CREDIT

THE CHAOS TO COME

Natural disasters have wreaked havoc on the planet in the past twelve months, and some say that things will only get worse. **Quirin Schiermeier** assesses the world's growing vulnerability to catastrophe.

In sheer numbers, the death toll of floods, earthquakes, tsunamis, volcanoes and cyclones is small — 80,000 in an average year. Even the recent spate of catastrophes ranks surprisingly low among the scourges of humanity. With the Indian Ocean tsunami and the Kashmir earthquake, disasters in the past 12 months claimed more than 400,000 lives — the highest toll since 1970. But more than three times that number are estimated to have died on Earth's roads in the same period; more than twenty times as many died of avoidable childhood diseases.

To dwell on the averages, however, is to miss the point. Catastrophes are not average; they are the great exceptions. Most of us have seen road-traffic accidents, but few of us have witnessed a natural disaster. They are ruptures with the everyday that change cities, countries and sometimes whole regions forever. They can even change patterns of thought. The Lisbon earthquake of 1755 and its associated tsunami, which struck while the city's churches were celebrating All Saints' Day, shook the faith of millions and altered that century's intellectual landscape irrevocably.

It is the fact that they are rare and exceptional that makes it very hard to plan for natural disasters. Problems that crop up less than once a generation — even, in some cases, less than once a millennium — are easily overlooked. Experts can anticipate some natural disasters, but their predictions and assessments often count for little compared with the pressures of population and development, which increase the number of people in harm's way. As more people crowd the planet, particularly in vulnerable coastal areas, they risk disasters of unprecedented proportions. Hence the paradox that the twentieth century, benefiting from the most advanced technology in human history, saw more deaths due to natural disasters than any previous century had. There is even the chilling possibility that the current century will beat the previous one's tally of 3.5 million deaths.

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TSUNAMIS

Past More than 60,000 people were killed in Lisbon in 1755 by an earthquake and the resulting tsunami (pictured). About 300,000 have been reported dead or missing following the great Indian Ocean tsunami of December 2004. Tsunamis can be triggered by a range of disturbances, including earthquakes, underwater landslides and asteroid impacts.

Future Low-lying coastlines in Sumatra, China, Peru and the eastern Mediterranean are considered at greatest risk. Early-warning systems, public education, and land-use regulation offer the best chance of saving lives.

The science behind predicting disasters is uncertain. But with the best geological and meteorological knowledge in hand, along with models that assess the vulnerability of different populations (see 'Insuring for disaster', overleaf), experts are starting to quantify just how grim the future will be. Steve Sparks, a volcanologist at the University of Bristol, UK, has looked at analyses of current trends by the German reinsurance firm Munich Re. "The world can now expect three to five major events per year, which each kill more than 50,000 people," he says.

The mechanisms behind these disasters are not new; the basic factors that underlie volcanic eruptions, earthquakes, cyclones and floods are well understood, and so is the geographic distribution of risk. But there are still three mysteries: where and when a disaster will strike; what unforeseen consequences there might be; and how to get policy-makers and the public at large to take the problems, and the uncertainties, seriously.

Public preparedness rarely keeps pace with scientific knowledge. "The science," says Sparks, who recently organized a meeting on natural disasters at the Royal Society in London, "is not getting through to policy-makers, planners and populations." US meteorologists had often warned that their worst-case hurricane scenario would involve a storm breaking the protective levees around low-lying New Orleans. And that's exactly what happened on 29 August with Katrina, which left 1,300 dead — the largest death toll from a natural disaster in the United States since the 1928 Okeechobee Hurricane. Geologists had long warned of the possibilities of large earthquakes along the Himalayan front, like the one that struck Kashmir in October, and in the Sumatran trench off Indonesia, where the tsunami was born last December.

The very enormity of the Indian Ocean tsunami is, in fact, a good example of unforeseen consequences. The seismic risk in the area was known, but the scope of the resulting tsunami, which affected a dozen countries, was totally unexpected. Unlike in Hawaii and Japan — where tsunamis are a relatively frequent phenomenon, and where education projects and early-warning systems exist — many people in southeast Asia, India and eastern Africa had never even heard of such waves. The death toll was particularly high in the 'shadow zone' near the Equator, where tropical cyclones rarely occur and people have lived safely by the sea for centuries.

Risk-management experts predict that a tsunami of similar scale is likely to happen only once every 500 years. Nevertheless, nations around the Indian Ocean are funding an early-warning system similar to the Pacific Tsunami Warning Center in Hawaii — the first set of buoys was installed last month. Critics charge that the technology could rust at the bottom of the ocean long before the next big wave strikes[1], but to some extent this misses the point. Many holders of insurance never need to make a claim, but that doesn't mean it was silly to buy a policy.

UNDERWOOD & UNDERWOOD/CORBIS

HURRICANES

Past The Great Hurricane of 1780 killed 22,000 in Martinique, St Eustatius and Barbados. In 1900, an unnamed storm wiped out the Texas island of Galveston (pictured) establishing Houston as the state's main port.

Future Experts point to several scenarios that could be worse than August's Katrina, including a category-5 hurricane racing up the US east coast and into Manhattan. Low-lying parts of eastern India and Bangladesh are at high risk of large fatalities from flooding and storm surges. Population growth along coasts increases vulnerability.

History lessons

Letting the past be a guide to the future is not entirely satisfactory. Hemant Shah is the president of Risk Management Solutions (RMS), a company based in Newark, California, that constructs risk models for the insurance industry. He echoes the US defense secretary, Donald Rumsfeld: "The challenge for the industry really is to think about the unknown unknowns." More thinking along those lines might have led to a greater appreciation of the tsunami risk in the Indian Ocean. But analysis of the past does at least provide data for imagining future scenarios — experts can envisage the consequences of a repeat of the Lisbon earthquake, for example.

A team led by Shinji Toda, of the Geologic Survey of Japan in Ibaraki, and Ross Stein, of the US Geological Survey in Menlo Park, California, has been re-evaluating seismic risks to Tokyo in light of past earthquakes. In a report submitted to the Japanese government, the researchers found that a replay of the 1855, magnitude-7.3 Tokyo earthquake that killed 7,000 people could devastate the city and send shocks through the world's financial markets. The problem is that no one understands the 1855 earthquake well enough to predict accurately when it

Insuring for disaster

The impact of natural disasters on the insurance industry often bears little relation to death tolls. A pair of hurricanes from 2005 — Katrina and Wilma — may together cost insurance companies a record US$40 billion. And European winter storms with almost no fatalities can still cost billions.

Such bills make modelling risk vital for insurers. Models help companies adjust their policy prices to their 'risk appetite', decide how much reinsurance to buy and how much additional capital to hold.

In 1995, Lloyd's of London began asking its 66 underwriting syndicates to report estimated losses from hypothetical disasters based on historical examples. Scenarios included major earthquakes in California, the US Midwest and Japan, and windstorms in Florida and Europe. The resulting 'realistic disaster scenarios' help Lloyd's to assess the insurance market's vulnerability to big losses.

With few major natural disasters in the 1970s and 1980s, the insurance industry was ill-prepared for 1992's Hurricane Andrew and 1994's Northridge earthquake. Together, these cost insurers $30 billion; at least nine companies were rendered insolvent. Other crises, such as the 1995 Kobe earthquake in Japan and the 2001 terrorist attacks on the United States, have also had an effect — over the past decade, the cost of reinsurance has grown 40-fold.

To help insurance companies cope, risk-management specialists draw up models of disasters. They can calculate the frequency of a certain size of event (see table) and tell an insurance company with a given portfolio how big a loss it can expect.

The models usually consist of three modules. A high-resolution hazard module predicts the physical effects that might be expected at a given point from sources such as historical records, windspeed maps or seismic data. A vulnerability module then predicts the damage that an event, depending on its strength and duration, would do to local buildings and infrastructure. Finally, a financial module calculates an insurance company's effective losses given such damage, taking into consideration its portfolio and the location of its policies.

Frequency of event	Size of event (measured in fatalities)		
	Earthquake	Flood	Volcano
1 in 100 years	472,000	98,000	34,000
1 in 500 years	1,052,000	520,000	74,000
1 in 1,000 years	1,446,000	1,061,000	97,000

Data provided by Risk Management Solutions

The models vary widely in robustness. They work well for calculating losses from hurricanes and earthquakes in the United States. But in places where there is little information from historical disasters, from Australia to Morocco, risk modelling is difficult and uncertain.

And for some of the most apocalyptic scenarios — a meteorite impact or a mega-tsunami in the Atlantic Ocean — modelling doesn't work at all. "It is a real concern for the insurance industry that no models exist for some of the worst things that could happen," says Iwan Stalder, head of catastrophe perils at Zurich Financial Services in Switzerland. "But we have to accept that some risks are simply unquantifiable for underwriting." **Q.S.**

AFP/GETTY IMAGES

Shattered: the destruction caused by the Indian Ocean tsunami was largely unforeseen.

might happen again, and thus to quantify the risk. "There's an enormous amount of uncertainty," says Stein.

Tokyo's peculiar vulnerability to earthquakes, which arises from its position at the junction of three tectonic plates, is a chronic worry for the global financial system. But in casualty terms, there are places that concern seismologists more. The worst earthquake of the twentieth century, and possibly the worst in history, was China's Tangshan earthquake in 1976, which may have killed more than half a million people. Some seismologists think that the ever-growing cities in earthquake belts across Asia, many filled with unstable buildings, mean that a million-fatality earthquake is possible in the near future; Sparks mentions Istanbul, Tehran and Sumatra's Padang as likely sites. Tehran, a city of 12 million with what one expert at RMS calls "some of the scariest construction known to man", is a particular worry: just as Tokyo has the potential for an earthquake with disproportionate financial impact, one in Tehran would have a huge geopolitical impact.

Floods of fire

Volcanic eruptions are also bound to do more damage in the future than in the past, simply because more people live in their path. Here some degree of warning is more likely than it is with earthquakes, but it cannot be relied on. And although cities such as Naples, at the foot of Italy's Mount Vesuvius, face the most obvious dangers, other situations could result in more deaths. Robert Muir-Wood, chief researcher at RMS, notes that a major tragedy could happen if an eruption reached a major city just outside an immediate evacuation zone, to which people had fled for shelter.

An additional concern is that we have no historical experience of what a really large volcanic eruption might look like. The twentieth century's most lethal eruption, in Martinique in 1902, was far smaller than the giants of the nineteenth century. The 1883 eruption of Krakatoa in Indonesia obliterated the island and sent plumes of volcanic ash drifting around the globe for years, and the Tambora eruption of 1815 affected climate all over the world. Even mighty Krakatoa was at least an order of magnitude smaller than the Santorini eruption, which effectively wiped out the Minoan civilization in the eastern Mediterranean around 1400 BC.

Hurricanes, by contrast, are more tractable. There are limits to their size and destructive power, they have seasons, and their tracks can be forecast with some degree of accuracy. They are also frequent enough for people to take seriously, especially if given the right sort of warnings and information. In the United States, the National Hurricane Center in Miami, Florida, is responsible for issuing storm warnings when Atlantic hurricanes threaten the coast. It now produces maps, available on the web and through television broadcasts, that forecast storm paths with an accuracy that has improved by 50% in the past 30 years.

Most coastal residents pay attention only when a hurricane is threatening their particular part of the coast, so this information has to be targeted to the right place, at the right time and in the right way. "Meteorology means nothing to 99% of my viewers," says Steve Lyons, a hurricane expert and anchorman of the popular US Weather Channel. "We need to translate the meteorology into impact. It's like telling people in a town very concretely: 'It's gonna blow your roof off, so you better run'."

But it is not all about listening to the media. Teaching people how to notice warning signals from nature — such as shaking ground or a

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VOLCANOES

Past The past two centuries have seen more than a dozen volcano disasters that caused at at least 500 deaths. One such was Mt Pelee's eruption in 1902 (pictured). Affected regions are mostly in the developing world, including Indonesia, Colombia, Mexico, Guatemala, Martinique, Papua New Guinea, Cameroon and Congo.

Future Were the 1815 eruption of Indonesia's Tambora to happen today, 15,000 people might be killed. Volcanologists are struggling to develop timely warnings for mountains that have lain dormant for many years and could erupt at a moment's notice.

AP/EMPICS

The death toll of the Kashmir earthquake is still rising.

receding ocean — can save lives in all sorts of natural disasters. Other relatively simple measures include planning escape routes and evacuations, and reconsidering land use in regions threatened by floods, storms, landslides and avalanches. A 2004 World Bank report on the cost of natural disasters in the 1990s estimates that $40 billion invested in risk reduction and preparation could have cut the decade's final bill in half, from $535 billion to $255 billion. It also estimates that, over the past four decades, $3.15 billion invested in flood control by China has averted $12 billion in losses.

Such mitigation strategies have worked to save lives most dramatically during floods, says Muir-Wood. In China, for instance, flood casualties have dropped throughout the century, in part because of investment in protection systems and evacuation plans. In the 1930s and 1940s, 4.4 million people died from flooding in China; in the 1950s and 1960s, that number dropped to 2 million, and by the 1970s and 1980s it was 14,000.

Still, the Indian Ocean tsunami and Katrina have highlighted the failure of society as a whole to take preventative action, says Maxx Dilley, a geographer at the Disaster Reduction Unit of the United Nations Development Programme (UNDP) in Geneva. From international organizations to local decision-makers, those in charge are realizing that they need to know how natural events become tragedies. "A lot of things are coming to a head," says Dilley. "There is an international push to focus more on risk identification and management, as opposed to post-disaster emergency action."

Several organizations, including the UNDP, the Red Cross and the International Strategy for Disaster Reduction, have recently published reports outlining improved risk-management strategies[2–4]. They emphasize putting more resources into preparedness — restricting the expansion of cities in earthquake-prone regions, for example. Science, says Dilley, should be the basis of all these activities. But the fragmented research community is not positioned to provide the right input, he adds: "What you need are planner-friendly common views, as opposed to highly specialized scientific papers."

To address the issue, a group of experts led by David King, Britain's chief science adviser, has suggested setting up an International Science Panel for Natural Hazard Assessment. Such a panel would function like the Intergovernmental Panel on Climate Change, sorting through a flood of scientific information and creating a generally accessible summary of the latest findings. And the UNDP and World Bank are working with Columbia University's Earth Institute in New York on a project to identify high risks, and give governments and local planners the data to recognize them.

"This is the kind of information," says Sparks, "that, had it been available ten years ago, would have allowed governments in southeast Asia to take precautions against the tsunami." ■

Quirin Schiermeier is *Nature*'s German correspondent.

1. Alversen, K. *Nature* **434,** 19–20 (2005).
2. *Reducing Disaster Risk: A Challenge for Development* (United Nations Development Programme, 2004).
3. *World Disasters Report 2005* (International Federation of Red Cross and Red Crescent Societies, 2005).
4. *Living with risk: A global review of disaster reduction initiatives* (International Strategy for Disaster Reduction, 2004).

BETTMANN/CORBIS

EARTHQUAKES

Past The devastation of San Francisco in 1906 (pictured) is legendary, but the deadliest earthquake known happened in China: at least half a million died in the Tangshan disaster of 1976.

Future Specialists point to China, the Himalayan front or the city of Tehran as possible locations for the first earthquake to cause a million casualties. Events in Tokyo, California and the Mississippi Valley are likely to cause the most economic damage. Improving construction standards and emergency plans could significantly reduce fatalities.

KEYSTONE/GETTY IMAGES

FLOODS

Past Seven of the ten deadliest flood disasters in the twentieth century have occurred in China. More than 6 million people died from drowning, starvation and disease during the three biggest floods in 1931, 1939 and 1959.

Future China is building its controversial Three Gorges Dam, to be completed in 2009, in part to reduce flood risk. Central America, Bangladesh, Taiwan and elsewhere remain at risk from heavy rains. Dams and other barriers, as well as re-naturalization of river courses, may help. Low-lying countries such as the Netherlands are accustomed to inundations such as that pictured above, but climate change may increase flood risk.