PART I
Management of Disasters

1 Introduction

Everyday life is overwhelmed by critical phenomena that occur on specific spatial and temporal scales. Typical examples are floods, bridge collapses, stock market crashes, or the outbreak of diseases. All these phenomena might have, whenever they occur, significant negative consequences for our lives. They often result from complex dynamics involving interaction of innumerable system parts within three major systems: the physical environment; the social and demographic characteristics of the communities that experience them; and the buildings, roads, bridges, and other components of the constructed environment. In nonscientific terms, such events are commonly referred to as *disasters* (Bunde et al., 2002).

The terms *hazard*, *vulnerability*, *disaster*, and *risk* are interpreted and understood by different people in different ways. Before progressing with detailed discussions of many topics related to disaster management, let me provide the meaning of these terms in the context of this book (UN/ISDR, 2004).

Hazard is a potentially damaging physical event, phenomenon, and/or human activity, which may cause loss of life or injury, property damage, social and economic disruption, or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydrometeorological, and biological) and/or induced by human processes (environmental degradation and technological hazards). Hydrometeorological hazards include natural processes or phenomena of atmospheric, hydrological, or oceanographic nature, which may cause loss of life or injury, property damage, social and economic disruption, or environmental degradation. Examples of hydrometeorological hazards are floods, debris, and mud flows; tropical cyclones, storm surges, thunder/hailstorms, rain and windstorms, blizzards, and other severe storms; drought, desertification, wildland fires, temperature extremes, and sand or dust storms; and permafrost and snow or ice avalanches.

Vulnerability is susceptibility to suffer loss or a set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility of a community, an individual, an economy, or a structure to the impact of hazards.

Disaster occurs when a hazard triggers vulnerability and disruption of the functioning of a community or a society that is so serious that it causes widespread human, material, economic, or environmental losses, which exceed the ability of the affected community or society to cope with using its own resources. A disaster is a function of

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Systems Approach to Management of Disasters: Methods and Applications, By Slobodan P. Simonović the risk. It results from the combination of hazards, conditions of vulnerability, and insufficient capacity or measures to reduce the potential negative consequences of risk. The distinction between natural and other types of disasters is blurred. Many of the deaths resulting from the Hurricane Katrina, New Orleans, in 2005 were caused by dike collapses. A number of assessment studies following the event found that many parts of the complex flood protection infrastructure were not designed and maintained up to existing standards and regulations. Despite the fact that nature created the hurricane, the disaster was intensified by human action or a lack of it. The term *disaster* in this book will be used in its broadest sense and the distinction between natural and other types of disasters will not play an important role.

Risk combines the notions of hazard and vulnerability. It is the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted, or environment damages) resulting from interactions between natural- or human-induced hazards and vulnerable conditions. Conventionally risk is expressed by the notation:

$$\text{Risk} = \text{Hazards} \times \text{Vulnerability} \tag{1.1}$$

One important consequence of the definition (1.1) is that a high probability hazard with small consequences has the same risk as a low probability hazard with large consequences.

The longer time period records (traced back to 1900 while more reliable after 1950) show a relentless upward movement in the number of disasters (Figure 1.1) and their human (Figure 1.2) and economic impact (Figure 1.3).

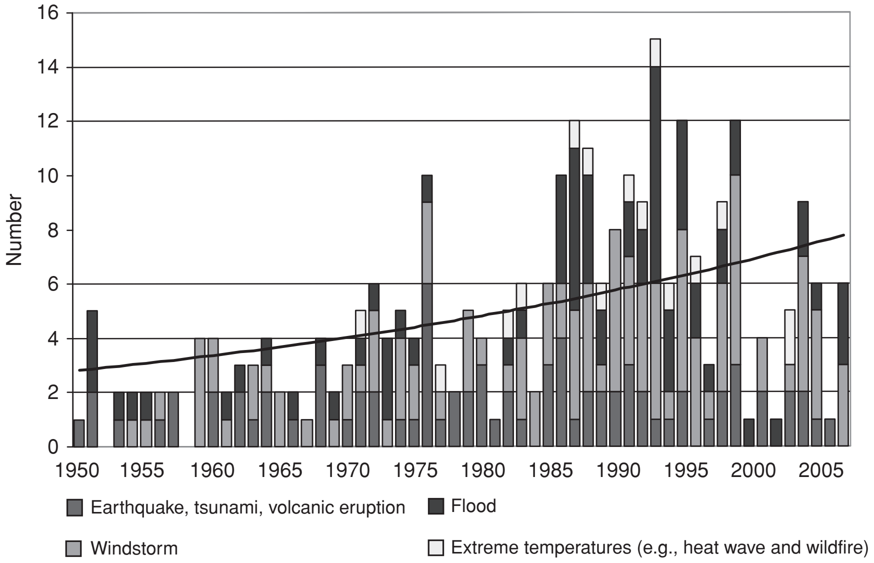

Figure 1.1 Great natural disasters 1950–2007, number of events (after Munich Re, NatCatSERVICE, 2008).

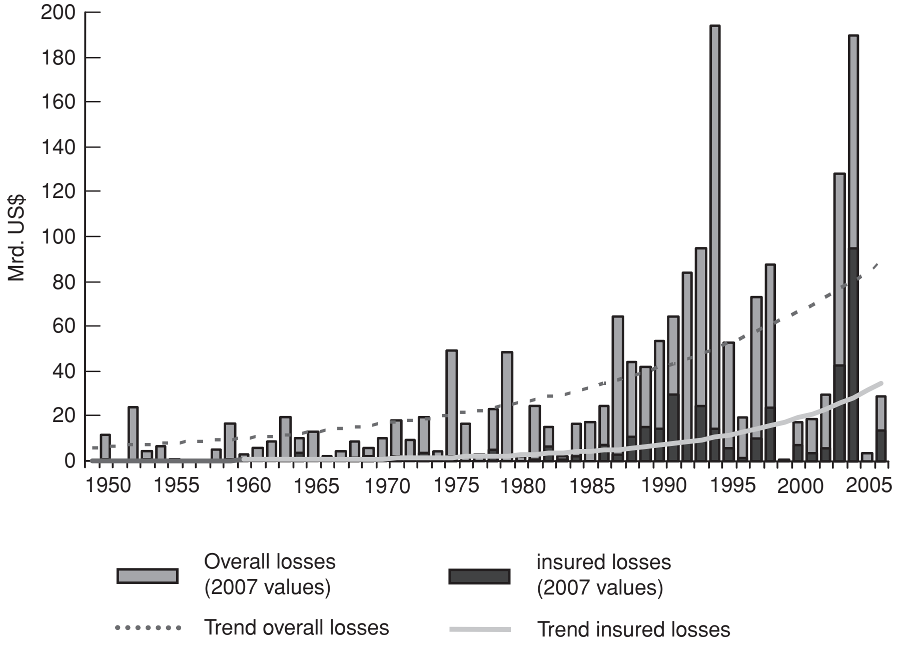

Figure 1.2 Great natural disasters 1950–2007, overall and insured losses (after Munich Re, NatCatSERVICE, 2008).

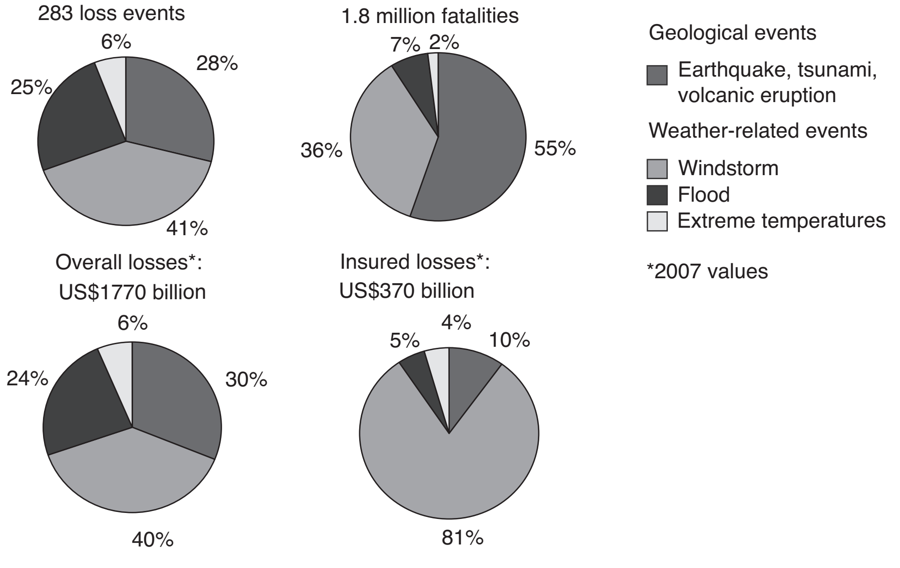

Figure 1.3 Great natural disasters 1950–2007, percentage distribution worldwide (after Munich Re, NatCatSERVICE, 2008).

A comparison of the annual figures verifies the serious increase in great natural disasters. The frequency of these events more than doubled between 1960 and 2005. The 276 great natural disasters in the period under observation are attributed, in almost equal proportions, to earthquake/volcanic eruption, windstorm, and flood. The most fatalities were caused by earthquakes and volcanic eruptions (55%). Economic losses have increased by a factor of 6.7, insured losses by a factor of 13.5, and the trend remains an upward one. As far as insured losses are concerned, windstorm losses are way ahead, accounting for nearly 80% of the US$340 billion.

It is troubling that disaster risk and impacts have been increasing during a period of global economic growth. On the good side, a greater proportion of economic surplus could be better distributed to alleviate the growing risk of disaster. On the bad side, it is possible that development paths are themselves creating the problem: increasing hazards (e.g., through global climate change and environmental degradation), human vulnerability (through income poverty and political marginalization), or both.

1.1 ISSUES IN MANAGEMENT OF DISASTERS—PERSONAL EXPERIENCE

We learn from experience. Here is a personal story of the 1997 flood on the Red River. At the time of “Red River flood of the Century” I lived in Winnipeg, Manitoba, Canada.

1.1.1 Red River Flooding

Situated in the geographic center of North America, the Red River originates in Minnesota and flows north (one of eight rivers in the world that flow north). The Red River basin covers 116,500 km^2 (exclusive of the Assiniboine River and its tributary, the Souris) of which nearly 103,600 km^2 are in the United States (Figure 1.4). The basin is remarkably flat. The elevation at Wahpeton, North Dakota, is 287 m above sea level. At Lake Winnipeg, the elevation is 218 m. The basin is about 100 km across at its widest. The Red River floodplane has natural levees at points both on the main stem and on some tributaries. These levees (some 1.5 m high) have resulted from accumulated sediment deposit during past floods. Because of the flat terrain, when the river overflows these levees, the water can spread out over enormous distances without stopping or pooling, exacerbating flood conditions. During major floods, the entire valley becomes the floodplane. The type of soil in this region also contributes to flooding because, while the topsoil is rich, beneath it lies anywhere from 1 to 20 m of largely clay soil, with characteristic low absorptive capacity. Water tends to sit on the surface for extended periods of time. In general, the climate of southeastern Manitoba is classified as subhumid to humid continental with resultant extreme temperature variations. Annually, most of the precipitation received is in the summer rather than the winter. Approximately three-fourths of the 50 cm of annual precipitation occurs from April to September. Consequently, most years spring melt is well managed by the capacities of the Red River and its tributaries. However, periodically, weather

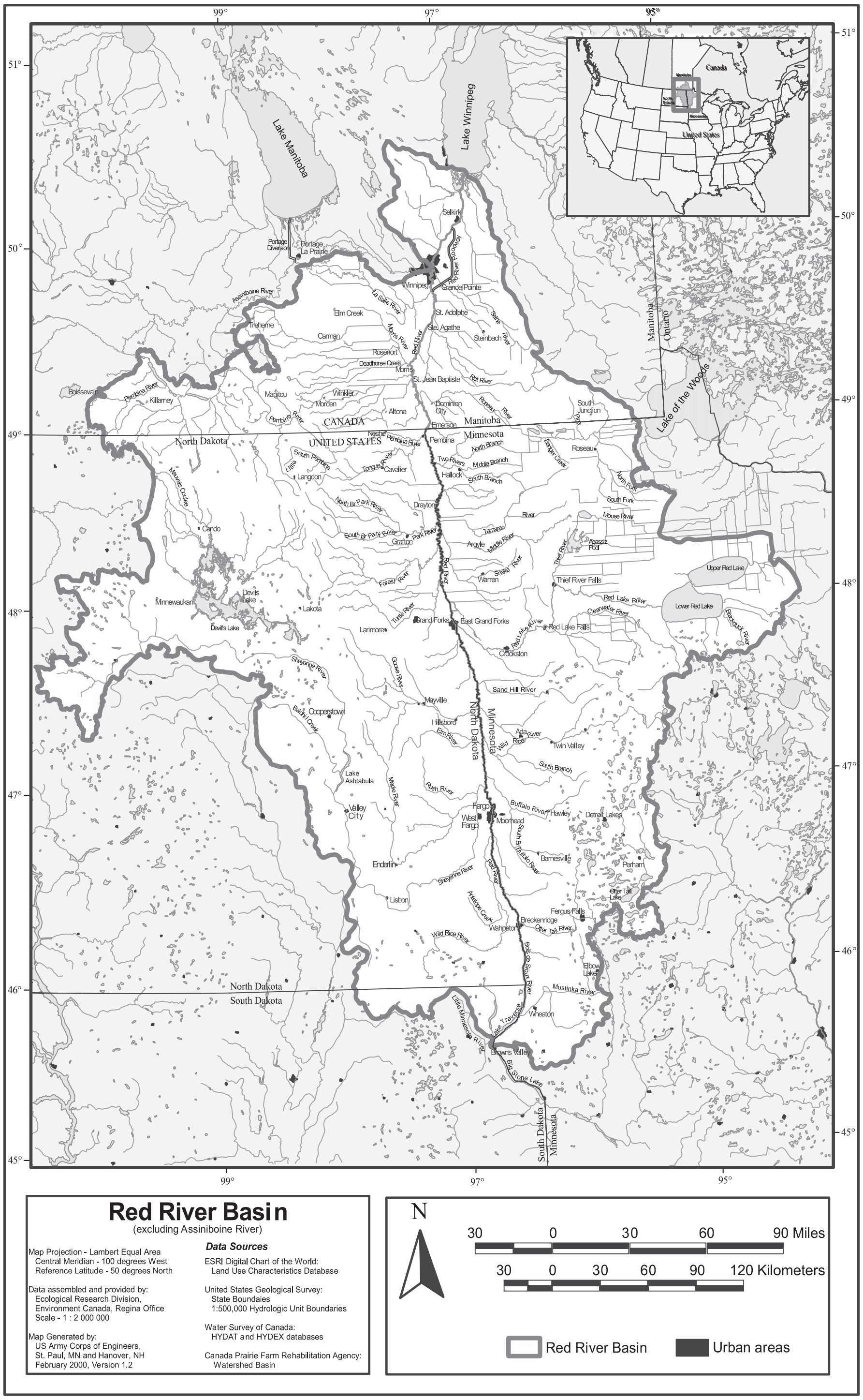

Figure 1.4 Red River basin.

conditions exist that instead promote widespread flooding through the valley. The most troublesome conditions (especially when most or all exist in the same year) are as follows: (a) heavy precipitation in the fall, (b) hard and deep frost prior to snowfall, (c) substantial snowfall, (d) late and sudden spring thaw, and (e) wet snow/rain during spring breakup of ice.

In Manitoba, almost 90% of the residents of the Red River/Assiniboine basin live in urban centers. Metropolitan Winnipeg contains 670,000 people, and another 50,000 live along the Red River north and south of the city. The Red River valley is a highly productive agricultural area serving local, regional, and international food needs. There has been an extensive and expanding drainage system instituted in the basin to help agricultural production by increasing arable land. The purpose of agricultural drainage is to remove, during the growing season, water in excess of the needs of crops and to prevent sitting water from reducing yields. However, the contribution of drainage activities, if any, to flooding and damages is both a concern and a source of disagreement. Faster removal of the spring water from the fields is considered to be one of the contributors to the regular spring flooding in the basin. Often problems with maintenance of drainage infrastructure are claimed as a source of infield flooding.

The basin floods regularly. Early records show several major floods in the 1800s, the most notable being those of 1826, 1852, and 1861. In this century, major floods occurred in 1950, 1966, 1979, 1996, and 1997 (Table 1.1). The Red River basin has 25 subbasins, which have different topography, soils, and drainage that result in different responses during flood conditions. One common characteristic is overland flow during times of heavy runoff. Water overflows small streams and spreads overland, returning to those streams or other watercourses downstream. Existing monitoring and forecasting systems do not track these flows well, leading to unanticipated flooding. The earliest recorded flood in the basin was in 1826, although anecdotal evidence refers to larger floods in the late 1700s. The flood of 1826 is the largest flood on record; it was significantly larger than the devastating 1997 flood. A sudden thaw in April 1826, followed by ice jams on the river and simultaneous heavy rainfall, had water on the Red River rise 1.5 m downtown in just 24 hours. Preservation of life took precedence over preservation of property, thus losses were enormous. Whole houses were carried by the River. The estimated maximum flow was 7362 m^3/sec. The water apparently took more than 1 month to recede completely.

TABLE 1.1 Red River Floods in m^3/sec (after IJC, 1997)

Location	1950		1979		1997	
Red River at Emerson	May 13	2670	May 1	2620	May 2	3740
Red River at Winnipeg	May 19	3058	May 10	3030[a]	May 4	4587[a]

[a] Computed natural flow as would have occurred without existing flood control works.

A pivotal event in the Red River flood history was the 1950 flood, which was classified a great Canadian natural disaster based on the number of people evacuated and affected by the flood. A very cold winter and heavy snowpack in the United States, combined with heavy rain during runoff, were the primary causes. All towns within the flooded area in the upper valley had to evacuate. More than 10,000 homes were flooded in Winnipeg and 100,000 people evacuated. A plan to evacuate all 350,000 people in Winnipeg was prepared, although luckily it did not have to be used.

Most of the flood management planning in Manitoba was initiated after the 1950 flood. This flood was the turning point in the history of flooding and flood control in Manitoba's portion of the Red River basin. Construction of elevated boulevards (dikes) within the City of Winnipeg and associated pumping stations was initiated in 1950. The current flood control works for the Red River valley consist of the Red River Floodway, the Portage diversion and Shellmouth Dam on the Assiniboine River, the primary diking system within the City of Winnipeg, and community diking in the Red River valley (Simonović, 2004). Following the 1950 flood on the Red River, the federal government and the Province of Manitoba set up a fact-finding commission to appraise the damages and make recommendations (Royal Commission, 1958). The commission recommended in 1958 the construction of the Red River Floodway (completed in 1966), the Portage Diversion (completed in 1970), and the Shellmouth Reservoir (completed in 1972). As a consequence of the concern over flood protection for the Red River Valley, a federal-provincial agreement led to the construction in the early 1970s of a series of ring dikes around communities in the Valley. Moreover, financial aid programs encouraged rural inhabitants to raise their homes, as well as to create individual dikes around their properties. All the decisions regarding the capacity of the current flood control works were based primarily on economic efficiency—getting the largest return for the investment.

1.1.2 "Red River Flood of the Century," Manitoba, Canada

Sunday, April 6, 1997, was a day off for most people, including me, but it was not a standard day of rest. Our house on Kirkbridge Drive in the south part of the town was surrounded by drifts of snow, at some places up to the window frames. Our driveway, service road, and the street were covered by snow, at places deeper than 1 m (see Plate 1 in the color plate section). Our plans to do some late shopping and finalize preparations for our daughter's birthday on April 11 ended up in serious snow-moving activities. The city was virtually shut down.

Radio was announcing that the whole Red River valley from North Dakota to Lake Winnipeg was already under the snow varying in depth from more than 2 m along the upper reaches to more than 1.5 m around Winnipeg (more than most people could remember seeing). Temperature just began to peak over the freezing level when this massive snowstorm piled more snow on an already high snow cover. Flooding was an already accepted certainty in the valley. Early forecasts of my colleague and friend Alf Warkentin from the Water Resources Branch were a 10% chance for flood as bad as that of 1979. That flood inundated southern Manitoba and turned it into a lake 90 km long from north to south and 20 km across at its widest point. After the blizzard, Alf's forecast was revised and the Red River valley was facing a flood bigger than the flood of 1950.

Life slowly returned to normal after the weekend. However, the work of Emergency Management Manitoba and Water Resources Branch just started. Preparations for the flood were in full swing. Life, for me and for many citizens of Winnipeg, was kind of unreal. Yes, the big flood was coming, but Winnipeg had resources other smaller municipalities did not. We had engineers and infrastructure and operations departments that had expertise and experience with flooding.

Our home was close to the southern border of the City and my way to University was taking me across the Pembina Hwy—the main north–south artery cutting across Winnipeg. I was going to work to administer the final exams in my courses, meet with students, attend the administrative meetings, and at the same time something serious was going on. Everyone was talking about the flood. The flood was a reality south from Winnipeg. Red River Valley was under siege. My contacts in the Water Resources Branch were providing regular information about the hectic effort to get the best estimate of what is going to hit us and to get prepared as good as we can and as soon as we can. My children were taken from the school to help the sandbagging effort. I offered help to some friends living close to the river. Busloads of school kids, complete strangers, church groups, neighbors, office managers let off work, and anybody able-bodied showed up for sandbagging duty (see Plate 2 in the color plate section).

On my way to work, waiting for the green light at the crossing with Pembina Hwy, I would witness heavy mechanization moving south; later tracks full of soldiers and volunteers; even later school buses full of people being moved from the valley to safer locations. People from the Water Resources Branch like Larry Whitney, emergency flood spokesman (who numerous times delivered lectures in my courses), Rick Bowering, head of the Water Resources, and Doug McNeil from the City became everyday guests in every Winnipeg home through a regular process of updating information about the incoming flood. About 8 million sandbags were laid into ramparts around Winnipeg. It is not known how many sandbags were used outside the City because each municipality took care of those matters. But at one point, the province leased a 747 jet for $225,000 to airlift 3 million sandbags from California to the Red River Valley.

April 19 was a special day. Nearly 2 weeks had passed since the blizzard, and under the bright sun the massive snow blanket had begun to melt. Our neighbors in North Dakota were fighting the flood. Cities were falling to the Red, one after another. All this information was coming to us, but nothing hit us as hard as the front page of the Winnipeg Free Press on Sunday, April 20. It showed the downtown Grand Forks—the Security Building submerged in Red and on fire. It was a strange image showing two forces of nature acting together with destructive power, and nature was winning. Grand Forks was under the water and 35,000 people were rendered homeless. This image, repeated on the TV many times and shown in other local papers, got stuck in my mind. It was real and coming at us. My wife insisted on moving furniture from the basement. I was checking the backup (backflow) valve that for those who did not have it became a valuable commodity. All backup valves were sold out in town and people were ordering them from all over Canada and the United States.

The battle with Red was raging in the Valley (see Plate 3 in the color plate section). Tremendous effort to protect the property and reduce the damage was going on in parallel with the expansion of the water over the land. The “Red Sea” reached up to 37 km wide and covered 1850 km^2 in Manitoba. On April 27, my colleague and friend Prof. Wendy Dahlgrin took me for a flight on her small plane above the southern Manitoba. Our flight route and altitude were under the control of the military. My stomach did not agree with the bumpy flight of a small plane. However, one picture remains in my mind (see Plate 4 in the color plate section). From the altitude we were flying on, all I was able to see was water. We flew from Winnipeg south to the Canada–US border and back. The river channel could be recognized only by the tops of the trees still above the water level. The picture looked unreal. Farmhouses still above the water and townships protected with ring dikes looked like small islands in the ocean.

The towns of Emerson, Morris, Ste. Agathe, St. Adolphe, Grande Point, and farms around the Valley were receiving help from volunteers, responsible agencies, and Canadian Arm Forces. The ring dikes around communities were raised. Shortly after midnight on Tuesday, April 29, 1997, the Red River struck the small town of Ste. Agathe, 25 km south of Winnipeg (see Plate 5 in the color plate section). It was the first indication that parts of Manitoba thought safe could be vulnerable. The water did not flood from the east side as one might expect, that is, where the Red River flows past the town and where the town dike was built. Instead, the water blindsided the village from the west, flowing overland and crossing Highway 75. All other communities survived. Beside Ste. Agathe, the Red River flood got in one more bite. It took that bite at Grande Pointe, a suburb of Winnipeg bordering southeast city limits. One hundred Grande Pointe homes were flooded. It was time for heroics because, in spite of Winnipeg’s and the province’s best efforts, the planning and preparations were not complete.

The province introduced the mandatory evacuation of thousands of rural people living outside ring dikes. The order created bands of “outlaws” who ignored the authorities and drove their boats through flooded fields to save their homes and those of others. *Royal Canadian Mounted Police* (RCMP) wanted evacuation and they wanted it in a hurry. They thought there was a grave threat to life, and therefore, pressured other authorities into supporting an evacuation. Shortly after Grand Forks went under on April 18, the province moved out 3400 Red River Valley residents. This was not controversial. Most were people in the ring dikes or who had health or mobility issues. But on April 23, Emergency Management Organization (EMO) dropped the bombshell. It announced a total evacuation of the valley, about 17,000 people. Within days, more than 800 rural homes were reported flooded.

Some residents did not follow the orders. They stayed and raised the height of dikes, plugged leaks in dikes, and made sure pumps were running and properly positioned. They also phoned owners when they discovered problems.

Water was at the doorstep of Winnipeg. The city filled 6.5 million sandbags. But even 6.5 million bags were not enough. City built 14 earth dikes inside the city limits. The floodway was used to maintain the 24.5 ft level at James Avenue. That was considered to be the level that the city’s dikes could be expected to hold back.

Maintenance of 24.5 ft level at James Avenue meant almost a week where the Red was at its record high level in Winnipeg and almost two weeks where it was above the level it had reached in any previous year (even the pre-floodway 1950). Emergency dikes were under enormous strain and plugging leaks became a 24-hour-a-day job. Hectic pace to protect the city was confronted with surreal "life as usual" for most of the people leaving and working in the city. My wife was scheduled to have a surgery and the St. Boniface hospital, located very close to the river, was hardly keeping the schedule. Before the date of surgery the hospital was closed for some time. Fortunately, the impact of the Red on the work of St. Boniface hospital did not affect my wife. Surgery was done on time and we learned immediately after about another closure of the hospital. The only similar emotion to what I was experiencing during these days was described in the book *Poplava* (Flood in Serbian language) for those who can read the language of the place where I was born (Nenadic, 1982). I felt anxiety, nervousness, fear, and helplessness, together with a tremendous need to do something, to add some meaning to this waiting time.

The water was still coming up. The last frontier was the extension of Brunkild Z-dike designed to keep the Red River water out of the La Salle River (considered at that time Winnipeg's Achilles' heel). The La Salle is the Red River's last tributary before Assiniboine and it flows into the Red at La Barriere Park in St. Norbert. That is north of the floodway gate and behind Winnipeg's primary diking system. As many as 100,000 Winnipeggers, including my family, would be forced from their homes if enough water got over the high ground and came down the La Salle. Resources were scarce and available time was short. The province put all its energies and earth-moving equipment into a 72-hour dash to build the 24-km Brunkild Z-dike extension (see Plate 6 in the color plate section). When the water reached the critical Brunkild gap on April 29, the Z-dike blocked the way.

The river had crested in Winnipeg on May 1, and all the city's defenses held. But a water elevation of 24.5 ft above winter ice levels at the James Avenue pumping station was considered all Winnipeg could safely handle, so floodway gates were raised to hold water inside Winnipeg to that level.

Not everyone understands exactly how the floodway works (see Plate 7 in the color plate section). Its two gates are actually in the Red River, where the river and diversion channel meet. The two gates are raised to elevate water enough to push it into the diversion channel. The reason the water level has to be raised is because there is a large mound at the opening of the diversion channel to stop ice going into the floodway. Large ice would damage bridges and other structures along the floodway.

But raising those gates caused artificial water levels south of the floodway. On May 2, some 125 of 150 homes in Grande Pointe took on water. The province initially denied the floodway had caused artificial flooding. But a review later determined that the floodway operation caused artificial flooding of 2 ft above what water levels upstream should have been. Many residents of Grande Pointe felt "sacrificed."

With the river crest passing the city on May 1 the flood was not over. Communities north from Winnipeg were just starting their battle with Red and Winnipeg with those south of the city were embarking on a difficult path of recovery. Many homes were bought out because their location made flood-proofing too difficult. For example, on

St. Mary's Road just south of Winnipeg, 25 homes were purchased by the government because the cost of flood-proofing was too high.

Assessment of damage started in May. However, the process was slow and plugged with problems (see Plate 8 in the color plate section). Initially, the province was only going to pay 80% compensation to flood victims, even though 90% of the money came from the federal government. Claimants had to pay 20% deductible, and the maximum government compensation was to be $100,000. The premier of Manitoba was adamant about these terms. His explanation at the time is still being quoted today: "If you live on the floodplane, you have to take some responsibility." Many residents immediately south from the floodway gates were convinced that it was not the floodplane, but the floodway, that caused their homes to be deluged. In the 1999 election, Grande Pointe got its revenge. New Democratic Party (NDP) candidate upset the Conservative incumbent by a mere 111 votes. The roughly 130 voters from Grande Pointe that went to the NDP made the difference. Compensation to flood victims was eventually raised. The province finally eliminated both the $100,000 cap, and the 20% deductible, for Disaster Financial Assistance funds. Compensation covered essentials for living only.

At the end a total of 3747 private homes had claims for flood damage approved according to the province's Emergency Management Organization. Another 633 flood damage claims from full-time farms were approved. Also, claims for 383 full-time businesses were approved. The Disaster Financial Assistance payments for those claims reached $257 million. That does not include business losses.

In addition to the government support, the effort of many volunteers and donations from all over the country made a difference. In the Red River Valley south of Winnipeg, the Mennonite Disaster Service (MDS) built 14 new homes, did major reconstruction on 71 homes, minor reconstruction on 28 homes, relocated 5 homes, and cleaned 802 flooded homes and yards. MDS volunteers put in 21,061 volunteer days, worth an estimated $2.5 million in labor. MDS used donations of nearly $1.9 million for food, transportation, and lodgings for volunteers. They also used donations to buy building materials, for which they were later reimbursed by Emergency Measures Organization, so people did not have to wait for their claims to be settled before they had roofs over their heads.

The most humbling event may have been the donations that poured in to help flood victims. The Canadian Red Cross collected $25 million in donations from more than 144,000 private citizens across the country. But 70% of the $25 million came from other Manitobans. The Red Cross employed 250 people on flood relief, and mobilized another 2200 volunteers in Manitoba. It helped rebuild or restore 230 homes, and plug gaps between government aid and family incomes.

Salvation Army also provided free cleanup supplies, toys for children, tickets for local sporting events, and covered grocery costs. It even took seniors on a 2-day bus trip to Gimli.

Many families in the valley were under stress. The financial bottom line for people just collapsed. There were divorces, there were suicide attempts, and trauma teams were working overtime to help population under stress (Morris-Oswald and Simonović, 1997).

By letters of June 12, 1997, the Governments of Canada and the United States requested the International Joint Commission (IJC) to examine and report on the causes and effects of damaging floods in the Red River basin and to recommend ways to reduce and prevent harm from future flooding. The IJC is a binational Canada–United States organization established by the Boundary Waters Treaty of 1909 that assists the governments in managing waters shared by the two countries for the benefit of both. To assist it with the Red River flood of 1997 binational investigation, the Commission has appointed an International Red River Basin Task Force. The Task Force, composed of members from a variety of backgrounds in public policy and water resources management, was to provide advice to the Commission on matters identified in the letters from governments. The Governments asked the Commission to examine a full range of management options, including structural measures (such as building design and construction, basin storage, and ring dikes) and nonstructural measures (such as floodplane management, flood forecasting, emergency preparedness, and response) and to identify opportunities for enhancement in preparedness and response that could be addressed to improve flood management in the future. I was appointed to serve on the Task Force together with four more members from Canada and five members from the United States. For more information, please consult the IJC International Red River Basin Task Force's Web site at http://www.ijc.org/rel/boards/rrbtf.html (last accessed July 21, 2008).

Work on the Task Force was an experience of a lifetime. I participated in a large number of public hearings across the Canadian and US parts of the basin, literally meeting thousands of people affected by the flood. I had an opportunity to hear horror stories of those who lost everything; listen to the rage of people who felt left without assistance; and meet with those who worked hard to save their families and property from damage. This work brought me in touch with basin managers in Canada and United States too. We had extensive meetings with representatives of all governments (local, provincial/state, and federal). I was part of many technical, social, and environmental studies commissioned by the IJC. For the first time in my professional life I got an opportunity to understand the full extent of the impact my work has on people, environment, and society in general. The Task Force prepared a December 1997 interim report (IRRBTF, 1997) that cautioned against complacency and made 40 recommendations for better flood preparedness in the short term. At the end of our work, we submitted the final report (IRRBTF, 2000).

The International Red River Basin Task Force defined required projects, coordinated the funding and scheduling, exercised quality control, provided oversight of subgroups, synthesized the findings, and prepared the recommendations. The Task Force established three subgroups—database, tools, and strategies—to conduct or direct much of the data collection, model development, program evaluation, and to prepare preliminary recommendations. Each subgroup included experts from both the United States and Canada. The concept for accomplishing the required tasks included three main activities: database development, modeling, and the development of damage reduction strategies. A coordinated database was found to be fundamental, as it supports the development of models and flood damage reduction strategies. Each of these working topics ended up as a key element in the decision support system. The

Task Force's final report (IRRBTF, 2000) drew together the findings of the subgroups and made recommendations on policy, operations, and research issues.

The IJC used the final report as the basis for public hearings in the basin prior to the submission of its report to the governments. Public participation was an important part of the process. Following the distribution of the Interim Report, the IJC and the Task Force conducted a series of public meetings throughout the basin in February and October 1998. The results from these meetings were incorporated into the work plan. Efforts were made to keep people in the basin informed throughout the study using the Internet, news releases, and other means of contact. Public and technical inputs were invited throughout the study period.

The fact that this work involved two countries implied two different ways of doing business, two political systems, two or more ways of collecting, analyzing and storing data, and many other political dichotomies. These dichotomies created a unique challenge for this work, but the reality that floodwaters do not recognize an international border made a basin-wide approach to flood management an imperative. Although this work did not develop a comprehensive basin-wide water management plan, the work of the Data, Tools, and Strategies Groups contributed to more effective and efficient floodplane management, facilitated integrated flood emergency management in the basin, and fostered improved international cooperation and communication.

In investigating what can be done about flooding in the Red River basin, the Task Force examined the issue of storage—through reservoirs, wetlands, small impoundments, or micro-storage—and drainage management. The conclusions (IRRBTF, 2000) are:

> **Conclusion 2**: It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.
>
> **Conclusion 4**: Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.

Since the Task Force concluded that storage options provide only modest reductions in peak flows for major floods, a mix of structural and nonstructural options were examined. Winnipeg, the largest urban area within the basin, was found to remain at risk. The city survived the 1997 flood relatively unharmed, but it cannot afford to be complacent. If it had not been favored with fair weather during late April 1997, it could have suffered the fate of its southern neighbors. The Task Force made a number of recommendations to address the city's vulnerabilities and better prepare it for large floods in the future. To achieve the level of protection sufficient to defend against the 1826 or larger floods, major structural measures on a scale equal to the original Floodway project were found to be needed to protect the city. Two options were suggested: expansion of the Floodway and construction of a water detention structure near Ste. Agathe to control floodwaters for floods larger than 1997. After detailed feasibility studies, the Floodway expansion project was selected as a preferred alternative.

Structural protection measures are only part of the response to living with major floods. The Task Force looked at a wide range of floodplane management issues to see how governments and residents might establish regulatory and other initiatives to mitigate the effects of major floods and to make communities more resilient to the consequences of those floods. It made a number of recommendations on defining the floodplane, and adopting and developing building codes appropriate to the conditions in the Red River basin, education, and enforcement.

In an effort to gain a better understanding of the flooding issues, and in recognition of weaknesses in technological infrastructure within the basin, the Task Force devoted much of its energy and resources to data issues and computer modeling. On reviewing current data availability, the Task Force concluded that further improvement and maintenance of the Red River floodplane management database was required. Federal, state, and provincial governments and local authorities needed to maintain a high level of involvement in further database development and in improving data accessibility. The Red River Basin Decision Information Network (RRBDIN, 2005) now provides information about water management within the basin and links to other relevant resources. While RRBDIN concentrates on information and activities on the US side, the Government of Manitoba has been involved in collecting and disseminating flood information from the Canadian side (Province of Manitoba, 2005). Information from RRBDIN includes databases, references, technical tools, communication tools, and GIS data, as well as the most up-to-date information available on weather and flood forecasting. The Task Force found difficulty in securing public access from Canadian agencies to data and other flood-management-related information. The Task Force recommended that Canadian data be made available at no cost and with no restrictions for flood management, emergency response, and regional or basin-wide modeling activities. The Web site of the Government of Manitoba now provides up-to-date reports on daily flood conditions, in the form of maps and reports, along with miscellaneous information on flood management. A prototype version of the real-time flood decision support for the Red River basin is operational (Province of Manitoba, 2004).

In year 2000, I moved from Winnipeg and accepted a job with the University of Western Ontario and the Institute for Catastrophic Loss Reduction. However, my link to the flood of 1997 did not end there. In May of 2008, I organized the fourth International Symposium on Flood Defense in Toronto (http://www.flood2008.org, last accessed July 21, 2008). One plenary session of the Symposium was devoted to the Flood of the Century: "Red River Flood of the Century—10 Years Later."

Has it really been 10 years? Yes, judging by major improvements in flood protection since 1997. Winnipeg's floodway now provides protection from a one-in-300-year flood, and will be up to one-in-700-year protection by the time it is completed. It is costing $665 million (the largest infrastructure investment in Canada in 2005).

A new system of earthen dikes and preformed concrete walls protecting Grand Forks in North Dakota and Minnesota from a one-in-250 year flood is functionally complete. The Grand Forks system cost about US$400 million.

But outside those centers, the approach to flood-proofing in Manitoba versus North Dakota is quite different. In North Dakota, you will not see any houses elevated against flooding like in Manitoba, and you will see only a handful of personal ring dikes. Instead, North Dakota and Minnesota chose to use federal money from FEMA (Federal Emergency Management Agency) to buy out homeowners on the floodplane, instead of protecting them. Behind the decision to buy out homeowners is a government cost–benefit analysis. Government determined that it would be simply cheaper to buy people out than protect them. That was after looking at such things as the cost to protect a home versus its value, how many times it has flooded, and how many times it may flood in the future.

Minnesota has been especially aggressive about buyouts. But on the west side of the river in North Dakota, which has a much smaller tax base, many rural people have been ignored because there was not enough money. Their homes that were damaged by flooding still sit at the same elevations as in 1997. In North Dakota today, there are still 1100 rural residences on the Red's floodplane. Authorities do not know the level of flood protection for those homes. What is known is that very few have received government assistance to protect themselves. In the ongoing buyout program, FEMA pays 75% of a home's preflood value, the state pays 10%, and the county and homeowner split the remaining 15%. Most of the buyouts in North Dakota were in the cities, and most of those were in Grand Forks. There were 850 homes and 50 businesses bought out in Grand Forks. There were more than 1200 buyouts in that state between federal programs FEMA and the Federal and Urban Development program.

Contrast that with Manitoba where the government has bought out fewer than 75 homes in the Red River Valley since the big flood. Manitoba did a cost–benefit analysis too, but concluded it was better to help people stay on the land. The Red River Valley is an extremely prosperous agricultural area, and people do need to live in that floodplane to do their business. Flood protection allows businesses to develop with a level of security that they are not going to be damaged by a major flood.

North Dakota does not help fund the elevating of houses above flood levels, like in Manitoba. However, North Dakota and Minnesota have run small programs to help rural homeowners build individual ring dikes. Under the program, North Dakota agrees to finance a ring dike 50-50 with the landowner, committing a maximum US$25,000. The ring dikes for farms are costing well more than $50,000, so the farmer must pay much more than $25,000. Minnesota's program is more generous, with the state picking up 75% of costs. However, only a finite amount of funding is available for the American program, and many people have not been approved. Washington does not pay into the program. Since the program began, in 2001, 120 rural landowners have applied for assistance to build a ring dike in North Dakota. Just 16 have received funding so far. About double that number have been approved in Minnesota.

That is a meager number compared to Manitoba. Since 1997, a total 1830 rural homeowners in Manitoba's Red River Valley have received federal and provincial money to protect them from flooding. Today, virtually every home in the Red River Valley is protected to 1997 flood levels, plus 2 ft. Manitoba homeowners received on average $40,000 apiece to elevate their homes, build a dike, or otherwise fortify their residences. The feds and province cost-shared the program 50-50. The total program spending came to $73 million. Under the program, Manitoba homeowners could get up to $60,000 in government funds to build a ring dike or elevate a home, the most common types of flood protection. They had to contribute $10,000. But many landowners reduced their $10,000 share down to a small amount because the province knocked off dollars for labor, like a farmer using his or her tractor to help build the mound (they were paid hourly rates), and compensation for the soil they took from their land to build the mound.

It is always interesting to see how governments spend their money in Canada versus the United States, and how much they spend. Yet direct comparisons are not fair. One should not forget that North Dakota suffered much more damage than Manitoba, and had a much bigger hole to climb out of. The 1997 flood cost the state US$3.7 billion, including estimates of losses to businesses, according to FEMA. Still, public money has not flowed in the United States like in Manitoba.

Manitoba has done a much better job, flood-proofing its towns and villages, too. Every community along the Manitoba portion of the Red River is protected. There are 13 communities with new ring dikes: St. Mary's Road, Grande Pointe, Rosenort, Niverville, Gretna, Aubigny, St. Pierre-Jolys, Lowe Farm, Riverside, Rosenfeld, Ste. Agathe, and Roseau River. The cost of those dikes was shared 50-50 by federal and provincial governments. They have also improved the dikes for Dominion City, Emerson, Letellier, St. Jean Baptiste, Morris, St. Adolphe, and Brunkild. In total, 2133 homes and businesses have received new or upgraded protection in the form of community ring dikes at a cost of $42 million. Federal and provincial governments paid 90% of that, and rural municipalities 10%.

The same cannot be said in North Dakota. The city of Fargo is still waiting on flood-proofing funds from Washington after 1997. The delay in Fargo getting flood protection is important because memory and the urgency for flood protection fade with time. Federal funding in the United States is extremely tight now because of the costs of both the Iraq war and the flooding of New Orleans. In Breckenridge-Wahpeton, a series of diversions and dikes have been constructed and offer better protection but are still only half-finished. Construction has been idle for 2 years because federal funds have dried up. The town of Drayton, 45 km south of the Manitoba border, is very susceptible to flooding but cannot get any flood-proofing dollars.

In North Dakota, various government officials were pleased with how the state withstood the 2006 flood. Only about 10 homes were flooded. In Manitoba in 2006, only one home had serious flood damage, and that was a home in which the owner had refused flood-proofing assistance after 1997.

Today, Grande Pointe has a ring dike. Ste. Agathe has a ring dike too. The Brunkild Z-dike is now permanent. Casings for 500 wells on Manitoba's floodplane also have been raised to 1997 levels, plus 2 ft, so aquifers are not contaminated. Winnipeg also fared well in 2006, which compared to the 1996 flood. With about 200 homes now protected by a ring dike for Kingston Row and Kingston Crescent, the city needed just 20,000 sandbags last year.

The water- and climate-monitoring network in the Red River Valley has been upgraded at a cost of more than $1.5 million. This included activating or establishing

34 monitoring stations and installing 165 new climate stations. Manitoba forecasting office has dozens of satellite water monitors in the Red River, 60 new rain gauges in streams, and computer flood modeling programs.

A total of 1830 Red River Valley homes and businesses outside Winnipeg received individual flood-proofing since the flood at a cost of $73 million from federal and provincial governments. An additional 2133 homes and businesses have been protected by community ring dikes since the flood at a cost of $38 million from federal and provincial governments. Municipalities cost-shared 10%, raising the total to $42 million.

This is the end of my private story of the Red River Flood of 1997. I decided to provide this detailed experience in order to (a) illustrate the level of complexity that one natural disaster can bring, (b) demonstrate the need for a new approach to natural disasters management, and (c) offer the context for the set of tools presented in this book as one potential approach to address complexities in the management of natural disasters. The personal message I took from this experience was written on one temporary sandbag dike at Rosenort—“No Man is an Island” (see Plate 9 in the color plate section).

1.2 TOOLS FOR MANAGEMENT OF DISASTERS—TWO NEW PARADIGMS

Management of natural disasters has a long tradition in many countries around the world including Canada. There is no reason to abandon the approaches that have been used to date and the knowledge that has been accumulated through experience. However, there are some troubling questions about why are the losses shown in Figures 1.2 and 1.3 on such a sharp rise and why more progress does not appear to have been made. There is no shortage of ideas about what can be done to improve the disaster management tools and their implementation to achieve more impressive results on the ground than those realized so far. In the context of this book any empirical, analytical, or numeric procedure used in the process of disaster preparedness, emergency management, disaster recovery, and disaster mitigation and prevention is referred to as a “tool.”

The application of various tools for disaster management during the last 50 years shows a pattern of change. Some of the lessons summarized by the National Research Council (1996), the Global Disaster Information Network (1997), Mileti (1999), Woo (1999), Godschalk et al. (1999), Stallings (2002), Bunde et al. (2002), Kohler et al. (2004), and Skipper and Jean Kwon (2007) are noted below.

Domain-specific lessons

1. Disaster losses are increasing. Precise estimate of losses is impossible since there is no systematic reporting method and no single repository for loss data in many countries.
2. Disaster losses are affecting global economies. Currently, disaster losses from natural disasters in developing countries represent only a small fraction

of GNP. However, the situation in the developing world is quite the opposite. With the trend of increasing losses, individual disasters will represent more significant fractions of the GNP of affected countries and may affect global economies.

3. Disasters have a broad social impact. Disasters impose deaths, injuries, and monetary losses. However, they can also redirect the character of social institutions, result in new and costly regulations imposed on future generations, alter ecosystems and disturb the stability of political regimes.
4. The nature of disasters is changing. Disasters are becoming more complex. They are the result of the interaction of, and changes in, the physical environmental systems that produce extreme events, the people and communities that experience those events and the constructed environment that is affected.
5. Climate change is increasing the frequency and magnitude of natural disasters. It is widely accepted that climate change will cause an increase in convective storms, floods, drought, and extreme temperature events.
6. Population increase creates serious disaster management problems. As areas become more densely populated, their exposure to hazards increases. Differences in socioeconomic status, gender, and race, or ethnicity result in a complex system of wealth stratification, power, and status, which in turn results in an uneven distribution of exposure and vulnerability to hazards, disaster losses, and access to aid, recovery, and reconstruction.
7. Diminishing strength of the built environment. The ability of public utilities, transportation systems, communications, critical facilities, engineered structures, and housing to withstand the impacts of extreme natural forces is not as strong as is believed.
8. Environmental impacts. Enabling human settlements in certain areas changes the exposure of environment and its vulnerability to disasters.
9. Postponing catastrophic losses. Some mitigation activities are not really preventing damage but merely postponing it. For example, communities behind a levee get a sense of security that fosters the construction of structures at risk to floods larger than those that were designed for. If the postponement amounts to many years, the accumulated losses could be enormous.
10. An interdisciplinary approach is required for solving disaster management problems.
11. The public must be involved in the management of disasters.
12. Institutional change, education, training, and cooperation are necessary in order to address the disaster management in the future.

Technical lessons

1. Integrated planning and management based on the use of systems analysis is a very efficient approach to finding solutions for complex disaster management problems.

2. Mathematical modeling tools have an application in disaster management.
3. Decision support tools including optimization models can be considered for mitigation, planning as well as emergency operational and recovery applications.
4. Improved tools for planning and decision making are necessary, together with well-coordinated databases.
5. Complex disaster decision-making processes require technical support.
6. Training and institutional development play an important role in the practical application of optimal disaster management strategies.
7. Uncertainty, ambiguity, constant change, and surprise characterize disaster management. Most management strategies unfortunately have been designed for a predictable world and static view of natural disasters.

The existing disaster management framework needs to evolve to begin to cope with the complexity of the factors that contribute to disasters in today's and tomorrow's world. As a start, this book offers shifts in thinking about disasters. Two new paradigms are identified that will shape future tools for management of natural disasters. The first focuses on the complexity of the disaster management domain and the complexity of the modeling tools in an environment characterized by continuous, rapid technological development. The second deals with disaster-related data availability and the natural variability of domain variables in time and space that affect the uncertainty of disaster management process.

1.2.1 The Complexity Paradigm

The first component of the complexity paradigm is that disaster management problems in the future will be more complex. Domain complexity is increasing (Figure 1.5). Further population growth, climate change, and regulatory requirements are some of the factors that increase the complexity of disaster management problems. Disaster management strategies are often conceived as too shortsighted (design life of dams, levees, bridges, etc.). Short-term thinking must be rejected and replaced with disaster management schemes that are planned over longer temporal scales in order to take into consideration the needs of future generations. Planning over longer time horizons extends the spatial scale. If resources for disaster management are not sufficient within the affected region, transfer from neighboring regions should be considered. The extension of temporal and spatial scales leads to an increase in the complexity of the decision-making process. Large-scale disaster management process affects numerous stakeholders. The environmental and social impacts of complex disaster management solutions must be given serious consideration.

The second component of the complexity paradigm is the rapid increase in the processing power of computers (Figure 1.5). Since the 1950s, the use of computers in disaster management has grown steadily. Computers have moved from data processing, through the user's office and into information and knowledge processing.

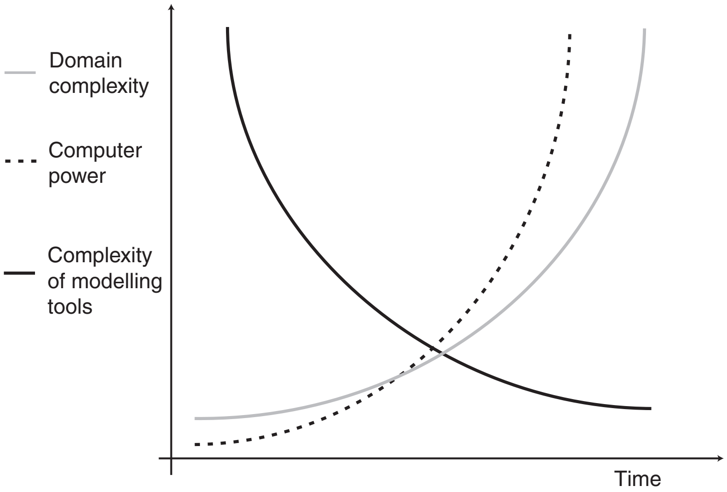

Figure 1.5 Schematic illustration of the complexity paradigm.

Whether the resource takes the form of a laptop PC or a desktop multiprocessing workstation is not important any more. It is important that the computer is used as a partner in more effective disaster management (National Research Council, 1996; Global Disaster Information Network, 1997; Stallings, 2002). The main factor responsible for involving computers in the disaster decision-making processes is the treatment of information as the sixth economic resource (besides people, machines, money, materials, and management).

The third component of the complexity paradigm is the reduction in the complexity of contemporary systems tools (again, see Figure 1.5). The most important advance made in the field of management in the last century was the introduction of systems analysis. Systems analysis is defined here as an approach for representing complex management problems using a set of mathematical planning and design techniques. Theoretical solutions to the problems can then be found using a computer. In the context of this book, systems analysis techniques, often called "operations research," "management science," and "cybernetics," include simulation and optimization techniques that can be used in four-phase disaster management cycle (discussed in detail in Chapter 2). Systems analysis is particularly promising when scarce resources must be used effectively. Resource allocation problems are very common in the field of disaster management and affect both developed and developing countries, which today face increasing pressure to make efficient use of their resources.

Simulation models can play an important role in disaster risk assessment, emergency management, and mitigation planning. Early simulation models were constructed by a relatively small number of highly trained individuals. These models were quite complex, however, and their main characteristics were not readily understood by nonspecialists. Also, they were inflexible and difficult to modify to accommodate site-specific conditions or planning objectives that were not included in the original model. The most restrictive factor in the use of simulation tools is that there is often a large number of feasible solutions to investigate. Even when combined with efficient techniques for selecting the values of each variable, quite substantial computational effort may lead to a solution that is still far from the best possible. Advances made during the last decade in computer software have brought considerable simplification to the development of simulation models (High Performance Systems, 1992; Lyneis et al., 1994; Powersim Corporation, 1996; Ventana Systems, 1996). Simulation models can be easily and quickly developed using these software tools, which produce models that are easy to modify, easy to understand, and that present results clearly to a wide audience of users. They are able to address disaster management problems with highly nonlinear relationships and constraints.

Numerous optimization techniques are available for use in disaster management too. Most resources allocation problems can be effectively addressed using linear programming (LP) solvers introduced in the 1950s (Dantzig, 1963). LP is applied to problems that are formulated in terms of separable linear objective functions and linear constraints. However, neither objective functions nor constraints are in a linear form in most practical disaster management applications. Many modifications can be used in real applications in order to convert nonlinear problems for the use of LP solvers. Examples include different schemes for the linearization of nonlinear relationships and constraints, and use of successive approximations. Nonlinear programming is an optimization approach used to solve problems when the objective function and the constraints are not all in the linear form. In general, the solution to a nonlinear problem is a vector of decision variables that optimizes a nonlinear objective function subject to a set of nonlinear constraints. No algorithm exists that will solve every specific problem fitting this description. However, substantial progress has been made for some important special cases by making various assumptions about these functions. Successful applications are available for special classes of nonlinear problems such as unconstrained problems, linearly constrained problems, quadratic problems, convex problems, separable problems, nonconvex problems, and geometric problems. The main limitation in applying nonlinear programming to disaster management problems is in the fact that nonlinear algorithms generally are unable to distinguish between a local optimum and a global optimum (except by finding another better local optimum). In recent years, there has been a strong emphasis on developing high-quality, reliable software tools for general use such as MINOS (Murtagh and Saunders, 1995) and GAMS (Brooke et al., 1996). These packages are widely used in different fields for solving complex problems. However, the main problem of global optimality remains an obstacle in the practical application of nonlinear programming. Dynamic programming (DP) offers advantages over other optimization tools since the shape of the objective function and constraints do not affect it. DP requires discretization of the problem into a finite set of stages. At every stage, a number of possible conditions of the system (states) are identified, and an optimal solution is identified at each individual stage, given that the optimal solution for the next stage is available. An increase in the number of discretizations and/or state variables would increase the number of evaluations of the objective function and core memory requirement per stage. This problem of rapid growth of computer time and memory requirement associated with multiple-state-variable DP problems is known as “the curse of dimensionality.” Some modifications used to overcome this limitation of DP include discrete differential DP (an iterative DP procedure) and differential DP (a method for discrete-time optimal control problems). In the very recent past, most researchers have been looking for new approaches that combine efficiency and ability to find the global optimum. One group of techniques, known as evolutionary algorithms, seems to have a high potential. Evolutionary techniques are based on similarities with the biological evolutionary process. In this concept, a population of individuals, each representing a search point in the space of feasible solutions, is exposed to a collective learning process, which proceeds from generation to generation. The population is arbitrarily initialized and subjected to the process of selection, recombination, and mutation through stages known as generations, such that newly created generations evolve toward more favorable regions of the search space. In short, the progress in the search is achieved by evaluating the fitness of all individuals in the population, selecting the individuals with the highest fitness value and combining them to create new individuals with increased likelihood of improved fitness. The entire process resembles the Darwinian rule known as “the survival of the fittest.” This group of algorithms includes, among others, evolution strategy (Back et al., 1991), evolutionary programming (Fogel et al., 1966), genetic algorithms (Holland, 1975), simulated annealing (Kirkpatrick et al., 1983), and scatter search (Glover, 1999). Significant advantages of evolutionary algorithms include:

- no need for an initial solution;
- easy application to nonlinear problems and to complex systems;
- production of acceptable results over longer time horizons; and
- the generation of several solutions that are very close to the optimum.

During the evolution of systems analysis, it has become apparent that more complex analytical optimization algorithms are being replaced by simpler and more robust search tools. Advances in computer software have also led to considerable simplification in the development of simulation models.

1.2.2 The Uncertainty Paradigm

The first component of the *uncertainty paradigm* is the increase in all elements of uncertainty in time and space (Figure 1.6). Uncertainty in disaster management can be divided into two basic forms: uncertainty caused by inherent variability of physical components of the system and uncertainty caused by a fundamental lack of knowledge. Awareness of the distinction between these two forms is integral to understanding uncertainty. The first form is described as *variability* and the second one as *uncertainty*.

Uncertainty caused by variability is a result of inherent fluctuations in the quantity of interest (i.e., the atmosphere, biosphere, hydrosphere, and lithosphere). The three major sources of variability are temporal, spatial, and individual heterogeneity. Temporal variability occurs when values fluctuate over time. Values affected by spatial

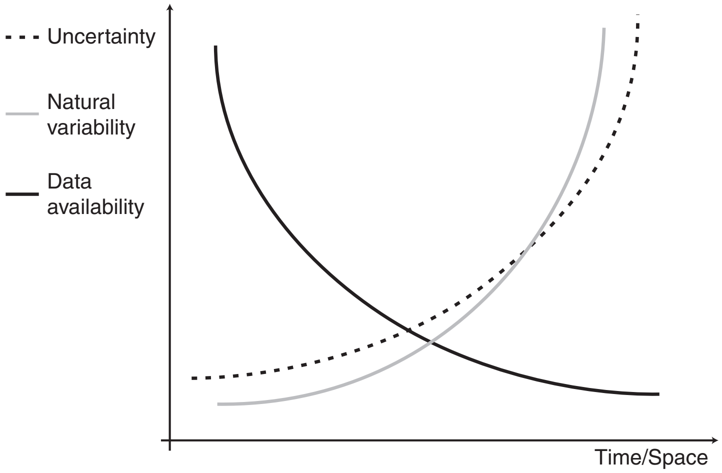

Figure 1.6 Schematic illustration of the uncertainty paradigm.

variability are dependent upon the location of an area. The third category effectively covers all other sources of variability. In disaster management, variability is mainly associated with the spatial and temporal variation of physical variables (precipitation, river flow, wind speed, etc.). The more elusive type of uncertainty is caused by a fundamental lack of knowledge. It occurs when the particular values that are of interest cannot be assessed with complete confidence because of a lack of understanding or limitation of knowledge.

The second component of the uncertainty paradigm is the decrease in disaster data availability (Figure 1.6). Meteorological information on cloud cover, fog, rain, high winds, hail, snow cover, and runoff are necessary for severe weather disaster management. The numbers of gauging stations in operation worldwide, as reported by World Meteorological Organization (WMO), is very impressive. The *INFOHYDRO Manual* (WMO, 1995) estimates that there are nearly 200,000 precipitation gauges operating worldwide and more than 12,000 evaporation stations. For example, monitoring is taking place at more than 64,000 stations for discharge, at nearly 38,000 for water level, at 18,500 for sediment, at more than 100,000 for water quality, and at more than 330,000 for groundwater characteristics. Despite the apparently high global numbers, the stations are not uniformly distributed, and there is a shortage over large areas. The financial constraints of government agencies that are responsible for the collection of disaster-related data have resulted in reductions in the data collection program in many countries. In many countries, disaster data collection activities are very fragmented. A similar fragmentation is observed at the international level. Of particular concern are the gaps in the existing data relative to the informational requirements. Many authors agree that current data collection networks are inadequate for providing the information required to understand and explain changes in natural systems. Given the reductions in the funding of data collection activities, it is clear that a change in the approach to data collection activities is essential.

The third component of the uncertainty paradigm is the increase in natural variability of disaster-related factors of the earth's physical systems (again, see Figure 1.6). Water flow of importance for flooding exhibits both temporal (between years and seasons) and spatial variation. The water flow from the basin is the integrated result of all physical processes in the basin. The topography, the spatial distribution of geological phenomena, and land use are the main causes of spatial variability of flow. Observed natural variability is being affected by climate change. One of the most important aspects of studying the consequences of global warming is estimating possible changes in the extreme conditions (maximum and minimum river discharges, temperatures, etc.). On the one hand, an increase in maximum floods can be expected, and on the other hand, so can a more frequent occurrence of severe droughts. Both could have major economic and ecological consequences.

1.3 CONCLUSIONS

The idea of surprise extremes needs to be broadened (Mileti, 1999). Disaster researchers and practitioners around the world would benefit from embracing a systems approach in their work. Viewed in systems way, disasters can be seen as the anticipated result of interactions among the earth's physical systems, human systems, and the constructed environment. All these systems and their subsystems are dynamic and with constant interactions among them. This complexity is what makes disaster problems difficult to solve.

Various systems tools are available for potential implementation in disaster management. They rely on mathematical modeling of real physical systems and transfer of solutions found to work on the models into real environments. In the past, stakeholders not actively involved in the development of a model tended to mistrust the results of the model. Computer power has increased and costs have fallen to the point that all stakeholders in the resource can play a very important role in disaster management.

Technology is already a facilitating force in political decision making, and will be more so in the future. Spatial decision support systems using object-oriented programming algorithms are integrating transparent tools that will be easy to use and understand. National and international databases, both static and dynamic, now provide much of the necessary information in digital form. The trend will continue for providing public access to all disaster-related data at reasonable cost and in a user-friendly format, and this will play an important role in supporting tools for disaster decision making.

The speed with which data and ideas can be communicated has historically been a control mechanism of scientific progress. The Internet began in 1968 by connecting four hosts. As of March 2008, almost 1.5 billion hosts were connected to multiple computer networks according to the Internet Usage and World Population Statistics (http://www.internetworldstats.com/stats.htm, accessed July 2008). Virtual libraries, virtual databases, virtual forums and bulletin boards, web-enabled software packages, and the use of "write once—run anywhere" languages (such as Java by Sun Microsystems) will create new opportunities for disaster managers.

The future of disaster management will be difficult in both the developing and developed world. My hope is that the tools discussed in this book, supported by good data communicated through powerful networks, will empower people to make wise decisions on how to make best use of limited resources and minimize disaster losses.

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EXERCISES

1.1 Describe the largest disaster experienced in your region.

- **(a)** What were its physical characteristics?
- **(b)** Who was involved in the management of the disaster?
- **(c)** What is, in your opinion, the most important disaster management problem in your region?
- **(d)** Give some examples of the disaster mitigation works in the region.
- **(e)** What lessons can be learned from the past management of disasters in your region?
- **(f)** What are the most important principles you would apply in future disaster management in your region?

1.2 Review the literature and find a definition of integrated disaster management.

- **(a)** Discuss the Red River example presented in this chapter in the context of this definition.
- **(b)** What would you do, in addition to what has been done, in this case to make flood management decisions in the Red River basin sustainable?

1.3 Discuss characteristics of the disaster from Exercise 1.1 in the context of two paradigms presented in Section 1.2.

- **(a)** What are the complexities of the problem in Exercise 1.1?
- **(b)** Identify some uncertainties in the problem.
- **(c)** Can you find some data to illustrate the natural variability of regional conditions?
- **(d)** How difficult is to find the data? Why?

1.4 For the problem in Exercise 1.1, identify the factors that will provide for sustainable disaster management decisions. What are the spatial and temporal scales to be considered?