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Flood Risk = Hazard • Values • Vulnerability

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Abstract: *Worldwide, flooding is probably the number one cause of losses from natural events. No region in the world is safe from being flooded. As the flood risk is a function of the flood hazard, the exposed values and their vulnerability, the increase in flood losses must be attributed to changes in each of these aspects. While flood protection measures may reduce the frequency of inundation losses, appropriate preparedness measures lessen the residual financial risk considerably. Besides public and private measures, insurance is a key factor in reducing the financial risk for individuals, enterprises, and even whole societies. In recent years, the demand for flood insurance has been growing. This is forcing the insurance industry to develop appropriate solutions. At the same time it is vital for the insurers to know the probable maximum losses they might face as the result of an extreme event.*
Keywords*: flood types, flood disasters, flood risk, flood preparedness, flood insurance*

Introduction

In many parts of the world, flooding is the leading cause of losses from natural phenomena and is responsible for a greater number of damaging events than any other type of natural hazard. According to the data collected by Munich Reinsurance Company (Munich Re), roughly half of all fatalities due to nature's forces and a third of the economic losses can be attributed to flooding (Munich Re, 2000). Flood damage has been extremely severe in recent decades, and it is evident that both the frequency and intensity of floods are increasing. In the past ten years losses amounting to more than US$ 250 billion have had to be borne by societies all over the world to compensate for the consequences of floods. There are countries, such as China, where flooding is a frequent, at least annual, event and in others, such as Saudi Arabia, where inundation is rare but its impact is sometimes no less severe. No populated area in the world is safe from being flooded. However, the range of vulnerability to the flood hazard is very wide, in fact wider than for most other hazards. Some societies (communities, states, regions) have learned to live with floods. They are prepared. Others are sometimes completely taken by surprise when a river stage (or the sea) rises to a level neighboring residents have never experienced before in their lives.

The dramatic increase in the world's population, in certain regions in particular, creates the necessity to settle in areas that are dangerous (Kron, 1999b). Additionally, the movement of political, social, and other refugees, the increased mobility, and the attractiveness of areas that have a beautiful natural environment and a mild climate lead to people settling in places whose natural features they do not know. They are not aware of what can happen and they have no idea how to behave if nature strikes.

During the last few decades, many floodplains have been occupied by residential areas and industrial parks. These areas are usually flat and not necessarily good for agricultural use. The nearby rivers have been tamed and confined in narrow strips by dikes, and cheap and attractive land has been reclaimed. Towns and villages have declared these areas residential areas and, therefore, many potential buyers of property counted on there being no flood hazard to be feared.

Types of Flood

In insurance contracts, flooding is defined as a "temporary covering of land by water as a result of surface waters escaping from their normal confines or as a result of heavy precipitation." There are three main types of flood and a number of special cases (Munich Re, 1997). The main types are: storm surge, river flood, and flash flood; special cases include tsunami, waterlogging, backwater (e.g., caused by a landslide that blocks a water course), dam break floods, glacial lake outburst floods (GLOF), groundwater rise, debris flow events, and others.

Storm surges can occur along the coasts of seas and big lakes. They bear, along with tsunamis, the highest loss potential of water-related natural events, both for lives and for property. Improved coastal defense works have prevented very high losses in developed regions during the recent past, but the loss potential of storm surges remains huge.

River floods are the result of intense and/or persistent rain for several days or even weeks over large areas, sometimes combined with snowmelt. The ground becomes fully saturated and the soil's capacity to store water is exceeded. It behaves as if it were sealed and the precipitation runs off directly into creeks and rivers. The same effect is produced by frozen ground, which also prevents the water from infiltrating into the soil. River floods build up gradually, though sometimes within a short time. The area affected can be very large in the case of flat valleys with wide flood plains. In narrow valleys the inundated area is restricted to a small strip along the river, but water depths are great and flow velocities tend to become high, with the result that mechanical forces and sediment transport play a major role in causing damage. Although inundation due to river floods starts from a water course and is somewhat confined to its valley, the areas affected can be far greater than those hit by storm surges.

Flash floods sometimes mark the beginning of a river flood, but mostly they are local events relatively independent of each other and scattered in time and space. They are produced by intense rainfall over a small area. The ground usually is not saturated, but the infiltration rate is much lower than the rainfall rate. Typically, flash floods have an extremely sudden onset. A surge may rush down a valley that does not even have a creek at its bottom. Such a flood wave can propagate very quickly to locations some tens of kilometers away, where the rainstorm is not even noticeable. From this fact comes the – probably true – saying that "in a desert more people drown than die of thirst." Forecasting flash floods is almost impossible, with lead times for early warnings on the order of minutes. Although flash floods usually occur in a relatively small area and last only a few hours (sometimes minutes), they have an incredible potential for destruction.

Flash floods are not only associated with fast flowing water in steep terrain, but also with the flooding of very flat areas, where the slope is too small to allow for the immediate runoff of storm water. Instead, water accumulates on the surface, in depressions that are sometimes not even noticeable or in other lower lying areas such as street underpasses, underground parking garages, and basements. Hence, the term "flash" denotes something that happens quickly and not something that moves quickly.

Flat areas also are prone to another kind of widespread flooding called waterlogging. In China this is a common phenomenon. Extended rainfall of considerable depth – in some areas associated with the term "plum rain" (mei yu) because of its occurrence during the season when the plums ripen (June to July) – inundates sometimes the whole landscape.

Recent Flood Disasters

Reinsurance companies, due to their worldwide activities, are among the best sources for natural disaster statistics (Kron, 2000; Munich Re, 2000). Their analyses focus on three aspects: the number of people affected (fatalities, injured, homeless), the overall economic damage to the country hit, and the losses covered by the insurance industry.

Natural disasters resulting in thousands of deaths almost always hit poor countries and are mainly caused by earthquakes. The poverty aspect is related to the higher vulnerability in less developed countries (poorer quality of structures, more people) to the cause (earthquakes) and the sudden onset of such events, which strike without warning. In the past (more than ten years ago), floods also were responsible for a huge number of deaths. This is not so today, because early warning has become more operational, more reliable, and, hence, more effective.

In the statistics of economic losses floods take a leading position. While two earthquakes (Kobe: US$ 100 billion; Northridge: US$ 44 billion) still have been the costliest natural disasters so far, floods, which usually affect much larger areas than earthquakes and occur much more frequently, have at least the same importance. Not only the great disasters, but also the vast number of small and medium-sized events causes tens of billions of dollars of losses every year for economies and severe distress to people. Floods are responsible for probably more damage than all other destructive natural events combined. Additionally, the financial means spent by societies all over the world on flood control (sea dikes, levees, reservoirs, etc.) is a multiple of the costs they devote to protection against other impacts from nature.

Table 1 shows the greatest flood losses in recent years. It is apparent that China is the country whose economy suffers most and most regularly from such disasters. It

Table 1. The costliest floods since 1990 (original values, not adjusted for inflation)

Rank	*Year*	*Country/Countries (mainly affected regions)*	*Economic losses US$ billion*	*Insured (%)*
1	1998	China (Yangtze, Songhua)	31	3
2	1996	China (Yangtze)	24	2
3	1993	USA (Mississippi)	21	6
4	2002	Central Europe (Elbe, Danube)	19	16
5	1995	North Korea	15	0
6	1993	China (Yangtze, Huai)	11	0
7	1994	Italy (North)	9.3	<1
8	1993	Bangladesh, India, Nepal	8.5	0
9	2000	Italy (North), Switzerland (South)	8.5	6
10	1999	China (Yangtze)	8.0	0
11	1994	China (Southeast)	7.8	0
12	1995	China (Yangtze)	6.7	1
13	2001	USA (Texas)	6.0	58
14	1997	Czech Rep, Poland, Germ. (Odra)	5.9	13

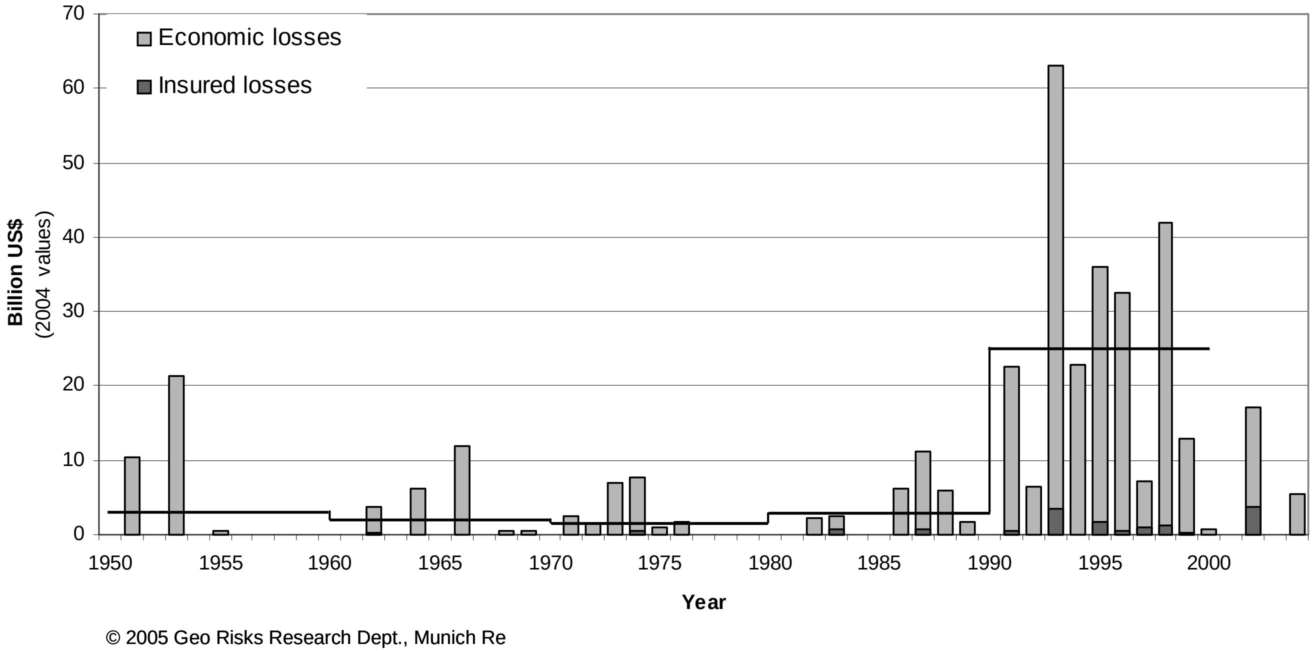

Figure 1. Great Flood Disasters 1950 – 2004. Note: The tsunami disaster in 2004 is not considered; it is included in the statistics as an earthquake loss

also becomes clear that great flood losses can occur in practically any region of the world.

The insured share of flood losses from these major events has usually been relatively small. For the insurance industry, windstorms are clearly the most critical loss events, simply because the insurance density is highest for this type of peril. However, a tendency towards higher insurance densities for flood may be observed worldwide and, in particular, a tendency towards extreme single insurance losses due to water. A good example of this is Tropical Storm Allison, which drenched the Houston/Texas area with over 750 mm of rain in just five days in June 2001 and caused insured losses of US$ 3.5 billion. With economic losses of US$ 6 billion, this event ranks 13 in Table 1, having by far the highest share of insured losses of the 14 events listed.

Table 1 does not reveal any trend. However, a distinct change in flood losses over time becomes apparent in Figure 1. Here the losses from great flood disasters for each year since 1950 are plotted versus time. The average annual losses from such catastrophes in the period since 1990 have become a multiple of the values in the previous decades.

Natural catastrophes are classed as being *great* if they cannot be handled by the affected country/region alone, but require interregional and international assistance. This is usually the case when thousands of people are killed, when hundreds of thousands are made homeless, or when a country suffers substantial economic losses, depending on the economic circumstances generally prevailing in that country. Great catastrophes can be analyzed very well in retrospect because even records that go back several decades can still be investigated today. If the statistics were based on all the loss information collected (including small and medium events), the influence of advanced communication technology over the past decades would introduce an unacceptable bias.

Losses that have been experienced describe the past. What can be expected in the future must be based on these experiences, on the one hand, but on the other hand, on the analysis of each loss event in order to determine the respective factors that exerted their influence on it. From this analysis an expected value can be derived for a (future) loss, which is called *risk.*

Definition of Risk

The term *risk* is understood in different ways by different people. While this plurality in usage may often be of no consequence, *risk* should be defined, for scientific discussions, in an unambiguous and consistent way. In the scientific community, it is widely agreed that risk is the product of a hazard and its consequences. Where there are no people or values that can be affected by a natural phenomenon, there is no risk. In a similar way, a disaster can only occur when people are harmed and/or their belongings damaged. A very strong earthquake in an uninhabited region without human property cannot result in disaster. Similarly, a strong earthquake in a well-prepared region will not be catastrophic. In a poorly prepared region, however, even a moderate tremor may cause a devastating catastrophe. The earthquake *hazard* is clearly highest in the first case, while the earthquake *risk* is highest in the third case. Hence, three components determine the risk:

1. the hazard**:** the threatening natural event including its probability of occurrence;

2. the values or values at risk: the buildings/items/humans that are present at the location involved;
3. the vulnerability: the lack of resistance to damaging/destructive forces.

In its most simple form, the risk is computed by multiplying these three components. If values at risk and vulnerability are combined to form the variable C denoting the consequences resulting from a single event with the probability P, the risk – from only this one event – can be written as

$$R = C \cdot P \tag{1}$$

Usually, however, natural hazards do not manifest themselves in one single event with a given probability of occurrence, but in many different forms with an almost infinite number of variations. In the case of the hazard being flood discharges Q, Equation 1 must therefore be written in an integral form

$$R = \int_{Q_a}^{\infty} C(Q) \cdot f(Q)\ dQ \tag{2}$$

where $C(Q)$ is the costs/losses caused by a given discharge Q and $f(Q)$ is the probability density function of the discharge. The integration must be performed for the whole region above the flood value Q_a, for which losses start to occur.

In general, this integration cannot be done analytically, except for certain specific combinations of $C(Q)$ and $f(Q)$. For example, if a linear function of $C(Q)$ is chosen for $Q_a<Q<Q_b$ with values $C(Q) = 0$ for $Q < Q_a$ and $C(Q) = C_{max}$ = const. for $Q > Q_b$, and the one-parameter exponential distribution is chosen for the discharge probability density function (see Figure 2)

$$f(Q) = \lambda\, e^{-\lambda(Q-Q_o)} \tag{3}$$

Equation 2 can be integrated directly and written as

$$R = \int_{Q_a}^{Q_b} \frac{C_{\max}}{(Q_b - Q_a)} \cdot (Q - Q_a) \cdot \lambda\, e^{-\lambda(Q-Q_o)}\, dQ + \int_{Q_b}^{\infty} C_{\max} \cdot \lambda\, e^{-\lambda(Q-Q_o)}\, dQ \tag{4}$$

After some calculations the following equation is obtained (Kron, 1993)

$$R = C_{\max} \cdot \frac{e^{-\lambda Q_o}}{Q_b - Q_a}\left[Q_a e^{-\lambda Q_b} - Q_b e^{-\lambda Q_b} + \frac{1}{\lambda}\left(e^{-\lambda Q_a} - e^{-\lambda Q_b}\right)\right] + C_{\max} e^{-\lambda(Q_b - Q_o)} \tag{5}$$

In practice, such analytical calculations for assessing the risk are seldom possible, mainly because the data base usually is very thin. Instead, simplified procedures are applied (Munich Re, 1997).

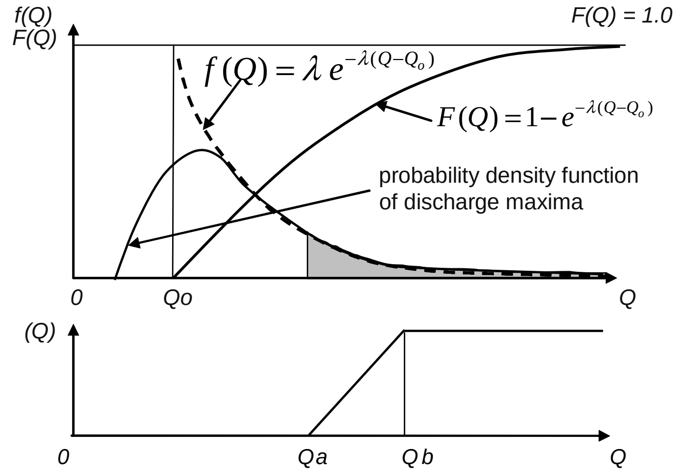

Figure 2. "True" probability density function of discharge maxima, approximated probability density function, *f(Q),* cumulative distribution function, *F(Q),* and consequence function, *C(Q)*

Reasons for the Increasing Flood Risk

The fact that flood catastrophes are becoming more and more frequent and severe – and the flood risk is, therefore, higher – although protection and preparedness measures have been improving, is addressed in the following by highlighting some aspects of each of the three components that determine the risk.

Increasing Hazard

Over the past decades there have been a number of developments that have certainly caused changes in the flood hazard, i.e. in the occurrence frequency and magnitude of high flows. Practically all of these developments must be attributed to human activities, even the ongoing shift in the hydrologic regime due to climate change.

The development of new settlement areas directly leads to a reduction in the storage volumes of natural retention areas. Flood plains are occupied by new settlements or otherwise heavily used. This often requires river training in the form of channel straightening and dikes that sometimes even prevent agricultural areas from being flooded. In this way flood peaks and their propagation velocities become higher and increase the flood hazard downstream. In a similar way, the increase in anthropogenic ground sealing by parts of the catchment being covered by impermeable or at least less permeable surfaces such as houses, roads, parking lots, etc. causes a further increase in the runoff and – in some cases – in the peak flows in the rivers. However, one should be wary of blaming the above changes for the increase in the flood hazard everywhere. While they may have dramatic consequences in some areas (particularly in small catchments), their influence usually becomes smaller and finally almost negligible as the size of the catchment and river network increases. A flood along a large river is not created by impermeable urban areas; it needs quasi-impermeable rural areas as well. This "natural impermeability" is caused by antecedent rainfall that soaks the soil and uses up its storage capacity.

Lumped assumptions that link higher flood peaks to higher flow velocities are not always valid either. In a river system, the crucial point is how the hydrographs from the various branches act together, i.e. how they are superimposed on each other. Hence, a faster propagating flood wave from a major tributary may even be advantageous if it enters the main river before the peak from the upstream drainage area has arrived there, and, therefore, alleviates the situation.

One certain consequence of faster flowing water is increased erosion of the channel and its bed. This may increase the threat to bridge piers and abutments, dikes, and embankments, and reduce the storage capacity of reservoirs where the sediments settle. But as far as the higher flood hazard is concerned, erosion processes in the catchment are a more important factor. In many places, a change in the use of land (agricultural areas instead of pastures and forests) is a major reason for a dramatic increase in the sediment transport rates of rivers and deposition rates in downstream reaches. This deposition not only causes the bed levels to rise, but also leads to the retention areas along the rivers being filled with sediment, and, hence, more and more inactivated. The water-covered areas along the Yangtze River between Yichang and Jiujiang shrank from 15,000 km^2 in 1945 to 300 km^2 in 2000. More than 1,000 lakes with a total volume of 50 billion m^3 disappeared. Dongting Lake's bed has been rising at a rate of 4.5 cm per year; of its 19th century area of 6,300 km^2 a mere 2,700 km^2 is left, and the storage capacity has fallen from probably well above 40 billion m^3 to 17 billion m^3 (Yu, 2001). In the Jingjiang reach, the Yangtze River bed today is 8 to 15 m higher than parts of the surrounding floodplain (Wu and Jiang, 2001). These developments seem to be the main negative result of the deforestation of areas in the river's upper sub-catchments in Sichuan. The often-blamed increased runoff from deforested areas probably has a less decisive influence on floods in cases where hundreds of millimeters of rain fall.

Finally, the implications of a changing climate should not be forgotten. In many places the hydrologic impact of climate change on floods is not primarily due to the increased annual rainfall depth but to the shift in the seasonal rainfall pattern. A strong tendency towards a higher variability in weather parameters (e.g., rainfall intensity) is expected, leading to more pronounced extremes, in terms of both flood and drought. On the global scale, the expected temperature increase of 1.4 to 5.8°C by the end of this century (IPCC, 2001) will lead to higher rainfall amounts and to higher probabilities of extremes.

Increase in Values

The dramatic increase in the world's population and in particular in certain regions certainly constitutes the main reason why losses from natural disasters have been almost exploding in recent decades. The increase in losses from natural events is a direct function of the number of people who must or wish to settle in flood-prone areas, and a function of the increasing values they possess and their greater susceptibility to water.

Floodplains (and coastal plains) are, if one neglects the flood hazard, well suited for development. They are flat, provide easy access to process and cooling water, allow transport of raw materials and products by boat and are easy to develop with roads, water and power networks, and other lifelines. The river is usually thought to be "tamed" by a dike, and residents and property owners feel safe, especially if no major event happens in the first few years after they have occupied the land. In such a situation, huge values are built up in the form of buildings, equipment, and stocks. Additionally, many jobs are dependent on the industries and businesses located on floodplains, which becomes a problem as soon as production or business is interrupted by inundation and people cannot work or even go to work.

Generally speaking, people today own more things than ever before and things with higher values as well. The boiler for the central heating system, a freezer, a high-tech washing machine, and many other such items are typically located in the lower parts of a building, most often in the basement. Due to their weight or because they are fixed to the building, some of these devices are difficult to move to a higher level when a flood rises. Furthermore, many home owners have changed their basements from storage rooms for coal, wood, potatoes, apples, preserves, and all kinds of unused or seldom used stuff into party cellars, children's playrooms, and home offices equipped with computers.

The situation is basically the same in business and industrial buildings too. Here, electronic and electrical installations such as computer centers, air-conditioning control centers, and elevator machinery are the typical and highly vulnerable contents of basements. Underground parking garages for employees and customers are component parts of most new office buildings. Although cars are relatively easy to remove, they still represent a very high loss potential which could be realized in the event of a flash flood when there is no lead time for warning.

Increasing Vulnerability

In former times, most belongings were hardly susceptible to damage by water. The ones that were could be carried to a safe place and even if they were lost, the damage was relatively minor. Today's contents often suffer total damage when they get in contact with water. Especially electric and electronic machines, appliances, and other devices are highly vulnerable to humidity and dirt and other pollution particles, which are always found in flood waters.

The change from stove heating to central heating is maybe the most important difference. Not only the central heaters are installed in the basement and cannot be removed, but there are also oil tanks that can lead to severe pollution when they are flooded. This means much more effort has to be put into the flood protection of low-lying parts of residential buildings.

An important aspect is the already mentioned feeling of security many people have along water courses. Improved and sometimes sophisticated flood control systems consisting of reservoirs, retention basins, and levees make sure that floods with a high frequency (once every few years on average) do not cause any problems. People ignore the fact that they live in areas endangered by floods and often "forget" their exposure in a surprisingly short time after a flood they have actually experienced, and after a period of raised awareness they return to ignorance.

Recent large flood events in Europe have revealed some factors that influence the extent of flood losses. In December 1993 and in January 1995 the Rhine River and some of its tributaries experienced two extreme floods with recurrence intervals of more than 50 years in its middle and lower reaches. The economic losses from the second event (US$ 320 million) were only about half as big as those from the first (US$ 600 million), although the two events were of comparable size. One of the main reasons for this difference was the fact that the previous flood event was still fresh in people's minds, i.e. they knew what to do when the water rose again, and they had learned some lessons and had taken appropriate action (e.g. replacing oil burners and tanks with gas heating).

In contrast, practically no lessons were learned in Northern Italy from a flood event in 1994. Settlement practice in Italy is still far from being effectively monitored and controlled. Houses are often still built very close to torrent-type creeks and rivers. These were destroyed in large numbers by the raging waters in 1994 and again in 2000. Besides flooding many areas, the torrential rainfall in October 2000 – up to 740 mm in four days at some locations – also triggered numerous disastrous landslides and debris flows.

Italy is not an atypical example though. The land-use situation in other countries is not good either. The floods in the United Kingdom in the autumn of 2000 led to various political initiatives aimed at stricter land-use regulations, and the very same aspects were discussed in Germany after the August 2002 floods. In China, polders built to store flood waters are today occupied by millions of people and are not usable anymore. One example is Jingjiang polder on the Yangtze River. It would be impossible to evacuate the 600,000 residents in time if a big flood were to occur, and they would face an inundation depth of six to nine meters.

The Partnership for Risk Reduction

A loss event will happen practically anywhere sooner or later. The lower the frequency of such incidents, the stronger the tendency of the threatened individuals, companies, etc. to shift the responsibility for protection and preparedness to public authorities and agencies (state, provincial, local governments, non-governmental disaster assistance, and relief organizations, etc.). This attitude also depends, of course, on the respective society. While the people in some countries tend to prefer not to worry about natural hazards and ask the government to take care of the risks (and pay for this "service" in the form of taxes), the people in other cultural environments tend to rely much more on themselves. Both extremes are not ideal. The most efficient way to cope with nature's destructive forces is on the basis of cooperation between the people and the government plus a third component, the insurance industry. An integrated approach must be adopted, in which all three components must be involved (Figure 3). Among them, the tasks can be shared to come up with an efficient and hopefully optimal strategy for risk reduction, which also means loss reduction and disaster prevention. Only combined efforts that include initiatives, activities, awareness, preparedness, appropriate response to an event, etc. by the three groups allow minimization of the total costs and prevent and mitigate the impacts from floods and other natural events.

Minimization of costs, however, does not necessarily mean minimization of losses. Costs also include the financial means necessary to provide a certain minimum level of protection by building and maintaining the basic disaster control measures. Structural and non-structural measures are very expensive. Their costs increase non-linearly with the level of protection. Hence, a compromise must be found between the cost of construction and expected losses. If, as an example, constructing a flood control system that is designed for a 50-year recurrence interval costs 10 currency units (CU) plus 0.5 CU per year for maintenance, personnel, and interest, the total cost during an assumed lifetime of 30 years is 10 + 30 x 0.5 = 25 CU. If, instead, a scheme providing a 100-year safety is constructed with basic costs of 25 CU and overheads of 0.7 CU/yr, the total amount is 25 + 30 x 0.7 = 46 CU. Further assuming expected losses from events larger than 50-year events to be 1 CU per year, for events larger than 100-year events 0.6 CU per year, a loss reduction by going from the 50-year scheme to the 100-year scheme of (1 – 0.6) x 30 =

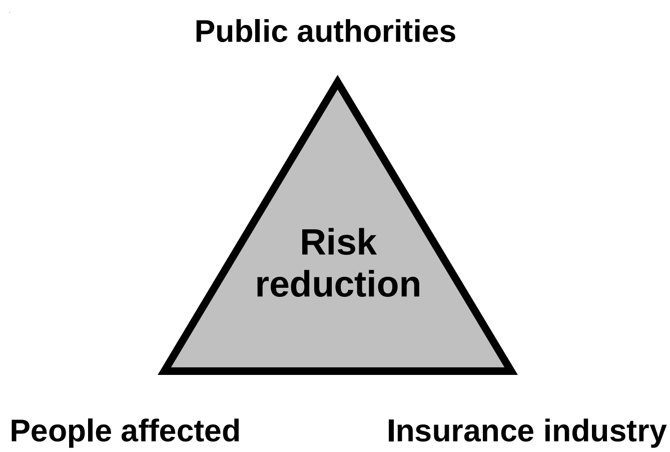

Figure 3. The partnership for risk reduction

12 CU during the 30-year lifetime is obtained. This is much less than the difference in costs of 46 – 25 = 21 CU. In this case the increase in safety is – from a purely monetary point of view – not justified.

Such calculations become difficult if non-monetary losses and benefits are involved, in particular the threat to human lives. Among further features that may also influence the decision and make the decision-makers refrain from deciding on the basis of cost-benefit analyses are endangered natural habitats (which may be affected negatively either way, by the high-safety or by the low-safety option, depending on the specific case), inconvenience, if only for certain people, and even such aspects as national pride.

In general, a society must agree upon the basic flood protection level for everybody, which is paid by the whole community, i.e. by the affected and by the unaffected citizens alike. While one society is willing to provide a high level of safety, the other shifts responsibility for protection to the individuals, who must then decide how much risk they want to bear themselves and how much they want to transfer to insurance. According to this decision the responsibility is distributed among the three components of Figure 3.

Public Authorities

The public sector is responsible for the basic needs that are not directed to individuals but to a larger part of the community. Measures to be provided by the state include

- flood control management;
- structural measures such as dams, reservoirs, retention basins, polders, levees, flood bypasses, flood channels, diversions, etc.;
- non-structural measures such as monitoring, forecast, runoff control, early warning systems;
- preparedness measures;
- education of and information to the public;
- communication systems, dissemination of warnings, alarm plans, evacuation plans;
- selection and training of personnel for emergency staff;
- relief services;
- land-use planning and enforcement of land-use restrictions;
- immediate re-establishment of lifelines and speedy reconstruction of damaged infra-structure after a disastrous event; and
- grants, low-interest loans, and/or tax relief for badly hit disaster victims (individuals and companies).

People Affected

Given a basic level of protection, this second group is the one that can reduce material losses most effectively. Preparedness means taking appropriate measures that protect buildings and particularly their inside from being damaged by a flood. Structural measures provide continuous protection, non-structural measures allow people to cope more effectively with a flood event. Preparedness starts with the use of water-proof concrete (e.g., coated concrete) for the lower parts of a building (basement and ground level), continues with having temporary strengthening devices available (e.g., steel shutters for basement windows, stop logs for shutting underground parking garages, etc.), and ends with emergency equipment such as sandbags, sand, shovels, and other necessary tools. The most effective way to reduce losses is to move goods to a higher elevation, where they are safe from flood, at the onset of an event. Preparedness and emergency actions require awareness of the threat by the people concerned and their willingness to reduce losses. The incentive for the latter may be dampened or encouraged by various boundary conditions that are closely related to the state's flood warning and flood control systems as well as to the financial assistance provided either by the state or by insurance in case of loss. This makes it clear how intertwined the contributions of the three components of the risk reduction triangle in Figure 3 are and how crucial it is to have a well-balanced preparedness scheme.

Insurance Industry

Besides public and individual measures, insurance is an important factor in reducing the financial risk for individuals, enterprises, and even whole societies where natural hazards are concerned. Proper insurance can considerably mitigate the effects that extreme events have on individuals, enterprises, and society and can prevent them from being ruined.

The purpose of insurance is to protect the insured from excessive losses that substantially threaten their living or business conditions. Insurance is not meant, though often used, to compensate relatively minor damages. While from the point of view of an insured who has paid his premiums for many years it is understandable that he is interested in being reimbursed even in the case of a minor loss, this demand is exactly the reason why premiums are higher than they could be. Insurance companies regulate small claims usually without detailed investigations because this un-bureaucratic feature of customer service is a very effecient promotion instrument.

One very important contribution the insurance industry can make towards loss reduction is to raise the willingness of home and business owners to defend their property against flood damage. At a first glance, insurance may not seem to enhance this willingness. On the contrary, being insured makes people believe they are less vulnerable, and, as a consequence, they usually become less concerned, often somewhat indifferent, and sometimes even welcoming to the destructive event. While the latter observation is not necessarily widespread it certainly is far from being absent. With adequately structured premiums, however, insurance is a powerful means of motivating the insured to take measures aimed at loss reduction. The key to this goal is a deductible, i.e. the share the insured contribute to their losses during an event.

The measures taken by the insurance industry go beyond simply providing monetary assistance in the event of a claim. They execute loss analyses and build up loss databases. With risk inspections they make a contribution to better design of structures so that future events will be less harmful. Finally, they contribute – through publications, seminars, and lectures – to education and creating awareness among the public, decision makers, and technical experts.

The Role of Reinsurers

Billion-dollar catastrophes cannot be borne by a local insurance market without major damage to the insurance industry itself. Even in strong markets such as the United States, great events leave their traces. Hurricane Andrew wiped out about a dozen primary insurance companies in the American Southeast in 1992. The burden from claims exceeded by far the capacity of these companies, and they went bankrupt. To prevent such things from happening and to protect themselves from bankruptcy, insurance companies must assess the probable maximum losses they may be confronted with and prepare for them. One aspect, often the main aspect, of preparation is to seek reinsurance. Reinsurance is insurance for insurance companies.

While most insurers concentrate their business on a particular country or region (e.g., the United States, Europe) most reinsurance companies do business worldwide. How effectively this idea of transferring local losses via the reinsurance sector to a worldwide system works is shown by the example of another hurricane, Gilbert, which hit the Caribbean in 1988. Jamaica in particular suffered great losses; its economy was hit by losses amounting to about US$ 1 billion, of which 70 percent was insured. The US$ 700 million would have destroyed the Jamaican insurance industry completely. It survived because nearly 99 percent, or US$ 690 million, was reinsured and was, therefore, paid by the world's reinsurance industry. For the local companies a mere 10-million-dollar obligation remained.

A reinsurance rate of more than 95 percent is typical for developing countries. In developed countries, reinsurance rates range between 50 and 90%, depending on the strength of the primary insurance companies in the region. Since reinsurance costs money, large primary companies tend to keep a larger portion of the risk themselves. For example, the series of winter storms in Europe in 1990 cost insurers US$ 9.8 billion, of which the reinsurers paid 6.4 billion (65 percent). Similarly, of Hurricane Andrew's US$ 17 billion insured losses bill, 50 percent was paid by the reinsurance sector.

Flood Insurance

The basic problem in flood insurance is the difference in the demand for coverage from potential clients who are exposed to flooding and the offer made by the insurance sector (Kron, 1999a). Most people have certain – and they think good – perceptions of the flood hazard to which they are exposed. The ones who have already experienced flooding on their property are aware of the threat; others, even if they live close to a river, ignore the danger or just do not believe that they can be affected at all. Often their perspective is wrong. About half of all losses from floods occur far away from major rivers and outside major events that hit large areas and whole river systems. Instead, these loss events (flash floods) occur in relatively small areas, but with potentially extreme intensity and with high frequency (although not at the same site). Even property on the slopes high above the valley floor may be damaged by excessive rainfall that runs off on the surface and right into the houses. If this is made known to the majority of the people, the conditions for effective flood insurance are good.

Only a relatively small proportion of the cover for buildings and contents in any given insurance market is exposed to river floods. However, the areas affected are always the same and flooding on a specific river occurs at almost regular intervals and cannot be regarded as an unforeseeable event. Only people in these flood-prone areas seek insurance. On the other hand, those to whom the insurance companies are willing to give coverage are not interested, because they feel their exposure is low. Hence, if an insurance company wished to sell individual policies on a voluntary basis, the insurance premiums would have to be so high that policyholders would normally find them prohibitive. This phenomenon is called adverse selection or anti-selection.

In the case of the storm surge hazard, the effect of adverse selection is even more severe. Furthermore, the extremely high loss potential during a single event in connection with a very low probability that it happens, makes the calculation of premiums difficult (this is the problem of multiplying a very low and a very high number or "zero times infinity"). Therefore, storm surges are, in general, not insurable.

In contrast to this, flash floods have a relatively uniform probability in time and space. The necessary geographical spread of objects at risk is given and the community of people who are insured is large, i.e. the frequency of someone being hit by an extreme event is low. As a consequence, the premiums can be kept low, too. Consumer demand for insurance protection could be developed on a broad front, and adequate premiums can be calculated with a relatively high degree of reliability. Hence, flood damage caused by flash floods is insurable without any problem.

There is no reasonable insurance solution that can possibly make insurance companies settle all the losses that may be incurred. Instead, a certain amount has to be borne by the insured before the insurance becomes effective, i.e. deductibles must be introduced. Such a structure has advantages for both the insurer and the insured. On the one hand, the insurer does not have to settle masses of small losses and saves a lot of administrative costs besides loss compensation money. On the other hand, the client may only become insurable at all if he pays a share of the losses.

Hazard Zonation

Premiums for flood insurance must reflect the individual exposure. It would be unfair and inexplicable to clients if each member of an insured community had to pay the same premium not taking into account the individual risk his property is exposed to. In mass business – i.e. for private homes and small businesses plus their contents – the effort required to assess the exposure of a certain building must be seen in the context of the annual premium income for one such object, which is in the range of perhaps US$ 50 to US$100. Therefore, an individual assessment of the risk and the calculation of an individual premium for these objects are impossible, so that the premium must be fixed on the basis of a flat-rate assumption. For this, zones with a similar flood hazard must be identified and/or defined, within which the premiums are constant.

The German insurance industry, for example, established a rating system that defines the exposure of all areas of the country to river floods according to four exposure classes:

I small exposure: Areas that are affected less than once per 200 years on average; objects there are insurable without restriction.

II moderate exposure: Areas that are affected by floods in the recurrence interval range of 50 to 200 years; objects in these areas are basically insurable.

III high exposure: Areas that are affected by floods in the recurrence interval range of 10 to 50 years; objects in these areas are basically insurable.

IV very high exposure: Areas on flood plains that are affected by floods with recurrence intervals of up to 10 years; objects in these areas are in general not insurable, but under certain conditions they may become so.

In order to come up with a zonation system that covers all of Germany, the areas along all significant water courses had to be considered. These water courses were defined by a digital river network called "ARC-Deutschland" (scale 1:500,000; total length of the rivers included: 35,110 km). The required task was (a) to provide different *T*-year discharges in and (b) to compute the corresponding water levels and flooded areas at any cross section of each of the chosen water courses. The hydrological and hydraulic computations were carried out with the help of a Geographic Information System (Kron and Willems, 2002). An example of zonation is shown in Figure 4.

Flood PML Assessment

Like clients, insurance and reinsurance companies must protect themselves against high losses in order to assure their survival. Therefore, they are required to perform accumulation control, i.e. assess the probable maximum loss (PML) they may experience during an extreme event. Each company must decide on the reserves it needs and its reinsurance requirements. PML calculations are based on scenarios that assume a major event hitting a large area or an area with a high concentration of values. It is not obvious beforehand which scenario will determine the

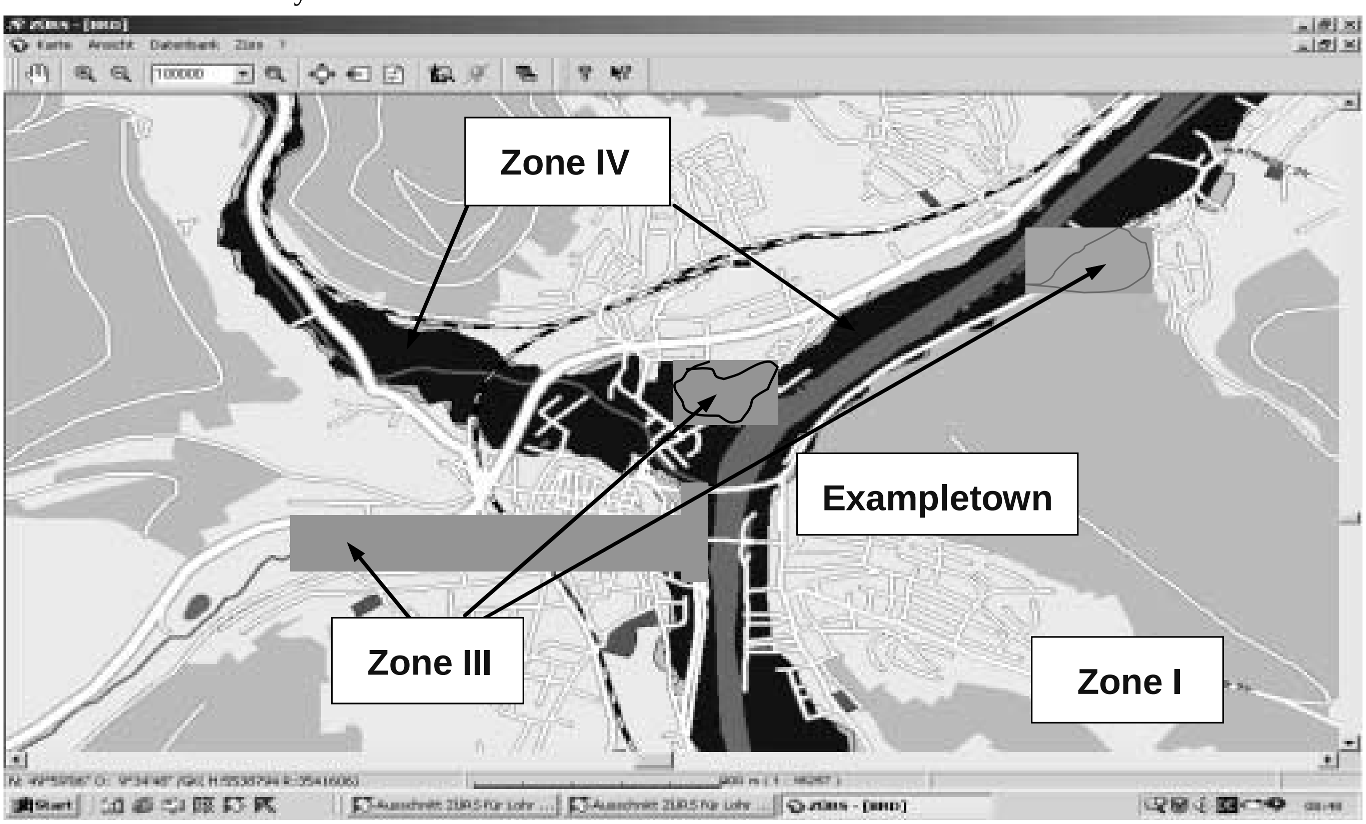

Figure 4. Example of the flood hazard zonation by the German insurance industry. Note: in the example there is no Zone II

worst case for a given company as the expected losses depend on the company's portfolio, and particularly on the spatial distribution of its liabilities. For each company a different scenario may determine the PML.

PML models have been available for many years as a means of calculating maximum losses from earthquakes and windstorms. For the analysis of floods, such tools were not available until recently. Flood events are much more influenced by small-scale and local aspects, which include soil conditions and topography, the exact location of objects (elevation) and the effectiveness of flood control measures. Therefore, such models require considerably more detail and sophistication.

A model developed by Munich Re in cooperation with the Institute for Applied Water Resources and Geoinformatics (Kron and Willems, 2002) makes it possible for the first time to carry out accumulation analyses of flood events occurring in Germany. Eight different accumulation scenarios were chosen. They represent regions (Figure 5) that may be hit by an extreme flood simultaneously. It is unlikely that the whole country will be affected by such an event at one and the same time. In the PML analysis the values of liabilities of a given portfolio affected in each scenario are determined and the probable losses estimated for fictitious 10-year to 200-year flood events.

The calculations are carried out in five steps. First the discharges for given frequencies are determined using hydrologic stochastic regionalization (hydrologic analysis). With the river network and digital terrain model the water levels and the corresponding flooded areas can then be determined (hydraulic analysis). As only property damage is of interest, flooded settlement areas are identified (spatial analysis). The expected losses are estimated from the number of objects affected and loss averages (portfolio analysis). This is done on the basis of postal code areas because portfolio data are aggregated in this form. The final step consists of summing up the loss values for all postal codes in the regarded flood accumulation zone to obtain the probable maximum loss (accumulation).

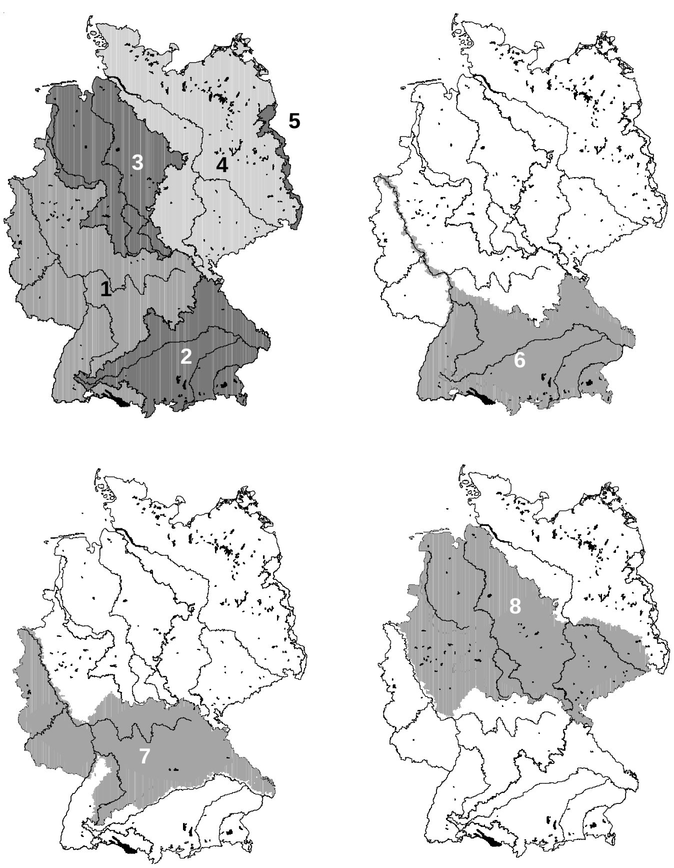

Figure 5. Accumulation scenarios for flood losses in Germany (1 = Rhine; 2 = Danube; 3 = Weser-Ems; 4 = Elbe; 5 = Odra; 6 = South; 7 = Centre; 8 = North)

Conclusions

It is commonly agreed that flood risk is increasing worldwide. As the risk must be considered a product of hazard, values at risk, and vulnerability, each of these components must be taken into account and analyzed if one is looking for the reasons for this increase. It turns out that the main driving factors are the almost exploding development in the values people place in flood-prone areas and the much higher vulnerability of the things they own. Additionally, increased – though sometimes forced – mobility brings people into areas whose natural features they are not familiar with. As a consequence, they do not know how to react in an extreme situation. On top of this, the hazard situation concerning hydrological events is also changing as a result of the ongoing process of climate change, which in most regions has a tendency to intensify extremes.

Risk reduction must, therefore, not only address hazard reduction, e.g. through the erection of flood protection structures, but also aim for the integration of each individual in this process. Insurance, as a third component, completes the individual's financial risk management. The extent of insurance affected people/companies may want can be chosen between the extremes of "no cover – no premium" and "full cover – high premium," depending on the individual judgment of the risk situation.

Flooding has become an important topic for the insurance industry and its significance will continue to grow in the future. The increasing demand for insurance coverage and the pressure for proper insurance concepts from all sides are forcing the insurance industry to develop solutions for flood coverage. Various countries have already established insurance schemes for this type of hazard, some in the form of insurance pools, others on an individual basis. The types of contracts range from obligatory to completely voluntary coverage, and from all-risk policies to flood-only policies. There are advantages and disadvantages in all these concepts and none can be declared the best. It is certainly advisable, however, to offer multi-hazard packages, thus combining the flood risk with other risks such as earthquake, landslide, windstorm, hail, subsidence, snow-load, etc. to avoid adverse selection.

In Germany, the insurance industry is currently promoting flood insurance and has started to tackle the problem by establishing flood hazard zones. The identification of the different zones has been achieved in a concerted action not only by the whole community of German insurers (and some reinsurers) but also in close cooperation with public water resources authorities. Despite the fierce competition in the market the intention is clearly to come up with a unique zonation system valid for all companies that will even help the state in its efforts to enforce land-use planning that is compatible with the flood hazard.

Parallel to the primary insurers that need risk zoning for the purposes of acquisition and designing a premium structure, reinsurers – as part of their service to the primary insurance companies and in the interest of their own business – need hazard zoning to calculate the expected losses that the insurance industry might face as the result of an extreme event threatening a company's existence. It was with this in mind that Munich Re developed the world's first flood loss accumulation model for an entire country. The model has been operational for Germany since 1999. A similar model has been developed for the United Kingdom, and models for other countries will follow soon.

About the Author

Wolfgang Kron, a hydraulic engineer and hydrologist, is the Head of Hydrological Risks in Munich Re's Geo Risks Research Dept., the scientific unit of the world's largest reinsurer for matters related to natural hazards and natural disasters. Besides his main topic, flooding, his expertise comprises mass movements (such as landslides, avalanches, etc.) as well as disaster reduction and disaster statistics in general. He is a member of numerous national and international boards dealing with issues related to natural disasters, in particular those that are water-related.

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