Science and the Future of Mankind
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EARTH SCIENCES: REMARKABLE SCIENTIFIC PROGRESS, EXTRAORDINARY OPPORTUNITY FOR HUMAN BETTERMENT[1]

FRANK PRESS[2]

Humankind enjoys the benefits of living in a unique place. No other known planet has the same balance of conditions necessary to sustain life as we know it. However, in this paper I want to discuss some of our planet's hazards – namely, earthquakes, volcanoes, storms, floods, and the like.

Although I will discuss mostly rapid onset natural hazard events, one must add in these times the perils of El Niño, global warming, industrial accidents, environmental degradation and other consequences of humankind's interaction with the natural environment. Science progresses by challenging conventional wisdom and teaching the world to think in a fundamentally new way. And that is what we need to do about natural hazards.

You will note that I refer to these events as natural hazards, not as natural disasters. The distinction is deliberate. We cannot stop volcanoes from erupting or the earth from shaking. On occasion, winds will blow outside this hall and level the beautiful trees of Rome.

Our planet is affected by an external engine energized by solar radiation and an internal engine driven by Earth's internal heat. They are beyond our direct control. The external engine drives our weather and climate. It has made life possible on Earth but it also is responsible for storms and floods. The internal engine produced the continents, the atmosphere, and the oceans. But it also produces the Mount Pinatubo volcanic eruption and earthquakes in Turkey. As one philosopher said, "Man lives by geological

[1]This paper is an updated version of reports I have given elsewhere on several occasions. It includes new scientific results and recent changes in policy.

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consent subject to change without notice." In scientific parlance, "geophysical extremes are inevitable."

Natural hazards are rare, low-probability events that are natural and unstoppable. Natural disasters are the unfortunately common consequences of these extreme events when they collide with people. As one observer remarked, "we can't control mother nature but we can affect human nature." What he meant was disasters can be mitigated because how humans choose to live with the natural environment can be changed by a combination of new scientific knowledge and improved public policies.

Millions of people now die unnecessarily. I believe that reducing disasters – which is to say, the toll of natural hazards – is one of the great challenges of our times. We have the scientific knowledge and practical know-how to partially overcome phenomena that have devastated mankind since before Biblical times. And through science we can learn to do more. It is an opportunity of historic significance. And it is what I will discuss with you today

First, I will outline the extent of the problem and discuss the new scientific and engineering possibilities that allow for improved societal response. Then I will discuss international efforts initiated by scientists and engineers that have begun to show results. The views of public officials in many countries, rich and poor, are changing from fatalism to a proactive and informed pursuit of policies to limit the destructiveness of natural hazards.

The Grim Statistics of Recent Natural Disasters

So let us begin by reminding ourselves just how common and severe natural disasters are. According to the International Decade of Natural Disaster Reduction (IDNDR as it is known), an organization of the United Nations, in the past twenty to thirty years, natural disasters killed more than 3 million people worldwide. More than a billion people have been adversely affected. They have suffered homelessness, injury and disease, catastrophic economic losses, and other personal tragedies. The Munich Reinsurance Company predicted that global economic losses were likely to double in the period 1995-2000. According to the International Red Cross the global losses related to disasters currently amount to some $440 billion each year. In the United States the losses from natural disasters now average about $1 billion per week, with an accelerating trend.

Nearly every nation of the world is at risk from rapid-onset natural hazards. Every year our planet experiences about 100,000 thunderstorms,

10,000 floods, and thousands of earthquakes, wildfires, landslides, avalanches, and tornadoes. There are hundreds of volcanic eruptions and tropical cyclones. Most of these events result in human losses that escape being counted in the casualty and economic loss statistics that were cited earlier.

What I would like to emphasize today is that most of the human tragedy of death and destruction from natural disasters occurs mainly in the developing world. Two-thirds of the world's population lives in developing nations, and these countries bear 95 percent of all disaster casualties. A single major disaster can result in hundreds of thousands of deaths and can set back economic progress in a developing country by as much as five years. The statistics numb the mind. The loss of life per million of population is twelve fold greater in the developing world than in the United States. The economic loss in my country of about a billion dollars a week may seem high, and it is, but annually it amounts to only about 0.7% of the gross domestic product. In poor countries it has been as much as 50% of the G.D.P. In these cases economic development is slowed if not turned negative as scarce resources are diverted to emergency and recovery efforts.

It is easy to see why the impact of these hazards is growing worse by the year despite our increased understanding of them. This is true for several reasons.

– First, the world's population is continuing to grow, and many people are settling in areas of high risk, such as flood plains, coasts, seismic zones, or mountain slopes susceptible to landslides.

– There are 20 megacities in the world with populations exceeding 10 million people. This density of urban population continues to grow for demographic and economic reasons.

– Still another reason that natural hazards are claiming a continually rising number of victims is that so many of the world's buildings and other structures, both new and old, remain unsafe. When a natural disaster hits these areas, not only are more people hurt immediately, but critical life support systems are interrupted, leading to further health problems.

– All this expansion also has altered the natural environment. Deforestation in the Amazon, for instance, has caused an increase in flooding, landslides, and soil erosion. Overgrazing of arid grasslands has accelerated the process of desertification and drought in sub-Saharan Africa.

– Failure to use the existing knowledge developed by scientists and engineers to reduce the vulnerability of structures to earthquakes, storms, floods and other hazards must be reckoned as a factor in these pessimistic statistics.

– And the increasing globalization and interconnectiveness of the world's economy makes it clear that no nation is immune from an immense disaster that can strike anywhere in the world. Disasters can trigger disinvestment and the flight of capital, inflation, indebtedness, bankruptcy. For example, if the great earthquake that struck Tokyo in 1923 were to repeat (as it eventually will) the damage could exceed $1 trillion. According to the Bank of Tokyo such losses could propagate beyond Japan and upset the global economy. For example, Japan could be forced to recall its foreign investments and reassess its role in international financial institutions. This could well precipitate a world recession.

In my own country, millions of people living near the New Madrid fault in our Midwest risk a similar fate due to construction codes that have ignored the possible repeat of a great earthquake that occurred early in the eighteenth century.

The Role of Science in Reducing the Destructiveness of Natural Hazards

The tradition of humankind studying terrifying natural phenomena dates back to ancient times, of course. Our ancestors explained these cataclysms through religious myths, astrology, and the like. Then, with the advance of science, came a truer understanding of hazards as natural phenomena.

Today we understand the origins of earthquakes and volcanic eruptions in terms of the modern theory of plate tectonics. Similarly, there is growing knowledge of the general circulation of the atmosphere, its interaction with the oceans and the generation of weather.

My own background is in geophysics, and I am amazed by what has been learned about earthquakes just since I was in graduate school. The same is true of volcanology, meteorology, and other disciplines, although one also finds an increasing – and very healthy – blurring of these specialties. There are now underway new theoretical approaches, new kinds of experiments, and new data, generating new understanding at a remarkable rate.

Here are some examples of technologies that are now available that can contribute to monitoring and warning systems:

– It is now possible to determine in advance of an earthquake the probability that ground accelerations will exceed certain levels in a district so that building designs and regulations are appropriate for the degree of hazard.

– Real time processing of seismic signals can provide an alert within three minutes via commercial paging systems to police, fireman, utilities,

trains, medical and public health authorities. Using GIS the degree of damage in different sectors can be assessed and within hours or less post-disaster rescue and relief agents can reach the neediest districts.

– Real time response can also occur in another way. With computerized digital arrays of seismographs, an earthquake can be located and its time and size determined in about a minute. This information can be signaled instantaneously, well before the slower traveling seismic waves arrive. In some locations such as Mexico City, several hundred kilometers from the earthquake belt it is vulnerable to, a warning can be issued some 70 seconds before the arrival of the most destructive seismic waves – possibly time enough to shut down gas transmission lines and power plants, get fire engines out of their buildings, get school children into protected areas, stop trains and other appropriate actions.

– Many types of volcanic eruptions are predictable from space and from ground observations with sufficient certainty to evacuate affected populations.

– Satellites can monitor severe storms and computers can predict their paths with increasing accuracy.

– Ocean storm surges can be predicted days in advance – very important to places like the Bay of Bengal and the Adriatic Sea.

– The development of advanced Doppler radar technology has greatly advanced our ability to predict tornadoes and other weather-related hazards.

– Computer modeling of watersheds has led to more accurate flood alerts.

– Warning systems for tsunami and landslides are now available for many locations.

Current forefront research is opening the way to new technologies with great potential to reduce even more dramatically losses from natural disasters. Here are some examples:

– Most earthquakes and volcanoes occur at boundaries where tectonic plates collide, separate, or slide past one another. Plans are being made to place instruments at all of the boundaries of a plate that would measure microseismicity, strain accumulation, thermal activity, chemical changes in fluid emanations, and other potentially premonitory indicators of hazardous events.

– Plans are being made to drill into the San Andreas Fault, the most dangerous fault in the United States, at a depth of some five kilometers. Instruments will be emplaced in this zone which could illuminate the nucleation process of earthquakes.

– Synthetic Aperature Radar interference patterns obtained from satellite observations can reveal strain accumulation and release at earthquake faults and show the swelling of a volcano prior to an eruption.

– New satellites such as TERRA can monitor Earth's vital signs such as land, sea, and air temperatures, clouds, aerosols, water vapor and green house gases, ocean currents, winds, pollution, and ecological changes. These can be used to provide earlier warning of severe storms, volcanic eruptions, predict El Niño events, and signal global climatic change.

Unfortunately, many of the currently available technologies I have described earlier are available only in those countries that have the technical, human, and material resources to use them. Hopefully this will change. Nevertheless, there is an enormous amount that can now be accomplished more generally by using knowledge and technical systems that have been around for several decades. The problem is putting all of this know how into general practice – getting the word out to the villages and cities where people need it most, particularly those in the developing world. It requires education that goes beyond individuals and families. It also needs to include training programs for architects, engineers, insurance agents, city planners, teachers, reporters, *and especially government policy makers*. H.G. Wells stated it very well when he wrote: "Human history becomes more and more a race between education and catastrophe."

The first step is risk assessment which combines information on a physical hazard with information on vulnerability to determine the likely impact of a hazardous event. It provides estimates of deaths and injuries, property damage, and economic losses that are likely to occur. Once this assessment is made, a community can undertake disaster reduction programs appropriate for the risk, and organize warning and evacuation strategies to reduce those impacts.

Let me give you some examples. Consider Hurricane Gilbert. This 1988 storm was the most powerful hurricane ever recorded in the Western Hemisphere. Three hundred sixteen people died. That was a substantial loss of life, but it was far lower than the death tolls from hurricanes of smaller magnitude that have swept through the Caribbean. Those earlier storms claimed lives not in the hundreds, but in the tens of thousands. The main difference with Hurricane Gilbert was that people and governments were well prepared. Weather reports and storm tracks were timely and accurate. The public was educated to heed these warnings and to take appropriate actions. Land use restrictions and building codes were in place to minimize the loss of life and property in the Caribbean island nations

and Mexico. Governments had emergency teams standing by to provide assistance. So today people are alive to share their memories of Gilbert rather than being remembered among its victims.

Another example is the 1991 eruption of Mt. Pinatubo in the Phillippines. An international team of scientists developed a risk map of the area. Arrays of instruments were established to monitor the seismic activity, the swelling of the volcano as the magma flowed upward, the geochemistry of its emanations. On the basis of these data an alert was issued to the government which then broadcast a warning and proceeded to evacuated more than 80,000 people. Only 300 people perished from this, one of the great eruptions in human history.

Contrast this with a worst case example – the 1985 eruption of the volcano Nevada del Ruiz in Columbia. Scientist warned authorities about the dangers of this volcano when hot gases would sweep across the snow pack near the summit. They had prepared a preliminary hazard map. Unfortunately, there was no government office available to receive this information, no warning or evacuation systems were in place. The eruption followed the course predicted by the scientists and a meltwater-mud flow engulfed and buried the town of Armero. All of its 23,000 inhabitants perished. As the British philosopher John Locke observed, “Hell is truth seen too late.”

It is a sad commentary on our times that the industrialized nations can employ life and property saving measures much sooner and more effectively than those in the less affluent countries. It is a moral imperative that these measures and their associated technologies be made available more widely.

In 1984 I gave a talk before a world conference of engineers calling on the international scientific and engineering communities to become engaged in reducing the toll of natural disasters. The message resonated across professional communities and was endorsed by organizations representing tens of thousands of scientists and engineers. It was recognized from the beginning that addressing disasters with technology was only the precursor to hazard management, which involves the messy political process of balancing interests and priorities, and of implementing change. So, obviously, another challenge we faced was to work with political decision-makers, to apply our improved scientific understanding and technological capacity, to develop both long-term protective measures and shorter-term warnings.

In particular it was necessary to engage the United Nations because of its ability to communicate with and enlist the leaders of every country, rich and poor, large and small. In this we were successful. In response to the ini-

tiatives of scientists and engineers in many countries, acting on their new awareness of the opportunities for disaster mitigation, the United Nations declared the 1990s to be the International Decade for Natural Disaster Reduction. I consider it one of the highlights of my career that I helped launch this international program.

To quote Javier Perez de Cuellar, the Secretary-General of the United Nations in the early years of the decade: "The Decade offers an opportunity for the United Nations to demonstrate its catalytic ability to bring together the diversity of skills, resources, and groups needed to stem the losses from natural disasters...It has the moral authority to call for disaster reduction efforts by all nations, including the developing ones where the toll from such disasters is most tragic in terms of human losses and economic setbacks."

The "Decade," as it has come to be called, ended last year. However with pressure from the developing nations there will be continuing involvement of the UN. Looking back at its accomplishments

– The decade helped to mobilize scientists, political leaders, and others to overcome people's fatalism about natural hazards.

– Disaster preparedness offices were organized and hazard assessments were prepared in many countries for the first time.

– Training programs increased the number of disaster professionals by the hundreds.

– Warning systems and evacuation plans were established widely.

– Country development plans were scrutinized for their vulnerability to disasters.

– Disaster mitigation and sustainable development plans have begun to be coordinated.

Although much more could have been done, fewer people will suffer in the years ahead. And as research continues and the new knowledge gained is put to use, large reductions in human and material losses become possible.

I feel strongly that acting to prevent natural disasters is the mark of a civilized society and a primary role of modern government. As a scientist I take great pride that this progress has its roots in science and technology.

So my message in this paper is clear. The human race is more vulnerable than ever to natural hazards. But it also has growing power to predict and provide early warning of many of these hazards and reduce the devastation of all of them. Taking into account the enormous costs of post-disaster relief, pre-disaster mitigation is viewed by many experts as cost effective. A judicious blend of science and technology with enlightened public policy and education could change the course of history.