element of flood protection is the acceptable risk of dike overtopping. This risk is set by Parliament, upon advice of a committee of wise men.[37] The current risk is 1/1,250 year, that is, river dikes and other water works should be built such that they fail less than once every 1,250 years. The tolerated risk is so low because the would-be damage is so high. Should a dike break or be overtopped, a large polder would fill with fast-streaming water. It would take months to get the water out. The acceptable risk does not comprise a valuation of personal risks.

Confronted with a higher peak flow, one could do several things. First, water-management authorities could hope that the Germans would solve the problem, and store excess water somewhere in a reservoir. The current discussion in Germany suggests that this is an unlikely scenario, for several reasons. One such is that water management is the terrain of the *Bundeslaender* rather than the federal government, which hampers any structural solution to the flood problems along the Rhine.[38] Another reason is that building (temporary) reservoirs is not the preferred option from a German perspective.[4]

Second, one could accept more frequent floods. This is not an option in the Netherlands. The 1995 evacuation of 1 in 60 of the population is still fresh in people's minds, and not to be repeated. Recent attempts to introduce flood risk insurance failed for lack of interest by insurers and reinsures.[2,35,39,40] The Netherlands is becoming a "zero-risk" society, that is, the tolerance of involuntary risks is low and decreasing.

Third, one could build higher dikes. This runs against the trend of ecologicalization, and is counter to the recently adopted government policy of no more dike reinforcement. Dikes are considered ugly and spoil the landscape. Dikes are also expensive, particularly if done properly. A lot of river dikes were built and rebuilt over the centuries. It is seldom known what they were made of, and thus they are difficult to reengineer.[4] Furthermore, there is always a residual risk of dike failure, particularly in the light of the uncertainty about climate change projections. Floods in the densely populated areas of Brabant and South Holland or the petrochemical industry near Rotterdam would be extremely expensive. Therefore, it would be better to relocate flood risks, which is hard to achieve with additional dike building.

Fourth, one could increase the discharge capacity of all three branches by deepening and widening the riverbed. However, getting the water as quickly as possible to the North Sea would cause other problems. Increasing discharge capacity would reduce water flows in summer, which, particularly if combined with higher temperatures, would enhance the probability of droughts, hurting nature, recreation, agriculture, drinking water resources, and navigation. The current, already elaborate system of sluices would need to be substantially and expensively extended to prevent this. Reliable and speedy navigation is important for Rotterdam Harbor, competing as it does with Antwerp and Hamburg. Standards for navigability of the Rhine are laid down in a treaty between the Netherlands and Germany.[3]

Fifth, one could dig a fourth branch. This would be expensive and risky, since such a branch would need to run against natural geography and would require land already used for other purposes.[4] This branch would inevitably flow through *'t Gooi*, which is hilly and populated by well-to-do and well-connected people.

Sixth, one could introduce a bypass. A bypass is a river branch that only occasionally discharges water. A report by Delft Hydraulics[4] opts for this idea. Fig. 1 shows the consequences. If the discharge of the Rhine at Lobith is less than 15,000 m^3/s, everything remains as it is now. All water in excess of 15,000 m^3/s is discharged northward, through the countryside of the province of Gelderland and Overijssel, and later joined with the IJssel to mouth in the IJssel Lake, from where the water would need to be discharged or pumped into the Waddensea. The bypass plan contains two more features. The Waal is turned into a canal, so that navigation is improved. The Lek is turned into a nature reserve.

The bypass as advocated by Delft Hydraulics is obviously not the only option, and probably not the best one.[9] It is the most detailed proposal, however, and clearly demonstrates the scale of intervention that is required to durably manage river flood risks in the Netherlands. In the next section, we review the institutional implications of intervention at this scale.

4. INSTITUTIONAL RESPONSE

The implications of the bypass plan for the provinces of Gelderland and Overijssel are quite drastic. Fig. 2 compares the current and the proposed situation. Large stretches of land would need to be set aside for the newly created bypass. Isolated houses and hamlets would need to go, and some villages and towns would need to be protected by circular dikes. The occasional flooding would be detrimental for agriculture, so that nature development would be the alternative, perhaps combined with estates. The bypass is designed so as to minimize such impacts, but they are still large.

Fig. 2. The proposed bypass and restructured IJssel River. The light areas are currently flood-safe, but will occasionally flood in the proposed situation.[4]

Placed in the context of *democratization*, it is unclear whether the bypass or a similar plan will succeed. Locals would be asked to leave house and hearth for a questionable cause. In a series of interviews we conducted in the area,[6] one of interviewees remarked "Climate change? Ha! One professor says it gets wetter, the other says it gets drier." The fact is that the current decision-making process gives considerable weight to "not in my polder" feelings. The results of the series of interviews suggest that farmers may be willing to move, provided that financial compensation is adequate. However, they would regret the breakup of social life. Recent migrants to the region particularly appreciate the current, open landscape,

9 See Reference 36 for tools to evaluate adaptation to climate change in the water-resources sector. Yohe and Tol[38] develop their own method and, applying it to the case of the Rhine, conclude that dike reinforcement is the most likely adaptation option.

and thus oppose new dikes and other infrastructure. Both groups, however, would be willing to accept individual losses for the greater good, provided that social benefits are clear to them. On the other hand, these people could and would resist government plans if the necessity is unclear, compensation inadequate, or if something goes wrong in the communication process. This group of people is well organized, and effectively influenced the planning of the *Betuwelijn* (a major new railroad) and dike reinforcements in the same area.[3]

Another issue is that the people of Gelderland and Overijssel would be asked to bear most of the costs (that is, increased flood risks), whereas the benefits (reduced floods risks) would largely befall the people of Brabant and Holland. Over the years, Dutch flood management has consistently upheld the principle of spatially equalized flood risks.[37] Similar regional sentiments, particularly tensions between center (i.e., Holland and Utrecht) and periphery (the rest of the country), have played a role in the management of the Limburg Meuse. People in Limburg subsidize flood management in the west of the Netherlands, while flood risks are substantially higher in Limburg. This is one of the reasons why the central government currently seeks to reduce flood risks in Limburg. Similar arguments may lead to political problems for the bypass plan for the Rhine River.

The Delft Hydraulics plan is not inconsistent with the trend of *ecologicalization*, particularly because the Waal does not need higher dikes and the Lek is turned into a nature reserve. The actual bypass requires engineering, though, and new dikes are needed to protect the towns and villages of Gelderland and Overijssel. As mentioned above, the plan disregards upstream solutions in Germany, ignoring the trend of *internationalization*.

The plan requires *integration* to be taken two steps further. Most importantly, water management and land-use planning need to be interwoven. At the moment, the relevant authorities merely talk to one another, and only occasionally listen. A recent example is the *Betuwelijn*, the planned location of which gets in the way of flood safety reinforcements.

The difficulties in getting different authorities and other stakeholders to agree on policies and actions that address problems overarching specific interests are recognized. New ideas for water management[41] focus on the process of finding feasible approaches to deal with an uncertain future rather than on attempting to find support for a preengineered solution to a predefined problem. The initiative of Delft Hydraulics may be seen as an attempt to start such a process.

Just how hard this is is shown by the *Maaswerken* project. This project aims to improve flood safety along the Meuse. At the same time, it seeks to further commercial mining of sand and gravel and to develop nature. Integration and ecologicalization are thus at work, and so is internationalization since the Meuse cannot be controlled without extensive cooperation with Belgium. In fact, the project includes a slight revision of the international border. The project planning is accompanied by extensive consultation with local and regional stakeholders. The *Maaswerken* project thus combines all elements of possible Rhine projects, although the *Maaswerken* project is smaller, less complex, and less controversial than a restructuring of the Rhine. Nonetheless, the *Maaswerken* project is plagued by troubles.

Ever since its inception in 1990, the project has been overtaken by events, including floods along the Meuse (in 1993 and twice in 1995) and the Rhine (1995), new regulations from The Hague (on flood management, spatial planning, and nature conservation), and new initiatives from Brussels (on international flood management, on water management, and on nature conservation). Initially envisaged as three separate projects, the *Maaswerken* project grew more complex over time. Priorities were revisited time and again—on average, once every year; the emphases shifted from gravel exploitation, to nature conservation, to flood safety, and back—in every possible sequence. The budget was often revised too, and funding continues to be uncertain. Stakeholders grew impatient and tired of the frequent changes. Initially cooperative locals withdrew support, while gravel companies and property speculators press forward. Van der Grijp and Warner[5] extensively discuss the project.

As discussed above, this project is smaller, simpler, and less controversial than the Rhine bypass project. If implementing the *Maaswerken* is so difficult, how feasible are large-scale interventions in the Rhine?

5. CONCLUSION

Climate change could seriously increase flood risks in the Netherlands. This is recognized by the water-management authorities, which have the technical capacity to keep flood risks at or below current levels. The Netherlands is also rich enough to pay for technical solutions. However, a structural solution—such as the bypass plan sketched above—would require strategic thinking, political courage, individual sacrifice for the greater good, and integration of land-use planning and water management. The current institutional setting is such that a structural solution is likely to give way to incidental solutions. Dutch water management has a long history of partial and short-term solutions. Continuing along this path will entail increasing flood risks as well as suboptimal adaptation.

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Stakeholder Views on Flood Risk Management in Hungary's Upper Tisza Basin

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With escalating costs of flood mitigation and relief, a challenge for the Hungarian government is to develop a flood mitigation and insurance/relief system that is viewed as efficient and fair by the many stakeholders involved. To aid policymakers in this task, this article reports on a recent study to elicit stakeholder views on flood risk management in the Upper Tisza Basin, including views on appropriate means of reducing losses and for transferring the residual losses from the direct victims to taxpayers or an insurance pool. This study is part of a project to develop an integrated approach to flood risk management coordinated by the International Institute of Applied Systems Analysis (IIASA) in collaboration with Swedish and Hungarian researchers. The discussion begins by describing the background of flood risk management problems in the Upper Tisza Basin. The results of interviews carried out with selected key stakeholders and the results of a public survey eliciting views on flood risk management are reported. The final section draws conclusions on incorporating stakeholder views into a flood risk management model, which will be used to illustrate policy paths at an upcoming stakeholder workshop. The conclusions are also of direct interest to Hungarian policymakers.

KEY WORDS: Floods; flood risk management; integrated risk management; catastrophe models; stakeholder views; insurance

1. INTRODUCTION

In Europe, Hungary ranks only behind the Netherlands with respect to flood exposure. Over half of the country's territory, two-thirds of its arable land, and one-third of its railways are exposed to riverine, groundwater, and flash floods. Estimates show that losses from flooding could reach almost one-quarter of the GDP of river flood basins, or 7–9% of the total GDP of the country.(1)

One of the highest flood risk areas in Hungary, and one of the poorest regions in Europe, is the Upper Tisza river basin in the northeastern part of the country. The intensity and frequency of flood disasters in this region, and throughout Hungary, appear to be increasing because of development and farming practices in the exposed areas, deforestation and other land-use practices, the regulation of the rivers, and neglect of the drainage systems.(2) Worsening weather extremes due to climate change may also be a contributing factor.(3) Because most of Hungary's rivers, including the Tisza, originate outside of the country, flood risk management in Hungary can be effective only with the cooperation of its seven bordering countries.

With increasing losses, the Hungarian government is concerned about continuing its tradition of taking almost full responsibility for flood risk management, including flood prevention, response, relief, and public infrastructure repair. The central government has invested huge sums in a vast network of protective levees, including about 3,000 kilometers

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of levees along the Tisza River. Without these levees there would be extensive flooding in the country, for example, a flood occurring on the Tisza River could inundate up to 16,000 km^2 or around 17% of Hungary's territory.[4] This levee system is proving insufficient with worsening flood conditions, and it is expensive to maintain. Moreover, there are value conflicts, for example, whether to continue protecting the residents of high-risk areas with levees or to renaturalize the river to enhance the ecosystem.

The Hungarian government takes full responsibility for private damages in the event of a levee breach, and victims from all types of floods usually receive a great deal of public relief. This social solidarity with flood victims, which is typical of all the formerly socialist countries of central Europe, has become a major concern to the Hungarian government since it has embarked on a fiscal austerity program so as to qualify for European Union membership. Government officials would welcome more private responsibility in reducing and insuring flood losses; however, many Hungarians regard the transfer of liability for flood losses to citizens in very poor areas, such as the Upper Tisza region, as unfair. One of the more controversial issues in Hungary, and throughout central Europe, is thus the respective roles of the government and the private market in providing relief to flood victims.

The challenge for the Hungarian government is to develop a flood mitigation and insurance/relief system that is viewed as efficient and fair by the many stakeholders involved. To aid policymakers in this task, this article reports on a recent study to elicit stakeholder views on flood risk management in the Upper Tisza Basin, including views on appropriate means of reducing losses and for transferring the residual losses from the direct victims to taxpayers or an insurance pool. This study is part of a project coordinated by the International Institute of Applied Systems Analysis (IIASA) in collaboration with Swedish and Hungarian researchers.[3] The purpose of the project is to develop an integrated approach to flood risk management in the Upper Tisza region, in which stakeholder views are incorporated into a flood-catastrophe model.[5,6] This model will provide important information on policy alternatives for managing flood risks in the Upper Tisza region in an upcoming workshop involving stakeholders and Hungarian policymakers.

In the next section, we describe the background of flood risk management problems on the Upper Tisza River. In the third section, we report on interviews carried out with selected key stakeholders, and in Section 4 we present results of a survey administered to the Hungarian public. The final section draws conclusions for Hungarian policymakers.

2. FLOOD POLICY IN THE UPPER TISZA BASIN

The Tisza River originates in the northeastern Carpathians in the Ukraine and flows from Romania and Slovakia to Hungary, and eventually into the Danube in Serbia (see Fig. 1). Pecher *et al.*[7] point out that from 1877 to 1933 the average period between high-water discharges resulting in disastrous floods on the Tisza River was 18 years; from 1933 to 1964 it was only three to four years. Since 1998, record-breaking water levels of the river have occurred annually, but the extensive network of levees surrounding the river has prevented major losses. The flood of 2001, however, burst through the protective levees and caused extensive damage. Approximately 17,000 people were evacuated, 1,000 houses completely destroyed, and another 2,000 houses damaged. Estimated direct losses amounted to approximately U.S.$180 million, or 0.4% of Hungary's GDP.[8] Since flood waves originating in upstream Ukraine arrive in Hungary at very high speed, there is a little time for warning and preparation.

Communities in the Upper Tisza region, and especially the high-risk areas near the Tisza River and its tributaries, are among the poorest in Hungary. The area is predominately rural with 200,000 inhabitants of 114 villages and four towns. Most settlements are located far from the cities with bad road connections, and only 22% of the settlements have access to the railway network, compared to the country average of 38%. Especially among the less qualified Roma population, the rate of unemployment in the region is very high—24% in 1999 compared to the country average of 9%. For the employed, 35% work in agriculture, 25% in industry, while approximately 40% of the active population works in the service sector. Incomes from agricultural activities are typically small, and agriculture by itself cannot support the local population. Riverine floods and inland waters have aggravated this situation considerably. There are communities, for instance, where free seed was distributed, but residents were not willing to sow mainly on account of the flood risk.[9]

[3] This project, "Flood Risk Management Policy in the Upper Tisza Basin: An Integrated Approach," is being carried out by IIASA in collaboration with the Hungarian Academy of Sciences and Stockholm University. It is funded by the Swedish FORMAS.

Fig. 1. Hungary and the Tisza River.

On the other hand, the area has a large and undeveloped potential for recreation, tourism, and nature conservation. There are pristine, almost untouched, areas surrounding the meandering Tisza River, and its floodplain is sprinkled with old villages, traditional farms, and historic buildings. Tourism was on the rise until 2000, when the area was stigmatized by a cyanide spill into the Szamos and Tisza Rivers caused by the breakage of a tailings impoundment maintained by the AURUL Australian-Romanian joint venture mining company in northwestern Romania. Until this episode, water sports had developed intensively in the area; however, infrastructure supporting these sports remains underdeveloped, and there is large uncertainty about the future of the region with regard to tourism.

The central government accelerated its levee-construction program for the Upper Tisza River and its tributaries in 1998, after which a World Bank study queried whether the benefits to this poor region justified the costs.[1] Following the levee breach of March 2001, the insufficiency of this program was widely recognized, and the government has begun discussing other flood mitigation measures, including the construction of emergency reservoirs in Hungary and upstream Ukraine, increasing the capacity of the main riverbed, and changing land-use practices in the flood plains.[10]

These discussions have become controversial and sometimes contentious. The water authorities, among others, view structural measures as essential for protecting the lives and livelihoods of villagers in the high-risk areas. Alternatively, environmentalists, among others, increasingly view structural measures as detrimental to the ecosystem of the region and as contributing to flood risks downstream. The environmentalists' discourse includes taking down the levees in some areas and renaturalizing the river. This would require relocating residents and possibly even some villages out of the high-risk areas.

The taxpayers' role in compensating the victims of floods has also become controversial. As a case in point, the rebuilding or repair of the damaged homes and buildings from the 2001 flood was criticized as extensive, especially since many of the homeowners also received insurance payments. With escalating losses throughout Hungary, this policy is not only becoming prohibitively expensive, but is increasingly viewed as encouraging undesired development in flood-risk areas.

In comparison even with western Europe and the United States, a large percentage of Hungarian households, almost 60%, carry flood insurance offered by one Hungarian and 16 foreign-owned insurers. The reason for this high insurance uptake is that flood policies are "bundled" with residential property insurance, which is required for a homeowner mortgage. In the poor Upper Tisza region, however, only about 40% of the households hold property insurance. The premium for homeowner flood insurance is independent of the risk; in fact, insurers charge all households in Hungary an equal percentage of their property insurance premium to cover flooding. This has resulted in significant cross-subsidization from persons living in low-risk areas, for example, in large cities including Budapest and Szeged, to persons living in high-risk areas, for example, in villages in the Upper Tisza region. Thus, not unlike the United Kingdom and France and many other countries in western Europe, a cornerstone of the present Hungarian insurance system is cross-subsidization of premiums.

Flood insurance does not cover victims for commonly incurred damages, including water seeping under the levees, drainage problems, and, most importantly, standing water due to raised groundwater levels. Flood insurance is not offered at all in areas unprotected by levees, and no commercial insurance is available for crops or businesses. For these reasons, many consider flood insurance in its current form to be insufficient and recommend government intervention to establish well-defined and more comprehensive insurance practices.[1]

Policymakers in Hungary, like in many other countries in Europe, are considering legislating a national flood-insurance system. There are many options for combining the public and private sectors. For example, the U.S. National Flood Insurance Program (NFIP) offers public insurance that is mandatory for those holding a bank mortgage. The U.S. system is moving toward risk-based premiums to eliminate cross-subsidization. Alternatively, France's system is private but backed by taxpayer funds. It is based on a concept of social solidarity, with deliberate cross-subsidies across regions and hazards.

The World Bank study makes a specific recommendation for Hungary. For the first tier, the government would provide compensation of a limited amount to all households that suffer losses from flooding. As a second tier, flood insurance would be available from commercial insurers (up to a specified level) to everyone living in a flood risk basin on an indemnity basis (meaning cross-subsidies from low-risk to high-risk insureds). As a third tier, private insurance may be available on an actuarial risk basis.[1]

3. STAKEHOLDER INTERVIEWS

Nearly all Hungarians have a stake in the flood risk management system for the Upper Tisza region, either directly by their exposure to flood risks or indirectly by their tax payments for flood mitigation relief and their foregone public amenities because of flood relief expenditures. As a case in point, after a Tisza flood in 1998 the central government delayed construction of part of the Budapest subway in order to divert funds for flood relief to Tisza victims. For the purpose of eliciting stakeholder views on flood risk management strategies for the Upper Tisza region, face-to-face, open-ended interviews were carried out with the actively involved stakeholders. These included 24 persons representing central, regional, and local government agencies, farmers and entrepreneurs, NGO activists, and insurance companies. The interviews formed the basis for a public survey, or survey to those stakeholders more indirectly involved, which will be reported in Section 4. The purpose of the interviews was to elicit opinions on the factors responsible for the apparent increase in flood risks in the Upper Tisza Basin and the consequences of the flooding. In addition, the interviewees were asked to express opinions on their preferred policy strategies to reduce these risks, their preferred measures for providing relief to flood victims, and their preferences for the design of a private and/or public flood insurance program for Hungary.

3.1. Factors Increasing Flood Risks

Without exception, all the interviewees considered flood risks to be increasing in the Upper Tisza region and in Hungary. The following reasons were given: technical/structural deficiencies, land-use changes, institutional changes, and lack of private mitigation measures.

Most stakeholders regarded technical/structural deficiencies, namely, the poor quality of the flood protection systems, as the major flood risk factor. Many expressed the view that the post-1990 democratic governments did not allocate sufficient funds for the maintenance and improvement of the levees. In addition, some interviewees claimed that the existing monitoring systems are inadequate. This concern is transnational since flood waves arrive from the upstream countries of Romania and the Ukraine, and some interviewees pointed to the undeveloped state of the Ukrainian monitoring system.

A group of respondents attributed more blame for the increase in the severity of flood risks in the Upper Tisza region to deforestation and other land-use factors. In particular, the environmentalists considered the problem to stem from worsened soil erosion due to extensive clear felling and forest cutting in the Ukraine. The wooded area of the Ukraine's Transcarpathian region has recently been reduced by a half or even two-thirds of its former area.[7] Soil erosion leads to a decrease in the water-retaining capacity of both the vegetation and the soil and can partly explain why the flood waves now arrive much faster to the Hungarian Tisza River. Environmentalists also emphasized the continuing canalization of rivers as contributing to flooding in Hungary. This situation has been exacerbated by the construction of the levees, which adds to the narrowing of the riverbed, resulting in a further acceleration of its flow. The construction of levees upstream increases flood risks downstream.

Interviewees also pointed to institutional changes, particularly the impaired financial basis of the highly centralized water-management authorities after the political transition. Before 1990, the national water authority had a staff of 25,000 persons spread between Budapest and 12 regional branches. Today, the staff numbers about 4,000 persons. Nevertheless, some interviewees considered the organization of water management in Hungary as still fairly good. Others raised the issue of poor cooperation between the water authorities and the municipalities. This is particularly problematic with regard to standing-water issues, which require the cooperation of private landowners, municipalities, local water associations, and the national water authorities.

Although the lack of private, individual actions for flood prevention and response was considered a minor issue with regard to riverine floods, in the case of standing water it was often mentioned as a major factor of risk. Blocked water drains and clogged culverts were attributed to inappropriate maintenance resulting from the ignorance and negligence of landowners. As a result of land privatization, a new group of landowners has emerged who have little experience in preventing standing water.

Interestingly, few interviewees mentioned changed patterns in rainfall or changing climatic conditions as an important long-term contributing source to flood losses in the Tisza region. Although it was acknowledged that recent weather extremes have increased, this was viewed as within the normal variability. None of the respondents mentioned global climate change as leading to the increased incidence or severity of floods in this region.

3.2. The Consequences of Floods in the Upper Tisza Basin

According to most respondents, the most serious consequence of floods in the Upper Tisza Basin during the past years has been damage to agriculture, especially to the crops of arable lands. In three consecutive years since 1998, the subsistence farmers in this area suffered severe losses that depleted their reserves and resulted in considerable economic and social problems. In the longer run, floods and standing water lead to hardening of the soil, which makes it difficult to cultivate, further reducing the already low productivity of the affected areas. In the words of a local mayor (all interviews are anonymous):

> Due to the series of floods and draughts, the soil here becomes hard. Since this is a local problem, the authorities do not care and we do not get any compensation for this. What we receive is the average compensation given all through the country, although lands here are of lower quality, and we are at a greater risk. (Interview excerpt, June 14, 2000)

According to some interviewees, the most serious consequence of the floods is the difficulty in planning farming activities. Commercial insurance for crop risk is not available, even if the farmers could afford it.

As a consequence of the repeated flood disasters, many residents try to survive by diversifying their activities and starting businesses that are less sensitive to floods. They grow plums and walnut on the floodplains, process the crops (jam making), pursue home craft activities (traditional carpet weaving, embroidery), or use the floodplains as grazing land. However, most of the interviewees believe that due to the social, economic, and ecological factors—among others, the flood risks—the region is not suitable for supporting its current population.

Besides farming, another activity of increasing importance in this area is tourism. Since tourism is mainly a summer activity when water levels are low, floods and standing water have a less significant impact on tourism than they do on farming. On the other hand, water-quality problems have considerable consequences. The 2000 cyanide-contamination incident continues to stigmatize the area, resulting in significantly fewer summer tourists. Again, according to a local mayor:

> We take care of the health of the tourists, just like of our own health. However, this year they are not coming here. Many tourists cancel their reservations, and we see that most rooms will be empty. This is very sad because a number of people invested in improving their houses to host tourists. (Interview excerpt, June, 14, 2000)

3.3. Mitigation Strategies

The majority of the interviewees considered the strengthening and heightening of the existing levees as inevitable, even if only along certain sections of the river. They pointed out that if the construction program had taken place in the past few years, it would have cost largely the same as has been spent on flood-fighting efforts. Opinions differed, however, on whether to heighten the whole levee system, which was supported by most of the water-authority experts, or to pursue alternative solutions such as partially renaturalizing the floodplains and removing levees to create natural reservoirs, solutions supported by most of the mayors.

There was almost unanimous agreement on the value of reforestation in the catchment area, especially in the Ukraine, although there was a great deal of pessimism on how effective the government could be in this endeavor. A few stakeholders went so far as to propose that Hungary help finance reforestation in upstream Ukraine, which was also targeted for measures to improve the monitoring systems. There was widespread consensus on the value of constructing new reservoirs and, again, many considered the Ukraine as the more efficient location. Respondents cautioned, however, about the difficulty of controlling Ukrainian reservoirs, and several persons actually identified suitable areas in Hungary. There were also opponents, who considered the construction of reservoirs more expensive and less efficient than renaturalization of the floodplains.

The active stakeholders saw a large, but varied, role for the central government in preventing flood damage in the Upper Tisza area; however, this role did not extend to flood response measures. With a greatly reduced budget, the Water Management Authority now calls on local resources, including privately owned vehicles and equipment, to respond to threatening flood emergencies. The majority of the respondents approved of this switch to more private involvement and indicated that the recently increasing financial support (since 1998) of the water authorities has irritated the public in the region. According to an interview with a local mayor:

> Water management [in Hungary] does not work well, because the authorities do not really care. If they do not receive the funding they wish, they do not prepare properly, and if there is a problem, they say it happened because they had not received sufficient funding. Even if they receive money, they do not use it properly. They are not forced to do things efficiently, and they are not interested in doing so. (Interview excerpt, June 14, 2000)

This reliance on private citizens and property also extended to another prevention measure, the maintenance and reconstruction of the drainage systems. Because of the private, municipal, and state ownership of the systems, it was agreed that the situation calls for a coordinated program, possibly with a large role for the local water associations established by private landowners. In the words of a water-management official:

> The present problem with inland waters is due to the new owners' failure to loosen the lower soil. The soil has become plugged, and so it can't absorb the water from the downpours. In addition, the drains became plugged, and the canals full of mud. We have had certain things repaired where the problem was the greatest, but we didn't correct everything. The most neglected is the canal system of the land owners; somewhat better is that maintained by the local water associations, and the one belonging to the water management authority is quite good. But each works only if the others are in order . . . The land owners have duties, they are supposed to contribute to the maintenance of the drainage system, or they have to join the associations. (Interview excerpt, May 19, 1999)

This was reinforced in an interview with a representative of a local water association:

> We have inherited a system of inland water management that works well, but we didn't inherit the legal regulations to accompany it. Citizens who receive a land ownership right should also receive the duties that come with it, the duty of maintaining the drainage system. (Interview excerpt, May 19, 1999)

Although no blame was attributed to residents, businesses, and farmers in high-risk areas, everyone agreed on the importance of building restrictions within the endangered areas. Economic incentives were considered appropriate, and many suggested that government compensation of flood losses be withheld from those building without a permit. However, opinions were varied with regard to providing financial incentives for transferring people out of the inundated areas. Some expected that many people would move away anyway because of the manifold problems in the region. Others claimed that the local people are happy where they live and would not welcome the idea of leaving, even with financial support.

Economic incentives to promote individual measures were also considered appropriate for encouraging more flood-resilient livelihood strategies. However, due to the extended inundation in the areas affected by standing water, only the plantation of reed was proposed. Many emphasized the scarce resources of most local farmers, suggesting that the government help finance the costs of land-use changes with loans and subsidization. With the exception of the drainage systems and livelihood strategies, most interviewees attributed little responsibility for reducing flood losses to the local population and thus did not consider public information as being an essential tool in risk mitigation. A minority disagreed and proposed longer-term programs to raise public awareness of the risks and their mitigation, for example, the maintenance of the drainage systems, suitable zones for construction, and appropriate building methods.

Finally, a number of stakeholders took a more ecological view of the flood risk issue in the Upper Tisza region by proposing renaturalization of the floodplains and remediation of wetlands. Some even argued that "the land belonging to the river should be given back to the river." These interviewees proposed areas that might be reasonable to inundate in the case of high-water episodes. They also proposed areas where a drainage system, similar to the medieval canal system, could be established to ensure inundation of the wetlands and storage of water.

3.4. Compensation and Insurance

Throughout Hungary, there is extensive public relief to private victims of floods. The recent policy of the government has been to compensate victims for 100% of their losses if the cause of the flood is insufficiency of the levees, but for only 50% of their losses if the cause is not directly connected to the government's negligence in providing protection. Transfers also exist within the insurance system since premiums are not based on flood risks. Recently, these transfers have become controversial, as evidenced, for example, by the large press coverage of the curtailment of construction of the Budapest subway line in 1998. Moreover, with limited government resources, many view flood relief as reducing other types of government transfers. This has created conflicts between farmers and authorities, between municipalities and central government, the flood victims and the insurance companies, the affected and unaffected regions, and Budapest and the countryside. This resource competition is apparent from the following statement made by a local mayor.

> Many attack the county [Szabolcs-Szatmár-Bereg county in the Upper Tisza Basin] because it has received a lot of compensation. At the moment, the financial resources are so scarce that the government can only support a region at the disadvantage of others. . . . Now, everyone gets so little that no one is inclined to self-sacrifice. (Interview excerpt, May 21, 1999)

As would be expected from competition for scarce resources, the stakeholder views on the necessity, extent, and financing of victim relief after a major flood were divergent. Yet, none of the interviewees questioned victim relief and compensation from the central government following the 1998 and 1999 floods. This changed somewhat after the flooding of 2001, when the government compensated 100% of structural damages.[11]

The interviewees were also questioned with regard to the existing and potential role of flood insurance for municipal structures and private property. As mentioned earlier, about 40% of the property owners in the Upper Tisza region have private property insurance, but with limited coverage. In addition, all the mayors interviewed claimed to have flood insurance policies for local government buildings, although it is not possible to cover other infrastructure, such as roads, bridges, and pipelines. The reported experience with private insurers, however, was rather negative. Many commented on the reluctance and delays of the insurers to pay legitimate claims, and they viewed the limited coverage as a major problem. According to a mayor from the region:

> The insurance companies did not help, although had there been a levee breach, they would have paid a fortune. It would have been very nice of them to give even a small amount to the victims. (Interview excerpt, June 13, 2000)

A representative of an insurance company held a different opinion:

> We were very fair with our clients. While flood insurance does not cover seepage, we thoroughly investigated each case and compensated many victims on an individual basis. Our contracts issued before 1996 covered cases where water levels exceeded the level of the 100-year flood, but those issued after 1996 covered only cases of levee overtopping, where the concept of a levee includes the temporary sandbags as well. This is why many clients with pre-1996 contracts were compensated in spite of the lack of levee overtopping, while others with post-1996 contracts were not. (Interview excerpt, June 28, 2000)

In Hungary, there has been some discussion on requiring private and public flood insurance in high-risk areas. The mayors rejected a policy of mandatory flood insurance for all local government property, but other local stakeholders were more receptive with regard to private property insurance. Some argued that homeowners should take financial responsibility for their losses; however, many respondents rejected private responsibility and considered flood relief to be a citizen's right of protection.

With the government's interest in reducing its liabilities, it is not surprising that experts from the national authorities were more open to innovative ideas regarding the role of private insurance, as well as in favor of incentives for promoting more individual initiative to reduce flood losses. One interviewee at the county level proposed that private insurance be encouraged with economic incentives, for example, only those who buy insurance for insurable risks (e.g., overtopping of the levees) should be eligible for government compensation for uninsurable risks (e.g., standing water). National policymakers proposed other types of incentives, for example, that property insurance premiums be tax deductible or that subsidized catastrophe loans be offered to homeowners and companies for building safer buildings, for improving existing ones, or for moving to safer locations.

To share the risks of agricultural losses, some interviewees proposed the introduction of voluntary, mutual, nonprofit organizations. The proponents argued that the operation of mutuals would increase individual responsibility and reduce the involvement of the central government without the disadvantage of paying the administrative costs and profit of the private insurance companies. Such organizations already exist in Hungary, for example, self-insurance associations for agricultural risks, although flood- and standing-water losses are not covered. The problem is that these voluntary associations are financially very vulnerable and may become insolvent in the case of cumulative catastrophes. According to the interviewees, the system should involve the government as a reinsurer for such associations.

3.5. Strategies for Mitigation and Disaster Relief

This short discussion based on stakeholder interviews points to at least three different types of strategies the Hungarian policy community can take for reducing flood losses in the Upper Tisza region and for offering relief to the victims of floods. At one extreme, the Hungarian government can continue to absorb a large share of the costs of mitigation and public relief by continuing its investments in the levee program and its generous compensation of flood victims. This will likely lead to a worsening of the central government's budget deficit and encourage undesired development in the flood-prone areas. Even with these drawbacks, there was substantial support among the stakeholders for continuing investments in structural measures and significant scepticism about the ability of the local population to cope without central government protection.

Alternatively, the government can withdraw resources from this area and rely more strongly on market forces to encourage individual responsibility for reducing losses and for insuring against them. This would likely lead to increased diligence on the part of farmers and landowners, but also to an increased burden on an already vulnerable population and possibly to out-migration and the abandonment of some historic villages in the area. There was little support for a radical switch to individualized measures; yet many stakeholders recognized that private insurance could play a more important role.

Another policy strategy is oriented to the ecological preservation of the area and would include subsidized programs to help farmers change land-use practices, the renaturalization of the river by removing levees in some areas, and the provision of infrastructure for soft tourism. Insurance may be an option, but only by circumventing the commercial insurers with nonprofit mutual insurance arrangements. This should not preclude social solidarity in providing flood relief and compensation. Sceptics of this approach point out that these measures will not reduce the risks to already existing villages, may require relocation of villagers and farms, and will not solve the government's budgetary problem.

The interviews revealed that most of the respondents would prefer a mixed strategy, combining elements of each of these three strategies. Particularly among the local stakeholders, many were in favor of an ecological policy path, but only with continued involvement of the central government in providing protection and relief. The environmentalists also preferred the ecological approach, but with a surprising degree of support for market-based strategies, including the involvement of insurance companies. Only one mayor expressed explicit preference for a radical switch to a more market-based strategy.

4. THE PUBLIC SURVEY

Based on the stakeholder interviews, a questionnaire with face-to-face interviews was administered to 400 persons. The purpose of the questionnaire was to elicit views of the public on Hungary's options for reducing flood risks and providing relief to the victims. Four separate locations in Hungary were chosen in order to include stakeholders at risk to flood as well as stakeholders who subsidize those living in high-risk areas through their tax and insurance payments. Two of these areas are located along the Tisza River: the upstream, rural flood basin in the Upper Tisza catchment area and the downstream city of Szolnok (see Fig. 1). The other two areas are located in the west of Hungary and are exposed to little risk of flooding: a hilly region in Zala county and the city of Székesfehérvár in the Transdanubian region. The study thus included two high-risk and two low-risk, two rural and two urban areas. The sample size in each area was 100. Settlements in rural areas were chosen randomly, and the number of participants was determined according to population size. The sample was selected to be representative in terms of gender and age for each region.

The questionnaire contained 24 questions, of which nine could be answered with "yes," "no," "maybe," or "don't know." With the exception of one open question, the remaining 14 questions gave the respondent a list of possible options, which they ranked partially or fully in order of importance or relevance. They could also add options and comments. In the following, we report on selected results of the survey.

4.1. Causes and Consequences of Floods

Respondents were asked to choose the four most important causes of increasing flood losses in Hungary from a list of 11 options. Table I shows the most frequent answers, which included the improper maintenance of the levees, the clearing of large forest areas in the catchment area, and the insufficient height and strength of the levees. Almost half the interviewees implicated the neighboring countries and (contrary to the interviews) global climate change as among the main reasons for increasing flood losses. Significantly, the least important cause was attributed to the local people taking insufficient preventive measures or building in flood-risk areas. At the same time, one-third of the respondents blamed the authorities for having issued building permits in areas with high inundation risk. These results confirm the views of the key stakeholders that Hungarians tend to blame their government or neighboring countries for the country's escalating flood losses, and few appear to hold those living and working in the high-risk areas as contributing substantially to this escalation.

There were regional differences in these responses. Those living in the high-risk areas, and especially residents of the rural Upper Tisza region, attribute less blame to the Hungarian authorities for the insufficiency of the levees and for their failure to restrict building; they attribute more blame to ecological factors such as climate change and to deforestation in the upstream countries. The recent series of record-breaking water levels in this region may explain this response.

The second question asked respondents to rank the three most serious consequences of floods from a list of nine (to which they could add options). As shown in Table II, more than half the respondents considered the damages to homes, summer houses,

Table I. What Are the Main Causes of Increasing Flood Losses in Hungary?

	Chosen by (%)*
The water-management organizations have fewer resources	21
Due to global climate change, more intensive rainfalls and snowmelts are experienced more frequently	42
Levees are not sufficiently high and strong	57
Large forest areas have been cleared in the river basin	63
Authorities have issued building permits for	34
areas where the risk of inundation is high	34
Levees have not been properly maintained	73
Regulation and damming of rivers have changed the water runoff	20
Persons living in the area are not taking sufficient measures to prevent losses	8
Warning systems are not early enough	12
Neighboring countries do not take sufficient measures to reduce flooding downstream	46
Too many people have chosen to build and live in flood risk areas	10

*Respondents were asked to choose four.

Table II. What Are the Most Serious Negative Consequences of Floods in Hungary?

	Chosen by (%)*
Homes, summer houses, and property are damaged	58
Farming activities become impossible	45
People are distressed and often become ill	45
Roads, utilities, and public buildings are damaged	40
Pollution is spread by flood waters	37
The ecosystem becomes unbalanced	31
The income from farming activities becomes highly uncertain	25
Property values decrease in the endangered areas	12
Tourism is decreased	4

*Respondents were asked to choose four.

and other property as the most serious consequences. Somewhat fewer respondents emphasized the disablement of farming activities and the distress of the flood victims, and the least frequent responses included the decrease in tourism and the decrease in property values.

Residents of the Upper Tisza region gave significantly more emphasis to damages to houses and summer homes (78%), impacts on the health of victims (58%), and disablement of farming activities (56%) than did respondents in the other three regions. Those living in the two rural areas attributed more significance to the contamination of the inundated areas (37% and 46% in the Upper Tisza and the Zala region, respectively), while those living in the urban centers gave more emphasis to damages to public buildings and roads (53% and 50% in Szolnok and Székesfehérvár, respectively) and the resulting imbalance of the ecosystem (44% and 38%, respectively).

4.2. Mitigation Strategies

When asked whether anything can be done to reduce flood losses, only 9% of the respondents responded negatively. Table III shows the most frequent answers to the question of what measures would be most effective in reducing flood losses (a maximum of three measures could be selected from a list of 11). Consistent with the first question, the most frequently selected measures included heightening and strengthening the existing levees and reforestation in the catchment area. Maintenance and reconstruction of the drainage systems, as well as preventing construction in high-risk areas, were selected at a lower frequency. Twenty-one percent of the respondents considered the removal of selected levees as an important mitigation measure, which is significant considering that this measure is a radical departure from the traditional policy of protecting the settlements with levees. Lower rankings were given to other alternative measures, such as informing the public, financial incentives to encourage inhabitants to migrate out of high-risk areas, introducing alternative agricultural practices, renaturalization of parts of the river, and support of the water-management authorities.

Table III. What Measures Do You Think Would Be Most Effective for Reducing Flood Losses in Hungary?

	Chosen by (%)*
Heightening and strengthening the existing levees	74
Reforestation	61
Maintenance of the drainage systems	45
Preventing construction in high-risk areas	27
Removing levees to increase catchment areas	21
Development of forecasting and warning systems	21
Provision of more resources to water-management authorities	16
Financial support for transferring people out of high-risk areas	14
Informing the public about flood risks and their mitigation	10
Introducing appropriate agricultural activities	9
Renaturalization of parts of the river	6

*Respondents were asked to choose four.

The regional distribution of the first ranked mitigation measures is shown in Fig. 2. The rankings show little regional deviation with regard to the most popular mitigation measure of improving the levees, but there is more deviation regarding other measures. Reforestation is particularly emphasized in the settlements along the Tisza River, both in the Upper Tisza region and in Szolnok, whereas removal of selected levees to increase the floodplain is, not surprisingly, most emphasized in downstream Szolnok. It is also not surprising that persons living in areas less affected by floods prefer zoning restrictions on building in floodplains and stricter controls on individual behavior.

The respondents were asked to give their opinion on who should take the most responsibility for reducing flood losses. The responses strongly indicate that the public stakeholders believe that responsibility should be mainly in the hands of the central government rather than in the hands of property owners living in high-risk areas. The central government was ranked in first or second place (of four alternatives) by 92% of the respondents, the neighboring countries by 51% of the respondents, the municipalities by 49%, and the property owners by only 10% of the respondents. Although respondents from all sample regions consider the role of the central government as the most important, significantly fewer in the Upper Tisza region ranked the central government as carrying most responsibility, and significantly more respondents in this region ranked the upstream countries as being mainly responsible. The role of the municipalities and the property owners is considered somewhat more important in the cities (Szolnok and Székesfehérvár) than in the rural regions, perhaps because of the extreme financial problems facing smaller communities.

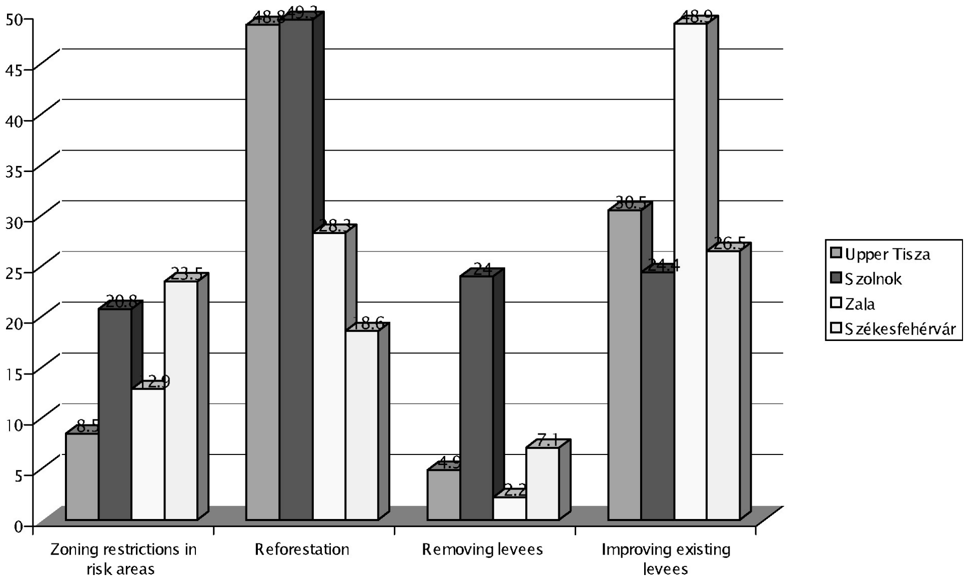

Fig. 2. Respondents' views on reducing flood losses by region.

Given the strong stakeholder perception that flood problems in the Upper Tisza region are greatly aggravated by deforestation and other practices in upstream Ukraine and Romania, a question of how these countries would finance mitigation measures was included. Interestingly, as shown in Table IV, 80% of the respondents thought that Hungary should help finance flood protection investments in the upstream countries. This might include, for example, the construction of levees in Romania and the Ukraine. This support was somewhat stronger in rural areas.

4.3. Compensation and Risk Sharing

As shown in Table V, a large majority of the respondents would fully or partially support Hungary's generous public compensation system on the grounds of social solidarity. At the same time, switching to more individual responsibility was also fully or partially supported by an equally large majority of the respondents. Indeed, later questions on the form of relief systems show a great deal of support for a joint public-private insurance system for Hungary. A community based mutual insurance system was somewhat less popular, but even this option received full or partial support from 80% of the respondents.

Table IV. To What Extent Should the Hungarian Government Pay for Risk-Reducing Investments in Upstream Countries?

	Upper Tisza	Szolnok	Zala	Székesfehérvár	Total
Fully (%)	32	35	35	45	37
Partly (%)	45	44	43	38	43
Rather not (%)	7	19	13	17	14
Do not know (%)	16	2	9	0	6

There are major differences on this issue between the regions. Not surprisingly, as shown in Fig. 3, governmental compensation based on solidarity has more sympathy in the higher-risk Upper Tisza and Szolnok regions, whereas a system based on individual responsibility and private insurance receives a more sympathetic view in the less affected regions and in the cities. Although persons not exposed to flood risks appear less enthusiastic about helping those in risk areas with their tax contributions, there is still an astonishing degree of support across the regions. In a later question, we see that this solidarity appears to stem from the view that the Hungarian government is at fault when private persons suffer flood losses. Moreover, the survey confirmed statements made by the active stakeholders that there is a great deal of suspicion of commercial insurance companies, which may explain the apparent popularity of mutual insurance pools across all the regions (Fig. 3). The respondents were also queried about who should receive compensation and to what extent. Table VI shows that the majority of the respondents agree on a system in which all victims would be compensated in proportion to their

Table V. Government Compensation, Insurance, and Pooling

To what extent do you agree with the following statements?	Fully Agree%	Partly Agree%	Disagree%	Do Not Know%
Social solidarity requires that government compensate flood victims for damages that occur to their homes and livelihood	48	41	7	4
Everybody should take more responsibility for flood risks and those who can afford it should purchase private insurance	40	50	6	4
Locals should pull together and create a fund that could help flood victims in case of a disaster	37	43	14	6
It does not matter what you do, flood victims will lose a lot	7	29	51	13

losses. Significantly fewer respondents would approve a system of equal compensation to everyone, and 14% would approve a system of compensating only those who have built their homes with permits. An even lower number of respondents would make compensation contingent on other conditions, such as low incomes of the recipients or their insurance coverage, and only very few would not provide compensation at all. It is remarkable that approximately 75% of the respondents agree that the government should compensate every victim regardless of the victim's economic circumstances or role in preventing losses.

Considering Hungary's history of government protection against flooding, it is not surprising that about half (51%) of the respondents justify relief to flood victims on the grounds that flood protection is the *responsibility* of the government and thus flooding is the fault of the government. About one-quarter of the respondents (26%) justified victim relief on the grounds that the government has always provided compensation, and only 19% justified financial support to the victims on the solidarity principle. Among the cons, 34% of the respondents thought that compensation is too costly for the taxpayers, 23% thought that compensation often goes to the wealthy, and 22% were concerned that compensation discourages people from purchasing insurance.

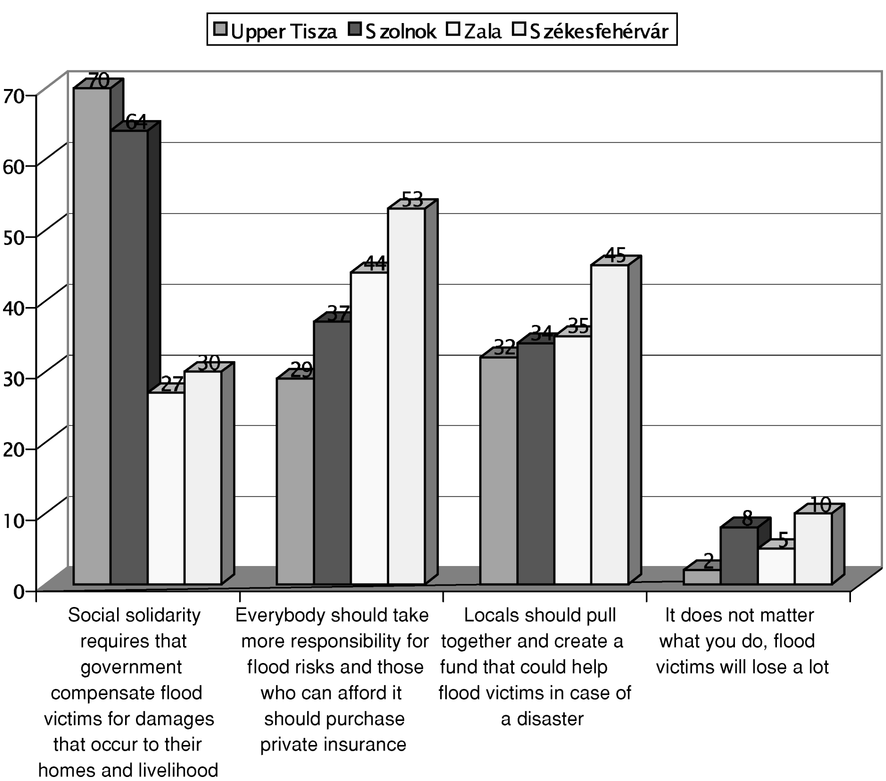

Fig. 3. Respondents' views on risk sharing by region.

Table VI. Forms of Government Compensation to Flood Victims

After a major flood, the Hungarian government should compensate . . .	Chosen by (%)
All victims by a certain percentage of their losses	57
All victims by the same amount, above which they can choose to have insurance	19
Only needy victims, that is, not owners of vacation homes or well-to-do businesses	7
Only victims with flood insurance	3
Only victims who have not built their homes in high-risk areas without a permit	4
Nobody	0

Turning to incentives for private mitigation, it can be recalled that most respondents thought that flood victims could do little to protect themselves. Even so, another question showed that 65% of the respondents were of the opinion that households, businesses, and communities can be encouraged to take measures to reduce flood losses, but mainly by not building in high-risk zones. The differences between the regions are high. For example, in the low-risk communities of Zala, 83% of the respondents were of this opinion compared to only 45% in the high-risk Upper Tisza region. As shown in Table VII, most respondents saw a top-down approach as most effective, for example, the authorities not issuing building permits in high-risk zones. Around half of the respondents would agree on the government compensating only those who have taken the necessary measures to reduce flood losses, and about one-third would support lowered insurance premiums to reward private loss-reduction measures. Significantly fewer respondents consider incentives such as a reduction of government compensation or an increase in insurance premiums in high-risk areas as desirable.

Table VII. How Should Households, Businesses, and Communities Be Encouraged to Reduce Flood Losses?

	Chosen by (%)
The local authorities should pass zoning regulations and strictly enforce them	80
The central government should make compensation after a flood contingent on loss-reducing measures before the flood	53
Insurance companies should offer lower premiums to households, businesses, and communities that have taken prespecified loss-reducing measures	39
Insurance companies should raise premiums of those living in high-risk areas to encourage people to leave and discourage people building their homes in these areas	14
The central government should compensate far less of the losses from a flood	4

It can be recalled from the interviews that there is a great deal of support for protecting villages from life-threatening floods, although in some cases it may be cost effective to encourage, by decree or financial incentives, the relocation of residents and even whole villages out of very high-risk areas. In a question addressing this alternative, approximately two-thirds of the respondents opposed relocation and were of the opinion that every settlement at risk should be protected at any cost. However, the support came mainly from the Upper Tisza area, where this opinion was held by 93% of the respondents. In the safe Zala region, alternatively, only 42% were of this opinion, and in downstream Szolnok, 32% of the respondents supported financial aid to help high-risk communities move to nearby, safer areas. Only 3% of the Upper Tisza respondents found this policy attractive.

4.4. Insurance

Although a large majority of respondents are fully or partially in favor of continuing Hungary's generous public compensation system to flood victims, it can be recalled from Table V that a majority of interviewees were at the same time in favor of more individual responsibility. Exploring this issue further, as shown in Fig. 4, over 60% of the sampled persons (but fewer in the Upper Tisza region) thought it desirable that property owners have insurance against flood losses, and only about half as many (but higher in the Upper Tisza region) shared this opinion on the condition that low-income individuals receive public assistance in purchasing insurance. Of those holding these opinions, 41% reportedly did so because insurance could reduce government compensation to the

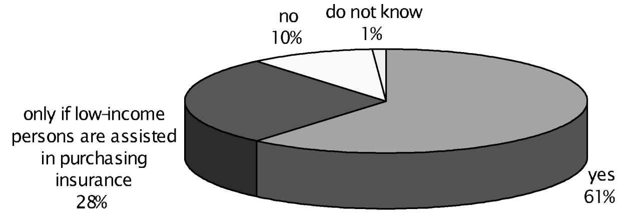

Fig. 4. Respondents' views on the question of whether property owners should insure themselves against flood damage.

victims and 25% because private insurance companies might assist governments in building flood defenses. Only a small proportion of the interviewees justified their opinion on fairness or efficiency grounds, that is, that property owners should take more responsibility or that risk-dependent premiums would provide incentives for loss mitigation. Although private insurance was viewed for the most part as desirable, only about one-third of the respondents thought it should be mandatory and another third thought it should be conditional on assistance to low-income persons.

The cross-subsidization of insurance premiums, not surprisingly, received far more support from the two high-risk areas (65% and 38% in the Upper Tisza region and Szolnok, respectively). However, considering that this practice is contrary to the economic interests of premium payers in low-risk areas, it is remarkable that 24 and 31% of respondents in Zala and Székesfehérvár, respectively, were supportive of cross-subsidization. Again, social solidarity appears to play an important role in the attitudes of many Hungarians.

Turning to the question of financing losses to public infrastructure, almost half the respondents (45%) would not stray from the present practice of restoring infrastructure damage at the expense of the Hungarian taxpayer. Still, one-third of the respondents (32%) would support the idea of municipalities purchasing insurance (it can be recalled that many mayors in the Upper Tisza region carry limited insurance on public structures). Putting the burden on local taxpayers or putting it on future taxpayers by taking loans are considerably less popular measures.

The stakeholder interviews, combined with information on the policy discourse, revealed a number of possible options for a Hungarian flood-insurance system. Four (incomplete) options were presented to the questionnaire respondents, who were asked to choose the one they preferred or to suggest an alternative. The responses are shown below (10% of the respondents had no opinion).

- All property owners must purchase private flood insurance, and the private companies are required to cover all flood risks at the same premium regardless of risk (14% of the respondents chose this option).
- All flood victims receive a fixed and equal amount of compensation from the government, regardless of the extent of their damage. To cover losses above this amount, property owners and businesses can voluntarily purchase private insurance (50% of the respondents chose this option).
- All households, farms, and businesses can voluntarily purchase flood insurance covering all types of floods from the government (15% of the respondents chose this option).
- Households, businesses, or farms form a mutual insurance pool (11% of the respondents chose this option).

Mandatory flood insurance was more preferred in high-risk regions, whereas voluntary local associations were more preferred in low-risk areas. The possibility for purchasing flood insurance from the government is preferred mostly by urban respondents, whereas the public-private insurance system is more preferred in rural regions. Although there are regional differences, it is interesting that half the respondents support a mixed public-private system of victim relief. This is consistent with earlier results indicating that many Hungarians regard government compensation and private insurance as complementary.

5. CONCLUSIONS

This study elicited views from stakeholders active in the policy process and from the public on developing a flood risk management program for Hungary, and particularly for the Upper Tisza region. From an initial set of stakeholder interviews, three scenarios or policy paths emerged: a business-as-usual path characterized by central government authority and responsibility; a market path characterized by individual responsibility; and an ecological path characterized by fewer structural interventions and more reliance on local initiatives. This study showed the strongest support for the traditional, business-as-usual role of the central government; however, there was also strong support for complementing this path with more individual initiative, and more limited support for the ecological policy alternatives. Considering the long-standing tradition of the central government providing comprehensive flood protection throughout Hungary's extensive floodplains, the strong minority views supporting more individual initiative and ecological alternatives are noteworthy and policy-relevant in light of the government's intent to reduce its budget deficit as a condition for European Union membership.

Taking a business-as-usual path, the Hungarian government can continue to absorb a large share of the costs of mitigation measures and public relief/reconstruction by persisting with its investments in structural flood-mitigating programs and its generous relief to flood victims. This will protect vulnerable villages like those in the Upper Tisza and allow farming to continue in the floodplains; however, it will also lead to a worsening of the central government's budget deficit, encourage undesired development in the flood-prone areas, and increase flood risks downstream. Despite the drawbacks, there was strong stakeholder support for this policy path. The most preferred mitigation measures included structural interventions, for example, strengthening and heightening the levees, constructing new reservoirs, and improving the monitoring system. Although the public survey respondents also put a great deal of emphasis on ecological issues, such as deforestation, the continuation of central government interventions was hardly questioned. The emphasis on central government responsibility also dominated opinions on government compensation of flood victims, which most stakeholders viewed as highly desirable. Social solidarity for flood victims, even those with sufficient economic means and those who have illegally located in flood-risk zones, was strikingly apparent. The justification for this solidarity was attributed largely to the fault of the government in not protecting the victims from the flood event.

Alternatively, the government can withdraw resources from flood protection and relief and rely more strongly on market forces to encourage individual responsibility for reducing losses and for insuring against them. This would likely lead to increased diligence on the part of households, farmers, and landowners, and also to an increased burden on an already vulnerable population, forcing more out-migration and possibly the abandonment of some historic villages in the area. Most interviewees and questionnaire respondents rejected this radical shift to individual responsibility, but many did support important measures in this direction. Except for the view that landowners and communities should take more responsibility for the problem of standing water, there was little notion of individual loss-reduction measures and, more remarkably, little acknowledgment that public information could be useful. At the same time, a majority of respondents, and a strong majority in low-risk areas, saw a role for the government in zoning regulations to restrict construction in the vulnerable regions. However, this did not go so far as supporting the relocation of residents out of repeatedly flooded villages. A majority of respondents, regardless of their risks, held the opinion that all high-risk settlements should be protected regardless of the costs.

There was cautious support for voluntary private insurance, and one of the most important results of this study from a policy perspective was the widespread support of a mixed public-private system for flood relief and reconstruction. Particularly those in the Upper Tisza region, but also remarkably many respondents facing no flood risks, held the opinion that the government should compensate all victims regardless of their individual circumstances and regardless of the precautions they had taken. Importantly, most would combine government compensation with private insurance and/or community self-insurance schemes.

A third policy strategy is oriented to sustainable development and the ecological preservation of Hungary's floodplains with subsidized programs for helping farmers change land-use practices, renaturalizing the river by removing levees in some areas, reforestation, and providing infrastructure for soft tourism. Many in the Upper Tisza region favored this strategy but with little acknowledgment that it may require relocation of villagers and farms and that it will not in the short term solve the government's budgetary problem. Some elements of this strategy, particularly reforestation, were attractive across regions, but other elements were less popular, for example, removing levees and renaturalizing the river. However, this later strategy became significantly more salient for key policymakers following the most recent flood incident. In 1998, flood waters came within millimeters of topping the levees, causing many to appreciate the marginal benefit of allowing the river to flood some areas. From a policy perspective, the new popularity of removing levees in selected areas is another important result of this study.

The public survey indicated that a flood risk management strategy in Hungary will likely not gain widespread support from the active and public stakeholders unless it combines elements of the business-as-usual, market-based, and ecological policy paths. Indeed, the importance of a combination of these strategies was evidenced by the widespread view that increasing flood losses can be attributed to the insufficient development of flood defense facilities, inappropriate land-use practices in the catchment area, and the ecological imbalance. Moreover, a mixed public-private system for the provision of victim relief and reconstruction, which combines taxpayer support with private insurance, was overwhelmingly supported. These insights have formed the basis for developing policy scenarios as input to a catastrophe model of the region. The simulated policy paths will be presented to participants of an upcoming stakeholder workshop on flood risk management for the Upper Tisza region.

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Infrastructure in Developing and Transition Countries: Risk and Protection

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This article examines two possible strategies for financing post-disaster infrastructure rehabilitation in developing and transition countries: relying on *ex ante* financing instruments (including insurance, catastrophe bonds, and other risk-transfer instruments) and *ex post* borrowing or credit. Insurance and other *ex ante* instruments will increase a country's stability, especially if the government authorities have a difficult time borrowing or otherwise raising funds after a major disaster; however, these instruments have an opportunity cost and can reduce the country's economic growth potential. The cost-benefit tradeoff is therefore one between economic growth through infrastructure investment and added solvency and stability for the economy. This article develops a model to illustrate this tradeoff. The model, which views the infrastructure of a developing or transition country as a nondiversifiable portfolio that generates returns, can provide a basis for evaluating alternative financing options depending on the country's objectives in terms of growth, solvency, and stability.

KEY WORDS: Natural catastrophes; infrastructure protection; risk management

1. INTRODUCTION

With increasing frequency, natural disasters are destroying infrastructure essential to economic development in developing and transition countries. As described by Munich Re,(1,2) in comparison to the decade of the 1960s, the frequency of severe natural catastrophes has increased by a factor of three and the direct economic costs have increased by a factor of nine. Although the direct damages of approximately $70 billion a year from natural disasters seem evenly split between the developed and developing (including transition) countries, the per capita impact on the developing or transition countries is nearly 20 times as great as in the developed world.

Concern about these costs has generated considerable activity in the international development community. The United Nations declared the 1990s the International Decade of Natural Disaster Reduction. The World bank created the Disaster Management Facility to direct the bank's responses to disaster losses. Each of these organizations has spawned a series of activities focused on natural disasters and developing and transition countries.

In most countries, reconstruction of damaged infrastructure is financed by post-event measures. These measures usually include increased borrowing or diversion of existing budgeted funds to finance reconstruction. The World Bank has provided $14 billion in post-natural-disaster reconstruction financing during the past 20 years.(3) This is nearly 250% of the amount provided for reconstruction work following civil disturbances.

During the past decade, the scientific understanding of the causes and consequences of natural catastrophes has dramatically improved. Models to

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estimate the frequency and severity of catastrophic events have been coupled with techniques to measure the vulnerability of capital stock to catastrophe losses. This has not only improved the probability estimates of natural catastrophes, but also of the potential consequences of these events. Although sophisticated modeling of both the nature and costs of natural catastrophes exists for developed countries, little reliable data on the risks of natural catastrophes has been developed for developing and transition countries. Further, in the developed world, the tool used for complex financial planning to absorb the costs of catastrophes is modeling. Today, insurance absorbs more than half of the economic losses from natural catastrophes in the developed world. Also, the use of catastrophe-insurance-related tools has been increasing significantly in recent years. In contrast, less than 2% of losses from natural disasters are insured in the developing world.

Ex ante financial planning for natural disaster reconstruction financing does not practically take place today as a result of a wide-ranging number of factors. Among those is the lack of theory to support *ex ante* risk transfer for a country. This article develops a theory for countries based on the behavior characteristics of insurance companies. The premise is simple. Developing countries own a portfolio of assets necessary to sustain economic growth. Among those assets is publicly owned infrastructure. From these assets, an expected annual return is anticipated. The assets are in geographically defined regions and subject to loss from natural disaster events. This loss between assets is a correlated loss. Assuming that *solvency* and *stability* are the objective of the policymakers, *ex ante* risk transfer is more efficient than *ex post* reconstruction financing. Solvency is the ability to meet all payment obligations within the observation period. Although countries do not go bankrupt, insolvency causes turmoil and should be avoided. Stability refers to a predictable growth path without ups and downs of the economic development, expressed, for example, in GDP (see Section 4.1).

The article proceeds along the following path. Section 2 describes a developing or transition country's portfolio of infrastructure assets. The section draws a parallel between the portfolio of infrastructure assets owned by a developing or transition country and the portfolio of insurance policies owned by a geographically constrained insurance company. It suggests that a country may benefit from reducing the variance of its portfolio through risk transfer, just like a small insurance company. Section 3 outlines the risk of loss to the portfolio described in Section 2. Section 4 describes a model to measure the benefit of risk transfer for the infrastructure portfolio. Section 4.1 posits two objectives, solvency and stability, to evaluate the optimum behavior of a developing or transition country. These two constraints are those classically imposed to evaluate risk transfer decision processes. Section 5 reports the simulation results. Finally, Section 6 draws policy conclusions. The Appendix details the mathematical specifications for the model and the impact of correlated risk on a portfolio of assets.

2. THE PORTFOLIO OF PUBLIC INFRASTRUCTURE

In what follows we compare the benefits of risk transfer versus *ex post* reconstruction financing for developing and transition countries. A useful starting place is to examine why private entities in the developed world engage in risk transfer for catastrophes. The answer to this problem lies in understanding the distinctive nature of catastrophic risk.

Catastrophic risk is typified by its low frequency and high severity. The high severity of damage results from the correlation of damages in a geographically defined region. If an earthquake occurs, it will generally cause damage to all property within its proximity. Floods and windstorms have similar characteristics: they tend to cause damage to most property within a geographically defined region. For insurance companies, this causes a particularly difficult problem. Because of the law of large numbers, insurance works best for frequent independent risks with relatively small damage per event.[4] Geographically constrained insurance companies cannot reduce the risk in their portfolio of insurance policies by adding more policies, which would be the outcome if the law of large numbers worked to their benefit. Rather, they reduce the risk of their portfolio of insurance policies by purchasing reinsurance that acts as a hedge for their accumulated portfolio risk. In fact, the biggest purchasers of catastrophe reinsurance in relationship to their capital base are smaller capitalized, geographically constrained insurers.[5]

This behavior of the small, geographically constrained insurance companies is consistent with portfolio theory of risk spreading. The theory would advise the insurance company to reduce the variance of the risk of its portfolio by adding negatively correlated risk to its portfolio. By so doing, it reduces the variance of its whole portfolio. This article will explore these phenomena in more detail later.

Can we learn anything from this behavior of small insurance companies that may be helpful in addressing the desirability of risk transfer for developing and transition countries? This article argues that governments of developing and transition countries "own" a portfolio of risk with peculiar characteristics that may benefit from risk transfer.

3. THE RISK OF INFRASTRUCTURE LOSS

Most developing and transition country governments own a large portion of the infrastructure needed for their development.[(3)] Depending on the size of the country, its exposure to natural hazard loss, and its stock of infrastructure, losses from natural hazards impacting the country can cause significant loss to the infrastructure stock. Annually, approximately U.S. $20 billion of infrastructure is lost from natural catastrophic events.[(6)] Since a catastrophe could impact a significant portion of the infrastructure within a country, the losses to the infrastructure are correlated. In this sense, a geographically constrained country is similar to a small, geographically limited insurance company. Is there a portfolio strategy available that will reduce its exposure?

The portfolio of loss to the infrastructure of a developing or transition country has some distinctive characteristics. The portfolio consists of fixed assets. Once in place, infrastructure, like most real property assets, tends to be permanent. The investment in the infrastructure is presumed to have a fixed rate of return over the life of the asset. The rate of return is generally based on a cost-benefit analysis made at the time of the original investment decision. The World Bank estimates the infrastructure projects for which it has provided financing have annually earned on average 17% of the cost of the project.[(3)] The infrastructure is exposed to damage loss, either from natural disasters, civil disruption, or lack of proper maintenance. Portfolio theory generally applies where the total amount available for investment is known, but the rate of return on the assets is unknown. Portfolio theory explains how to maximize the rate of return within defined constraints. The primary planning tool is changing the individual assets owned in the portfolio. With a portfolio composed of correlated assets, maximizing return at reduced risk is aided by adding to the portfolio assets with return characteristics that are not correlated to the return characteristics of the existing portfolio.

The portfolio strategy to deal with the risk of loss of the infrastructure of a developing or transition country is different. This portfolio consists of a set of assets that are expected to create a predetermined rate of return. The risk is in the loss of the asset base through damage by natural catastrophe. The asset base is geographically fixed. The risk of loss from natural catastrophes is correlated both temporally and spatially, as subsequent sections of the article will detail. The portfolio strategy is aimed at reducing the risk of loss from natural catastrophes to infrastructure and preserving the expected return from the infrastructure investment.

4. DESIGN OF THE MODEL

For purposes of this article, we assume a country with an initial infrastructure base of 100. The infrastructure depreciates over a 30-year period. Annually, the country has the ability to borrow an amount equal to 10% of its existing infrastructure base. This assumption captures the ability of a country, based on existing economic performance, to increase external borrowing related to infrastructure. The additional borrowing can be used for one of three purposes: add new infrastructure, replace damaged infrastructure lost through natural catastrophic events, or purchase risk-transfer protection for the existing infrastructure. This assumption is based on existing experience with developing and transition countries and how they finance losses from natural catastrophes. Some studies suggest that a portion of new loans for developing countries are made to replace lost infrastructure, and that previously approved loans are diverted to pay for losses.[(7)] Generally, the new and diverted credits are structured to remain within a perceived borrowing limit for a country based on its existing economic performance. We arbitrarily assume that the perceived borrowing limit for infrastructure purposes is 10% of the existing level of infrastructure.

The assumed interest rate for all borrowing is 8%, which is a blended rate of the average of 17% now paid by developing countries on commercially issued sovereign debt and the much lower concessional interest rate on borrowing for developing and transition countries from international development banks. Deutsche Bank estimates that the blended rate for developing countries for all borrowing is 8–9%.[(8)] Principal and interest on all borrowing is amortized over a 10-year period. It is assumed that the rate of return on the infrastructure investment is 15%, whether existing or new infrastructure. This is slightly lower than the average return of 17% returned on existing World Bank infrastructure projects. It is assumed that the infrastructure is subject to risk of loss of 25% of total infrastructure once every 25 years (a 4% event). It is assumed that risk transfer to cover a full 25% loss of infrastructure can be purchased at a rate equal to 1.25% of the infrastructure. This rate represents the risk rate of 1% (equivalent to the event likelihood multiplied by the size) and an expected return to the professional risk taker equivalent 25% of the risk rate. Under current pricing for catastrophe risk transfer, this rate would be very high.[(9)]

With these assumptions in mind, we propose the following structure of a model to address policy options to deal with the cost of catastrophes.

1. The total value of the infrastructure owned by the government in the country under consideration in year t is *I(t)*. Infrastructure depreciates at a rate of d. A catastrophic event may destroy the fraction $\delta(t)$ of infrastructure, where δ is a random variable.
2. The strategy of the government is to take every year 100 w% of the previous year's value of infrastructure as loans. This amount is invested in infrastructure.
3. The loans have to be paid back with fixed annuities within 10 years and interest rate of q.
4. The yearly return *R(t)* is 100 v% of the value of the infrastructure.
5. The government may purchase an insurance that covers damages up to 100 δ_{max}% of the infrastructure in year t. The risk premium is γ. If the infrastructure is insured, then damages up to 100 δ_{max} of the infrastructure value are fully insured. If the damage exceeds this threshold, only the insured part (that is exactly 100 δ_{max} of the infrastructure value) is reconstructed.

4.1. Solvency and Stability

Why should the government prefer insurance over *ex post* financing? As we will argue and illustrate in a numeric example, insurance increases two desired properties of the economic development path: solvency and stability.

Solvency is the ability to fulfill payment obligations. We propose *probability to be able to fulfill the payment obligations within the considered period* as a measure of solvency risk.

Stability refers to the property of constant growth. An economy that grows steadily at a predictable rate is more attractive to foreign investors than an economy that grows at the same rate but for which the growth values fluctuate and exhibit negative growth in some years.

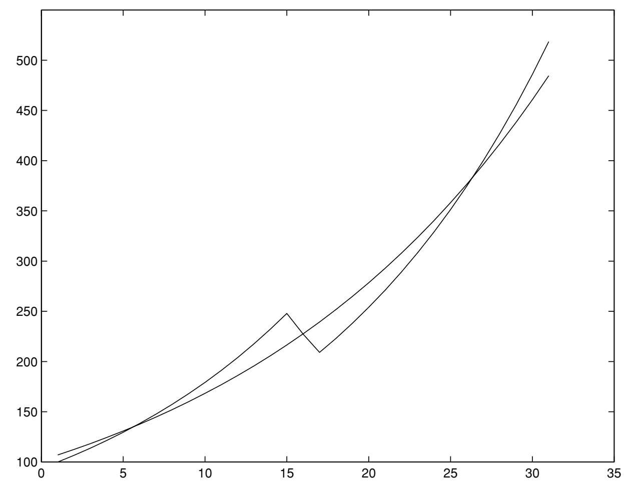

Fig. 1. An unstable path and its nearest stable path.

We measure the instability of an economy by an *instability index*, which is defined as follows: if *G(t)* is a path of an economic quantity, like GNP, tax revenue, or net income, let $\tilde{G}(t)$ be the path that is closest to *G(t)* and has constant growth. To be more precise we define:

$$\tilde{G}(t) = \exp(a + bt),$$

where the constants a and b are chosen such that the distance

$$\sum_{t=1}^{T} [\log G(t) - \log \tilde{G}(t)]^2 \qquad (1)$$

is minimized. To put it differently, $\log \tilde{G}(\cdot)$ is the linear regression line associated to the data $(t, \log G(t))$, $t = 1, \ldots, T$. We call the minimal value in Equation (1) the *instability index* of $G(\cdot)$. Notice that the instability index is zero if the path *G(t)* has constant growth. It increases with the fluctuations of the growth values $\frac{G(t+1)-G(t)}{G(t)}$ of the path.

As an illustration Fig. 1 shows an unstable path and its nearest stable (= constant growth path). The instability index of this path is the (squared) distance between the two curves.

5. THE SIMULATION RESULTS

The model described above and specified in detail in the Appendix was simulated for 30 years using 1,000 random trajectories.

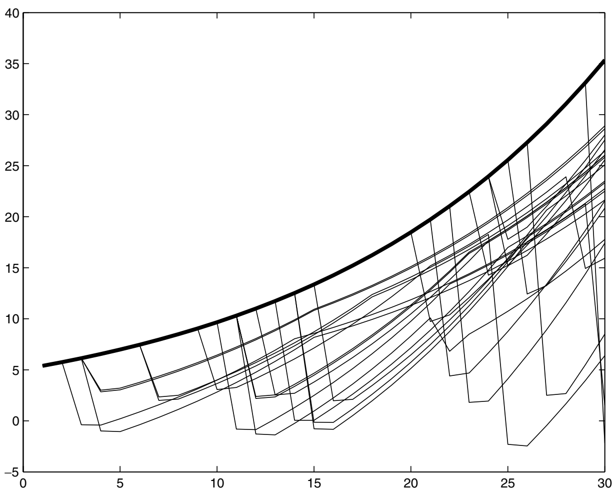

Fig. 2. Thirty typical paths of the profit $R(t) - O(t)$ over 30 years with no insurance. The thick line represents the nominal path (no event path).

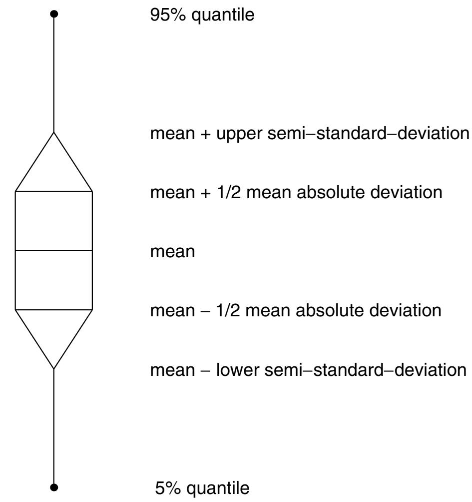

Fig. 4. Visualization of random distributions using a box plot.

Denoting the returns from infrastructure generated in year t as $R(t)$ and the payments for annuities and insurance as $O(t)$ the net profits are $R(t) - O(t)$.

Figs. 2 and 3 show an important tradeoff with insurance: stability and solvency are increased but at the price of a slightly lower mean growth. These figures demonstrate typical sample paths, but not how likely these paths are. To gain an insight on the probabilistic structure, we have plotted the probability distribution of net profit for Year 15 (see Fig. 5). To visualize selected parameters of the probability distribution, we use a box plot with specifications as set out in Fig. 4.

Fig. 5 shows that with insurance the probability distribution of the net profit becomes more concentrated: the extremes (high and very low profit) disappear and the range of possible values becomes smaller. To put it differently, insurance makes the profit more predictable.

We also calculated the solvency and instability index for this example. Recall that solvency is defined

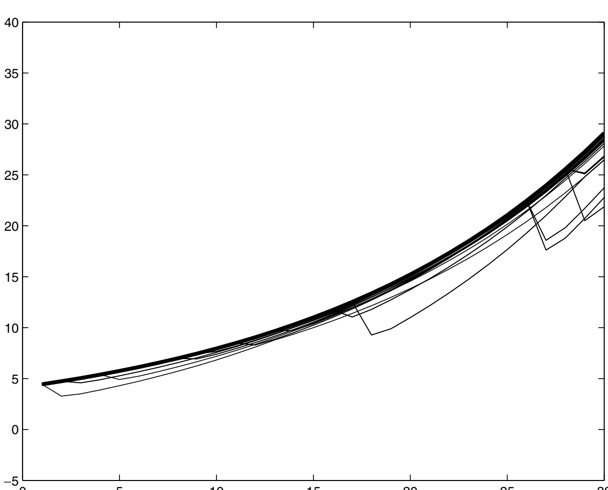

Fig. 3. Thirty typical paths of the profit $R(t) - O(t)$ over 30 years with insurance. The thick line represents the nominal path (no event path).

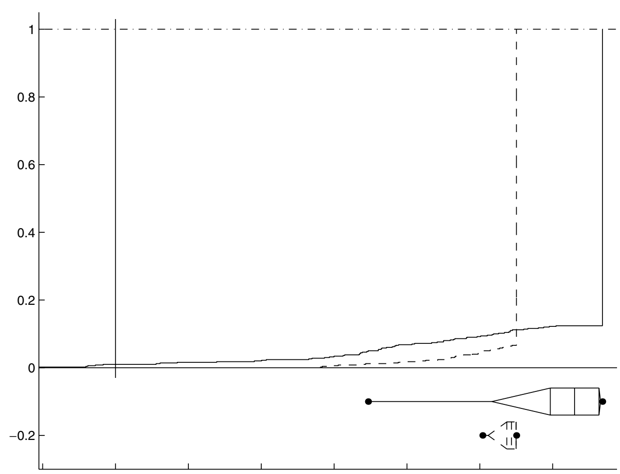

Fig. 5. The probability distributions of profit in Year 15 without insurance (solid line) and with insurance (dashed line), and box plots. The box plots at the bottom visualize the characteristics of the distributions.

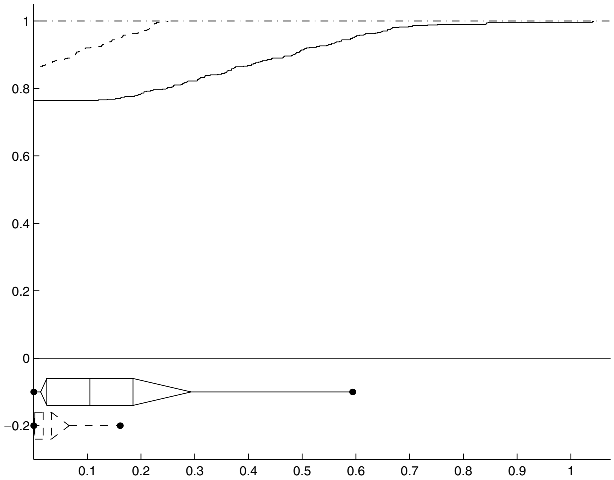

Fig. 6. The distribution of the instability index without insurance (solid line) and with insurance (dashed line), and box plots. The box plots at the bottom visualize the characteristics of the distributions.

as the probability that all financial obligations can be fulfilled within the 30 years period.

	No Insurance	With Insurance
Solvency	94.5%	100.0%

The instability index (see Section 4.1) varies from path to path. We show in Fig. 6 the distribution of this index in the two cases (without insurance and with insurance). It is evident from this picture that instability decreases considerably with insurance.

The results are not surprising. It is well known that risk transfer by insurance decreases variability and uncertainty at the price of reduced expected return.[11,12] We have introduced the notion of stability and defined a stability index to quantify this effect. A similar effect is the increase in solvency. Also, solvency can be quantified and put in relation with the costs of a reduced growth in the case of no event.

6. POLICY CONCLUSIONS

We have presented a portfolio model for infrastructure investment and protection for developing and transition countries. Our emphasis was on showing the effect of *ex ante* risk transfer on a country's solvency and stability.

Our approach considers insurance instruments as a means to improve a government's solvency and stability. Our analysis provides two broad policy conclusions. Risk transfer incurs cost in the current period, which reduces funds available for other uses. The classic question is whether the current cost and lost potential returns are justified. As this exercise suggests, a benefit is the increased stability of performance within a narrower range. Risk transfer reduces volatility of performance at the cost of potentially higher overall performance. This is intuitively obvious. For a developing country, the issue is whether guaranteeing minimal economic performance (i.e., earning sufficient income to guarantee interest payment on externally incurred debt) outweighs the potential loss of some economic performance. The modeling provides a basis for evaluating the alternative options based on the desired mix of policy outcomes. A second general conclusion is not one the authors have seen explored elsewhere. Because of the correlated nature of the risk of damage to infrastructure, the addition of more infrastructure in the same region increases the variability of loss for the whole portfolio of infrastructure assets. If the risk was not correlated, the addition of new infrastructure would decrease variability through the law of large numbers. This conclusion could have significant policy implications. It would mean that the more infrastructure that is in place, the greater is the benefit of risk transfer.

Related work was done by McKellar *et al.*[13,14] but with the focus on the question of how a lending institution like the World Bank can anticipate catastrophic events in its policy in order to guarantee (at least to a certain extent) stability of growth.

APPENDIX

Mathematical Specification

In this section, we present the equations of the model following the notation given in Section 4 of the text.

(a) The total value of the infrastructure owned by the government in year t is $I(t)$. Every year, an amount of $L(t)$ is borrowed and invested in the infrastructure. Infrastructure depreciates at a rate of d. In addition, a (random) catastrophic event may destroy a fraction $\delta(t)$ of infrastructure.
The system equation for infrastructure is

$$I(t) = (1 - \delta(t))[(1 - d)I(t - 1) + L(t)]. \quad \text{(A1)}$$

(b) Every year the government borrows $100\,w\%$ of the previous year's value of infrastructure.

$$L(t) = w \cdot I(t - 1). \quad \text{(A2)}$$

(c) The loans have to be paid back with fixed annuities within 10 years and interest rate of q. Therefore, a loan of L in year t requires payments of $f \cdot L$ in years $t+1, t+2, \ldots, t+10$, where

$$f = \left[\frac{1}{1+q} + \frac{1}{(1+q)^2} + \cdots + \frac{1}{(1+q)^{10}}\right]^{-1} = \frac{q}{1-(1/(1+q))^{10}}.$$

(d) The yearly return $R(t)$ is 100 v% of the value of the infrastructure.

$$R(t) = v \cdot I(t). \qquad \text{(A3)}$$

(e) The government may purchase insurance that covers damages up to 100 δ_{max}% of the infrastructure in year t for a price of

$$p(t) = [(1-d)I(t-1) + L(t)] \times \mathbb{E}[\min(\delta(t), \delta_{max})](1+\gamma),$$

where γ is the risk premium.

The outpayment (annuities) to be paid in year t is

$$O(t) = f \sum_{s=t-10}^{t-1} L(s). \qquad \text{(A4)}$$

If the infrastructure is insured, then damages up to 100 δ_{max} of the infrastructure value are fully insured. If the damage exceeds this threshold, only the insured part (that is, exactly 100 δ_{max} of the infrastructure value) is reconstructed.

If insurance was purchased, the distribution of the (noninsured) damage is

$$\bar{\delta}(t) = \begin{cases} 0 & \text{if } \delta(t) \leq \delta_{max} \\ \delta(t) - \delta_{max} & \text{if } \delta(t) > \delta_{max} \end{cases}$$

In the case of insurance, Equation (A1) has to be replaced by

$$I(t) = (1-\bar{\delta}(t))[(1-d)I(t-1) + L(t)] \qquad \text{(A1}'\text{)}$$

and because the insurance premium has to be paid, the payment Equation (A4) changes to

$$O(t) = f \sum_{s=t-10}^{t-1} L(s) + p(t). \qquad \text{(A4}'\text{)}$$

The model in the noninsured situation follows Equations (A1), (A2), (A3), and (A5), whereas the insured situation is described by Equations (A1′), (A2′), (A3′), and (A4′).

To summarize, introducing $c = \mathbb{E}[\min(\delta, \delta_{max})]$ $(1+\gamma)$ and $g = (1-d+w)$ we have introduced the following set of equations:

In the case of no insurance:

$$I(t) = (1-\delta(t)) \cdot g \cdot I(t-1)$$

$$R(t) = v \cdot I(t)$$

$$O(t) = f \cdot w \sum_{s=t-11}^{t-2} I(s)$$

In the case of insurance:

$$I(t) = (1-\bar{\delta}(t)) \cdot g \cdot I(t-1)$$

$$R(t) = v \cdot I(t)$$

$$O(t) = c \cdot gI(t-1) + f \cdot w \sum_{s=t-11}^{t-2} I(s)$$

Parameter Specification

The following parameter settings were used in the simulation:

Symbol	Meaning	Value
$I(0)$	value of infra-structure in year 0	100
d	depreciation of infrastructure	0.033
q	interest rate	0.08
v	yearly return on infrastructure	0.15
w	borrowing limit in relation to existing infrastructure	0.10
δ_{max}	fraction of insurable infrastructure	0.25
γ	risk premium for insurance	0.25

The distribution of δ is specified in the next section.

The Random Damage Model

The damage caused by natural catastrophes is correlated in time and space. Temporal correlation for all hazards, eq. earthquakes is a phenomenon observed by earth scientists, when disasters appear in a clustered way (see, for instance, data collected for U.S. windstorms[15]). In this section, we describe the model used to account for these correlations.

Let, in year t, $N(t)$ be the number of items (buildings, bridges, kilometers of streets, railroads, pipelines etc.) in the infrastructure portfolio. For simplicity, assume that each item has a value of V.

There is a random catastrophic event process with values 0 or 1. $\xi(t) = 0$ means that in year t, there is no event, whereas $\xi(t) = 1$ means that an event occurs.

To account for temporal correlation, we model ξ as a homogeneos Markov chain with the following transitions:

$$\begin{aligned}
&\mathbb{P}(\xi(t+1) = 0 \mid \xi(t) = 0) = 1 - p(1-\rho)\\
&\mathbb{P}(\xi(t+1) = 1 \mid \xi(t) = 0) = p(1-\rho)\\
&\mathbb{P}(\xi(t+1) = 0 \mid \xi(t) = 1) = (1-p)(1-\rho)\\
&\mathbb{P}(\xi(t+1) = 1 \mid \xi(t) = 1) = 1 - (1-p)(1-\rho)
\end{aligned} \tag{A5}$$

Here, $0 \le p \le 1$ and $0 \le \rho \le 1$ are two parameters. It is easily seen that for a stationary chain, $\mathbb{P}(\xi = 1) = p$ and that ρ is the correlation between $\xi(t)$ and $\xi(t-1)$.

The spatial correlation of the damage is taken into account by considering the following model for the damage for item i of our infrastructure portfolio in a specific year t.

If an event happens ($\xi(t) = 1$), the damage to item i in the infrastructure portfolio is $Y_i(t)$. Because of the spatial correlation, these random variables are not independent: there is an individual independent risk of damage $Z_i(t)$ to which each item i in the infrastructure portfolio is subject. However, with some probability r, the damage equals a common damage $Z_0(t)$ (catastrophic event, which because of spatial structure hits more items at the same time), i.e., for $1 \le i \le N$,

$$Y_i(t) = \begin{cases} Z_0(t) & \text{with probability } r \\ Z_i(t) & \text{with probability } (1-r) \end{cases}$$

Assume that all $Z_i(t)$ and $Z_0(t)$ are independent for all i and t and have the same distribution. Then $\mathrm{Corr}(Y_i(t), Y_j(t)) = r^2$, for $i \ne j$. The $Y_j(t)$ are independent, if $r = 0$.

Denote by $\eta_i(t)$ the switch variable $\mathbb{P}\{\eta_i(t) = 1\} = 1 - \mathbb{P}\{\eta_i(t) = 0\} = r$.

Since the value of the portfolio in year t is $V \cdot N(t)$, the relative damage to the portfolio in year t is

$$\delta(t) = \begin{cases} \frac{1}{V \cdot N(t)} \sum_{i=1}^{N(t)} Y_i(t) & \text{if } \xi(t) = 1 \\ 0 & \text{if } \xi(t) = 0. \end{cases}$$

Notice that

$$\begin{aligned}
\delta(t) &= \xi(t) \frac{1}{V \cdot N(t)} \left[\sum_{i=1}^{N(t)} Z_i(1 - \eta_i(t)) + Z_0(t)\eta_i(t) \right] \\
&= \xi(t) \left[\frac{1}{V \cdot N(t)} \sum_{i=1}^{N(t)} Z_i(t)(1 - \eta_i(t)) \right. \\
&\quad \left. + \frac{1}{V} Z_0(t) \frac{1}{N(t)} \sum_{i=1}^{N(t)} \eta_i(t) \right].
\end{aligned}$$

By the law of large numbers, as *N(t)* grows to infinity, we get the following limit expression:

$$\delta(t) = \xi(t) \left[\frac{1}{V} \mathbb{E}[Z_i(t)](1-r) + \frac{1}{V} Z_0(t) r \right].$$

Therefore we rewrite the model:

$$\delta(t) = \xi(t)[\mathbb{E}(\nu(t))(1-r) + r\nu(t)],$$

where $\nu(t) = \frac{1}{V} Z_0(t)$ is a sequence of independent random variables with values in [0,1], which indicate the relative size of the damage in the case of an event.

In particular, the following specification is used:

Symbol	Meaning	Value
p	the event probability	0.04
ρ	the temporal event correlation	0.05
r	the spatial damage correlation	0.6
ν	the relative damage per event	Unif[.0,.5]

In case of an event, the distribution of the relative loss δ is Uniform [0.1, 0.4], since this is the distribution of $[\mathbb{E}(\nu)(1-r) + r \cdot \nu]$.

The expected insured loss is $\mathbb{E}(\min(\delta(t), \delta_{max}))$. In our parameter setting, the value is $0.04(0.175 \cdot 0.5 + 0.25 \cdot 0.5) = 0.0085$.

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Sovereign Cat Bonds and Infrastructure Project Financing

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We examine the opportunities for using catastrophe-linked securities (or equivalent forms of nondebt contingent capital) to reduce the total costs of funding infrastructure projects in emerging economies. Our objective is to elaborate on methods to reduce the necessity for unanticipated (emergency) project funding immediately after a natural disaster. We also place the existing explanations of sovereign-level contingent capital into a catastrophic risk management framework. In doing so, we address the following questions. (1) Why might catastrophe-linked securities be useful to a sovereign nation, over and above their usefulness for insurers and reinsurers? (2) Why are such financial instruments ideally suited for protecting infrastructure projects in emerging economies, under third-party sponsorship, from low-probability, high-consequence events that occur as a result of natural disasters? (3) How can the willingness to pay of a sovereign government in an emerging economy (or its external project sponsor), who values timely completion of infrastructure projects, for such instruments be calculated? To supplement our treatment of these questions, we use a multilayer spreadsheet-based model (in Microsoft Excel format) to calculate the overall cost reductions possible through the judicious use of catastrophe-based financial tools. We also report on numerical comparative statics on the value of contingent-capital financing to avoid project disruption based on varying costs of capital, probability and consequences of disasters, the feasibility of strategies for mid-stage project abandonment, and the timing of capital commitments to the infrastructure investment. We use these results to identify high-priority applications of catastrophe-linked securities so that maximal protection can be realized if the total number of catastrophe instruments is initially limited. The article concludes with potential extensions to our model and opportunities for future research.

KEY WORDS: Catastrophe-linked securities; contingent capital; natural disasters; infrastructure; project finance

1. INTRODUCTION

Insurers and reinsurers, private entities who bear risk on behalf of their clients, use catastrophe-linked securities to protect themselves against insolvency in the case of a natural catastrophe.[1,2] Although private enterprise has already begun to find catastrophe-linked securities useful in reducing the variation of its costs, this hedge against disaster comes at a price: 100% of the expected cost of these catastrophes, plus a generous premium for assuming the risk, is paid to investors.[3–5]

To our knowledge, there has been neither a theoretical analysis nor even a compendium of potential motivations for sovereign governments to use such instruments. Given this lack of analysis, it is not surprising that no sovereign governments (or third-party infrastructure project funders, such as the

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World Bank) have issued such securities to protect themselves against catastrophe. We therefore address the question, "Why might the *sovereign government* of an *emerging nation* be interested in *employing catastrophe-linked instruments* to protect *infrastructure* investments, funded by a *third party*, *from low-probability, high-consequence* events such as *natural catastrophes*?"

2. GOVERNMENT CONCERN WITH CATASTROPHES

A private insurer or reinsurer worries about catastrophes because they trigger financial obligations, which may result in insolvency. It uses catastrophe-linked securities to prevent this insolvency and preserve its franchise value as a profitable ongoing concern.[(6)3]

A sovereign government worries about catastrophes because they trigger obligations to preserve the welfare of its affected citizenry, in addition to damaging infrastructure projects in progress. Catastrophes generate sudden funding requirements for emergency humanitarian aid, and at the same time they generate additional funding requirements to continue with works in progress. The consequence of omitting (or skimping on) such humanitarian aid is not insolvency, but increased suffering for the population, as well as political unpopularity, potential civil unrest, and a potentially guilty conscience for politicians. In particular, disbursing such humanitarian aid at generous levels seems incentive-compatible for government officials, who act as agents for the citizens, as well as prescribed by the charter of the government. That efforts of government officials to succor the populace will be pursued at a maximal level is practically guaranteed by political and media pressures (in addition to the force of genuine heartfelt sympathy for afflicted citizens). A government may find it worthwhile to issue state-contingent catastrophe securities to assure its ability to provide humanitarian aid at an efficient level, completely independent of any other reasons.

A relatively risk-averse government may also wish to protect its investment in wholly owned infrastructure features such as roads, schools, dams, electric utilities, and the telecommunications infrastructure, rather than self-insuring as most governments do.[4] These infrastructure investments, almost by definition, have the characteristic of offering high social benefit but diverse/scattered individual benefits, and so cannot be efficiently organized by the private market. Although the expected capital requirements for completing these projects are completely known *ex ante*, the stochastic character of the capital requirements (which we will term "emergency repair costs" in our example) requires some contingency planning to ensure that needed project funds are available. The government may in particular wish to assure liquidity immediately after a catastrophe, given that it rationally anticipates that all liquid resources will be devoted to humanitarian aid, to assure that these projects can be completed in a timely manner and without extraordinary costs caused by interruption. Such possibility of either sudden and unexpected financial distress due to catastrophe, or the adoption of inferior construction strategies because of the potential for future financial distress, leads to higher expected costs to complete such projects. The simple strategy of holding "capital inventory" to avoid these costs is, unfortunately, very costly for emerging economies.

3. BASIC STRUCTURE OF CATASTROPHE-LINKED SECURITIES

A catastrophe-linked security (or cat bond) is a contract between an issuer and an investor. The investor puts up a sum of cash at the beginning of the coverage period; this cash is held in escrow (under the control of a neutral third party) and invested in low-risk short-term securities until either a catastrophe occurs or the coverage period ends, whichever occurs sooner. The issuer offers to supplement this escrowed principal with a coupon payment, provided that no catastrophe occurs during the coverage period, at the end of the period and return both principal and interest to investors. The escrowed funds are not available for general-purpose use in the interim. In the event of a catastrophe, the investors will receive no coupon payment and some, or all, of their principal may be distributed to the issuer.[5]

The major benefit that these instruments offer to the issuer is an instantaneous inflow of cash (here, to

[3] The wish to avoid or reduce costs of financial distress and bankruptcy costs is a major rationale for a firm's demand for risk management tools. Detailed discussions of motivations for corporate risk management and, in particular, for risk-averse entrepreneurial decision making are given, e.g., by Mayers and Smith,[(7)] Greenwald and Stiglitz,[(8)] and Doherty.[(9)]

[4] Particularly for emerging-economy governments, high capital costs, representing large opportunity costs of future investment and consumption if the nation's capital base is depleted by a catastrophe, may make the role of "insurer of last resort" unattractive.

[5] For structures and conditions of recent cat bonds, see Reference 5.

the government) immediately following a prespecified catastrophic event (such as a flood, earthquake, or hurricane). This payment flows from an escrow account established at the time of issuance, and is not a loan or sovereign obligation—the principal need not ever be repaid by the government to any party, whether a catastrophe occurs or not. If there is no catastrophe during the coverage period, the escrowed principal is returned to the investors with the country having never had the use of it. If there is a catastrophe, the escrowed principal flows to the country free and clear of any repayment obligations. Under no circumstances does the country get the use of the capital under an obligation to repay it. This feature is likely to be quite important to an emerging economy, which already carries a substantial debt burden—particularly if the country's existing (senior) sovereign debt carries a covenant restricting the amount of additional debt that can be assumed.

Given the rather substantial premium that investors receive in return for accepting the risk to their principal, we might ask "Why might such a state-contingent catastrophe-linked security be more attractive to a sovereign government than more traditional types of financing?"

1. *Funds of the magnitude required to rebuild damaged infrastructure investments may not be available to emerging economies in advance*. Although substantial amounts of borrowing at the sovereign level may be desirable to support economic growth, the total amount of sovereign debt that a government can support may be sharply limited, either through explicit restrictive covenants on existing debt or by the market's unwillingness to advance additional funds for general purposes. A government nearing its total allowable-debt constraint has a substantial incentive to ensure that this constraint will not be violated in case of a catastrophe.
2. *Even if these rebuilding funds would be available during normal circumstances, they may not be available after a sufficiently severe catastrophe*. Unless provisions for emergency capital are arranged in advance, investors may be reluctant to make large new capital commitments if a catastrophe occurs that is sufficiently severe to threaten the stability of the national currency, create civil unrest, or cause default on outstanding sovereign debt. A rational response before making additional investment might be to "wait and see" whether the country's ability to repay the new debt has been compromised by the catastrophe.
3. *Portions of these funds are required immediately after the catastrophe to address catastrophe-induced difficulties*. The demand for liquid funds immediately after a catastrophe is extremely high, and the short-term opportunity cost of not having capital available immediately after a catastrophe is considerable, both for emergency humanitarian aid and for reconstruction. It is this high short-term social value of liquid assets that leads governments to divert capital flows earmarked for sponsored infrastructure projects to emergency humanitarian aid when all other sources of liquid assets have been exhausted. This short-term cash-flow problem is exacerbated when the infrastructure projects themselves suffer damage from the catastrophe and require reconstruction. A new roof for a nearly finished school may be required after a hurricane hits the area, for example; if this roof is not immediately installed, rain damage may dramatically increase the total cost of finishing the school. Delays in the availability of emergency-repair funds may therefore generate significant costs of financial distress after a disaster.
4. *The government may not desire to borrow more money in the future, even if allowed to do so at a competitive rate*. The government's overall financial strategy (prior to a catastrophe, but rationally anticipating its possibility) may be to *reduce* its overall level of borrowing, or to maintain its current optimal level, rather than potentially *increase* it if a catastrophe were to occur. The government may be willing to pay a premium to avoid disruption of the rationalizing of its financial structure on a *national* level, in much the same way we describe the gains from avoiding disruption on the *project* level in our later analysis. Furthermore, the nation's existing (senior) sovereign debt rating would benefit through a reduced anticipated default rate; lenders would presumably offer more favorable terms (or larger amounts at equivalent terms) if the risk of default due to a natural disaster (a disruptive event whose cash-outflow requirements that might contribute to default, if sufficiently severe), is lessened.

5. *The cost of capital for an emerging economy is high*. A sovereign government may be able to handle a larger deductible than a private company and still exhibit an aversion to self-insuring. Holding excess funds idle in inventory, against the possibility of unexpected cash needs, has a very high cost for an emerging economy—either an explicit cost of borrowing in the capital market, or a high opportunity cost based on depriving a socially desirable investment project of capital. It does not make sense to withhold large amounts of capital every year simply to hedge against an event that occurs only one year in ten.

3.1. Introduction to Project Disruption Costs

Funds may be diverted from infrastructure projects—even despite the sovereign government's genuine long-term commitment to the desirability of investing in these projects—to assuage short-term humanitarian and political needs immediately following a catastrophe. The timely application of these loaned funds to infrastructure development is a condition of the original loan agreement. Such diversion creates not only a technical default on the original agreement, but also a shortage of capital to be invested in the ongoing project. This unexpected lack of funds will certainly lead to increased costs over and above the damage that might have been done to the infrastructure project itself.

These costs may be explicit, through increased costs of project completion due to the disruption in a smooth flow of capital (requiring unexpected mothballing of the construction projects, relocation of construction materials, equipment, and personnel, as well as frictional hiring-and-firing costs and forced idling of capital equipment). These costs may also take the form of implicit, or opportunity, costs simply through the inevitable delay in having the completed project come online, and therefore pushing the onset of benefits from the completed project further into the future. In the special case of a durable investment (where, once paid for, the stream of benefits continues indefinitely) a one-year delay (for example, the completion of a technical institute) amounts to losing one year's worth of service (for example, one full graduating class of engineering students) forever. Sovereign governments value the stream of services from such infrastructure projects as direct contributions to social welfare, even if their returns are noncash items (a graduating class of engineers). In our cost analysis, we therefore include the opportunity losses of these foregone benefits from project completion to capture the full economic cost of project failure or delay.

Although the government's decision to divert funds to humanitarian needs is certainly a justifiable one (and may, indeed, represent the best use of available funds given that a catastrophe has occurred), it exerts an unintended negative externality on project costs. Planning for the contingency that all available liquid funds will be diverted can thus reduce the total expected costs of project completion. By assuring a ready source of capital when needed, construction progress on the infrastructure project can continue, avoiding not only project disruption costs but also delays in the project coming online.

The external sponsor of the infrastructure project may also benefit from the creation of a source of liquid capital, to be accessed only in the case of catastrophe. The sponsor is frequently forced to renegotiate the terms of the loan under unfavorable conditions, with the diversion of the original loan principal a *fait accompli*. Additional loan capital is requested to finish the partially complete project, even though the social benefits (and, thus, the potential pay-back capabilities) from the completed project have not increased. Although this unfavorable prospect (and the government's revealed history of unilateral renegotiation) would seem to discourage a lender from advancing more funds at the *beginning* of a project, the lender may feel compelled to invest additional funds in the *middle* stages of a project. Because, without additional funding, investments previously sunk into the project will amount to nothing—and the original loan principal will need to be written off as unrecoverable—the benefits from such previous investments are effectively "held hostage" to the funder's acquiescence to these terms. Borrowers' commitment to project completion may improve lenders' long-term willingness to provide funds, as we examine in Section 5.

Prearranged sources of contingent capital, such as event-triggered cat bonds, can generate cash quickly and thereby capture the benefit of immediate liquidity. On-the-spot post-catastrophe arrangements may take several weeks to accomplish, even for a creditworthy country far away from its maximal debt constraint using previously established contacts at investment banks.[10,11] A financial device, such as a catastrophe-linked security, will thus reduce the costs of financial distress and thereby generate value to a sovereign government and external project sponsors to the extent it can:

1. Eliminate the risk of project disruption due to damage to infrastructure projects in progress when emergency repair funds are not otherwise available, by supplying these emergency repair funds immediately upon damage to the project; and
2. Provide a ready source of immediate contingent capital for project completion when humanitarian aid requirements force diversion of all liquid resources, including ongoing project funding, even when the project itself is not damaged.

3.2. Enabling Commitment to Continued Project Funding

A sovereign government desires to split its current expenditures between consumption (emergency humanitarian aid after a catastrophe) and investment (continued funding for projects in progress). Its obligations extend first to the welfare of its citizenry, and only secondarily to the continued success of its investment projects (even though the fruits of these projects will determine future welfare of future citizens). Even though the optimal decision involves an intertemporal tradeoff balancing present humanitarian aid with future investment gains, there is always a strong temptation (particularly in a democracy) for the current government to overspend on present citizens. Resisting this temptation, although good for the country in the long term, may be politically infeasible (or undesirable) in the short term.

A government may therefore be able to improve its intertemporal capital management by investing in instruments that generate benefits that *cannot* be used for humanitarian aid, and that thereby commit the nation to continuing investment in infrastructure projects—a classic example of benefiting by following rules rather than discretion.(12)

This commitment benefit cannot be captured if the proceeds from catastrophe securities are paid in cash (which is, of course, fungible between investments in infrastructure and current consumption) to the government itself (which is the party caught in the invest/consume dilemma). For the government to create and capture this commitment benefit, the proceeds must be either:

1. Paid in a "currency" that advances the infrastructure investment task but cannot be readily converted to cash (e.g., bulldozers, construction labor, etc.); and/or
2. Distributed not to the central government, but rather to a party that has no temptation to spend on immediate emergency aid at the expense of investment. Whether the most effective distribution mechanism is to disburse directly to local project managers, to the third-party sponsor, or a wholly disinterested party remains a topic for future research.

4. MODEL OF EXPECTED COSTS OF FINANCIAL DISTRESS

As we have discussed, a multitude of costs may be avoided, and social benefit realized, by avoiding project disruption due to financial distress—whether through enabling defense of previously sunk costs against instantaneous depreciation due to the catastrophe, supporting cost-minimizing construction strategies, or accelerating the coming online of the new project. We now turn to a model of the size of these costs, and explicitly calculate values of these costs in a series of numerical examples.

We use a simple model to illustrate the magnitude of potential advantages from a sovereign cat bond or other form of state-contingent access to capital, such as a prearranged nonrecourse line of credit. We further assume that all projects currently underway are worth continuing.[6] We consider a sovereign acting as project manager for a certain project with a deferred payoff b, which is to be realized only on successful project completion. For convenience we assume two periods of required investment before the benefit occurs.

4.1. Project Cost Structure

The necessary investments are i_1 at the beginning of the first period and i_2 at the beginning of the second. Both investments must be made to achieve the benefit b at the end of Period 2.

[6] If this condition is not currently satisfied in the portfolio of funded investments, a simple supplementary method to free capital for repairs would be to discontinue those projects for which incremental future costs exceed incremental future benefits. We assume that the infrastructure investment portfolio has already been so rationalized before the decision about cat risk financing arises. If external contingent capital is available, only projects that are attractive given that contingent capital is available should be begun. As will be seen in our example, there will be situations when the initial attractiveness of the project depends critically on the availability of capital to see it through to completion.

The risk faced by this project is "catastrophic" in that (1) 100% of the value of the project is destroyed if not immediately repaired, and (2) the costs of repairs are large compared to the total amount of capital available to the project sponsor. A catastrophic event causes damage to the project with probability p in each period.[7] If a disaster occurs, all progress made on the project to date will be completely lost unless the project is "defended" by immediately carrying out an emergency repair. In the event of a disaster, the costs of emergency repair (e_1 and e_2 in Periods 1 and 2, respectively) must be invested by the end of the period in which the disaster occurred. If the emergency-repair investments are not made, the project returns to the original state and must be started over at the beginning of the next period.[8]

4.2. Information Structure

The magnitudes of e_1 and e_2 are known *ex ante*, as are other relevant parameters such as the net present value of the social benefit (b) that accrues to the country once the project is completed, the probability of a disaster (p), which is the same across all periods, and the discount rate (r). This is a single-decisionmaker problem; the probability of disaster is assumed to be independent of any model parameters, financing arrangements, or construction strategies used by the project manager.

4.3. Strategy Alternatives

The project manager chooses an investment strategy to maximize the (expected) net present value of the project opportunity. A strategy for this investment problem is thus characterized by the decisions concerning emergency repair in case of a disaster occurring in the different project stages. Assuming that no additional information can be derived during the process (e.g., on the disaster probability), and if there are no limitations to the availability of funds for emergency repair if needed, the decisions do not depend on the project history—in particular, on whether a disaster has already occurred. There are then five strategies a project manager must choose from.

- (R,R): Emergency repair will be done if a disaster occurs in the first period, the second period, or in both.
- (F,R): Emergency repair will be done only in the second period; if a catastrophe occurs in the first period, the project will be allowed to fail and restart.
- (R,F): Emergency repair will be carried out only in the first period; if a catastrophe occurs in the second period, the project will be allowed to fail and restart.
- (F,F): No emergency repair will be carried out, regardless of timing; the project will be allowed to fail and restart after any catastrophe.

Of course, the project manager also has the option of not investing at all (0), which will be chosen if the expected net present value of the result of the best strategy among (R,R), (F,R), (R,F), and (F,F) is negative.

4.4. Strategy Selection

The optimal strategy for the problem described above depends on whether it is attractive to pay for emergency repair in one or both project stages. Consider first the situation without any capital constraints, which means that there is always enough capital available to defend the project after a disaster if doing so would form a part of the optimal solution at that stage.

We want to derive explicit expressions for the net present values under the different strategies: $NV_0^{R,R}$, $NV_0^{F,R}$, $NV_0^{R,F}$, and $NV_0^{F,F}$. The discounted cash flows for these strategies and the possible scenarios are given in Table I. δ denotes the discounting factor, $\delta = \frac{1}{1+r}$. Note that since we assume that the project is restarted if a disaster happens and no emergency repair is carried out, the expected net present values themselves appear in the table as a cash-flow component whenever the project is let fail and restarted.

Considering each row of the table in turn, weighting each outcome by its probability and solving for the expected net present values of the project opportunity under the four strategies described gives

[7] Although we assume that disasters in Period 1 and Period 2 are independent, our model is easily adapted to account for serial correlation (either positive or negative) of disaster likelihood, allowing the capture of some interdependencies among events.

[8] Each time the project is allowed to fail we assume it will indeed be begun again in the next period, as the project was initially attractive and has the same (positive) expected NPV at the point immediately following the disaster, independent of its history, as it did at the initial decision point.

Table I. State-Contingent Cash Flows Resulting from Repair Strategy Choices

		Outcome			
		No Event	Event (only) in Period 1	Event (only) in Period 2	Event in Both Periods
	Probability	$(1-p)^2$	$p(1-p)$	$p(1-p)$	p^2
Repair Strategy	(R,R)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $-i_2\delta - e_2\delta^2$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta - e_2\delta^2$ $+b\delta^2$
	(F,R)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $+NV_0^{F,R}\delta$	$-i_1$ $-i_2\delta - e_2\,\delta^2$ $+b\delta^2$	$-i_1$ $+NV_0^{F,R}\delta$
	(R,F)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $-i_2\delta$ $+NV_0^{R,F}\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+NV_0^{R,F}\delta^2$
	(F,F)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $+NV_0{}^{F,F}\delta$	$-i_1$ $-i_2\delta$ $+NV_0{}^{F,F}\delta^2$	$-i_1$ $+NV_0{}^{F,F}\delta$

$$NV_0^{R,R} = \delta^2 \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot e_1 - \delta^2 \cdot p \cdot e_2,$$

$$NV_0^{F,R} = \frac{1}{1 - p \cdot \delta} \cdot \left[\delta^2 \cdot (1-p) \cdot b - i_1 - \delta \cdot (1-p) \cdot i_2 - \delta^2 \cdot (1-p) \cdot p \cdot e_2\right],$$

$$NV_0^{R,F} = \frac{1}{1 - p \cdot \delta^2} \cdot \left[\delta^2 \cdot (1-p) \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot e_1\right],$$

and

$$NV_0^{F,F} = \frac{1}{1 - p \cdot \delta - p \cdot \delta^2 + p^2 \cdot \delta^2} \cdot \left[\delta^2 \cdot (1-p)^2 \cdot b - i_1 - \delta \cdot (1-p) \cdot i_2\right].$$

The optimal investment strategy $\langle (i^*, j^*) \,|\, i, j \in \{R, F\} \rangle = \arg\max NV_0^{i,j}$ and the value of the project is thus $V(i^*, j^*) = \max\lfloor 0, NV_0^{R,R}, NV_0^{F,R} NV_0^{R,F} NV_0^{F,F} \rfloor$. Consider the following numerical example:

Example 1 : $r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10$

$e_2 = 15 \quad p = 0.1 \quad b = 40$

The values of the expected net present value (NPV) generated from the different repair strategies are shown in Table II.

The best of these strategies would be $NV_0^{R,R}$—to carry out emergency repair each time a disaster occurs—which yields an initial expected NPV for the project opportunity of 11.82. Since $NV_0^{R,R}$ is positive, this strategy is preferred to the strategy (0), which yields a payoff of 0.

Table II. NPV of Investment Strategies with Unlimited Capital

$NV_0^{R,R} = 11.82$	$NV_0^{F,R} = 11.5$	$NV_0^{R,F} = 10.63$	$NV_0^{F,F} = 10.3$

4.5. Financial Distress

Financial distress occurs when, during the investment process, a catastrophe occurs and a shortage of capital forces the sovereign to let the project fail in a case where emergency repair would otherwise be the preferred solution. Although financial distress does not occur in the absence of a catastrophic event, the potential for the costs of financial distress must be included in the original calculation of the value of the project opportunity. The *expected cost of financial distress* (ECFD) can be measured as the reduction in the expected net present value of the project opportunity due to the constraint-induced switch of strategy.

We denote the funds available for emergency repair by f. These funds represent, conceptually, the difference between the project manager's initial capital endowment and the funds that would be earmarked for the construction of the project (i.e., i_1 and i_2) if no catastrophes were to occur. Formally,

$$ECFD = NV_0^{\infty} - NV_0^{f},$$

where NV_0^{∞} represents the value of the project opportunity if an infinite amount of capital were available for emergency repair, and NV_0^{f} represents the value of the project opportunity given that only f units of capital are available for emergency repair, and thus that strategies possibly requiring amounts greater than f are infeasible.

4.5.1. Noncontingent Repair Strategies

Consider, as an illustrative example, the extreme case of no capital being available for emergency repair (i.e., $f = 0$) in a situation when (R,R) would be the best strategy given unlimited capital. Here the only feasible strategies are (0) and (F,F). Thus the expected cost of financial distress can easily be quantified as $min\lfloor NV_0^{R,R}, NV_0^{R,R} - NV_0^{F,F}\rfloor$, the lesser of the entire project value (i.e., the difference between $NV_0^{R,R}$ and 0) or the difference between $NV_0^{R,R}$ and $NV_0^{F,F}$. This cost of financial distress is always equal to $NV_0^{R,R} - NV_0^{F,F} > 0$, assuming that the emergency repair cost is not prohibitively high and that the project is attractive to begin in the first place.

Using the numbers introduced in Example 1 and under the assumption $f = 0$, the best feasible strategy (i.e., the best strategy that does not require the availability of any emergency-repair capital) is (F,F). So the expected cost of financial distress is $ECFD = NV_0^{R,R} - NV_0^{F,F} = 1.52$ for the parameters in Example 1.[9]

4.6. Contingent Repair Strategies

To calculate the cost of financial distress for the general case we first must introduce one additional possible strategy, which allows the decision of whether to repair in the second period to depend on the outcome of the first period:

- (R, R̃): Emergency repair will be carried out in the first period if necessary; in case of a catastrophe in the second period, the project will be defended only if there were no disaster in the first period.

Of course, this strategy cannot be more favorable than the ones mentioned above in the case of no capital restrictions (being inferior to either (R,R) or (R,F)), but it might be a constrained-optimal (second-best) solution if the project manager has just enough capital to carry out emergency repair one time, but not twice. The cash flows associated with strategy (R, R̃) are shown in Table III.

The expected net present value under (R, R̃) is thus

$$NV_0^{R,\tilde{R}} = \frac{1}{1 - p^2 \cdot \delta^2} \cdot \left[\delta^2 \cdot (1 - p^2) \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot e_1 - \delta^2 \cdot (1 - p) \cdot p \cdot e_2\right].$$

As can be easily verified, (R, R̃) turns out to be the constrained-optimal strategy for Example 1 in all cases where $15 \leq f < 20$. (In particular, if $f = 15$, (R, R̃) is the best strategy that does not ever require more than 15 units of capital; when $f > 20$ there is enough capital to pursue strategy (R,R).) (R, R̃) yields an ENPV of $NV_0^{R,\tilde{R}} = 11.71$ and a substantially lower cost of financial distress (ECFD = 0.11) in comparison to the $f = 0$ case.

From this simple example, we can make two observations.

1. The optimal strategy of whether to defend the project in Period 1, Period 2, or both depends on the amount of capital available. Also, the decision of whether to begin the project at all depends, via the choice of strategy, on the amount of capital anticipated to be available to conduct emergency repairs.
2. The costs of financial distress can be greatly reduced (by 93% in our example) by holding enough capital in reserve to accommodate one disaster. For events that are individually tolerable but become catastrophic when they occur in series, this is a powerful strategy. The reduction in ECFD for insuring against the *second* disaster in the series (in our example, 0.11) is modest compared to the benefit from insuring against the first disaster (in our example, 1.41).

We will now use a series of comparative static analyses to show the effects of varying important parameters.

[9] Note that the ECFD as introduced above should be seen as a lower bound to the expected opportunity cost of financial distress. We calculate expected net present values under the assumption that, in the case where the project is destroyed and no emergency repair is done, the project can be restarted immediately. This immediate restart, however, requires the availability of funds covering the necessary initial investment i_1 and the guaranteed availability of i_2 in the following period. In a financial distress situation, these funds, even if they are lower than the emergency repair costs, might be available only later. The net present value of this restart would then, of course, need to be discounted to reflect the effect of the delayed start on the future benefits from project completion. Incorporating this aspect of the opportunity costs of financial distress caused by the delay in the project's restarting, however, would only strengthen the point being made here about the usefulness of *immediate* availability of emergency funds, such as offered by state-contingent catastrophe securities.

Table III. State-Contingent Cash Flows Resulting from Repair Strategy Choices

		Outcome			
		No Event	Event (only) in Period 1	Event (only) in Period 2	Event in Both Periods
	Probability	$(1-p)^2$	$p(1-p)$	$p(1-p)$	p^2
Repair Strategy	(R,R)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $-i_2\delta - e_2\delta^2$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta - e_2\delta^2$ $+b\delta^2$
	(F,R)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $+NV_0^{F,R}\delta$	$-i_1$ $-i_2\delta - e_2\,\delta^2$ $+b\delta^2$	$-i_1$ $+NV_0^{F,R}\delta$
	(R,F)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $-i_2\delta$ $+NV_0^{R,F}\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+NV_0^{R,F}\delta^2$
	(F,F)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $+NV_0^{F,F}\delta$	$-i_1$ $-i_2\delta$ $+NV_0^{F,F}\delta^2$	$-i_1$ $+NV_0{}^{F,F}\delta$
	(R, $\tilde{\mathbf{R}}$)	$-i_1$ $-i_2\delta$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+b\delta^2$	$-i_1$ $-i_2\delta - e_2\delta^2$ $+b\delta^2$	$-i_1 - e_1\delta$ $-i_2\delta$ $+NV_0^{R,\tilde{R}}\delta^2$

4.7. ECFD as a Function of Initial Capital

First, we consider how the expected cost of financial distress depends on the amount of capital available for emergency repair. Based on the parameters given in Example 2, Fig. 1 shows the relationship between the value of EFCD and f.

Example 2 : $r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10$

$e_2 = 15 \quad p = 0.1 \quad b = 40$

f varies from 0 to 40

Note that, in accordance with intuition, the expected cost of financial distress is very high for the case of $f = 0$ (no capital being available for emergency repair). On the other extreme, because the best strategy is (R,R) in our example, the ECFD equals 0 only when the initial capital suffices for repairs in both periods.

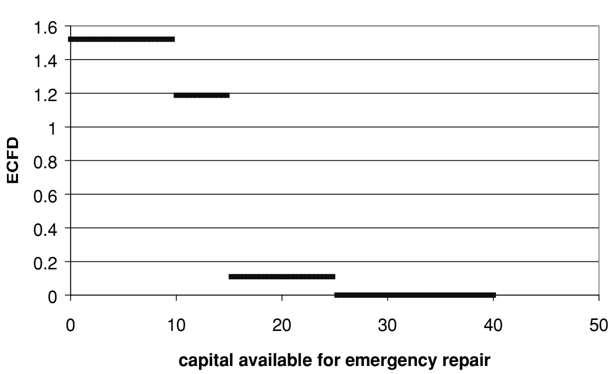

Fig. 1. ECFD and initial capital.

In this example, the emergency-repair cost in the second period is higher than in the first. In the case of amounts of available capital that allow defending the project only in the first period but not in the second, the best feasible strategy becomes (R,F) and the EFCD drops slightly from its highest level. The most dramatic incremental reduction of EFCD can be obtained by setting $f = 15$, enabling the project manager to repair in either the first or the second period, but not both—equivalent to having capital available to assuage one catastrophe but not two. This leads to the strategy (R, R̃) being optimal, which results in a different outcome from (R,R) only if catastrophes occur in both periods.

We thus note that the strategy (R, R̃), in conjunction with a limited amount of emergency capital reserves, can thus accomplish a significant portion of the benefit of the strategy (R,R) with an unlimited capital reserve. Note that this limited emergency capital reserve might be provided through a contingent financing instrument such as a cat bond, rather than representing idle funds held in inventory against the rare event of two sequential catastrophes. A cat bond designed to eliminate most of the costs of financial distress, while limiting the total amount of

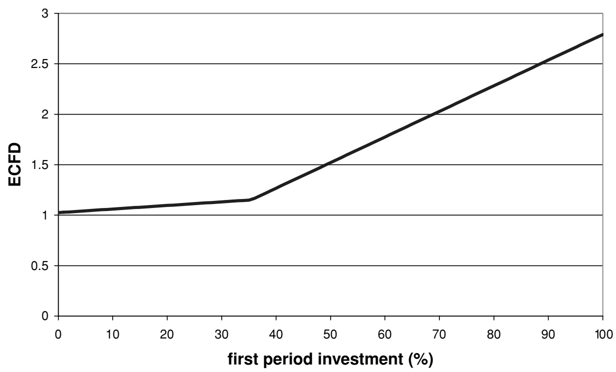

Fig. 2. ECFD vs. time structure of required investment.

investor capital at risk to that of a single disaster, ought to be constructed to pay for the *first* disaster that occurs, regardless of whether this disaster occurs in Period 1 or Period 2. A cat bond that pays for the second occurring disaster will be tapped much less often, but will also create much less reduction in ECFD.

4.8. Sensitivity of ECFD to Time Structure of Required Investment

We now consider how the expected cost of financial distress depends on the speed with which capital is committed to the project, that is, for a given project cost, what percentage of this cost must be committed during the first period, and how much may be deferred until the second.[10] Based on the parameters given in Example 3, Fig. 2 shows the relationship between the value of EFCD and this time structure of required investment.

Example 3 : $f = 0 \quad r = 0.1 \quad i_1 + i_2 = 20 \quad e_1 = 10$

$e_2 = 15 \quad p = 0.1 \quad b = 40i_1/(i_1 + i_2)$

varies from 0 to 1

From Fig. 2, we see that ECFD rises with the percentage of the total construction costs that must be committed during the first period. The dependency is piece-wise linear, as can be seen directly from the equations governing ECFD. For a low percentage of first-period investment commitment, the project manager would tend to *choose* to let the project fail (and restart) if a disaster were to occur in Period 1, even if unlimited repair capital were available. The larger this fraction of first-period commitment, the more attractive is the strategy (R,R). The kink in the curve marks the switch from (F,R) to (R,R) as the best unconstrained strategy.

4.9. Sensitivity of ECFD to the Cost of Capital

We now consider how the expected cost of financial distress depends on the cost of capital. The same cost of capital, r, is assumed to apply both for the pure rate of discounting project benefits (effectively, the opportunity cost of not having a project's benefits sooner) and for the implied rate of return paid on borrowed funds (effectively, the explicit cash outflow for interest payments). It should be noted that we assumed that r is relatively high for sovereign project managers in emerging countries, either based on high time value of incremental infrastructure investments or based on high borrowing costs in the financial markets. Based on the parameters given in Example 4, Fig. 3 shows the relationship between the value of EFCD and this cost of capital.

Example 4 : $f = 0 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10$

$e_2 = 15 \quad p = 0.1 \quad b = 40$

r varies from 0% to 60% per period

For the important region, the ECFD behaves like a function concave in the cost of capital and, in addition, does not react in a highly sensitive manner to small changes in the cost of capital. It should be mentioned that ECFD first increases and then decreases, reaching a local max at approximately 0.25 in Example 4. In this example (R,R) is always the unconstrained best strategy and (F,F) is the best capital-constrained strategy as long as these strategies both

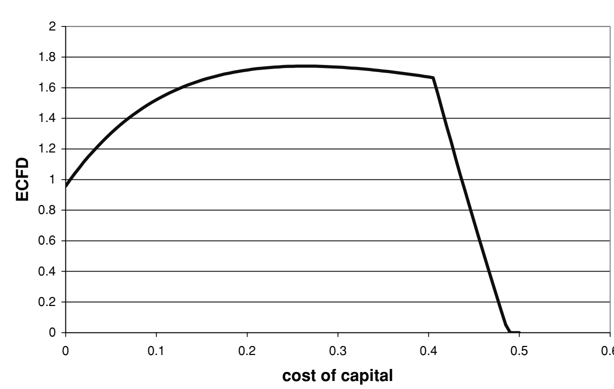

Fig. 3. ECFD vs. cost of capital.

[10] Note that in Example 3, $i_1 + i_2 = 20$ in all cases; only the balance between i_1 and i_2 will be changed.

have positive NPVs. The first kink of the curve is linked to the switch of the constrained best strategy from (F,F) to (0) at approximately $r = 0.4$; this occurs when the cost of capital becomes so high that the project is no longer attractive to begin (i.e., has a negative NPV). Once (0) becomes the best alternative strategy to (R,R), the ECFD decreases rapidly in the cost of capital—not because the problem of contingent capital is solved (because $f = 0$, no repairs can be made in any event), but simply because the attractiveness of the project falls rapidly in r but the constrained best outcome does not decrease any further.

An interesting extension to the model would be to incorporate the costs of borrowing the optimal amount of capital at the beginning of Period 1 with the goal of maximizing the overall expected benefit from the project including these capital costs. This optimal amount of capital to borrow would depend on the cost of capital both directly and indirectly. The direct effect of the cost of capital on the optimal amount to borrow comes about because interest payments would need to be made (and, implicitly, made from available cash) whether a disaster occurs or not—an expensive proposition when disasters are rare. The indirect effect occurs through the borrowings increasing f and thereby reducing ECFD, which itself depends on the cost of capital as shown in Fig. 3. The sensitivity analysis of the ECFD to the cost of capital if the *optimal* amount of capital were borrowed for each value of r would differ significantly from our analysis in Fig. 3, which assumes that a *fixed* amount (here, 0) is borrowed regardless of r.

4.10. Sensitivity of ECFD to the Probability of Disaster

We now consider how the expected cost of financial distress depends on the probability of a disaster occurring in any given period. The severity of the disaster is assumed to stay constant, although its probability changes. Based on the parameters given in Example 5, Fig. 4 shows the relationship between the value of EFCD and this probability that a disaster occurs.

$$\textit{Example 5}: \quad f = 0 \quad r = 0.1 \quad i_1 = 10 \quad i_2 = 10$$
$$e_1 = 10 \quad e_2 = 15 \quad b = 40$$
$$p \text{ varies from } 0 \text{ to } 1 \text{ per period}$$

In the left-hand portion of the curve, the net value of the constrained best strategy ((F,F) in this example) falls much more quickly than that of the unconstrained best strategy (R,R). Defending the project, especially in the second period, becomes more beneficial as p increases. One major difference between (R,R) and (F,F) as strategies is that (R,R) guarantees that the project will come online at the end of Period 2, at which time the benefit b will be realized for certain (albeit at a random cost). As p increases, the expected length of time until the project is completed increases under the (F,F) strategy. In addition, defending the project in Period 2 is particularly valuable as p increases because a completed project does not need to "run the gauntlet" of two periods of relatively frequent risks.

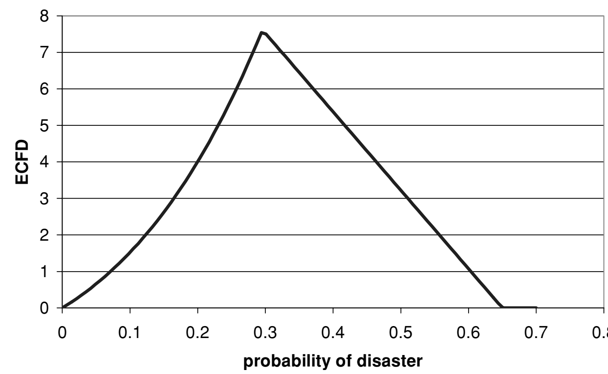

Fig. 4. ECFD vs. probability of disaster.

The kink in the curve (at around $p = 0.3$ in our example) is due to the switch from (F,F) to (0) as the optimal capital-constrained strategy. For large enough values of p, the project will suffer catastrophe so often that it should never be begun (i.e., will have negative NPV) if no emergency capital is available. In this case, the cost of financial distress (i.e., the opportunity cost of not having enough capital to defend the project, and therefore not enough to make *beginning* the project worthwhile) will thus be the same as the full project value under the unconstrained best strategy (R,R). This is the maximum possible level of ECFD, representing the loss of the entire project value for certain regardless of whether the disastrous events occur. This project value, in turn, decreases in p because the expected project completion cost is increasing (incorporating the expected costs of emergency repair) while its benefit remains constant. After a certain critical level (approximately 0.63 in our example), the likelihood of disaster is so large, and the expected damages before project completion so great, that the project manager is dissuaded from beginning the project even if an infinite amount of capital is available for emergency repairs.

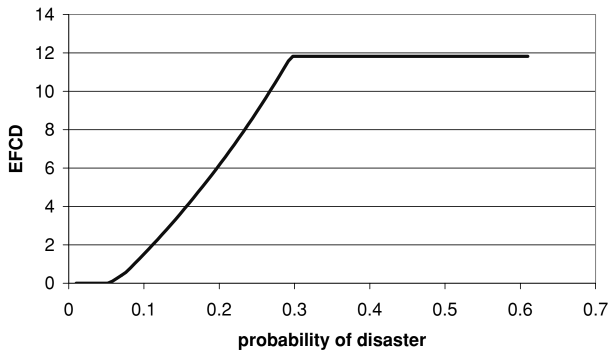

Fig. 5. ECFD vs. probability of disaster (expected loss held constant).

$$\textit{Example 6}: \quad f = 0 \quad r = 0.1 \quad i_1 = 10 \quad i_2 = 10$$
$$p \cdot e_1 = 1 \quad p \cdot e_2 = 1.5 \quad b = 40$$
p varies, but $p \cdot e_1$ and $p \cdot e_2$ are held constant

Fig. 5 shows that expected costs of financial distress caused by project disruption are higher for more frequent, less severe events than for infrequent but very severe events. The initial choice of (F,F) when severe events occur but rarely negates the impact of limited capital. If funding to repair a project is not going to be available in any event (either because the capital is not available, or because restarting the project is cheaper than repairing it), it does not matter to ECFD whether the disaster causes a $10,000 loss that *will not* be repaired or a $1 million loss that *cannot* be repaired. The frequency of the loss, however, increases either the expected length of time until this completion occurs (when these small losses cause the project to be restarted under the optimal repair strategy), which does not affect ECFD, or the expected costs of project completion (if these small losses would be repaired under the optimal repair strategy, but these repairs are impossible due to capital limitations). Frequent losses that cannot be repaired lead to substantial increases in ECFD; once these losses are frequent enough (which occurs at approximately $p = 0.3$ in Fig. 5), the project is no longer attractive, and ECFD achieves its maximum.

5. SUMMARY OF BENEFITS FROM PROJECT RISK MANAGEMENT

At the level of the sovereign government or the third-party sponsor, the reduction in ECFD will create three types of benefits that will increase the number of projects that can be accomplished on a given capital budget. For example, consider a capital budget of $15 billion, $12 billion of which is to be committed to new capital projects and $3 billion to be kept in reserve for emergencies.

First, at the simplest level, a reduction in expected completion costs of a representative project from $120 million to $100 million allows 120 such projects to be funded rather than 100. Alternately, the sponsor may be able to use this incremental savings of $200 million to fund some projects less attractive than the initial 100 that otherwise would not be in a priority position to receive capital.

Second, reducing the variance of the capital requirements of individual projects enables the government or third-party project sponsor to more efficiently commit its limited capital. The general structure of this financial optimization problem is as follows. Normally, the government or sponsor would commit less than 100% of its available capital, withholding a portion (here, $3 billion) to deal with extraordinary and unexpected funding requirements such as those caused by natural disasters (whether directly by damage to the ongoing infrastructure project, or indirectly due to unilateral diversion of project funds to humanitarian efforts). The optimal percentage of capital to reserve for these emergencies balances the costs of over-committing (using almost 100% of capital available at all times, maintaining only a small reserve for contingent funding, and thereby running the risk of inadvertently causing project disruption when several portfolio projects require extraordinary infusions of cash at the same time) against the costs of under-committing (allowing capital to lie fallow, which could otherwise be directed toward socially beneficial projects).

By increasing the predictability of required project financing, even if the expected amount of project funding remained unchanged, this utilization percentage could be increased without taking on additional risk of over-commitment—an increase in capital efficiency that comes at no one's expense. So, for example, availability of external contingent capital could allow the sponsor's effective $12 billion of infrastructure budget to grow to $14 billion of committable capital (with $1 billion left in reserve, rather than $3 billion). This effect combines with the reduction in project cost to enable 140 projects at the new lower cost and lower variance (again compared to 100 projects at the higher cost and higher variance) for the same $15 billion.

Finally, this effective 40% increase in efficiency (in terms of projects completed per dollar invested) may well attract additional capital into such project financing—a demand effect.[11] If the original $15 billion total allocation for capital projects were to grow to $20 billion because of this increased efficiency, the sponsor could accomplish 200 representative projects versus the baseline of 100—a 100% increase in effective infrastructure projects, without increasing the risk to the investors, based on only a 33% increase in capital.

6. MODEL EXTENSIONS AND TOPICS FOR FUTURE RESEARCH

We have addressed the question: Why might the *sovereign government* (or third-party project sponsor) of an *emerging nation* be interested in *employing catastrophe-linked instruments* to protect *infrastructure* investments, funded by a *third-party project sponsor*, *from low-probability, high-consequence* events such as *natural catastrophes*? We conclude by presenting some additional topics—requiring analysis beyond the scope of this article—related to the questions of how the government might use these bonds, how the instruments might be designed, and to what extent the market for such securities interacts with information conditions and government policy.

6.1. Challenges and Limitations Specific to Sovereign CAT Bonds

There are many challenges to implementing catastrophe-linked securities; these challenges have been discussed elsewhere. We consider only one, a unique issue for a sovereign government possessing widely dispersed infrastructure assets.

When considering only infrastructure projects, the sovereign government is the monopoly provider of these projects, and the monopsony buyer of cat risk protection. No other party (except, perhaps, for a third-party sponsor such as the World Bank) has an obvious insurable interest in these projects. The government can thus be thought of as having 100% market share in insuring its infrastructure, even though this infrastructure may be spread out over a very large geographic region. On the one hand, this 100% market share would seem to offer an opportunity to design a countrywide cat bond with low basis risk, as catastrophe-related damage to the entire country would correlate well with catastrophe-linked damage to countrywide projects. A portfolio of similar projects (such as a highway system) spread evenly nationwide could thus be protected by a country-level index instrument. Geographical dispersion of a highway system prevents the asset from being totally destroyed by a local phenomenon (such as a flood or earthquake), a form of built-in diversification and resistance to catastrophic damages from geographically concentrated risks.

Some countries incorporate such extremely large and diverse geographic scope (e.g., China) that it may be difficult to define appropriate triggers for such catastrophe-related instruments on a national scale—paradoxically, the infrastructure projects, even though geographically widespread, are not sufficiently uniformly subjected to or affected by disaster for national coverage to be a good proxy for project coverage. Thus, the same geographical dispersion makes it a challenge to design an instrument to protect the asset without introducing massive basis risk.

Ideally, however, instruments to protect *specific* infrastructure investments would be designed project by project to incorporate customization both at the geographic level (insuring against the appropriate hazards) and at the project level (generating the appropriate cash flows for reconstruction). This project-by-project design is relatively simple to do for a project of limited geographical area (such as a dam or a nuclear power plant) but very difficult to do for an infrastructure asset that, by its very nature, is geographically dispersed (such as a fiber-optic network or a highway system). Such projects may be too widespread for customized project coverage, yet not uniform enough for country-level coverage. It is not clear how this coincidence between common ownership and geographical dispersion can be resolved.

6.2. Leveraging Investment in Project Monitoring

The structure of the project funding arrangement may offer additional opportunities to support catastrophe risk transfer. Infrastructure projects in

[11] If we consider investment in infrastructure projects as a good to be consumed, this necessary condition for the sponsor to increase the total amount of capital committed as the price of project completion falls is that the elasticity of demand for projects to sponsor exceeds unity, i.e., that abs(ε)>1. If the third-party sponsor is indeed the monopoly supplier of sponsorship, that this condition will always be satisfied follows directly from the first-order condition of optimal quantity (choosing quantity in the elastic portion of the demand curve). Thus, this demand effect will always *increase* the amount of funding devoted to these types of projects.

emerging economies generally involve a third-party sponsor, such as the World Bank, that provides capital and investment advice to the sovereign government, and may have a supervisory presence during project completion, but that does not generally control the day-to-day management of the project. Investors in project-tied CAT risk securities can rely on the project sponsor to provide at least partial monitoring—especially on large-scale infrastructure projects in emerging economies, for which the sponsor may well have an advisory team onsite during critical portions of the project. This structure allows for the investors in the catastrophe-linked instrument to take advantage of the "delegated monitoring" provided by the project sponsor,[13] reducing investors' costs of providing financing for these risks. Indeed, investments facing severe risks will likely draw *more* sponsor attention and financial commitment, rather than less (a situation analogous to that examined by Calem and Rizzo[14] in the private sector). The project sponsor may thus serve an informational role in project management, as a well as a financial role.

If investors can rely on the third-party sponsor for documentation of damage done to the project, recommendations for cost-minimizing ways to conduct emergency repairs, and similar reports—even in the event that a disaster occurs—this monitoring will presumably reduce the extent of moral hazard. Of course, to ensure that the amount of monitoring performed (and the focus of the information gathered) will be optimal, considering the interests both of the sponsor and the investors, requires that the sponsor of the project either be the investor in the catastrophe bonds or have some sort of high-powered incentives as part of a contractual agreement to act in a way consistent with being the investors' agent. Even if this alignment of incentives is only partially achieved, however, some reduction in moral hazard should ensue. Given that the barrier against constructing perfect hedges against catastrophe involves a tradeoff of moral hazard versus basis risk,[15,16] this reduction in moral hazard, in turn, allows the catastrophe-linked instruments to be constructed so as to behave more like excess-of-loss reinsurance and therefore reduce basis risk.[12] This moral hazard may already be contained by the sponsor's monitoring; quantifying this reduction, and communicating it to investors, will reduce the cost of catastrophic risk coverage provided by financial markets.

[12] The optimal design of this security will thus need to trade off efficient incentives for investment in mitigation (arguing for a state-contingent payoff, statistically correlated to but causally independent of the actual losses to the project) versus incentives for accurate reporting of damages done to the project (arguing for an excess-of-loss payoff structure, which can reduce basis risk if payments are conditioned on truthfully reported actual losses).

6.3. Interaction of Project Financing and Moral Hazard

One reason catastrophe-linked securities hold such promise is that, unlike other insurance markets such as health or automobile coverage, the probability with which disasters occur, and the severity of the disaster measured purely in terms of natural forces (e.g., wind speed, flood height of a river, earthquake magnitude, etc.) cannot be affected (for good or for ill) by any actions of the government, its citizens, or any party interested in the payoff of the catastrophe-linked securities. The *damages* caused by a disaster of arbitrary magnitude may be increased, however, because of the effects of moral hazard (either through lack of effective mitigation investments before a disaster occurs, or error-prone claims adjustment techniques and lack of attention to cost-minimizing repair techniques after a disaster occurs). Determining how the costs of these *ex post* opportunities for moral hazard can be contained is an interesting subject for further research and simulation.

6.4. Comparing Sovereign and Private Corporate Capital Structures

The sovereign position of the project sponsor for infrastructure projects has both benefits and drawbacks. In addition to the politically motivated commitment problem noted above, sovereign governments operate under capital constraints that private companies do not. A corporation can finance its operations, investments, and expansions through issuing equity, issuing debt, or retaining earnings from operations. Sovereign governments cannot issue equity and typically do not retain earnings; their financing is, by necessity, primarily debt. Therefore, all else equal, governments will have less flexibility in (and, presumably, higher costs of) financing than would an otherwise similar large corporation who had the choice to issue either debt or equity. Furthermore, governments value smooth growth in gross domestic product (the equivalent of return on equity for private ventures) but are restricted in their ability to diversify; they are limited to investing in infrastructure projects inside their own borders, unlike private investors who can diversify their portfolios as a first line of defense against catastrophe. A government's cost of capital will also rise faster than an equivalent company's in case of losses that would lead to insolvency (default on traditional sovereign debt) because an emergency equity recapitalization is not possible. Incorporating catastrophe-linked securities into the expansion path that a government desiring economic growth might pursue will require additional analysis, to integrate the risk-hedging abilities of the cat risk securities with the lower (but still significant, for emerging economies) costs of traditional sovereign debt.

6.5. Optimal Construction Technique—Embedding Efficient Levels of Flexibility

The correct method of organizing projects—in terms of materials used, completion schedules, and tradeoffs among amounts of capital, labor, energy, and materials to be committed to the project—will also depend on how project risk is to be handled. Catastrophe-linked instruments expand the choice set for how project managers can handle such future risks. As we have seen, risk management techniques that eliminate costs of financial distress can lead to reductions in expected completion costs. The main alternative to contingent capital availability for creating resilience to unforeseen project risks is embedded real options. Even optimally organized projects suffering from capital-availability risk may incorporate such real options as a hedge that increase production costs in high-probability scenarios to reduce production costs in disaster scenarios.[17] Inasmuch as such real options are costly to embed in the project, there may be gains from changing the organization of projects, if risk can be hedged using financial instruments, through substituting external sources of capital for the most costly of these embedded real options.[13]

Either embedded options or contingent capital may produce reduced total expected cost of completion, as argued analogously by Simon.[18] cat bonds will reduce total cost when these real options are expensive to embed and where their removal or omission will reduce project completion costs when the cat bonds assume their risk-bearing function.

[13] Of course, if these embedded options *reduce* the expected costs, even absent their benefits of reducing uncertainty and the cost-increasing effects of uncertainty, they should be left in—even if contingent capital is also used to further reduce costs.

6.6. Interactions Between Catastrophe and Fiscal Policy

A natural catastrophe leads to an instantaneous depreciation of a nation's capital stock. The optimal speed of replacing this stock depends on many macroeconomic variables. Questions for macroeconomic theory analysis include: Is there any difference, in terms of fiscal stimulus, between a macroeconomic shock caused by disaster versus the traditional multiplier on government spending? and How should government fiscal policy be adjusted both immediately after the disaster, in terms of trading off present consumption and future investment (especially the optimal speed of rebuilding the destroyed capital)?

6.7. Hidden Benefits of Catastrophe Through Forced Modernization

In this article, we have focused on completing projects in process, rather than protecting existing capital in place. Not all capital in place, however, is created equal. Some capital in place is particularly productive and carries high opportunity costs of destruction; some is obsolete. What completed projects may incorporate an implicit *advantage* of having obsolete capital destroyed and replaced with newer vintage capital, funded by cat bond payments? What implications follow for evaluating various types of infrastructure assets' economic vulnerability to disaster? In particular, which completed-project assets should be so insured, and at what level of coverage? To what extent are there additional benefits from using a state-contingent risk-transfer instrument to protect such complete-project assets by providing one large reimbursement at the national level, rather than purchasing traditional "replacement cost" coverage for each asset individually? These questions can be addressed through a model similar to ours, emphasizing the true opportunity cost of foregone project benefits rather than the "book value" of completed projects.

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The Financial Management of Catastrophic Flood Risks in Emerging-Economy Countries

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This article examines the potential of pre- and post-disaster instruments for funding disaster response and recovery and for creating incentives for flood loss mitigation in countries with emerging or transition economies. As a concrete case, we discuss the disaster recovery arrangements following the 1997 flood disaster in Poland. We examine the advantages and limitations of *hedging instruments,* which are instruments for transferring the risk to investors either through insurance or capital market-based securities. We compare these mechanisms with *financing instruments,* whereby the government sets aside funds prior to a disaster or taps its own funding sources after the event occurs. We show how hedging instruments can be designed to create incentives for the mitigation of damage to public infrastructure using the flood proofing of a water-treatment plant on the hypothetical Topping River as an illustrative example. We conclude that hedging instruments can be an attractive alternative to financing instruments that have been traditionally used in the poorer, emerging-economy countries to fund disaster recovery. Since very poor countries are likely to have difficulty paying the price of protection prior to a disaster, we suggest that international lending institutions consider innovations for subsidizing these payments.

KEY WORDS: Flood; extreme events; disaster financing; mitigation; insurance; catastrophe; risk management

1. INTRODUCTION

This article examines the potential of pre- and post-disaster instruments for creating incentives for flood loss mitigation and for financing disaster response and recovery in emerging economies. We focus on emerging-economy countries and, more specifically, on the transition countries of central and eastern Europe, where Poland serves as an example. These countries face distinct and serious problems in preparing for and responding to major floods and other disasters. Low incomes for most of their residents combined with very limited private insurance have placed the burden of investing in loss prevention measures and aiding the recovery process of disaster victims primarily in the hands of the government.

In addition, a large share of flood disaster losses in emerging-economy countries occur in the public sector, namely, to public buildings and infrastructure, where the impact on the entire economy can be substantial. For example, damage to electricity lifelines for any length of time can cause business interruption losses and lead to the insolvency of some commercial enterprises, not to mention the impact this may have on the residential sector. The governments of emerging-economy countries are ill prepared to

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assume the financial costs of flood loss mitigation, response, and rehabilitation. After a disaster, these governments often experience difficulty raising funds to assist the recovery process because of fiscal, political, and other constraints on borrowing, taxes, or diverting funds from other domestic budgets or internationally financed projects. This is particularly true following large-scale disasters where the damage is high relative to the country's gross domestic product (GDP), as with Hurricane Mitch, which devastated Honduras in 1998.

There are two principal types of mechanisms available to governments to fund the costs of recovery: *hedging instruments* and *financing instruments*.[3] Hedging instruments are pre-disaster arrangements in which the government incurs a relatively small cost in return for the right to receive a much larger amount of money after a disaster occurs. Since the financial risk of the losses from future disasters is borne by another party, these hedging instruments are also referred to as *ex ante risk transfer mechanisms*. Insurance and capital market-based securities are examples of hedging instruments. The government obtains financial protection after a disaster by either paying a premium for insurance or interest on a capital market-based security.

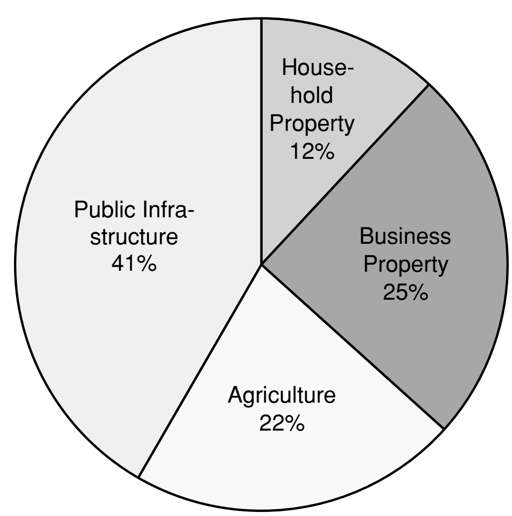
Financing instruments are arrangements whereby the government either sets aside funds prior to a disaster or taps its own funding sources after the event occurs. An example of a pre-disaster measure is a public catastrophe fund where the government implicitly self-insures by setting aside money to finance some of the recovery needs following a disaster. Alternatively, the government can mobilize its own financing sources by such policy instruments as imposing taxes, borrowing domestically or internationally, or diverting from the public budget.

To make the discussion of these two types of instruments more concrete, we focus on the impact of the 1997 Polish flood in the next section. Section 3 then examines the advantages and limitations of hedging instruments and how they compare to more traditional financing instruments. In Section 4, we show how insurance and capital market-based securities can be designed to create incentives for the mitigation of damage to public infrastructure using the flood proofing of a water-treatment plant on the hypothetical Topping River as an illustrative example. We conclude that hedging instruments can be an attractive alternative to the financing instruments that have been traditionally used in emerging economies to fund disaster recovery. Since very poor countries will have difficulty paying the price of risk-transfer instruments, we suggest that international lending institutions consider innovations for subsidizing these payments.

2. FINANCING DISASTER REHABILITATION: THE CASE OF THE 1997 POLISH FLOOD

In the summer of 1997, torrential rains caused several major rivers to break through flood dikes and cause disastrous flooding in southwestern Poland, the Czech Republic, and the eastern part of Germany. Poland was the hardest hit with more than 100 persons losing their lives and thousands left destitute. The flood was classified as having less than a 1 in 1,000 chance of occurring despite the possibility that climate change may be playing a role in increased precipitation.[(2)]

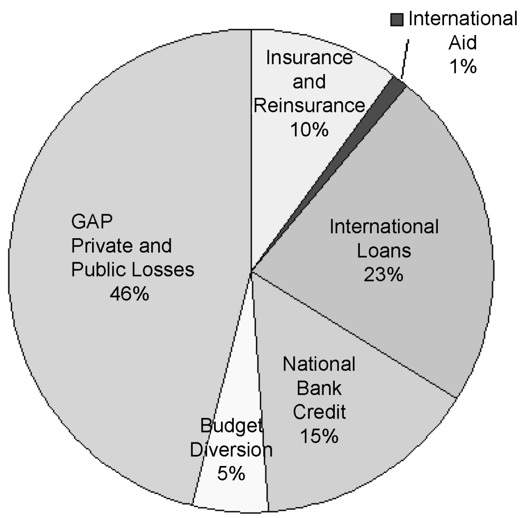
Direct property damage from the 1997 Polish flood has been estimated at about U.S. $3 billion or 2.7% of Poland's GDP.[(3)] As shown in Fig. 1, these losses were to household property (12%), business property (25%), agriculture (22%), and public buildings and infrastructure (41%). These damage figures do not include indirect losses in production and business disruption, which can be quite significant. In the discussion that follows, we focus on the financial responses of the private and public sectors to overall losses from the Polish flood disaster.



Source: Polish Statistical Bureau[(3)] (adapted).

Fig. 1. Direct losses from 1997 Polish flood.

[3] This distinction between hedging and financing instruments has been made by Doherty.[(1)]



Source: International Federation of Red Cross and Red Crescent Societies[(4)] and Kuc[(5)].

Fig. 2. The 1997 Polish flood: response as percent of losses.

2.1. The Role of the Private Sector

Traditionally, the Polish central government has provided relief by compensating victims for their private losses, which has added significantly to the government's post-disaster expenses incurred from repairing or replacing damaged public infrastructure. As Fig. 2 illustrates, the private and public expenses incurred from the 1997 flood were financed by private insurance, international aid and loans, a credit from the national bank, and diversions from other governmental budgets.

This financing, however, did not fully reimburse public and private victims for their property and infrastructure losses. The difference of about 46% of losses that was not covered by donations, insurance, and loans is illustrated in Fig. 2 by the GAP.

In Poland, the concept of individual responsibility and a viable private insurance market for providing protection are in their infancy. As shown in Fig. 2, only about 10% of the losses from the 1997 flood were covered by insurance (International Federation of Red Cross and Red Crescent Societies).[(4)] Prior to 1997, the Polish General Insurance Company (Powszechny Zaklad Ubezpieczen) was offering an insurance package covering natural disasters, including flood risk.[(6)] However, this insurance was rather expensive, and most households and firms in the region did not purchase coverage.[4] Private insurers recorded close to U.S. $0.25 billion in claims from the 1997 flood. Approximately half of these insurance losses were absorbed by international reinsurers.[(7)]

One hindrance to the private insurance market in Poland and throughout much of Europe is the lack of a concept of individual responsibility for the risks and losses. People increasingly expect protection from government against floods and hold the public sector responsible for compensating the victims. Floods are only partially seen as natural disasters or "acts of God" and are often framed as policy disasters, for example, lack of effective public policies for prevention and mitigation.[(8)] In a recent survey of the Hungarian public, the majority of the respondents viewed the government as primarily responsible for preventing losses from floods, as well as for compensating flood victims for their losses.[(9)]

Similarly in Poland, the public viewed the central government as largely responsible for the 1997 flood damage, mainly through its neglect in maintaining the system of dikes and preventing excessive exploitation of the forests.[(4)] Indeed, as the Polish flood waters rose, the prime minister made a public statement that uninsured victims had only themselves to blame for their financial losses and should not expect government help. This remark raised such a public outcry that the prime minister was forced to apologize.[(10)]

2.2. The Role of the Public Sector

The Polish public budget financed the 1997 post-disaster recovery and rehabilitation in three main ways: emergency response and cleanup; direct compensation or subsidized loans to the victims; and repair of damage to public property and infrastructure.[(10)] In the summer of 1997, the Polish government responded to the flood with more than half a billion U.S. dollars in private flood relief. In addition, there was extensive damage to public buildings and infrastructure—to more than 500 schools, more than 3,000 kilometers of roads, around 2,000 kilometers of rail lines, and hundreds of bridges. These damages have been estimated to be close to U.S. $1.2 billion or 41% of the total direct losses (see Fig. 1). A large share of the infrastructure damage was to water and sewage-treatment facilities. This underlines the importance of mitigating damage to water-treatment facilities, a topic we will turn to in Section 4.

The Polish government was not prepared for these financial outlays. In the absence of a catastrophe reserve, funds were initially diverted from other budgeted expenses, resulting in the freezing of

[4] Poland is not an exception in this regard. Globally, only about 8% of flood losses are insured, mainly in countries, such as the United States or France, with public insurance programs.[(11)]

public construction projects.[4] As shown in Fig. 2, the central government provided funds to cover approximately 15% of the total losses with a credit from the National Bank. The drawback of financing disaster recovery with this type of credit is that it is potentially inflationary, although in Poland the credit was quickly repaid at the market rate of interest.[5]

Even after borrowing from the National Bank, the Polish government was not able to fulfill all its promises and obligations for relief and infrastructure repair in a timely manner.[10] For example, it was estimated that due to lack of funds it would be several years before all the roads and bridges were repaired.[7] Limited financial assistance was provided from outside the country. For Poland and the Czech Republic, the United Nations Disaster and Humanitarian Aid agency recorded U.S. $10.3 million in relief assistance. Assuming that half of this sum was allocated to Poland, this covered only about 1% of the total direct losses (see Fig. 2).[5]

In Poland, aid in the form of low-interest loans from other countries covered about 23% of the losses (see Fig. 2). The European Investment Bank and the World Bank each approved U.S. $300 million to repair public infrastructure (roads, railways, bridges, and water facilities). In addition, the European Bank for Reconstruction and Development offered ECU 100 million in loans to damaged Polish and Czech cities.[4] Because the future taxpayers in Poland repay loans, only the subsidized interest counts as international disaster assistance.

With plans to join the European Union, the flood caught Poland in a tight fiscal austerity program. Hence, the central government declared that in the future it would transfer at least partial responsibility for disaster relief to new regional authorities. The second-level administrative authorities (*voivodeships*) have since been consolidated and given more financial resources. A third-level authority, the district, has been established to link the *voivodeships* with the communities. These regional authorities may play a more significant role in implementing risk management strategies for dealing with floods and other natural disasters.

2.3. Issues and Questions Raised by the Polish Case

In sum, the floods of 1997 in Poland illustrate the important role the Polish government plays in financing relief and rehabilitation after a flood disaster. The reasons for this include: (1) the lack of a concept of private responsibility and limited availability of private insurance; (2) the view that reducing the damages from natural disasters and compensating victims is primarily the collective responsibility of the government; (3) the relatively high losses to public buildings and infrastructure from the flood; and (4) the relatively small contribution of international aid and other forms of international loss spreading.

Individual households or businesses can take steps to prevent losses from floods, such as using water-resistant materials and water-tight closures for doors, windows, and other openings, building new structures at higher levels, or even moving out of flood-prone areas. Few, however, adopt these measures. In Poland, where per capita GDP is only slightly more than U.S. $4,000, the population living in high-risk areas cannot afford even relatively inexpensive measures to retrofit buildings or to relocate out of the floodplain.

The pre- and post-disaster response of the Polish government raises the following general questions regarding the financial risk management of disasters in Poland and other emerging-economy countries that we will address in the remainder of this article.

- What are the financial options available for governments to finance disaster recovery?
- What are the advantages and disadvantages, as well as the political constraints, of these financial options?
- What equity considerations need to be considered in choosing among these options?
- How can financing options provide positive incentives for the adoption of cost-effective loss mitigation measures?

3. GOVERNMENT OPTIONS FOR FUNDING DISASTER RECOVERY

Following the 1997 floods, *ex post* financing did not cover Poland's full losses and there were delays in repairing private homes and businesses, as well as roads, transmission lines, and other critical infrastructure. In poorer emerging-economy countries, these difficulties can be far more severe. In contrast to Poland, these countries' national debt burdens may make it impossible to issue government bonds or turn to other forms of borrowing following a major disaster. Additionally, the tax burden on the public may already be so high that there is no possibility of raising

[5] Throughout the developing world, international aid for natural disasters is relatively small. In 1996, for instance, catastrophe aid on the part of OECD countries was considerably less than U.S. $3 billion.[12]

funds domestically. This makes these countries dependent on subsidized loans and other forms of international aid.

Especially for very poor countries, some combination of hedging and financing instruments may be essential for aiding recovery from disasters. New infusion of capital is needed, given the small amount of private insurance, the limited ability of government to issue more debt or tap its reserves after a disaster, and the usually small amount of voluntary international aid that can be expected. Delays in infrastructure repair if recovery funds are not available will increase the length of household disruption and business interruption. These indirect costs are likely to greatly exceed the direct losses from the disaster.[13]

Such delays can also lead to secondary economic effects, such as deterioration in trade and government budget imbalances and increased incidence of poverty.[14,15] A timely recovery, on the other hand, will positively influence economic growth in the country. Macroeconomic models suggest that disaster shocks and rapid recovery periods following major catastrophes can have a significant positive effect on economic growth in the country.[16]

As we discuss below, the relative merits of hedging instruments versus financing instruments will depend on their costs, the political constraints, the risk aversion of those who absorb the catastrophe losses, and equity considerations. After discussing the characteristics of the different instruments, we examine the case for considering hedging instruments as an additional source of funding for future disasters.

3.1. Hedging Instruments

Like a private company, a government can hedge its risk of incurring large capital expenditures for post-disaster response and rehabilitation either by purchasing traditional insurance or issuing insurance-linked securities, such as catastrophe bonds, that can be bought and sold in the capital markets. A catastrophe bond (CAT bond) is an instrument whereby the investor receives an above-market return when a specific catastrophe does not occur (e.g., an earthquake of magnitude 7.0 or greater in the vicinity of Tokyo), but shares the insurer's or government's losses by sacrificing interest or principal following the event. With CAT bonds or other capital market instruments, insurers and reinsurers (and governments as insurers) can pay to transfer catastrophe risk to investors.

These relatively new instruments have been made possible mainly because of new scientific studies, engineering analyses, and advances in computerized catastrophe models that make it possible to estimate the risks and potential losses of future disasters more accurately than in the past.[6] The idea that governments in addition to private insurers and reinsurers might benefit from new hedging instruments has recently been proposed by Freeman *et al*.[18] Government or sovereign risk-transfer instruments could be designed in much the same way as they are for insurers. The main benefits of these instruments are that governments avoid having large capital outlays after the event and have a timely source of capital for disaster expenditures. If premium or interest payments are taken from general tax revenues, these hedging instruments spread the flood or other disaster burden to the general tax-paying public.

The size of the U.S. capital market alone is in the order of U.S. $26 trillion[19] and the average annual damage from floods is around U.S. $23 billion.[2] Hence these losses could be easily absorbed using these new financial instruments as sources of funds. However, these instruments have an associated cost to the risk-ceding government. In an ideal world, the wide distribution and diversification of catastrophic risks would result in premiums on insurance contracts or interest on CAT bonds that approximate the actuarial contract loss. In practice, the costs of risk transfer are above the actuarial fair price of these instruments. The fair premium does not account for the administrative costs, marketing expenses, and risk management services of the insurer/reinsurer. For insurance and CAT bonds that are tailored to reflect the specific conditions of the country and the hazard, these costs can be higher than for more routine risks.[19]

With regard to catastrophic insurance coverage, the relationship between the premiums and the actuarially fair price will vary depending on the available funds that insurers and reinsurers have for providing coverage. Several years ago, Froot and O'Connell[20] contended that the premium for catastrophe protection was considerably above its actuarially fair price. They attributed this differential to insufficient capital reserves, imperfect competition in insurance and reinsurance markets, ambiguity aversion by the insurer, inefficient underwriting practices, adverse selection, moral hazard, and/or government regulation.[7] More

[6] For more detail on these computer-based models and their opportunities, as well as their limitations, see Reference 17.

[7] The insurance premium may also reflect additional risk management services that need to be taken into account. We are indebted to Paul Freeman for clarifying this point.

recently, however, the premiums for catastrophic loss coverage offered by the insurance and reinsurance industry declined due to the large amounts of funds available for providing protection. Following the terrorist attacks of September 11 there was increasing concern by the investment community about providing coverage for catastrophic events and the price for this protection has risen; in the case of terrorist coverage, such insurance became unavailable or extraordinarily expensive.[21]

The interest premium on catastrophe bonds also reflects a concern by investors for the uncertainty of the risks associated with catastrophic events. An important question for the viability of catastrophe bonds is whether these high costs reflect only a temporary unfamiliarity on the part of investors with this new asset class. Bantwal and Kunreuther[22] suggest that the high spreads on CAT bonds may result from more fundamental issues that need to be resolved before they can play a significant role in transferring catastrophic risks. In particular, they contend that ambiguity aversion, myopic loss aversion, and fixed costs of education can account for the reluctance of institutional investors to enter this market.

If there are further declines in insurance premiums and/or the interest premium on CAT bonds decreases, can we expect these hedging instruments to become important for financing public disaster recovery in emerging-economy countries? Like any insurance instrument, this will depend on the degree of risk aversion of the government purchasing the instrument. This risk aversion, in turn, will depend on how the costs are passed on. If, for example, they are spread across many taxpayers such that no one individual bears significant losses, then in theory the government will be risk neutral. The importance of hedging instruments in the portfolio of a public authority will mainly depend on their relative attractiveness compared to more conventional financing options.

3.2. Financing Options

The public authorities in emerging-economy countries have several alternatives for financing disaster response and rehabilitation, including a catastrophe tax, a catastrophe reserve fund, government debt instruments, international bank loans, and a diversion of funds from their current budgets.

3.2.1. Catastrophe Tax

After a disaster, the government can raise funds for disaster rehabilitation with a tax. Like hedging instruments, a tax spreads the costs of the disaster response across the general public. If there is a social consensus that those not affected by the disaster should absorb a portion of the losses, a tax will be considered a fair way of paying the costs. If the public is risk averse and prefers smaller tax payments on a regular basis to the risk of a larger disaster tax, this would be a reason for the government to pay the extra costs for a hedging instrument. A tax also has the disadvantage that there may be large transaction costs to its implementation, and the funds will not be immediately available. For these reasons, in Poland, a tax was considered but rejected following the 1997 floods.[4] Finally, a catastrophe tax is often not possible for the governments of very poor countries since their taxpayers are already at the limit of what they can pay.

3.2.2. Catastrophe Reserve Fund

Many countries maintain a catastrophe reserve fund financed from tax revenues and invested in readily liquid assets. This financing option also spreads the costs among the taxpayers, but it differs importantly from a post-disaster tax. There is an additional cost equal to the foregone return from maintaining liquid funds and an additional benefit in having the funds immediately available with less transaction costs. A major problem with a fund is that it may not be able to supply sufficient funds, especially if the disaster occurs shortly after the fund is created. In principle, insurance companies also operate with a reserve to cover large outlays; however, private insurers are more concerned than the government that their reserves are sufficient to avoid insolvency and for this reason they diversify their insurance portfolio. In the absence of a solvency constraint, the government can assess the comparative attractiveness of a catastrophe fund by weighing the costs of holding liquid reserves in comparison with the costs associated with hedging instruments.

3.2.3. Government Debt Instruments

A common way for emerging-economy governments to raise funds after a disaster is to borrow from their central bank reserves or to issue government bonds. In Poland, a credit from the National Bank covered 15% of the 1997 flood losses. Although the interest on government-issued bonds will generally be less than the interest on CAT bonds or the premiums on insurance, there are disadvantages to this form of financing. There may be concerns about transferring the part of the disaster costs to future generations who will be burdened by this debt. In addition, issuing bonds or borrowing from central bank reserves will contribute to the budget deficit. This financing instrument may also transfer a part of the burden to the domestic and international investors in these bonds to the extent that the government defaults on its debt. The bond rating will depend on this default risk, which determines the cost to the government of borrowing funds.

3.2.4. *International Loans*

Emerging-economy governments have the opportunity to borrow at low interest rates from international lending organizations. This is a major financing source in the developing world. The World Bank estimates that it has loaned U.S. $14 billion over the last two decades to aid developing countries in their natural disaster response and rehabilitation,(15) and the Asian Development Bank estimates that 5.6% of its loans in the last decade were for this purpose.(23) In Poland, loans totaling about 22% of the direct losses from the 1997 flood were provided by the World Bank, the European Investment Bank, and the European Bank for Reconstruction and Development.(4)

Of course, the low interest charged on these loans makes them a very attractive financing instrument to emerging-economy governments. Through the interest subsidies, a portion of the costs is passed on to the shareholders of the international lending organizations and, eventually, to the taxpayers from the countries who provide funds to these organizations. Depending on the terms of the loan, the rest of the costs are paid by the present and future taxpayers of the borrowing country.

3.2.5. *Budget Diversions*

Governments of emerging-economy countries raise money for disaster response and rehabilitation by diverting funds from other budgeted items such as ongoing public infrastructure projects. This was the case in Poland after the 1997 floods, where the government froze infrastructure projects and used the freed-up funds for disaster recovery. This can be a rational response to a disaster if the marginal value of the funds for disaster response is higher than from its originally intended use. However, there may be hidden costs that are not taken into account, such as the costs of disruption of projects and the longer-term negative signals this sends to the international investment community.

International lending organizations are concerned about this form of disaster financing, since often funds are diverted from infrastructure projects that they are financing. The World Bank estimates, for example, that during the past decade up to 35% of its lending for infrastructure projects in Mexico has been diverted to finance disaster relief.(15)

3.3. The Case for Hedging Instruments

The relative merits of hedging instruments versus financing instruments will depend on their costs, the political constraints, the risk aversion of those who absorb the catastrophe losses, and equity considerations. The government should take account of these relative merits in deciding on the appropriate mix of financing and hedging instruments for covering the costs of future disasters.

In contrast to poor countries, most developed country governments have highly rated bonds and practically unlimited possibilities for post-disaster borrowing. For this reason, the case for these governments using hedging instruments as a cost-efficient alternative is greatly diminished. According to a representative of the Austrian Finance Ministry, raising post-disaster funds by issuing highly rated Austrian bonds is less expensive than an *ex ante* hedging instrument.(24) The transaction costs are lower for standard government bond issues, as are the interest rates, since there is little risk to the investors. After a declared catastrophe, the Austrian National Bank does not need the approval of the parliament for a budget change, so it can issue these bonds at very short notice. There may still, however, be equity advantages to a hedging instrument, since all the costs are borne by present-day citizens rather than by future generations.

The case for hedging instruments for Poland and other emerging-economy countries is not so clear. In a study of risk-transfer instruments for financing flood losses in Poland, Lizak(25) concludes that conventional financing instruments will have lower expected costs to the government. Yet, if a flood predicted to occur once every 100 years should occur early on in that period, the government authorities would incur less costs if they had purchased a CAT bond at the market rate. This study does not take into consideration the constraints the Polish government may have on financing alternatives, for example, the political constraints on government borrowing due to the fiscal austerity necessary for European Union membership. Yet, even this constraint is flexible as the Maastrich Treaty makes allowance for an exceptional and temporary budget deficit above the specified 3% if it results from an unusual event outside the control of the member state concerned.[8]

The case for hedging instruments is stronger for very poor countries that have difficulty raising funds after a major disaster because of low per capita GDP and an associated high risk of defaulting on their debt.[9] For "mega" disasters in very poor countries, there are clear advantages to taking steps in advance by purchasing hedging instruments. These instruments not only provide funds that would otherwise be difficult or impossible to raise, but the money is available immediately after a disaster (unless the trigger for the hedging instrument is based on losses from the disaster that may take time to fully estimate). By hedging its losses, the country will be able to accelerate its recovery.

Turning from the national government to the municipal and regional levels, there may be other considerations regarding the desirability of hedging. For instance, hedging instruments could play an important role for national governments to diffuse the responsibility for recovery to lower-level authorities if there is a view that those affected by the risk should bear some or all of the financial responsibility for recovery. In Hungary, the municipal governments already perceive little assistance from the national government and, for this reason, many authorities have insurance on public infrastructure. In other cases, the national government might lessen its financial responsibility by *requiring* the local or regional authorities to protect their infrastructure with insurance or by the purchase of CAT bonds. Otherwise, the political pressure at the local level for federal disaster relief may be too great to resist. If, on the other hand, there is a social ethic that disasters are the responsibility of the general taxpayer, then such requirements for financial protection at the local level would be inappropriate.

Financing instruments may also be difficult or very costly to implement. In some circumstances, for example after the Chernobyl accident, countries have imposed a disaster tax. But politicians are generally reluctant to turn to this unpopular alternative, and the citizens of very poor countries may be at their taxation limit. A catastrophe reserve fund may be politically more expedient, but there are high costs to holding a large reserve of liquid funds and the fund may not have time to accumulate sufficient capital before the disaster occurs. Finally, budget diversions are not only costly, but they disrupt government planning. Moreover, if the funds are diverted from internationally financed projects, they can diminish investor confidence in the country.

The expense of and constraints on government borrowing after a disaster may be the most compelling reason for governments to engage in the use of hedging instruments. Yet, as pointed out above, emerging-economy governments cannot easily afford the premium on insurance or the interest payments on catastrophe bonds. Organizations that provide loans to these countries, such as the World Bank, may be able to play an important role here.

To illustrate, the World Bank could serve as a broker by purchasing these bonds from emerging economies at a low interest rate and then issuing them to private investors. This would enable the government to obtain the bonds at lower cost while protecting the World Bank's investments in these countries. This type of arrangement would reduce the World Bank's need to provide subsidized disaster assistance, a role it played following the Polish floods of 1997.[(4)] In fact, humanitarian aid may be able to cover most of those losses that are uninsured.

4. LINKING LOSS PREVENTION WITH INSURANCE AND CATASTROPHE BONDS

A critical consideration in deciding on the comparative merits of hedging versus financing instruments is the effect this decision will have on the extent of anticipated damages. This section examines how insurance and hedging instruments in the form of catastrophe bonds can be combined with loss mitigation measures to reduce the overall damages of future disaster. We illustrate these concepts by focusing on a specific mitigation measure—flood-proofing a public structure to reduce future water damage.

Flood-proofing a structure involves the use of water-tight seals, water-resistant materials, water-tight joints, improving the strength of walls against hydrostatic presses, sealants that are impervious to water, and water-tight closures for doors, windows, and other openings.[(27,28)] Such measures have proven to be highly successful for preventing contact with or

[8] Council Regulation (EC) No. 1467/97 of July 7, 1997, Article 104s(2).

[9] This was not the case in Poland, where the default risk on Polish debt as viewed by the investment community did not change significantly following the 1997 flood. One reason for this was that domestic demand for the Polish bonds remained stable after the disaster.[(26)]

entry of flood waters and reducing damages from any water that does permeate the structure.

The structure we will focus on here is a water-treatment plant that provides clean water to residents and business in the surrounding area. Water-treatment plants are often located in floodplains so they are near well fields or the surface water that supplies the system. If the plant is flooded, this can have severe impacts on the operation of businesses as well as on the daily lives of residents in the area who rely on water from the plant.

The costs of shutting down a water-treatment plant can often be much greater than the repair of the structure itself. For example, the 1993 Mississippi River floods in the United States flooded the Des Moines (Iowa) Water Works plant that serves the city of Des Moines and adjoining communities. The plant was out of operation for 12 days and water was not safe to drink for another seven days. Businesses and government offices were forced to close because of lack of fire protection; bottled water and portable toilets had to be provided the residents. In fact, utility loss resulting from the 1993 midwest floods was a much more important cause of business closure in Des Moines than direct flood damage. Many businesses in the city had to suspend operations because of the loss of electricity, water, and sewer and wastewater services than because of a lack of customers and employee access to the business.(29) Contaminated water was also a major problem during the 1997 flood in Poland because there was considerable damage to water-treatment plants. Health officials broadcast warnings to the thousands of evacuees returning home that they should use only bottled water, in fear of outbreaks of dysentery, hepatitis, salmonella, and typhoid. In response, volunteer organizations from Austria and other countries set up temporary water-treatment facilities in the stricken areas.(4)

4.1. Estimating the Costs and Direct Benefits of a Mitigation Measure

To determine whether it is worthwhile to undertake a specific mitigation measure, one will want to undertake some type of benefit-cost analysis. Consider the decision on whether to flood-proof a water-treatment plant located on the banks of the hypothetical Topping River. One first needs to determine the costs associated with a specific set of mitigation measures. These include the relevant materials, personpower, and time associated with making the plant more flood resistant. It generally is not easy to specify these expenditures precisely, so some upper and lower estimates should be provided to reflect the nature of this uncertainty. The government can then evaluate the desirability of a particular mitigation measure over a realistic range of estimates regarding the costs of the project.

Mitigation measures reduce the direct and indirect impacts to the region following a disaster. Both of these effects need to be specified in evaluating the flood-proofing of a water-treatment plant. To undertake such an analysis, it is necessary to assess the degree of flooding of the Topping River. Hydrologists and engineers need to determine the probability that the Topping River will rise to certain levels and estimate the resulting direct damage to the water-treatment plant with and without flood-proofing. If the only losses incurred from flooding were the costs of repairing the water-treatment plant, then it would be a relatively simple matter to calculate the expected benefits from the loss-reduction measure. One would compare the damage to the plant for floods of different heights with and without flood-proofing the structure. The reduction in damage associated with each flood height would then be multiplied by the probability of this type of flood occurring. One would then sum all the figures to obtain the expected benefits from flood-proofing for any given year.

It is then necessary to consider the number of years that the plant would be operational and discount each future year's benefit to the present time period by using some agreed-upon discount rate. This would enable one to determine the expected discounted benefit of flood-proofing the plant. The mitigation measure would be considered attractive if the total costs of flood-proofing the water-treatment plant were less than its expected discounted benefits.

4.2. An Illustrative Example

For simplicity, and without loss of generality, assume that there is only a single type of flood that can occur on the Topping River and that the probability of such an event and the resulting losses are constant over time. We can characterize the problem as to whether the government should mitigate the water-treatment plant by defining the following terms:

- $C =$ up-front cost of mitigation measure
- $p =$ annual probability of flood (e.g., $p = 1/100$)
- $L =$ damage to water-treatment plant without flood proofing (e.g., $L = 500$)

- L' = damage to water-treatment plant with flood proofing (e.g., $L' = 300$)
- d = annual discount rate (e.g., $d = 0.10$)
- T = relevant time horizon (e.g., $T = 10$ years)

The decision as to whether to invest in a risk mitigation measure is determined by comparing the up-front cost of mitigation (C) with the expected discounted benefits [E(B)]. Assume that if a flood occurs on the Topping River within the T-year time horizon, the water-treatment plant will be restored to its pre-disaster condition and be functional again. Then [E(B)] can be characterized as follows:

$$\mathrm{E(B)} = \sum_{t=1}^{T} p(L - L'))/(1 + d)^t \qquad (1)$$

Consider the following simple example using the figures illustrating the notation above. Equation (1) now becomes:

$$\mathrm{E(B)} = \sum_{t=1}^{T=10} (1/100)(500 - 300)/(1.10)^t \qquad (2a)$$

$$\mathrm{E(B)} = \sum_{t=1}^{T=10} 2/(1.10)^t = 12.3 \qquad (2b)$$

On the average, the mitigation will yield twice the direct expected annual benefits so that over the 10-year time horizon it will yield total discounted expected benefits of 12.3. If the mitigation measure costs less than 12.3, then it is cost effective for the government to flood-proof the structure based on an analysis of direct expected benefits. If the water-treatment plant were expected to last for more than 10 years, E(B) would, of course, be greater than 12.3.

4.3. Indirect Benefits of Mitigation Measures

Floods and other disasters produce indirect or secondary impacts over time, such as family trauma and social disruption, business interruptions, and shortages of critical human services. These impacts need to be considered in evaluating specific mitigation measures.[30] The costs of some indirect impacts are easy to quantify, such as the expenditures associated with providing bottled water to residents because the water-treatment plant was not functioning. Other indirect impacts are less easy to determine and quantify. For example, how do you put a value on the loss of "community" associated with wholesale destruction of neighborhoods, of stress on families due to loss of homes or of fear and anxiety about having another home destroyed in a future flood?

In evaluating the benefits of a specific mitigation measure it is important to consider these indirect effects. Mitigating damage to water-treatment plants through flood-proofing would reduce the need to provide bottled water and toilet facilities to those residents who are not able to receive water. If a functioning water-treatment plant could have prevented some business interruptions, with the attendant disruptive effects on employees and the social fabric of the community, this would be considered an additional benefit of flood-proofing.[10]

More generally, one needs to take into account the *externalities* associated with disruption of a particular facility. The damage to the water-treatment plant created a set of losses to residents and businesses specifically because they could not receive pure water.

In the context of the Polish case, had the feared outbreak of disease from contaminated water during the 1997 floods actually occurred, then the human suffering and deaths, as well as the hospital costs and loss of work time, would have been additional costs of the damaged water-treatment plant.

4.4. Financial Incentives to Encourage Mitigation

In most emerging-economy countries, the authority and financing of disaster management is divided between the national, regional, and municipal authorities. In the past, municipalities in many central European countries have been dependent on the national government for their financial base, but this is changing as national governments place more responsibility on lower-level authorities. As pointed out in Section 2, there are newly formed regional authorities in Poland to implement risk management strategies for natural disasters. In Hungary, the 1995 Water Management Act continued state responsibility for operating and maintaining all state-owned structures, such as flood levees, through the 12 regional water authorities, but made local governments responsible for operating and maintaining municipal structures, such as water-treatment facilities.[31]

There are several reasons why these municipal and regional authorities may be reluctant to utilize some of their budget for investing in cost-effective mitigation measures to reduce future flood

[10] To the extent that other operations in Poland not affected by the disaster fill in the gap opened up by nonfunctioning businesses, then this is a transfer rather than a loss. If Poland needs to rely on imports from other countries because its own businesses cannot provide goods and services, then this is a loss to Poland.

losses for facilities such as a water-treatment plants. For one thing, the responsible public officials may underestimate the risks associated with a future flood by assuming that it will not occur over the next few years. Even if these authorities correctly perceive the chances of a flood occurring and the resulting damage with and without flood-proofing, they may underestimate the aggregate benefits of the mitigation measure by being myopic. For example, if a public official computes the benefits of flood-proofing only during his or her term of office, say three to five years, the mitigation measure may not be seen as cost effective. In the above example, a flood-proofing cost of 11 could be justified for a 10-year horizon but not for a five-year period.

In addition to short-time horizons, governments face severe budget constraints. A municipal or regional authority may decide not to incur the up-front cost of flood-proofing a facility, preferring to allocate these funds to measures that provide immediate benefits to the residents in his or her area, such as constructing a new school or hospital. Finally, there may be a lack of interest in loss-prevention measures if the local or regional authority anticipates disaster assistance from the national government for repairing the facility after a flood.

4.4.1. Role of Insurance

One way to provide post-disaster funds to municipal or regional authorities to cover the costs of repairing water-treatment plants and other public facilities would be through an insurance policy. If these authorities have readily available funds to repair infrastructure after a disaster, they will rationally not purchase insurance at a higher cost to them. Also, if the national governments are prepared to allocate post-disaster funds, which has been the case in many emerging-economy countries, the authorities will have little incentive to purchase insurance. However, with declining national budgets for disaster relief and rehabilitation, many municipal and regional authorities in the emerging-economy countries of central Europe have to depend increasingly on their own financial resources.

It is too early to assess the experience of the Polish regional authorities with regard to their disaster management strategies, including their portfolio of hedging and financing instruments. Taking another example, Hungary, it is notable that most municipal authorities voluntarily carry private insurance on public structures but not on their content. Ideally, the purchase of insurance can become an incentive for the local or regional authority to invest in cost-effective mitigation measures. More specifically, if a private insurer were to provide coverage against repairing damage to a water-treatment plant, it would base its premium on the figures provided by hydrologists and engineers with and without flood-proofing.

To illustrate how insurance could be utililtzed to encourage the flood-proofing of a water-treatment plant, consider again the Polish regional authority and the illustrative example in Section 4.2. Assume that an insurer offers to provide the authority with full coverage, such that it would pay for repairing the entire damage to the plant if a flood occurred. If the regional authority decided not to flood-proof the water-treatment plant, then the actuarially fair insurance rate would be determined by multiplying the probability of a flood (i.e., 1/100) by the resulting damage to the plant (i.e., 500) resulting in a premium of 5. If the plant were flood-proofed, then the actuarially fair premium would be 3 (i.e., $1/100 \times 300$). This means the insurer could reduce its premium for flood coverage by a 2 to reflect the expected annual reduction in claims it would have to pay the government for repairing damage to the water-treatment plant.

If Poland's regional authority were faced with budget constraints that made it difficult to incur the up-front costs of mitigation, then one option is for a commercial bank or an international organization such as the World Bank to provide it with a long-term loan for covering these costs. For example, if the cost of flood-proofing the water-treatment plant was 11, then a 20-year loan at an annual interest rate of 10% would require an annual payment of 1.06. The annual premium reduction of 2 for undertaking this mitigation measure would mean that the local or regional authority would save 0.94 (i.e., 2 – 1.06) each year. The decision to invest in cost-effective flood-proofing would have to be viewed positively if the authorities carried insurance and could acquire a long-term loan.

4.4.2. Role of Catastrophe Bonds

As pointed out in Section 3, catastrophe bonds can provide an additional source of funds to aid the recovery effort. They also provide an incentive for the local or regional authority to engage in loss-mitigation measures. Suppose in Poland that the regional authority knew that if a future flood of the Topping River occurred it would receive a certain amount of zlotys to aid the recovery effort, and this amount would be based on the height of the river when it flooded.

To the extent that damage to public facilities and infrastructure could be reduced through mitigation measures, there would be a lower expenditure on rebuilding these facilities. This would enable the regional authority to allocate more money to disaster victims than in the case where the facilities had not been flood-proofed.

The important point is that catastrophe bonds and insurance can be coupled with incentives and other regulatory mechanisms to reduce future disaster losses. They decentralize the decision-making process to the regional level by providing economic incentives to take steps now in order to save money later.

5. CONCLUSIONS

The governments of emerging-economy countries are largely responsible for flood disaster response and rehabilitation, as well as mitigation of the losses. Yet, they often experience difficulties in providing funds for these purposes. These difficulties can have long-term effects on the economies of these countries and the welfare of the public.

We have compared the relative merits of pre-disaster hedging instruments, such as insurance and catastrophe bonds, with financing instruments, such as post-disaster taxes and government borrowing. We have shown that this comparison is multifaceted. It depends on the costs and availability of these instruments, the risk aversion of those who will ultimately absorb the losses, political constraints, and equity considerations. We were particularly interested in the impact these instruments have on the adoption of disaster loss prevention measures.

The comparative attractiveness of pre-disaster hedging instruments will also depend on the nature of the hazard and the circumstances of the country. Building on experience from the 1997 flooding in Poland, there are a number of factors that may constrain the availability of financing alternatives in the future. In particular, post-disaster borrowing may be limited by fiscal considerations and the political difficulties of imposing a disaster tax or transferring funds from other budgetary commitments.

Hedging instruments may be particularly important for financing disasters in countries anticipating disasters that comprise a large proportion of their GDP. After such events the governments of poor countries will have an extremely difficult time raising sufficient funds from traditional sources. International lending organizations, such as the World Bank, will feel pressure following these events to provide loans to aid the recovery process, thus diverting funds from other development projects. If the country has insurance or has purchased CAT bonds in advance of the disaster, this will channel funds from international capital markets to aiding the recovery effort.

An additional advantage of hedging instruments is the economic incentives these instruments can create for preventing losses, thus encouraging municipal and regional government authorities to invest in cost-effective mitigation measures. For these and perhaps other reasons, it may be necessary to develop a set of requirements coupled with financial incentives to encourage the adoption of cost-effective mitigation measures. We have focused in this article on financial incentives, but recognize that a risk management strategy will also need to include well-enforced regulations, such as building codes and land-use regulations.

Poor countries will have great difficulty paying the costs of *ex ante* transfers. Since the World Bank and other lending organizations are concerned about the losses on their investments in these countries by having funds diverted to disaster relief, innovative financing mechanisms to aid these countries might be considered. Helping poor countries to afford these pre-disaster protective measures may not only be desirable on equity grounds, but would avoid having investors depicted as capitalizing on the potential catastrophic losses facing poor countries from future natural disasters.

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