COASTS – THE RISKIEST PLACES ON EARTH

Wolfgang Kron[1]

Risk is the result of a natural hazard, values at risk and their vulnerability. Coasts attract people and businesses and industries but are also subject to numerous threats from nature, some of which have, and will, become more serious due to the changing climate. Enormous catastrophe loss potentials have been created and are still increasing. Living with and reducing the risk requires awareness at all levels of society and partnership between the public authorities, the people and enterprises concerned, and the financial sector. A certain residual risk must be accepted and adequate measures ranging from engineering to behavioral aspects undertaken. A crucial factor for all coasts is stopping or slowing down anthropogenic climate change and adaptation to the increasing risk thereof.

INTRODUCTION: NATURAL DISASTERS ON COASTS

Figure 1: Casino in Biloxi, Mississippi after Hurricane Katrina (© Munich Re)

There are few natural catastrophes that are not somehow related to coasts. While not all of them occur right on the borderline between land and sea, their causes can either be found in meteorological events produced over the water or

[1] Geo Risks Research, Munich Reinsurance Company, Koeniginstrasse 107, 80791 Munich, Germany

in geological events that happen at the crustal plate boundaries along the continents or mid-ocean ridges. Wind forces and wave action from tropical and extra-tropical storms are normally at their most furious and consequential at the point of landfall. Clouds of low-pressure systems derive their water content from the sea. Tsunamis triggered by – even distant – earthquakes exert their highest destructive potential when they reach the coast. Even earthquakes and volcanic eruptions happen much more frequently near the coast than further inland, their origin being closely related to the formation of the continents (the best example is the Pacific fire belt).

It is also important, however, to recognize that not only are coasts subject to more intense and more frequent natural events, but they are also the places with the highest concentration of people and values. Disaster happens only if people are killed or injured and/or their possessions damaged or destroyed. In the same way, whether a location is risky depends on (a) the likelihood that a natural event may occur and (b) the presence of vulnerable items.

Both components, natural events and values at risk, have been and still are increasing unabated, especially along the world's coastlines. Rising sea levels, increased tropical cyclone frequencies and intensities (rain and wind), unprecedented flood experiences, on the one hand, and megacities with exploding populations and industrial development, on the other, are making coastal regions ever riskier.

LOSS STATISTICS AND TRENDS

We do need not to go far back in history to find examples of extraordinary events in nature that produced extreme catastrophes – extreme in different respects: in terms of scale (regional intensity or large-scale impact), number of fatalities, or financial losses.

The tsunami of 26 December 2004 killed more than 220,000 people in 13 countries around the Indian Ocean. In 2005, Hurricane Katrina presented the United States with a bill of some US$ 125bn (Figure 1). In Europe, Winter Storm Kyrill (January 2007) cost US$ 10bn, whilst losses due to flooding in the United Kingdom in June and July of the same year amounted to US$ 8bn, the insurance industry paying US$ 5.8bn and US$ 6bn, respectively. Bangladesh (2007) and Myanmar (2008) were hit by tropical cyclones that left thousands dead and vast landscapes destroyed by wind and flooding. Australia's east coast was beleaguered by four consecutive storms, in June 2007, that brought wind, rain, snow and high waves, and drove one big vessel onshore. Only in the case of Africa does one have to go back a few more years to the last major coastal disaster, with the exception of the tsunami mentioned above (which killed about 300 on that continent): namely, to 2000 and 2001, when large parts of countries in the southeast of the continent were submerged by a number of cyclones. Table 1 shows the 15 greatest natural disasters (in terms of monetary losses) in the five years from 2004 to 2008. All but one (the Sichuan earthquake) are related to coasts.

Table 1. The 15 costliest natural catastrophes since 2004					
Rank	Year	Event	Country/Region	Total losses US$ bn	Insured losses US$ bn
1	2005	Hurricane Katrina	Gulf coast/USA	125	61.6
2	2008	Earthquakes	Sichuan/China	>50	0.3
3	2004	Two earthquakes	Honshu/Japan	28	0.8
4	2004	Hurricane Ivan	Caribbean, USA	23	13.8
5	2008	Winter damage	China	21	1.6
6	2005	Hurricane Wilma	Caribbean, Mexico, USA	20	12.4
7	2004	Hurricane Charley	Florida/USA	18	8
8	2005	Hurricane Rita	Gulf coast/USA	16	12
9	2007	Earthquake	Niigata/Japan	12.5	0.3
10	2004	Hurricane Frances	Caribbean	12	5.5
11	2004	Earthquake/tsunami	Indian Ocean	10	1
	2007	Winter Storm Kyrill	Western Europe	10	5.8
	2008	Floods	Midwest/USA	10	0.5
14	2004	Hurricane Jeanne	Caribbean	9.2	5
15	2004	Typhoon Songda	Japan/South Korea	9	4.7

Some events not included in Table 1 are nevertheless worth mentioning because they were extreme on a regional scale. One of these was Cyclone Gonu, that caused flood losses of US$ 3.9bn (US$ 650m insured) in the Masqat area of Oman on the Arabian Peninsula in June 2007. Another was the Mumbai flood of June 2005. Almost 1,000 mm of rain in just one day produced US$ 5bn (US$ 770m insured) in flood losses in one of India's most industrialized and certainly most densely insured regions.

Munich Re's NatCatSERVICE, the world's largest natural catastrophe loss database, has systematically collected data since 1980. Today, it holds more than 26,000 data sets, adding between 700 and 1,000 each year. Additionally, important events before 1980 have been analyzed, in particular those where the affected region's ability to help itself was overtaxed and international assistance required because thousands were killed, hundreds of thousands made homeless, or substantial economic or insured losses (relative to the regional situation) sustained. These events, referred to as "Great Natural Catastrophes" (GNC) can be used as a base for trend analyses. Excluding the many smaller events avoids the bias introduced by the development of communication technology in the past 50 years. In the 1950s and 60s, news of local disasters from remote regions did not normally reach the world's media services. Today, in the age of internet, we quickly learn of any local loss event, no matter where it happens. GNC, however, are likely to be documented in the records of the affected countries and their consequences can be assessed and entered in the database. We found that the number of GNC and resulting monetary losses have seen almost exponential growth (Figure 2). As weather-related catastrophes predominate in terms of losses (70% of total economic losses and 90% of insured losses) and number of events (72%), the graph in Figure 2 would look very similar even without

earthquake and tsunami catastrophes. However, by number of deaths, geogenic disasters play an important role (Figure 3).
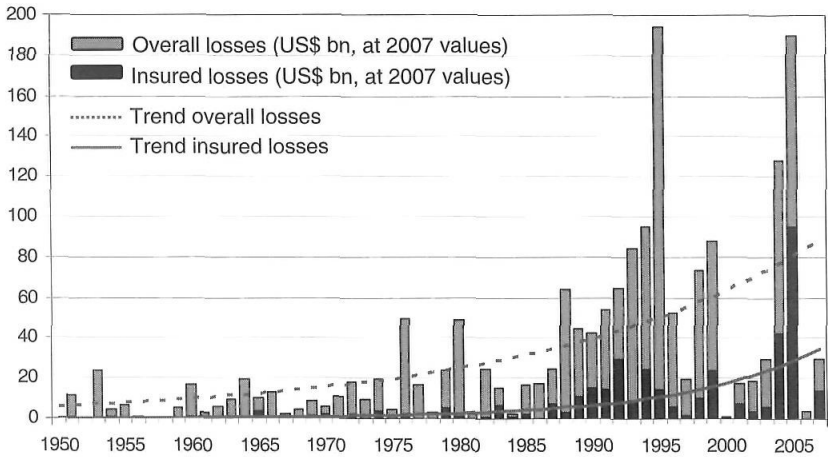

Figure 2: Trends in Great Natural Catastrophes: Economic and insured losses
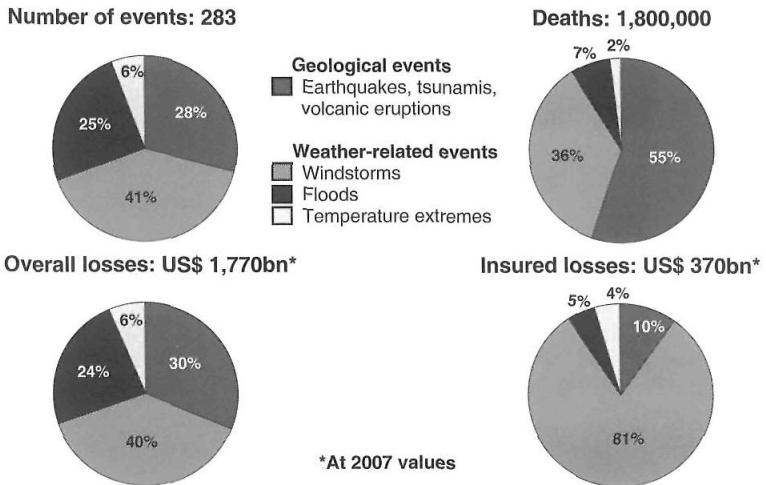

Figure 3: Great Natural Catastrophes 1950–2007: Breakdown by event (% worldwide)

The total number of loss events per year contributed by the three main groups of natural hazards (earthquakes, windstorms, floods) has clearly been rising since 1980 (Figure 4); for this period one can assume that the "collection bias" described above is not significant. The gradients of the trend lines seem to indicate a distinct difference between atmospheric and geogenic causes.

Assuming the socio-economic driving factors behind loss-generating events to be the same for all causes, the difference is likely to be due to changes in climate.
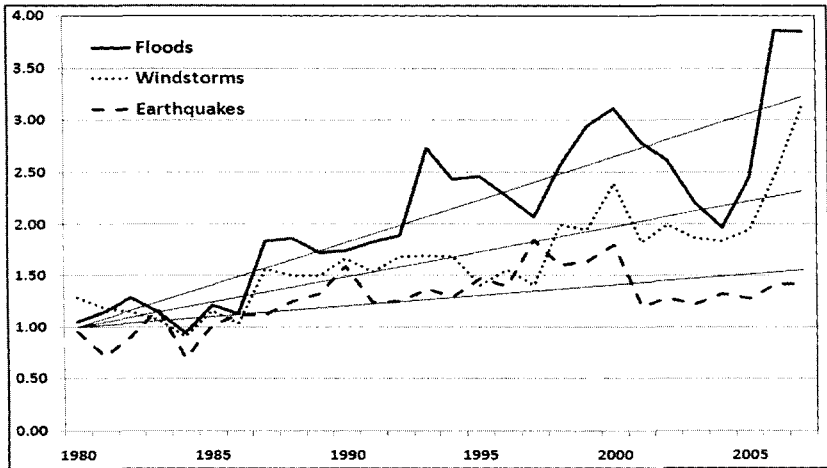

Figure 4: Relative number of loss events from different causes 1980–2007, normalized to the number of events according to the value of the respective trend line in 1980: Floods: 97; Windstorms: 138; Earthquakes: 67

CHANGING RISK

The increase in natural hazard losses is a direct function of the number of people who have to or wish to settle in risky areas, the values they possess and the susceptibility of those values to water. Hence, it is not the natural hazard in itself that accounts for the consequences of an extreme event.

What is risk?

The term risk is used in different ways in different situations. For the purpose of scientific discussions, it should be defined in an unambiguous and consistent way. Here, risk is understood – in a qualitative way – as the product of a hazard and its consequences, and accordingly determined by three components (Kron 2005):

1. Hazard H, i.e. the probability of occurrence of the threatening natural event;
2. Exposed values or values at risk E, i.e. the objects situated at the location involved;
3. Vulnerability V, i.e. the lack of resistance to damaging/destructive forces.

In its most simple form, risk is calculated by multiplying those three components.

$$R = H \times E \times V \qquad (1)$$

Where there are no people or values that can be affected by a natural phenomenon, there is no risk.

Coastal hazards

The hazard is the threat posed by natural processes which cannot be influenced. The strength of an earthquake, the maximum wind speed, the height of a surge or a tsunami are more or less outside mankind's control or even influence. Dykes do not affect the hazard. They should rather be considered part of the vulnerability factor as they reduce the impact of a high water level. There is one way, however, in which we can influence hazard: this is via human-induced climate change. Whilst mankind has played a part in making climatic peculiarities more severe, it can also take action to render the global climate more favorable again. This will be possible only in the long run, however. To reduce current and near-term risk we have to come up with other forms of response.

Coastal hazards are usually associated with weather hazards. However, the other, much rarer but for precisely that reason often much more dramatic hazards (in particular tsunamis), also need to be considered. Even on a sunny day, coasts can be hit by flood events whose cause is located thousands of kilometers away.

The implications of a changing climate are probably nowhere else as important as for coasts. The average global sea level is expected to rise by 20–60 cm by 2100 according to the 4th report of the Intergovernmental Panel on Climate Change (IPCC 2007). More recent findings, which consider increasing melting of the polar ice shields as well, suggest that this rise could even double (Rahmstorf 2007). The global temperature increase will also bring higher probabilities of extremes such as higher rainfall intensities, prolonged heat waves and droughts.

Values at risk

The dramatic increase in the world's population, in particular in certain regions, is the main reason why losses from natural disasters have virtually skyrocketed in recent decades. No other locations are as attractive to people as coastal areas. Today, one tenth of the world's population lives within 5 km of the coast, one third within 50 km and two thirds within 300 km. In addition to permanent residents, millions of tourists choose coastal regions as their holiday destination. In Florida, for example, 18 million residents (2005 figure, up from 100,000 in 1920) are joined by 86 million tourists every year (up from 0 in 1920).

Cities develop best given optimum access to mass transport. Ports are the entry and exit points of a nation's trade. Due to their often flat topography, coastal areas are also favorable places for industrial facilities that need a lot of space, and they are easy to develop. A 2007 study sponsored by the OECD (Nicholls et al. 2007) looked at 136 port cities around the world that have more than one million inhabitants.

Around 38% of the largest port cities are found in Asia, 27% are located in deltaic settings, again mainly in Asia. Cities on deltas are at lower elevations and therefore tend to have a higher coastal flood hazard. The 20 most exposed to

coastal flooding in their projected 2070 state were compared with their present-day situation. The comparison was made from two perspectives: population and exposed assets (i.e. the value of buildings, infrastructure, etc. within reach of a 100-year flood).

All but two (Miami and New York-Newark) of the most densely populated cities will be located in Asia and Africa in the 2070s. The total population of the 20 cities will be 113 million, i.e. 470% of the current 24 million. Some cities are expected to grow by a factor of over than 10 (Dhaka and Chittagong in Bangladesh, Ningbo in China), whereas the population of already highly developed cities (e.g. New York, Miami, Tokyo, Shanghai) will only double.

The list of cities with the highest exposed values is headed by Miami, which will remain at the top. Six of the top 20 are located in the USA and Europe. In all 20 cities, US$ 2,204bn are currently exposed to flooding; in 2070, that amount will exceed US$ 26,000bn, a more than 12-fold increase. Again, the growth rate of the American and European cities (mean increase factor less than 7) is far below the average. Each of the six Chinese cities listed grows more than 24 times, the outright leader being Qingdao, with a factor of 201.

Table 2. The 20 cities with the largest assets exposed to coastal flooding					
Rank	City	Country	Current (2005) exposed assets US$ bn	Future (2070) exposed assets US$ bn	Increase factor
1	Miami	USA	416	3,513	8
2	Guangzhou	China	84	3,358	40
3	New York-Newark	USA	320	2,147	7
4	Kolkata	India	32	1,961	61
5	Shanghai	China	73	1,771	24
6	Mumbai	India	46	1,598	35
7	Tianjin	China	30	1,231	41
8	Tokyo	Japan	174	1,207	7
9	Hong Kong	China	36	1,164	32
10	Bangkok	Thailand	39	1,118	29
11	Ningbo	China	9	1,074	119
12	New Orleans	USA	234	1,013	4
13	Osaka	Japan	216	969	4
14	Amsterdam	Netherlands	128	844	7
15	Rotterdam	Netherlands	115	826	7
16	Ho Chi Minh City	Vietnam	27	653	24
17	Nagoya	Japan	109	623	6
18	Qingdao	China	3	602	201
19	Virginia Beach	USA	85	582	7
20	Alexandria	Egypt	28	563	20
Total			**2,204**	**26,817**	**12**

Vulnerabilities

Vulnerability can refer to human health (human vulnerability), structural integrity (physical vulnerability) or personal wealth (financial vulnerability).

Residents of coastal settlements have always put a great deal of effort into protecting their properties against flooding and wave action. Building on wharfs in the past and giant projects such as the Dutch Deltaworks have proved reasonably successful. Such measures provide good protection against moderately frequent natural events, for which cities and industrial facilities now have very low vulnerability.

If we extend the scope to rare and very rare events we find vulnerability is suddenly extremely high – boosted by the high concentrations of exposed values in certain locations. It is very difficult to evacuate several hundred thousand people in just one day when a hurricane is approaching, and the same goes for saving 50,000 new cars waiting to be shipped from a port in the few remaining hours before a storm surge hits the coast. On 22 June 2008 a hailstorm damaged 30,000 new cars in the port of Emden, Germany. It took just 15 minutes to produce a US$ 150m loss.

Given a complex infrastructure (e.g. traffic and power networks) a failure in one place may cause domino effects that bring the whole system to a standstill. An important aspect in this context is the feeling that dykes protect fully. The fact of living in areas endangered by floods and other natural perils is ignored, or at least forgotten after a while, or people are lulled into a false sense of security, totally relying on coastal protection and preventive measures. It is also likely that systems which "always work" may not do so in the event of disaster.

In general, modern equipment is highly susceptible. Almost everything contains electric or electronic components and these items often suffer severely when exposed to flood water or even humid, salty air. The drying-out and returning to use of the past is no longer an option.

One fairly common consequence of urban growth is subsidence, caused, for instance, by groundwater extraction or sometimes simply by the weight of buildings erected on relatively soft and unconsolidated coastal soil. A few decimeters of subsidence can create huge problems in already low-lying port cities, some areas suddenly finding themselves below a given flood level or even below the average local sea level.

CLIMATE CHANGE

The world is getting warmer. All seven years from 2001 to 2007 rank among the eight warmest recorded since 1852, based on global mean temperature. Hence, there is no doubt that the average global sea level will rise. Whether the new level is 50 or 100 cm higher by the end of the century is a moot point, but problems will arise as a result. Small islands and large reaches of coast in a number of poor countries will disappear under water. Other regions will be able to avoid permanent flooding but will either lose their protection standard against storm surges (which may fall from a 1-in-500 to a 1-in-50-year chance of failing

to protect), or they will have to invest enormous amounts of money to keep the current standard at the same level. Among the most endangered regions are Florida, New York, and Shanghai, which can be found in Table 2.

There is strong evidence that the intensities of hurricanes in the Northern Atlantic and typhoons in the Western Pacific have increased and will further increase. In 2005, all previous storm records were broken in the North Atlantic (Munich Re 2006): there were 27 named tropical storms (the average number is ten, the previous record 21), 14 of which developed into hurricanes (average six, previous record 12). The 14 included Wilma, at 882 mb the most intense hurricane ever recorded in the North Atlantic, Rita (897 mb, ranking fourth), and Katrina (902 mb, ranking sixth). The latter became the most expensive natural disaster of all times (c.f. Table 1). Overall losses in the 2005 hurricane season totaled US$ 165bn (US$ 83bn insured). One main issue: will Europe find itself in the path of hurricanes? Were Storms Vince and Delta at the end of the 2005 season, which took an easterly course and hit Madeira and the Canary Islands, the harbingers of changing hurricane tracks?

In many parts of the oceans, wave heights and surge levels are expected to go up due to increased storminess. This will lead not only to higher wind setups but also to an increased threat to vessels and offshore installations. Again, the ocean regions of the North Atlantic and West Pacific, which are bordered by the coasts with the highest assets (USA, Europe, Japan, China), seem to be facing the most severe changes.

Apart from catastrophes of sudden onset, climate change will involve a number of other potentially severe consequences for seas and coastal regions. Melting polar ice will decrease the salt concentration in the water, affecting global heat transport and the composition of the ecosystems. Water exchange between ocean basins (e.g. between North Sea and Baltic Sea) may change. The intensification of tide dynamics will have consequences for tides and tidal currents and the transport of salt, sediment and ice, and interfere with certain morpho-dynamical processes, the likely result being increased coastal erosion. Seawater intrusion into estuaries and groundwater bodies will even affect ecosystems onshore and possibly lead to adverse economic consequences.

The fishing industry will have to deal with the immigration of southern species and displacement of cold-water fish, e.g. cod, to the north. The consequences may even affect engineering structures: if the growth and distribution of toxic algae increases they may settle on the surfaces of hydraulic structures and vessels, causing considerable damage in the form of what is termed bio-fouling. Last but not least, aesthetic aspects such as increased algae growth may considerably affect the attractiveness some beaches hold for tourists.

Climate change will bring a few advantages for navigation, e.g. more favorable ice conditions in the Northwest and Northeast Passages. But, compared with the adverse effects, this is likely to be "a mere drop in the ocean".

The study cited above (Nicholls et al. 2007) also looked into the effect of climate change compared with socio-economic developments on assets exposed

to flooding in the 20 cities of Table 2 (Figure 5). It was found that climate change and subsidence contributes between 6% and 53% to the exposure of assets in 2070.
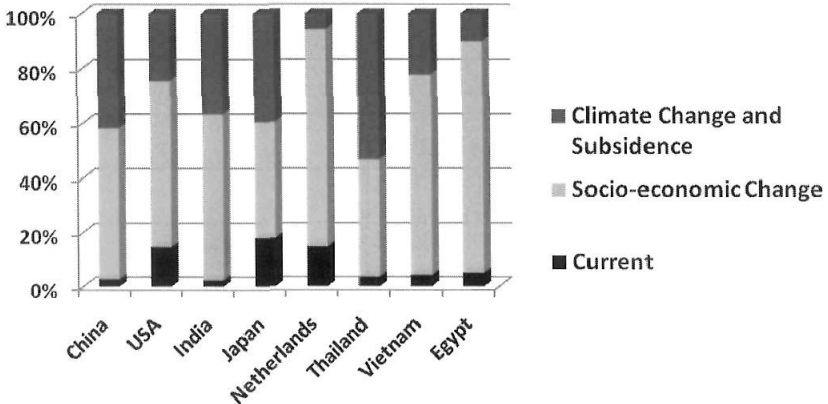

Figure 5. Contributions in per cent to the projected future assets in 2070 in the 20 port cities of Table 1 by current state, climate change, and socio-economic change (Source: Nicholls et al. 2007).

RISK REDUCTION

During the industrialization of the world in the past two centuries we believed we could react to the threats posed by nature through the introduction of better technical protection. Building codes were improved, dykes built, and measurement, observation and communication networks established, especially when satellites came into use. Understanding of physical processes was continuously increasing, resulting in enhanced early-warning and alert potential. In the wake of and relying on such developments, millions moved to, for the most part, attractive locations, so that immense values accumulated there. As beautiful and economically advantageous as many such areas are, once in a while they turn into disaster areas.

The most efficient way of reducing the risk is to avoid settlement in hazardous locations. If a house is not built alongside the beach but further inland on elevated land a storm surge cannot tear it from its foundations. Trying to prevent people moving to areas where they expect better living conditions is all very well in theory, but in practice it just does not work. Convincing people they should leave their homes and move elsewhere is an even more futile exercise.

Cities must, therefore, be protected against storm surges and other sea-bound hazards. The same is true of engineering structures which, by their very nature, cannot avoid exposure to marine hazards, namely harbors, offshore platforms and, to some extent, wind parks. The only way to reduce the risks they face is to reduce their vulnerability or increase their resistance and resilience using technical means.

Much has been achieved in the past decades in this regard. After the 1953 flood, the Netherlands spent billions of dollars on strengthening and raising their sea defense system; in the United Kingdom, London is now protected by the Thames barrier. Generally, the design of sea dykes aims at a failure probability with respect to overtopping in the order of less than 0.5% (once in 200 years). In the Netherlands this design criterion for the central part of the coast is as little as 0.01% (1 in 10,000 years).

The Dutch authorities have recognized, however, that the height of a dyke – assuming maximum water level to be the only load factor and overtopping the only design failure mechanism – is too short-sighted because it excludes other types of failure such as piping, erosion, sliding, gate failures, etc. The latter may have probabilities that are one order of magnitude higher; at the very least, the existence of a number of possible failure modes lowers the nominal probability of failure. The government has therefore set up the FLORIS project (Flood Risk and Safety in the Netherlands). Postulating that absolute safety from flooding does not exist and recognizing that flooding does not depend only on the probability a certain water level will be exceeded, the conclusion drawn is that the probability of flooding is not the factor of greatest concern, but that the criterion on which the decision-making should be based is the probable consequences of flooding. Firstly, the flood risk is computed specifically for all 53 of the country's dyke rings, taking into account not only the hazard but also the respective values at risk and their vulnerabilities. The goal is eventually to define the specific risk from the sea and from large rivers for different regions of the country.

In Bangladesh, where storm surges claimed 300,000 lives in 1970 and 139,000 in 1991, several thousand flood shelters, elevated structures to which people can flee when a surge inundates the land, have been built in the past two decades. In more recent surge events on a scale comparable to the two named above, the number of people killed was less than 5,000 in each case. By contrast, at least 85,000 died (plus 45,000 missing) when Cyclone Nargis struck Myanmar's unprepared Irrawaddy delta in May 2008.

Although technical flood protection is certainly the most important factor in preventing large disasters, we have to be aware that even the strongest and best-designed systems have a limited effect. The 2004 tsunami and Hurricane Katrina showed that 100% safety is not possible. Therefore it is crucial not to rely on a purely structural approach to the problem and to include soft factors as well.

Risk (and loss) minimization call for an integrated course of action. The flood risk must be borne on several shoulders: the state, the people and companies affected, and the financial sector, particularly the insurance industry. Only when they all cooperate with each other in a fine-tuned relationship and a spirit of risk partnership, can disaster prevention be really effective. In this context, maintaining high risk awareness at all levels of the society plays an important role.

Public authorities
The job of the state or the government is primarily to reduce the underlying risk for society as a whole. It provides access to observation and early-warning systems, builds dykes, deploys flood-retention areas, determines the framework for use of exposed areas by enacting statutory provisions, and prepares emergency plans, including programs to alleviate recovery (temporary housing, financial assistance, tax relief, etc.). In some countries, insurance programs are state-run. The responsibility for protection from flooding is largely shifted to public authorities. This differs from the position with earthquake and windstorm perils, where homeowners themselves are responsible for ensuring their houses are properly protected.

People and companies
Those immediately affected (individuals, companies, communities) have great potential for loss reduction. The crucial point is whether they can keep their risk awareness alive. Even those who do not overlook the danger of flood at the outset are often quick to forget about it, especially if nothing happens for prolonged periods. People rely on flood control systems, at the same time making their property more and more valuable by adding extra features that are often susceptible to water. Anyone proposing to erect houses or commercial buildings must be informed and educated to ensure they construct them in the appropriate manner. They need to check the exposure level of the values, and be ready to take action in an emergency. That action includes taking financial precautions to deal with catastrophic losses, e.g. by buying insurance.

Insurance industry
The true task of insurance companies is to compensate financial losses that would have a substantial impact on insureds or even constitute their ruin. Insurers carry the financial risk from events that have such a low probability that they cannot be considered foreseeable. Insurance redistributes the burden borne by individuals among the entire community of insureds. Ideally, that community is composed in such a way that all its members have some chance of being affected – even though the degrees of probability differ. Furthermore, insurers perform educational and public relations services, such as by publishing brochures drawing attention to the hazards and explaining how to deal with them (e.g. Munich Re 2008).

The reinsurance sector
Insurance companies, like private individuals, try to avoid volatility in their payments. Natural perils insurance is highly volatile. Large single losses (from one event) can be reduced if part of the risk is transferred to the reinsurance sector, where business is often transacted worldwide. Catastrophic losses that occur in one country are distributed all over the world, thus relieving the burden on the local insurance market and possibly even preventing its collapse.

Insurance, and especially reinsurance, companies have to be ready to pay large amounts of money after major events. For example, Munich Re faced claims in the order of US$ 2bn both in 2001, following the World Trade Center attack and in 2005, as a result of Hurricane Katrina. Despite the enormous amounts involved, the company's existence is not under threat. However, volatility is expensive. Money for payments must be made available very quickly and cannot be placed in long-term, and thus profitable, investments. With single loss amounts increasing, the whole financial market including banks, loan institutions, and investors is becoming more and more involved in covering risks (Kron 2008).

INSURANCE ASPECTS

Insurance against flooding, and in particular storm surges, is not widespread. Indeed, it is not even available in some countries. Among the problems encountered are adverse selection and lack of the loss data needed as a basis for calculating adequate premiums. Also, the extremely high loss potential ($\rightarrow \infty$) from a single event coupled with very low occurrence probability ($\rightarrow 0$) makes it difficult to calculate the risk and thus the premium; the result of such a calculation is highly uncertain. These are all factors that prevent storm-surge cover from being a popular product, both from the perspective of the insurance companies and their potential customers.

Adverse selection and multi-risk policies

In most countries, only a small proportion of buildings is exposed to storm-surge flooding. People in the areas concerned usually know that they are not living on safe ground and would like to obtain insurance cover. Those who live at some distance from the coast are not interested in buying cover. Hence, if an insurance company were planning to sell individual policies as part of a voluntary insurance scheme, the premiums would have to be so high that prospective policyholders would normally find them prohibitive. This phenomenon is called adverse selection or anti-selection.

Flooding typically affects certain parts of a country with a higher frequency than others. Whilst identification of the site-specific flood risk is indispensable, insurance packages, risk-adequate premiums and deductibles, and – to some extent – cross-subsidisation are necessary to achieve a viable portfolio. In practice, only obligatory insurance schemes seem capable of establishing a successfully functioning community of insureds with the necessary critical mass and an adequate geographical spread of risks. However, there is no single best or ideal flood-insurance solution. Instead, each solution has to be tailored to the specific hazard situation of the country concerned, and is to a large extent dependent on the long-term situation there. Although attempts have been made at political level to introduce obligatory flood insurance in a number of countries, voluntary covers are still widespread. In some countries, there are also legal problems in forcing people to insure against their own free will.

Adverse selection can be avoided by offering multi-risk insurance packages. The portfolio is then composed of various kinds of clients: those who live close to a river or the sea (flood risk), those in a geologically active region (earthquake risk), those on a mountain slope (landslide and avalanche risk), etc.

Hazard zonation and premium calculation

Premiums for the various hazards should reflect individual exposure. For the bulk of business – i.e. for private homes and small businesses and their contents – the effort required to assess the exposure of a particular building has to be seen in the context of the annual premium income for one such property, which may be in the order of US$ 50 in low-risk areas. Since individual assessment of the risk and calculation of an individual premium for such properties are impossible, the premium has to be fixed on the basis of a flat-rate assumption. For this purpose, zones that have a similar level of flood (earthquake, landslide) hazard have to be identified and/or defined, premiums being constant within a given zone. In most developed countries, hazard zone data of this kind are available.

On a global scale, Munich Re developed its first World Map of Natural Hazards in 1978. The 4th edition is now available, together with a DVD "Globe of Natural Hazards" (Munich Re 2009), which shows the worldwide distribution of all major natural perils (Figure 6) and provides a wealth of information on natural hazards and natural catastrophes. Several climate change related topics are included for the first time.

Figure 6. World Map of Natural Hazards (Munich Re 2009)

The annual net premium for insurance cover is the same as the expected average loss per year over a long period. Mathematically, it is determined in the same way as the risk (c.f. Eq.1). Insurance contracts are based on the status quo. If the hazard is high and the precautions taken minimal, the premium charged

will be high (assuming the property is at all insurable); if the hazard is low or protection standards high, the premiums charged can be low. In practice, insurers often recommend (or require) that precautionary measures (structural, emergency plans, etc.) be taken to reduce the risk and render it more calculable.

Pricing also has to take into consideration the cost of maintaining reserves for large losses. The probability of a single home, e.g. in the Netherlands just behind a sea dyke, being flooded is very small ($< 10^{-3}$), but if a loss does occur, thousands of other houses will be damaged at the same time and the overall loss will be enormous. Maintaining reserves against such a contingency costs a multiple of the amount that reflects the individual risk, and thus constitutes another component of the premium. The required annual premium is therefore not around 1‰ but might be as much as 1% of the insured value, which makes insurance cover practically unaffordable.

Modeling probable expected losses

Modeling within the insurance industry in the natural perils context is mainly aimed at estimating probable maximum (accumulation) loss (PML). Correct assessment of PMLs and holding adequate reserves are crucial to an insurer's economic survival. Compared with windstorm and earthquake, flood losses are much more difficult to model. This is true not only of riverine flooding but also of coastal flooding. Relatively small features can have major consequences: whether or not a dyke is overtopped (or possibly breached) and the protected area flooded may depend on a few centimeters' difference in water levels or a local weak spot in the protection system. Alternatively, a road or wall that is not even meant to keep water away from a site may in fact do so, and prevent damage. Modeling flood losses therefore requires considerable detail. It is not helpful to "lump together" large areas on the basis of averaged impact intensities, not least because the areas affected are much smaller and more confined than in the case of windstorm and earthquake hazards.

PML models are based on Eq.1. The values at risk are represented by the portfolio under consideration, i.e. the distribution of (insured) values in a country. Typical (average) loss rates for different types of building and given loads (wind speed, water level, earthquake intensity) are applied and account for vulnerability. The hazard is introduced by simulating a storm/earthquake/flood event in the area represented by the portfolio (Figure 7). Simulating a large number of – stochastically generated – events yields the same number of event losses. The losses are arranged according to size to form an (empirical) PML curve, from which the expected loss for a given return period can be read off, or the return period of a historical event with a known loss determined (Figure 8).
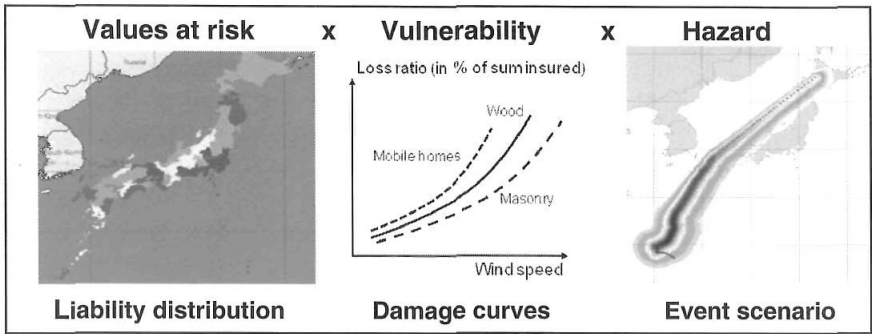
Values at risk   x   **Vulnerability**   x   **Hazard**

Loss ratio (in % of sum insured)

Liability distribution   Damage curves   Event scenario

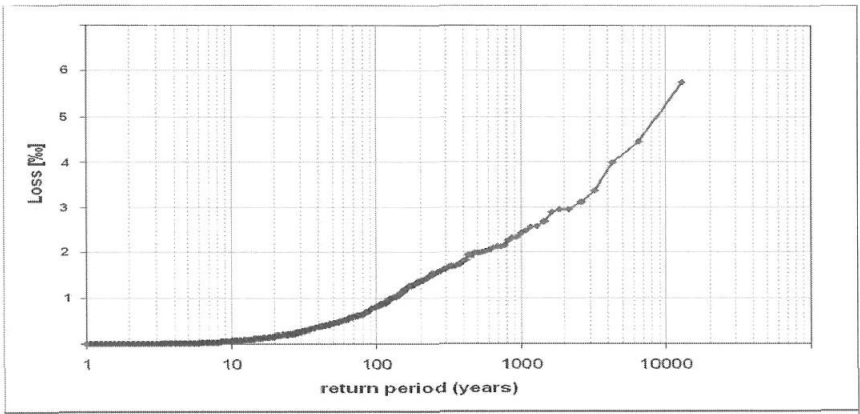**Figure 7. Principle of PML modeling**

Figure 8. Empirical PML curve (losses from a large number of simulated events arranged in order)

FACTS – EXPECTATIONS – SOLUTIONS

Facts

No other region is threatened more by natural perils than coasts. Coastlines are boundaries. The most obvious boundary is the one between water and land. The fiercest winds over land usually occur where storms make landfall. Where wind-driven water masses meet land they rise to storm-surge levels. Large waves and tsunamis, having traveled hundreds or even thousands of kilometers, expend their energy when they reach the coastline. Additionally a coast often represents the boundary between continental plates, making earthquakes and volcanic eruptions more frequent and likely.

Despite these hazards, people are attracted to coasts. Here, economic conditions are better and many other quality-of-life aspects more favorable than elsewhere. Besides residents, tourists make up a large proportion of the population in many places. Not being familiar with the hazards, they can be even more vulnerable than the local residents, often reacting in the wrong way. Most global trade crosses the oceans. Industrial and commercial companies prefer to be close to ports and transport their raw materials and goods over shorter distances. Some coastal regions rank among the top places in the world in terms of value accumulation. This aspect is the main driver of risk.

Hardly any type of natural hazard protection is as high as that against storm surges, in developed countries at least. However, vulnerability has been reduced only where relatively frequent events are concerned, and it is not possible to ensure absolute security. Extreme events can produce unbelievable losses.

Losses from natural disasters have already reached new dimensions, affecting coastal strips and cities. The top four losses of the last 20 years were: Hurricane Katrina (2005, US Gulf Coast, US$ 125bn), Great Hanshin Earthquake (1995, Kobe, US$ 100bn), Northridge Earthquake (1994, Los Angeles, US$ 44bn), Hurricane Andrew (1992, Florida, US$ 27bn). The natural disasters of the past 20 years that produced the most fatalities were the 2004 Indian Ocean tsunami (220,000), the storm surge in Bangladesh (1991; 139,000 deaths), the earthquake in Kashmir (2004; 88,000 deaths), and Tropical Cyclone Nargis in Myanmar (2008; 85,000 deaths). Seven of those eight events occurred near a coast.

Expectations

The only way to contain the mounting risk along coasts is by controlling settlement in high-hazard areas. This, however, is by and large a theoretical possibility in most regions. Development policy and land-use regulations just do not work, even when governments endeavour to impose them. We have to admit that we cannot really stop the concentration process in the short term.

In the same way we have to accept that climate change is a fact, and will increasingly make the situation worse. It is not something we can halt, let alone reverse, within the space of a few decades, even with a zero emissions policy. Today's CO_2 and temperature changes are caused by the emissions mankind introduced into the atmosphere in the 1970s and 80s. The most we can do is to slow down climate change.

Accordingly, coastal risk reduction will have to rely on adaptation measures. Where possible, coastal defense systems will have to be upgraded and strengthened. In this context new engineering techniques and more rigorous emergency procedures will become more and more important.

We must expect that rising sea levels will drive people from the areas they currently occupy, especially in poorer countries such as small island states, and in delta regions, The latter are very difficult to control by means of defense works due to their size and the number of river outlets.

Solutions

Forced abandoning of coastal areas due to sea-level rise induced flooding is one, albeit not voluntary, solution.

Structural engineering measures are crucial and irreplaceable. There are many new methods on the market for improving the stability of newly constructed and existing dykes. The accuracy of forecasting and quality of warning, alert and evacuation procedures have reached adequate levels, but can (and will) be improved. Refining and further developing existing techniques and new techniques will also help.

There will always be a residual risk. This must be placed on the shoulders of all groups in society, the government, the people concerned, and the insurance industry. Although it may not seem obvious, there is huge potential in this respect for reducing the overall risk to society due to natural hazards. Thus far, determining protection levels and designing corresponding structures are factors often based on the "principle of equal hazard" (i.e. every area should be safe from a 100-year flood). Whilst, from a fairness perspective, this makes sense, it does not in any way efficiently optimize the overall risk because it overlooks the fact that concentrations of high-value locations contribute far more to the risk than, for instance, agricultural areas with scattered dwellings. The Dutch approach that uses risk (not hazard) as the decision-making basis should be taken as a role model.

CONCLUSION

Great natural events are not avoidable. Great disasters are. Disasters are inevitably the net result of the largely negative effects of extreme natural events and the largely positive response to those events (including prepared response in the form of precautions). Catastrophes are not only products of chance but also the outcome of interaction between political, financial, social, technical, and natural circumstances. Effective safeguards are both achievable and indispensable, but they will never provide complete protection. The determining factor is awareness that nature can always come up with events against which no human means can prevail. As Aristotle (384–322 B.C.) said, "It is probable that the improbable will happen". We have to establish a culture that copes with all the components of risk. As engineers, we need to support this culture by being aware, open and honest. Pretending and announcing that we can make everything 100% safe is not only reckless but contradictory to our task of helping to achieve a risk minimum.

REFERENCES

IPCC 2007. *Climate Change 2007: Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (http://www.ipcc-data.org/ddc_ar4pubs.html).

Kron, W. 2005. *Flood Risk = Hazard · Values · Vulnerability.* Water International, 30 (1), pp. 58–68.

Kron, W. 2008. *Flood insurance –From clients to global financial markets*. In: Simonovic et al. (eds.) Flood Defence 2008. CD-Rom Proc. of the 4th International Symposium on Flood Defence, Toronto, Canada, 6–8 May 2008.

Munich Re 2006. *Hurricanes – More intense, more frequent, more expensive*. Munich Reinsurance Company, Munich, 39 pp.

Munich Re 2008. *Topics Geo – Natural catastrophes 2007*. Munich Reinsurance Company, Munich, 50 pp.

Munich Re 2009. *Globe of Natural Hazards*. Munich: Munich Reinsurance Company.

Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J., and Muir-Wood, R. 2007. *Ranking of the world's cities most exposed to coastal flooding today and in the future (Executive Summary)*, OECD Environment Working Paper No. 1 (ENV/WKP(2007)1), OECD, Paris, 11 pp.
    Full study:http://www.olis.oecd.org/olis/2007doc.nsf/linkto/env-wkp(2007)1

Rahmstorf, S. 2007. *A semi-empirical approach to projecting future sea-level rise*. Science Vol. 315 pp. 368–370.