Cambridge University Press
978-0-521-87293-5 - Large-Scale Disasters: Prediction, Control, and Mitigation
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Introduction

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IT WAS the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way—in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

(From A Tale of Two Cities *by Charles Dickens)*

Rumble thy bellyful! Spit, fire! spout, rain!
Nor rain, wind, thunder, fire, are my daughters:
I tax not you, you elements, with unkindness;
I never gave you kingdom, call'd you children,
You owe me no subscription: then let fall
Your horrible pleasure: here I stand, your slave,
A poor, infirm, weak, and despised old man:
But yet I call you servile ministers,
That have with two pernicious daughters join'd
Your high engender'd battles 'gainst a head
So old and white as this. O! O! 'tis foul!

(From William Shakespeare's King Lear*)*

This book is a collection of review-type chapters that cover the broad research field of large-scale disasters, particularly their prediction, prevention, control, and mitigation. Both natural and manmade disasters are covered. The seed for the project is the *U.S.–Egypt Workshop on Predictive Methodologies for Global Weather-Related Disasters*, held in Cairo, Egypt, 13–15 March 2006. Sponsored by the U.S. State Department and its National Science Foundation, the meeting organizers invited fifty American and Egyptian scientists, engineers, meteorologists, and medical personnel. Thirty formal presentations were made, and plenty of both formal and informal discussions were carried out. The 3-day conference concluded with two panel discussions, and its proceedings have been subsequently published (Gad-el-Hak, 2006). Despite its more limited title, the workshop's scope expanded considerably beyond predictive methodologies for weather-related disasters to include other types of natural and manmade disasters and their prediction, control, and management. This book reflects that expansion.

1.1 What is a large-scale disaster?

There is no absolute answer to this question. The mild injury of one person may be perceived as catastrophic by that person or by his or her loved ones. What we consider herein, however, is the adverse effects of an event on a community or an ecosystem. What makes a large-scale disaster is the number of people affected by it and/or the extent of the geographic area involved. Such disaster taxes the resources of local communities and central governments and leads those communities to diverge substantially from their normal social structure. The extreme event could be natural, manmade, or a combination of the two. Examples of naturally occurring disasters include earthquakes, wildfires, pandemics, volcanic eruptions, floods, droughts, and extreme weather phenomena such as ice ages, hurricanes, tornadoes, and sandstorms. Humans' foolishness, folly, cruelty, mismanagement, gluttony, unchecked consumption of resources, or simply sheer misfortune may cause war, energy crisis, fire, global warming, famine, air/water pollution, urban sprawl, desertification, bus/train/airplane/ship accident, or terrorist act.

In addition to the degree or scope of the disaster, there is also the issue of the rapidity of the calamity. Earthquakes, for example, occur over extremely short time periods measured in seconds, whereas air or water pollution and global warming are slowly evolving disasters, their duration measured in years and even decades, although their devastation, over the long term, can be worse than that of a rapid, intense calamity.

For the disaster's magnitude, how large is large? Herein, we propose a metric by which disasters are measured in terms of the number of people affected and/or the extent of the geographic area involved. The suggested scale is nonlinear, logarithmic in fact, much the same as the Richter scale used to judge the severity of an earthquake. The *scope* of a disaster is determined if at least one of two criteria is met, relating to either the number of displaced/injured/killed people or the adversely affected area of the event. We classify disaster types as being of Scopes I to V, according to the following scale:

Scope I	**Small disaster**	**$<$10 persons**	**or**	**$<$1 km^2**
Scope II	**Medium disaster**	**10–100 persons**	**or**	**1–10 km^2**
Scope III	**Large disaster**	**100–1,000 persons**	**or**	**10–100 km^2**
Scope IV	**Enormous disaster**	**1,000–10^4 persons**	**or**	**100–1,000 km^2**
Scope V	**Gargantuan disaster**	**$>10^4$ persons**	**or**	**$>$1,000 km^2**

We elaborate on this classification in Chapter 2.

1.2 Book contents

There are several recent books on natural disasters on the market, but less available on manmade disasters. Most books are written from either a sociologist's or a tactician's point of view, in contrast to a scientist's viewpoint.[1] A sample is listed in the Bibliography at the end of this chapter. Numerous journals deal at least in part with one aspect or another of large-scale disasters, whether it is technological, scientific, logistical, medical, economical, social, or political. Few archival publications are exclusively dedicated to disasters, for example, *Crisis Response Journal*; *Disaster Prevention and Management*; *Disaster Recovery Journal*; *Disasters: The Journal of Disaster Studies, Policy and Management*; *Journal of Homeland Security and Emergency Management*; *Journal of Emergency Management*; *Journal of Prehospital and Disaster Medicine*; *International Journal of Emergency Management*; *International Journal of Mass Emergencies and Disasters*; and *Natural Hazards*

[1] There are a few popular science or high school–level books on disasters—Engelbert et al. (2001) and Allen (2005)—and even fewer more advanced science books— Bunde et al. (2002).

Review. Numerous resources are available on the Internet. A Google search on the word "disaster" yielded 404,000,000 links, most of them of course irrelevant to the study of large-scale disasters. However, three portals and two university research centers, in particular, are worth listing herein because they lead to many useful sites in a well-organized fashion:

www.disastercenter.com/;
www.disaster.net/;
www.gwu.edu/~guides/sciences/crisis.html#use;
www.udel.edu/DRC/; and
www.colorado.edu/hazards/.

This book is divided into twenty-one chapters, covering many aspects of natural and manmade disasters, including their prediction, control, mitigation, and management. Use of scientific principles to improve prediction is emphasized. Following this introduction, the art and science of large-scale disasters are broadly described, including elaborating on the disaster classification scheme just introduced. Chapter 3 discusses multiscale modeling for large-scale disasters, and Chapter 4 focuses on the root causes of the same. Issues in disaster relief logistics, medical response, and health care capacity are then covered in Chapters 5 to 7. Chapters 8 to 10 discuss global warming, energy crisis, seawater irrigation, and anthropogenic aerosol-related hazards. Chapter 11 is devoted to tsunamis. Chapter 12 is concerned with the fundamentals of intermediate-scale dynamics of the upper troposphere and stratosphere, and Chapter 13 briefly covers coupled weather–chemistry modeling. Chapters 14 to 17 focus on climate prediction, climate change, impact on precipitation, and arid lands. Chapters 18 and 19, respectively, discuss the history and the present of numerical weather predictions. Finally, Chapters 20 and 21 introduce the International Charter and weather satellite measurements. *Large-Scale Disasters: Prediction, Control, and Mitigation* ties together the disparate topics encompassed by its title, and attempts to establish a common framework for predicting, controlling, and managing manmade and natural disasters, thus delivering a more integrated review of a coherent subject, in contrast to a mere collection of disparate chapters around a loose theme.

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2

The art and science of large-scale disasters

Mohamed Gad-el-Hak

> There was no pause, no pity, no peace, no interval of relenting rest, no measurement of time. Though days and nights circled as regularly as when time was young, and the evening and morning were the first day, other count of time there was none. Hold of it was lost in the raging fever of a nation, as it is in the fever of one patient. Now, breaking the unnatural silence of a whole city, the executioner showed the people the head of the king—and now, it seemed almost in the same breath, the head of his fair wife which had had eight weary months of imprisoned widowhood and misery, to turn it grey.
>
> *(From* A Tale of Two Cities *by Charles Dickens)*

> Alas, sir, are you here? things that love night
> Love not such nights as these; the wrathful skies
> Gallow the very wanderers of the dark,
> And make them keep their caves: since I was man,
> Such sheets of fire, such bursts of horrid thunder,
> Such groans of roaring wind and rain, I never
> Remember to have heard: man's nature cannot carry
> The affliction nor the fear.
>
> *(From William Shakespeare's* King Lear*)*

The subject of large-scale disasters is broadly introduced in this chapter, leaving much of the details to subsequent chapters. Both the art and the science of predicting, preventing, and mitigating natural and manmade disasters are discussed. The laws of nature govern the evolution of any disaster. In some cases, such as weather-related disasters, those first principles laws could be written in the form of field equations, but exact solutions of these often nonlinear differential equations are impossible to obtain, particulary for turbulent flows, and heuristic models together with intensive use of supercomputers are necessary to proceed to a reasonably accurate forecast. In other cases, such as earthquakes, the precise laws are not even known, and prediction becomes more or less a black art. Management of any type of disaster is more art than science. Nevertheless, much can be done to alleviate the resulting pain and suffering.

2.1 Are disasters a modern curse?

Although it appears that way when the past few years are considered, large-scale disasters have been with us since *Homo sapiens* set foot on this third planet from the Sun. Frequent disasters struck the Earth even before then, as far back as the time of its formation around 4.5 billion years ago. In fact, the geological Earth that we know today is believed to be the result of agglomeration of the so-called planetesimals and subsequent impacts of bodies of similar mass (Huppert, 2000). The planet was left molten after each giant impact, and its outer crust was formed upon radiative cooling to space. Those were the "good" disasters perhaps. On the bad side, there have been several mass extinctions throughout the Earth's history. The dinosaurs, along with about 70% of all species existing at the time, became extinct because a large meteorite struck the Earth 65 million years ago and the resulting airborne dust partially blocked the Sun, thus making it impossible for cold-blooded animals to survive. However, if we concern ourselves with our own warm-blooded species, then starting 200,000 years ago, ice ages, famines, infections, and attacks from rival groups and animals were constant reminders of humans' vulnerability. On average, there are about three large-scale disasters that strike the Earth every day, but only a few of these natural or manmade calamities make it to the news. Humans have survived because we were programmed to do so. We return to this point in Section 2.7.

This book is a collection of review-type chapters that cover the broad research field of large-scale disasters, particularly their prediction, prevention, control, and mitigation. Technological, scientific, medical, logistical, sociological, economical, and political aspects of both natural and manmade disasters are covered, some aspects to greater extent than others. The seed for the project is the *U.S.–Egypt Workshop on Predictive Methodologies for Global Weather-Related Disasters*, held in Cairo, Egypt, 13–15 March 2006. Sponsored by the U.S. State Department and its National Science Foundation, the meeting organizers invited fifty American and Egyptian scientists, engineers, meteorologists, and medical personnel. Thirty formal presentations were made and plenty of both formal and informal discussions were carried out. The 3-day conference concluded with two panel discussions, and its proceedings have been subsequently published (Gad-el-Hak, 2006a). Despite its more limited title, the workshop's scope expanded considerably beyond predictive methodologies for weather-related disasters to include other types of natural and manmade disasters and their prediction, control, and management. This book reflects that expansion. The subject of large-scale disasters is broadly introduced in this chapter, leaving many of the details to the subsequent chapters of this book, each focusing on a narrow aspect of the bigger scope. Both the art and the science of predicting, preventing, and mitigating natural and manmade disasters are discussed. We begin by proposing a metric by which disasters are sized in terms of the number of people affected and/or the extent of the geographic area involved.

2.2 Disaster scope

There is no easy answer to the question of whether a particular disaster is large or small. The mild injury of one person may be perceived as catastrophic by that person or by his or her loved ones. What we consider herein, however, is the adverse effects of an event on a community or an ecosystem. What makes a disaster a large-scale one is the number of people affected by it and/or the extent of the geographic area involved. Such disaster taxes the resources of local communities and central governments. Under the weight of a large-scale disaster, a community diverges substantially from its normal social structure. Return to *normalcy* is typically a slow process that depends on the severity, but not the duration, of the antecedent calamity as well as the resources and efficiency of the recovery process.

The extreme event could be natural, manmade, or a combination of the two in the sense of a natural disaster made worse by human's past actions. Examples of naturally occurring disasters include earthquakes, wildfires, pandemics, volcanic eruptions, mudslides, floods, droughts, and extreme weather phenomena such as ice ages, hurricanes, tornadoes, and sandstorms. Humans' foolishness, folly, meanness, mismanagement, gluttony, unchecked consumption of resources, or simply sheer misfortune may cause war, energy crisis, economic collapse of a nation or corporation, market crash, fire, global warming, famine, air/water pollution, urban sprawl, desertification, deforestation, bus/train/airplane/ship accident, oil slick, or terrorist act. Citizens suffering under the tyranny of a despot or a dictator can also be considered a disaster, and, of course, genocide, ethnic cleansing, and other types of mass murder are gargantuan disasters that often test the belief in our own humanity. Although technological advances exponentially increased human prosperity, they also provided humans with more destructive power. Manmade disasters have caused the death of at least 200 million people during the twentieth century, a cruel age without equal in the history of man (de Boer & van Remmen, 2003).

In addition to the degree or scope of a disaster, there is also the issue of the rapidity of the calamity. Earthquakes, for example, occur over extremely short time periods measured in seconds, whereas anthropogenic catastrophes such as global warming and air and water pollution are often slowly evolving disasters, their duration measured in years and even decades or centuries, although their devastation, over the long term, can be worse than that of a rapid, intense calamity (McFedries, 2006). The painful, slow death of a cancer patient who contracted the dreadful disease as a result of pollution is just as tragic as the split-second demise of a human at the hands of a crazed suicide bomber. The latter type of disaster makes the news, but the former does not. This is quite unsettling because the death of many spread over years goes largely unnoticed. The fact that 100 persons die in a week in a particular country as a result of starvation is not a typical news story. However, 100 humans perishing in an airplane crash will make CNN all day.

For the disaster's magnitude, how large is large? Much the same as is done to individually size hurricanes, tornadoes, earthquakes, and, very recently, winter storms, we propose herein a universal metric by which all types of disaster are sized in terms of the number of people affected and/or the extent of the geographic area involved. This quantitative scale applies to both natural and manmade disasters. The suggested scale is nonlinear, logarithmic in fact, much the same as the Richter scale used to measure the severity of an earthquake. Thus, moving up the scale requires an order of magnitude increase in the severity of the disaster as it adversely affects people or an ecosystem. Note that a disaster may affect only a geographic area without any direct and immediate impact on humans. For example, a wildfire in an uninhabited forest may have long-term adverse effects on the local and global ecosystem, although no human is immediately killed, injured, or dislocated as a result of the event.

The *scope* of a disaster is determined if at least one of two criteria is met, relating to either the number of displaced/tormented/injured/killed people or the adversely affected area of the event. We classify disaster types being of Scope I to V, according to the scale depicted in Table 2.1.

Table 2.1. *Disaster scope according to number of casualties and/or geographic area affected*

Scope I	Small disaster	<10 persons	or	<1 km^2
Scope II	Medium disaster	10–100 persons	or	1–10 km^2
Scope III	Large disaster	100–1,000 persons	or	10–100 km^2
Scope IV	Enormous disaster	1000–10^4 persons	or	100–1,000 km^2
Scope V	Gargantuan disaster	$>10^4$ persons	or	$>1,000$ km^2

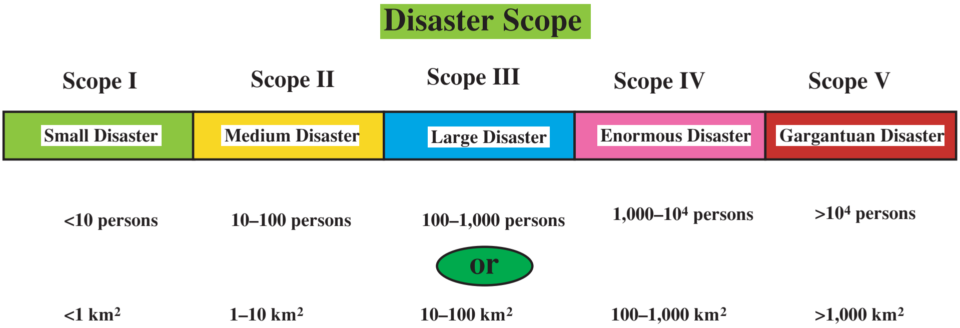

Figure 2.1 Classification of disaster severity.

These classifications are pictorially illustrated in Figure 2.1. For example, if 70 persons were injured as a result of a wildfire that covered 20 km^2, this would be considered Scope III, large disaster (the larger of the two categories II and III). However, if 70 persons were killed as a result of a wildfire that covered 2 km^2, this would be considered Scope II, medium disaster. An unusual example, at least in the sense of even attempting to classify it, is the close to 80 million citizens of Egypt (area slightly larger than 1 million km^2) who have been tormented for more than a half-century[1] by a virtual police state. This manmade cataclysm is readily stigmatized by the highest classification, Scope V, gargantuan disaster.

The quantitative metric introduced herein is contrasted to the conceptual scale devised by Fischer (2003a, 2003b), which is based on the degree of social disruption resulting from an actual or potential disaster. His ten disaster categories are based on the scale, duration, and scope of disruption and adjustment of a normal social structure, but those categories are purely qualitative. For example, Disaster Category (DC)-3 is indicated if the event partially strikes a small town (major scale, major duration, partial scope), whereas DC-8 is reserved for a calamity massively striking a large city (major scale, major duration, major scope).

The primary advantage of having a universal classification scheme such as the one proposed herein is that it gives officials a quantitative measure of the magnitude of the disaster so that proper response can be mobilized and adjusted as warranted. The metric suggested applies to *all* types of disaster. It puts them on a common scale, which is more informative than the variety of scales currently used for different disaster types; the Saffir-Simpson scale for hurricanes, the Fujita scale for tornadoes, the Richter scale for earthquakes, and the recently introduced Northeast Snowfall Impact Scale (notable, significant, major, crippling, extreme) for the winter storms that occasionally strike the northeastern region of the United States. Of course, the individual scales also have their utility; for example, knowing the range of wind speeds in a hurricane as provided by the Saffir-Simpson scale is a crucial piece of information to complement the number of casualties the proposed scale supplies. In fact, a prediction of wind speed allows estimation of potential damage to people and property. The proposed metric also applies to disasters such as terrorist acts or droughts, where no quantitative scales are currently available to measure their severity.

In formulating all scales, including the proposed one, a certain degree of arbitrariness is unavoidable. In other words, none of the scales is totally objective. The range of 10 to 100 persons associated with a Scope II disaster, for example, could very well be 20

[1] Of course, the number of residents of Egypt was far less than 80 million when the disaster commenced in 1952.

to 80, or some other range. What is important is the relative comparison among various disaster degrees; a Scope IV disaster causes an order of magnitude more damage than a Scope III disaster, and so on. One could arbitrarily continue beyond five categories, always increasing the influenced number of people and geographic area by an order of magnitude, but it seems that any calamity adversely affecting more than 10,000 persons or 1,000 km^2 is so catastrophic that a single Scope V is adequate to classify it as a gargantuan disaster. The book *Catastrophe* is devoted to analyzing the risk of and response to unimaginable but not impossible calamities that have the potential of wiping out the human race (Posner, 2004). Curiously, its author, Richard A. Posner, is a judge in the U.S. Seventh Circuit Court of Appeals.

In the case of certain disasters, the scope can be predicted in advance to a certain degree of accuracy; otherwise, the scope can be estimated shortly after the calamity strikes with frequent updates as warranted. The magnitude of the disaster should determine the size of the first-responder contingency to be deployed: which hospitals to mobilize and to what extent; whether the military forces should be involved; what resources, such as food, water, medicine, and shelter, should be stockpiled and delivered to the stricken area; and so on. Predicting the scope should facilitate the subsequent recovery and accelerate the return to normalcy.

2.3 Facets of large-scale disasters

A large-scale disaster is an event that adversely affects a large number of people, devastates a large geographic area, and taxes the resources of local communities and central governments. Although disasters can naturally occur, humans can cause their share of devastation. There is also the possibility of human actions causing a natural disaster to become more damaging than it would otherwise. An example of such an anthropogenic calamity is the intense coral reef mining off the Sri Lankan coast, which removed the sort of natural barrier that could mitigate the force of waves. As a result of such mining, the 2004 Pacific Tsunami devastated Sri Lanka much more than it would have otherwise (Chapter 11). A second example is the soil erosion caused by overgrazing, farming, and deforestation. In April 2006, wind from the Gobi Desert dumped 300,000 tons of sand and dust on Beijing, China. Such gigantic dust tempests—exasperated by soil erosion—blow around the globe, making people sick, killing coral reefs, and melting mountain snow packs continents away. Examples such as this incited the 1995 Nobel laureate and Dutch chemist Paul J. Crutzen to coin the present geological period as *anthropocene* to characterize humanity's adverse effects on global climate and ecology (www.mpch-mainz.mpg.de/ air/anthropocene/).

What could make the best of a bad situation is to be able to predict the disaster's occurrence, location, and severity. This can help prepare for the calamity and evacuating large segments of the population out of harm's way. For certain disaster types, their evolution equations can be formulated. Predictions can then be made to different degrees of success using heuristic models, empirical observations, and giant computers. Once formed, the path and intensity of a hurricane, for example, can be predicted to a reasonable degree of accuracy up to 1 week in the future. This provides sufficient warning to evacuate several medium or large cities in the path of the extreme event. However, smaller-scale severe weather such as tornadoes can only be predicted up to 15 minutes in the future, giving very little window for action. Earthquakes cannot be predicted beyond stating that there is a certain probability of occurrence of a certain magnitude earthquake at a certain geographic location during the next 50 years. Such predictions are almost as useless as stating that the Sun will burn out in a few billion years.

Once disaster strikes, mitigating its adverse effects becomes the primary concern: how to save lives, take care of the survivors' needs, and protect properties from any further damage. Dislocated people need shelter, water, food, and medicine. Both the physical and the mental health of the survivors, as well as relatives of the deceased, can be severely jeopardized. Looting, price gouging, and other law-breaking activities need to be contained, minimized, or eliminated. Hospitals need to prioritize and even ration treatments, especially in the face of the practical fact that the less seriously injured tend to arrive at emergency rooms first, perhaps because they transported themselves there. Roads need to be operable and free of landslides, debris, and traffic jams for the unhindered flow of first responders and supplies to the stricken area, and evacuees and ambulances from the same. This is not always the case, especially if the antecedent disaster damages most if not all roads, as occurred after the 2005 Kashmir Earthquake (Section 2.8.7). Buildings, bridges, and roads need to be rebuilt or repaired, and power, potable water, and sewage need to be restored. Chapters 5 to 7 cover some of the logistical and medical aspects of disasters.

Figure 2.2 depicts the different facets of large-scale disasters. The important thing is to judiciously employ the finite resources available to improve the science of disaster prediction, and to artfully manage the resulting mess to minimize loss of life and property.

2.4 The science of disaster prediction and control

Science can help predict the course of certain types of disaster. When, where, and how intense would a severe weather phenomena strike? Are the weather conditions favorable for extinguishing a particular wildfire? What is the probability of a particular volcano erupting? How about an earthquake striking a population center? How much air and water pollution is going to be caused by the addition of a factory cluster to a community? How would a toxic chemical or biological substance disperse in the atmosphere or in a body of water? Below a certain concentration, certain danger substances are harmless, and "safe" and "dangerous" zones could be established based on the dispersion forecast. The degree of success in answering these and similar questions varies dramatically. Once formed, the course and intensity of a hurricane (tropical cyclone), which typically lasts from inception to dissipation for a few weeks, can be predicted about 1 week in advance. The path of the much smaller and short-lived, albeit more deadly, tornado can be predicted only about 15 minutes in advance, although weather conditions favoring its formation can be predicted a few hours ahead.

Earthquake prediction is far from satisfactory but is seriously attempted nevertheless. The accuracy of predicting volcanic eruptions is somewhere in between those of earthquakes and severe weather. Patanè et al. (2006) report on the ability of scientists' to "see" inside Italy's Mount Etna and forecast its eruption using seismic tomography, a technique similar to that used in computed tomography scans in the medical field. The method yields time photographs of the three-dimensional movement of rocks to detect their internal changes. The success of the technique is in no small part due to the fact that Europe's largest volcano is equipped with a high-quality monitoring system and seismic network, tools that are not readily available for most volcanoes.

Science and technology can also help control the severity of a disaster, but here the achievements to date are much less spectacular than those in the prediction arena. Cloud seeding to avert drought is still far from being a practical tool, but still a notch more rational than the then-Governor of Texas George W. Bush's 1999 call in the midst of a dry period to "pray for rain." Slinging a nuclear device toward an asteroid or a meteor to avert its imminent collision with Earth remains solidly in the realm of science fiction