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CALDERAS

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Synonyms

Cauldrons

Definition

Calderas are volcanic depressions, roughly circular in surface plan, with a diameter greater than depth, and representing roof collapse into shallow underlying magma reservoirs.

Discussion

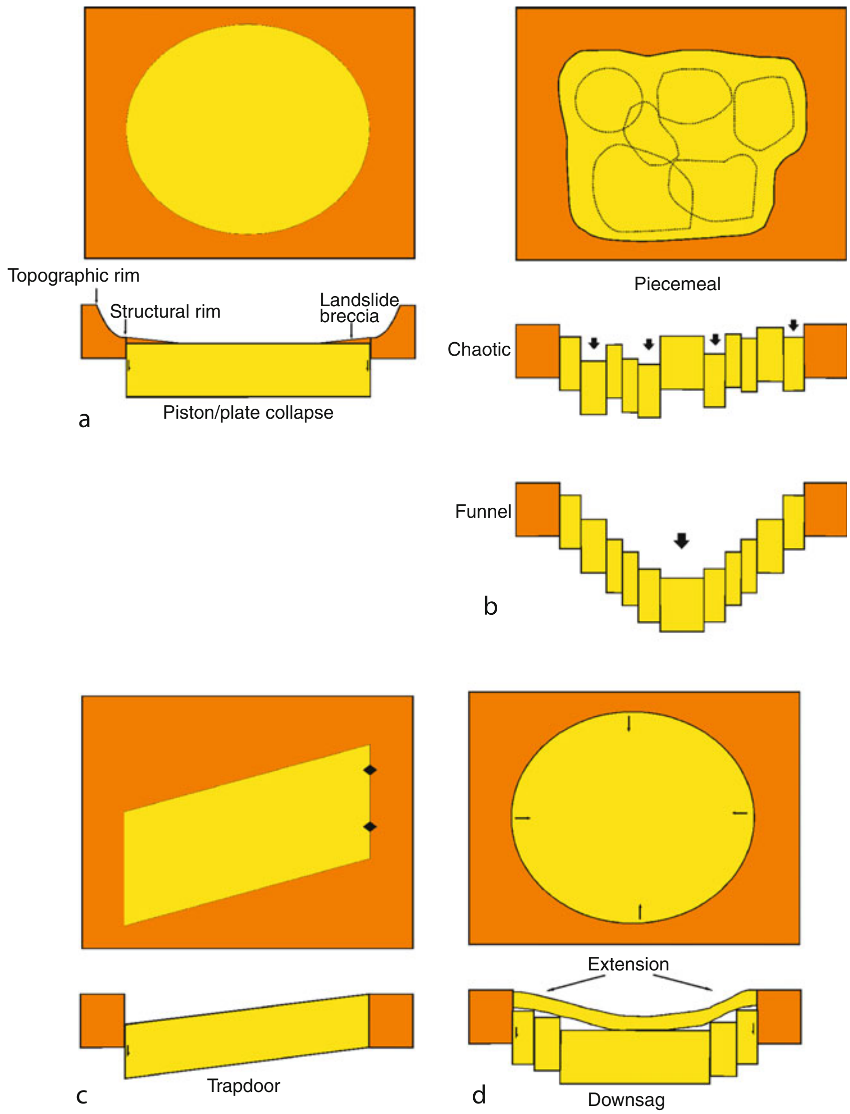
The term "caldera" comes from the Latin word "caldaria" meaning "boiling pot," and was originally used in the Canary Islands for any large "bowl-shaped" depression. Only in the last 50 years has their origin and potential hazards been fully appreciated. Calderas may occur in volcanoes of all compositions, in all tectonic environments, and show a wide range of forms. Consequently, it is difficult to classify calderas, although common collapse processes, provide "end-member" possibilities (Figure 1). The simplest form is "piston" or "plate" collapse within a cylindrical (ring) fault. This occurs within many smaller (typically basaltic) calderas, but is rare in larger (typically rhyolitic) structures. The latter are more likely to show either "piecemeal" collapse, around a number of centers in the caldera, or "downsag," where parts of the structure dip towards the center of the caldera. Regional faults can be an important boundary influence, and collapse may preferentially occur along one of these faults, with the opposite side showing "downsag," to produce a "trapdoor" caldera.

Many larger calderas have experienced multiple collapse events, often separated by tens of thousands of years. Such calderas should more correctly be called "caldera complexes". Each collapse is likely to be accompanied by explosive eruptions, usually producing pyroclastic flows, which deposit widespread ignimbrites (ash flow tuffs). Some of the ignimbrite will pond in the caldera (intra-caldera ignimbrite), whereas the remainder will be distributed radially around the caldera (outflow sheets).

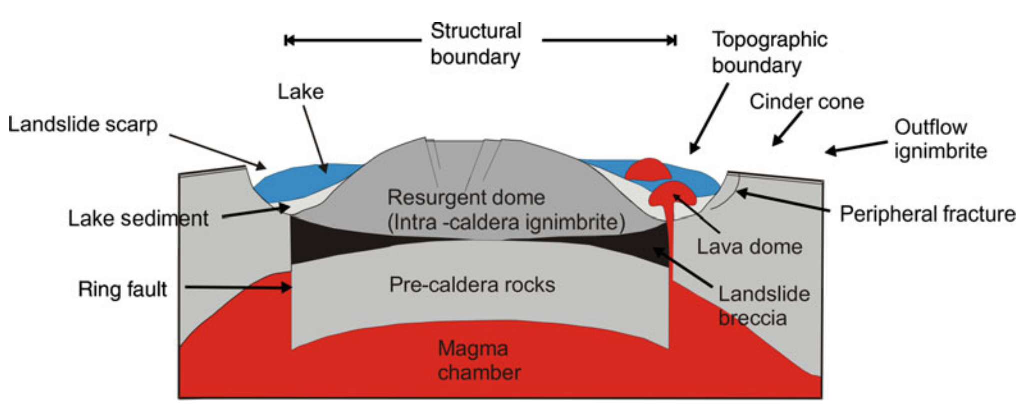
While collapse is the key to caldera formation and is rapid (hours to days), it is only one phase in a process that may take tens to hundreds of thousand years. Pre-collapse volcanism is common, sometimes accompanied by uplift ("tumescence"), and most rhyolitic calderas are followed by post-collapse volcanism (usually forming lava domes and airfall tephra), often accompanied by uplift ("resurgence"). A cross section of a generalized "piston" caldera is shown in Figure 2. Hydrothermal activity and mineralization is likely to occur throughout the life of a caldera volcano, but is particularly important in the post-collapse stages. Once volcanism ceases, erosion will progressively remove much of the surface volcanism (over millions of years). This structure is called a "cauldron," when caldera-floor rocks become exposed. Once a substantial amount of the underlying magma reservoir is exposed, the term "ring-structure" is commonly used.

Calderas are a major natural hazard. The accompanying pyroclastic flows can cause total devastation for hundreds to thousands of square kilometers around the volcano. The largest of these, the "Supervolcano" eruptions, can produce >1,000 km^3 of ignimbrite and can influence climate with fine ash remaining in the atmosphere to cause a "global winter" for many years! During pre-collapse tumescence and post-collapse resurgence, ground movement is likely, which will affect structures built in the area. While there are likely to be precursor events to caldera formation (e.g., earthquake swarms, gas discharge, etc.), such

P.T. Bobrowsky (ed.), *Encyclopedia of Natural Hazards*, DOI 10.1007/978-1-4020-4399-4,



Calderas, Figure 1 Four end-member mechanisms of caldera collapse: (**a**) piston-plate, (**b**) piecemeal, (**c**) trapdoor, and (**d**) downsag (From Cole et al., 2005).



Calderas, Figure 2 Schematic block diagram of a typical resurgent piston-type caldera, showing features that may be present in the structure (From Cole et al., 2005).

events do not always culminate in an eruption. Such "false alarms" are a major problem for effective prediction.

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Cross-references

Eruption Types
Krakatoa (Krakatau)
Magma
Nuee Ardente
Pyroclastic Flow
Volcanoes and Volcanic Eruptions

CASUALTIES FOLLOWING NATURAL HAZARDS

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Synonyms

Casualties; Fatal and nonfatal injuries; Mass casualty events; Natural disasters, forces of nature

Definition

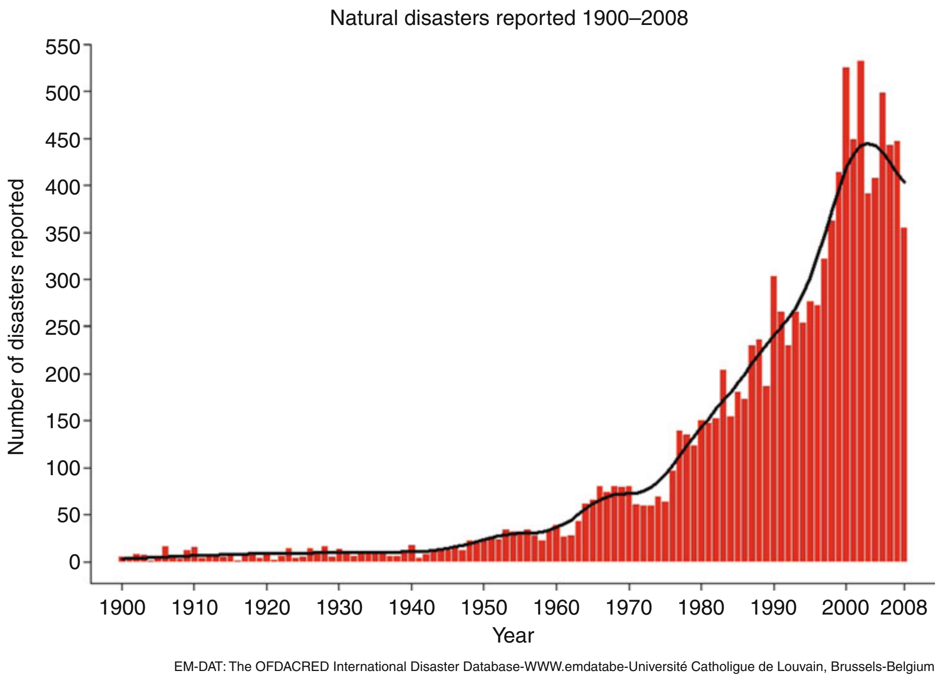
A casualty of a natural disaster can be defined as any person suffering a physical or psychological injury therefrom. Injury, in turn, is "unintentional or intentional damage to the anatomical structures or physiological processes of the body incurred from acute exposure to an exchange of energy (thermal, mechanical, electrical, or chemical), or the absence of such essentials as heat or oxygen" (p. 4, National Committee for Injury Prevention and Control, 1989; Driscoll et al., 2004). For the purposes of this contribution, a natural disaster is considered an event with one of the following: 10 or more human fatalities; 100 or more people affected; a state of emergency declared; and international assistance sought (Scheuren et al., 2008).

Introduction/background

Since the beginning of recorded history, natural disasters have been measured by the severity of their impact on human populations – beginning with the "Biblical flood" that apparently drowned all people on Earth, with the exception of one family group. More recently, it has been estimated that 6,367 natural disasters have occurred between 1974 and 2003, which involved approximately 3,135 fatalities per 100,000 population (Guha-Sapir et al., 2004). The number of people affected by natural disasters is much greater than the fatalities that occur due to such events. From 1989 to 2003, it was estimated that worldwide, approximately 13,706 persons were affected by any type of natural disaster, for every person killed (Guha-Sapir et al., 2004). Not all of the people affected by a natural disaster are physically injured – however this contribution focuses on those who experience injury as a consequence of natural disasters.

The incidence of reported natural disasters has increased substantially over the last 100 years (Figure 1). Advances in technology and communication account for some of this increase through better ascertainment, but there is also an element of increasing impact because of the rapid growth of the human population. Over the last three decades, there has been a decrease in the number of deaths caused by natural disasters, but an increase in the number of people affected by these events (Scheuren et al., 2008). These changes can be attributed to more people in bigger cities with more structures, but also to improvements in disaster preparedness, public awareness, infrastructure (e.g., anti-seismic housing and medical facilities), and our ability to manage and respond to disasters (Noji, 1992). Disaster epidemiologists, who measure and describe the health effects of disasters, and identify the factors that contribute to such adverse effects, have largely been credited with advocating for the introduction of such improvements (Noji, 1992). Whereas more people survive natural disasters, many of the survivors experience injuries and/or illness as a consequence, some of which require long-term rehabilitation and may impact on quality of life. The resultant medical burden in turn has implications for economies. The current approach to measuring the impact of disasters (the number of people affected) may therefore significantly underestimate the true public health impact of such events. An alternative approach, such as estimating Disability Adjusted Life Years (DALYS), may provide a more accurate description of the impact of natural disasters.

The severity of the impact of a natural disaster is determined by four factors: (1) population at risk (size, location, susceptibility, age distribution); (2) exposure to the effects of the disaster; (3) short-term and long-term adverse health effects resulting from such exposures; and (4) effect modifiers (building infrastructure; living conditions, communication systems including media and internet) (Dominic et al., 2005). For these reasons, the impact of a natural disaster is usually much greater in less developed regions, with higher population densities. Less infrastructure (including access to healthcare, water, electricity; financial assets and access to loans/insurance), greater communication difficulties, and less emergency response capacity exacerbate this situation (Guha-Sapir et al., 2004). Often, such regions/countries are more vulnerable to natural disasters given their geographical location (located on a flood plain or region of high seismic activity) or other environmental characteristics (e.g., soil degradation/erosion, pollution, deforestation) (Guha-Sapir et al., 2004).



Casualties Following Natural Hazards, Figure 1 Natural disasters reported in the period 1900–2008.

The proportion of casualties (number of fatalities and severity of injuries) that occur as a consequence of natural disasters is associated with delays in reaching victims, which is in itself dependent on factors such as communication systems and the density and integrity of buildings (Chang et al., 2003). Physical location during the event has been identified as a factor that increases risk of injury and death as the result of a natural disaster. Being in a multiple unit residential or commercial structure is associated with increased risk of injury/death following an earthquake (Peek-Asa et al., 2003). Therefore, areas where there is high proportion of multilevel buildings are likely to experience higher numbers of casualties from these types of events. The very young, the elderly, and people of low socioeconomic status are also more likely to experience worse outcomes after a natural disaster (Peek-Asa et al., 2003; Milsten, 2000).

Disaster types

Natural disasters can be categorized into a range of subgroups. The classification system recently developed by EMDAT (the International Disaster database) is used for the purposes of this contribution: Climatological (droughts, extreme temperatures, wildfires); Geophysical (earthquakes, volcanoes, dry mass movements); hydrological (floods, wet mass movements); and meteorological (storms such as hurricanes, cyclones, tornadoes, etc.). This focuses on the latter three hazard types.

Geophysical

From 1974 to 2003, an estimated 767 geological disasters occurred worldwide (Guha-Sapir et al., 2004). The main subtypes of geophysical natural disasters include earthquakes and volcanoes.

Earthquakes

There were approximately 660 earthquake disasters from 1974 to 2003, which resulted in 559,608 fatalities, and affected more than 82 million people (Guha-Sapir et al., 2004). It has been estimated that over 500,000 earthquakes occur every year, and 7–11 of these cause substantial fatalities (Ramirez and Peek-Asa, 2005). Over the past 200 years, approximately 1.9 million deaths have been reported due to earthquakes (Shulz et al., 2005). Of all natural disasters, the highest rate of mortality is associated with earthquakes – 36% of deaths that have occurred due to natural disasters from 1970 to 2009 were due to earthquakes (Centre for Research on the Epidemiology of Disaster (CRED), 2010).

In addition to the generic factors that impact on injuries from natural disasters described thus far, earthquake injuries depend on several factors: number of occupants in an affected dwelling, floor surface, and time of day (Milsten, 2000). The highest rate of post-disaster suicides is associated with earthquakes (Milsten, 2000; Friedman, 1994).

Injuries associated with earthquakes commonly occur due to being trapped inside buildings, falling, or being hit by falling objects. Injuries include: asphyxiation, hemorrhage, crush syndrome, internal injuries (abdominal and pelvic), severe chest trauma, upper and lower extremity injuries, fractures, soft tissue injuries, and multiple traumatic injuries (Chang et al., 2003; Milsten, 2000). Major head injuries are usually fatal and peripheral limb injuries are also characteristic of major earthquakes, as evident in the 2003 Bam (Schnitzer and Briggs, 2004) and 2005 Kashmir (Dhar et al., 2007; Redmond, 2005) events. A significant proportion of earthquake-related injuries are sustained in the post-disaster period (i.e., “clean up”) – where 22–47% of earthquake injuries have been cited as aftermath injuries (Milsten, 2000).

For instance, two catastrophic earthquakes had struck Haiti on January 12, 2010, devastating much of the country’s capital city, Port-au-Prince, and surrounding regions. Most of the fatalities were due to building collapses, which were in turn influenced by structures built on unstable land (International Strategy for Disaster Reduction, 2010). Estimates by the UN in late January suggest that in excess of 80,000 were killed as a consequence of this earthquake and 200,000 injured (United Nations, 2010).

Earthquakes can also trigger other types of natural hazards, which have different patterns of injury (e.g., tsunamis, landslides, floods) (Jones, 2006). For example, the Indian Ocean Tsunami that hit several countries across southeast Asia on December 26, 2004, was triggered by an earthquake (9.3 on the Richter scale). This event is considered to be the worst natural disaster in the last decade. It resulted in 226,408 deaths in 12 countries, with injuries estimated to be in hundreds of thousands, affecting more than two million people (ISDR, 2010; Guhar-Sapir et al., 2006).

Tsunami-related injuries most frequently occur due to exposure to the extreme water forces and pressures of a tsunami, as well as oxygen deprivation, chemical reactions due to contaminants, impact from debris, and flood-related fire consequences (Guhar-Sapir et al., 2006). Suction of debris back out to sea through receding waters can also cause injury (Guhar-Sapir et al., 2006). Drowning is the most common type of injury sustained during a tsunami, but many fatalities are also caused by respiratory complications from episodes of near drowning. Traumatic injuries, contusions, open wounds, fractures, head injuries, and compression barotraumas of the tympanic membrane are common (Guhar-Sapir and van Panhuis, 2005; Fan, 2006). In Thailand, the pattern of injuries that was described following the Indian Ocean Tsunami was of small-medium multiple injuries along the head, face, and extremities, as well as the back of head, back, buttocks, and legs (Guhar-Sapir and van Panhuis, 2005).

Volcanoes

Between 1974 and 2003, 123 volcanic disasters were reported, resulting in deaths of 25,703 people, and affecting in excess of three million people (Guha-Sapir et al., 2004). The worst volcano in modern history occurred in Colombia in 1985 with the eruption of Volcano del Ruiz, which killed some 21,800 people (Guha-Sapir et al., 2004). Injuries resulting from volcanoes are influenced by four factors: (1) eruptive variables (explosive: large quantities of gas, hot ash, and dust; effusive: large lava flows; combination), which influence the duration and chemical composition of emissions, and dispersal range; (2) toxin-specific properties; (3) patterns of toxic dispersal and persistence; and (4) biological variables (Weinstein and Cook, 2005). Injuries that occur close to the site of volcanic eruption can occur due to the explosion: burns (internal and external), trauma, lacerations, asphyxiation; or due to the emission of toxic gases (asphyxiation, airway constriction, burns; ocular injuries, upper airway, and skin irritations) (Weinstein and Cook, 2005; Weinstein and Patel, 1997).

Toxic elements (e.g., Sulfur, fluoride, chlorine, carbon, silica, mercury) and compounds can be ejected to significant distances, and consequently volcanic injuries often occur well after the initial explosion (Weinstein and Cook, 2005). Injuries can occur due to resulting electrical storms, reduced visibility, water supplies contaminated with toxic substances, and air/road crashes (Jones, 2006). Other common injuries in this category are: eye/skin/airway irritations, ocular injuries (foreign bodies in eyes, corneal abrasions), and sometimes suffocation (Jones, 2006; Weinstein and Cook, 2005).

Meteorological

From 1974 to 2003, 1955 windstorm disasters (cyclones, hurricanes, tornadoes) were recorded, resulting in 293,758 fatalities and affecting an additional 557 million people (Guha-Sapir et al., 2004). Cyclone Nargis, which struck Myanmar in Burma on May 2, 2008, has been identified as the second worst natural disaster in the last decade (ISDR, 2010). The cyclone resulted in the deaths of 138,366 people, but affected many more – 19,359 were injured, and approximately 2.4 million people were severely affected (Kim et al., 2010; World Health Organization, 2008).

Injuries from windstorm events are often classified according to the disaster phase during which they occurred (Shulz et al., 2005): pre-event; event; post-event. Falls, blunt trauma, lacerations, and muscle strains are common during the pre-event phase, as people prepare their properties and communities for the destructive winds (Shulz et al., 2005). Injuries associated with evacuation also incurred during this phase, including road traffic crashes (Shulz et al., 2005; Jones, 2006).

During windstorm events, individuals are at risk of injury from the direct exposure of the forces of the event (building collapse, flying debris, falling trees, power lines, etc.) (Shulz et al., 2005; Cook et al., 2008). The three most common injuries arising from such events are lacerations, blunt trauma, and puncture wounds, the majority of which are sustained to the lower extremities (Noji, 1993). For example, over half of the disaster-related injuries that occurred after Hurricane Iniki in 1997 were open wounds

(Hendrickson and Vogt, 1996; Hendrickson et al., 1997). Other common injuries experienced during windstorm events include: asphyxiation, abdominal injuries, spinal injuries, abrasions, contusions, sprains, fractures, ocular injuries, crush syndrome, carbon monoxide poisoning, ear/nose/throat injury, burns, and electrocution (Milsten, 2000; Shulz et al., 2005; Jones, 2006; Noji, 1993).

Injuries also occur due to storm surges, which can raise coastal waters many meters above normal tide level, and heavy rainfall, which can result in flooding (Cook et al., 2008). The principal injuries reported after such events include lacerations, blunt trauma, puncture wounds (often in the feet and lower extremities), and drowning (Cook et al., 2008).

Typically, the pattern of injury presentations changes in the aftermath (and associated cleanup) of wind storm events, and these injuries are often greater in number than injuries sustained during the event (Milsten, 2000). Electrocutions due to powerlines present a problem during this phase, but injuries such as lacerations, puncture wounds, abrasions, contusions, fractures, strains/sprains, insect stings, dog bites, and dermatitis are commonly reported as a consequence of cleaning up activities involving chainsaws, falls from heights, disturbing nests, etc. (Milsten, 2000; Shulz et al., 2005; Jones, 2006). Also common are burns (from using alternative light/heat sources such as candles, open fires, portable stoves, etc.) (Shulz et al., 2005). Injuries related to suicide attempts also occur during this phase (Jones, 2006).

Floods

An estimated 206,303 fatalities occurred as a consequence of 2,553 flood disasters between 1974 and 2003, affecting more than 2.6 billion people (Guha-Sapir et al., 2004). Whereas earthquakes have been responsible for the most natural disaster mortality, floods have affected the most number of people (ISDR, 2010). Of the estimated two billion people affected by natural disasters of any kind in the last decade, 44% were affected by floods (ISDR, 2010). Floods account for approximately 40% of all natural disasters, and importantly, can occur as a consequence of several other natural disasters (volcanoes, earthquakes, wind events, and tsunamis) (Jones, 2006). Much of the projected impact of future natural disasters is likely to occur in coastal areas, due to rising sea levels that will place these regions at increased risk of storm surges and flooding (Ahern et al. 2005; Dasgupta et al., 2007; 2009; Rodriguez et al., 2009).

The most common flood injuries are drowning, near drowning, and being hit by objects in fast flowing water (Jones, 2006; Ahern et al. 2005). A significant proportion of drowning/near drowning episodes are caused by vehicles being swept away (Milsten, 2000; Ahern et al. 2005). Hypothermia as a consequence of near drowning episodes is common (Jones, 2006). In a review of flood-related injuries, the three most common injury types were identified as: sprains/strains (34%), lacerations (24%), other injuries (11%), and abrasions/contusions (11%) (Ahern et al. 2005). Other types of injuries include multiple traumas, contusions, and minor cuts (Jones, 2006).

Suicides

This entry focuses on acute injuries experienced as a consequence of natural hazards. However, it is acknowledged that depression and suicides are commonly experienced after natural disasters – most typically after hurricanes, floods, and earthquakes (Ahern et al. 2005; Krug et al., 1998), with increased rates of both for up to 4 years post-disaster (Krug et al., 1999; Galea et al., 2005; Procter, 2005).

Long-term sequelae for casualties

Although most injuries that arise from natural disasters are specific and non-disabling, recovery for many individuals is challenging. Brain injury, amputation, or paralysis may require prolonged rehabilitation and institutional care (Pan American Health Organization and Pan American Sanitary Bureau, 2000). Orthopedic services are often limited in less developed countries, as are options for postsurgical management, such as fitting of prostheses, physical and occupational therapies, and other pathways for remobilization and return to daily activities (Dhar et al., 2007; Calder and Mannion, 2005). One year after the Gujarat earthquake of 2001, which killed 13,805 people and left 166,000 injured, many thousands still required assistance for paraplegia, poorly healed fractures, amputations, and other mobility problems (Chatterjee, 2002). Organ damage may also require long-term management, such as dialysis after renal crush injuries. Following the Armenian earthquake in 1988, the medical needs of 600 cases of acute renal failure – of which at least 225 victims required dialysis – created a second catastrophe described as the “renal disaster” (Sever et al., 2006).

Management to minimize casualties

Accurately estimating the impact of natural hazards in terms of fatalities, injuries sustained, and the long-term physical, psychological, social, and economic impacts can be difficult. There is no one agency that is responsible for collecting reliable, valid disaster data (current data sources include newspapers, insurance reports, government agencies, and humanitarian agencies) (Guha-Sapir et al., 2004). There is no standardized method for assessing damage (definitions, data collection methods), verifying information, and storing data (Guha-Sapir and Below, 2002). This is compounded by difficulties associated with obtaining data on populations affected by disasters (e.g., population size; geographical boundaries). Accurate data are essential to estimate the impact of the event, and for effective disaster management, and disaster preparedness.

Despite such limitations in disaster data, a sound public health approach can still be adopted to minimize casualties from natural disasters. Such a public health approach to injury control is based on a four-stage process that includes: defining the nature and extent of the problem; identifying associated risk and protective factors; developing effective interventions; and implementing these interventions in effective programs (Sleet et al., 1998). In the traditional injury epidemiology framework, the risk factors for injury relate to host, agent, and environment (Kraus and Roberston, 1992). Natural disaster–related injuries can be examined within this context (Ramirez and Peek-Asa, 2005). Host characteristics include demographics (age, gender, etc.), individual behaviors (running out of building, heeding evacuation warnings), and resiliency. In the natural disaster model, the agent is the energy (e.g., force of wind, magnitude of earthquake). The environment in this context is the physical location, including buildings, roads, and infrastructure where the natural disaster occurs. From the public health perspective, points of intervention most likely to reduce harm arising from natural disasters should focus on host and environment characteristics. Consequences of natural disasters can be direct or indirect (Combs et al., 1998). Direct casualties are those that occur due to the physical forces associated with the event, and indirect casualties are those that occur due to unsafe or unhealthy conditions that exist in the post-disaster phase. In public health terms, indirect consequences should be the target for intervention, as it is these factors that can be altered in the preparedness phase, and through effective disaster management.

Summary/conclusion

Over five billion natural disaster events have occurred in the last three decades, yielding more than two million deaths, and affecting more than 5.1 billion people. The incidence of natural disasters has increased significantly over the last 100 years. The World Climate Change Conference recognized that during the last five decades, nine out of ten natural disasters were the result of extreme weather and climate events (World Meteorological Organization (WMO), 2009). Further, climate change models demonstrate that there will be an increase in the frequency and intensity of extreme natural hazards such as heat waves, storms, floods, wildfires, and droughts (World Meteorological Organization (WMO), 2009; IPCC, 2001; Haines and Patz, 2005). Death and injury are direct consequences of natural disasters. Although there has been a reduction in fatalities from these events, many of the survivors experience injuries and/or illness as a consequence, some of which require long-term rehabilitation, and impact on quality of life. This has important implications for public health. Many factors influence the severity of the impact of a natural disaster, including the density, geographical location, and infrastructure and disaster response capacity. The impact of a natural disaster is usually greatest in less developed regions. The disaster type itself affects the severity of the impact, and different natural hazards yield different patterns of injury. We anticipate that the increased incidence and intensity of extreme natural hazards will be reflected in changing epidemiology of disaster-related injuries (e.g., more floods will result in more drowning/near drowning). Information about any natural disaster and the devastation it brings is limited by the quality of the data relating to the event. A unified system of definitions, data collection methods, verification, and storage will significantly improve disaster preparedness, management, and recovery.

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Cross-references

Asteroid Impact
Avalanche
Building Failure
Coping Capacity
Damage and the Built Environment
Disaster
Earthquake
Flood Hazard
Geological/Geophysical Disasters
Hurricane
Landslide
Natural Hazard
Volcanoes

CHALLENGES TO AGRICULTURE

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Definitions

Food Security: When all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life (USAID, 1992).

Introduction

Worldwide, farmers rely on a complex combination of seed, water, sunlight, and soil nutrients to assure a season of good production. Natural hazards can disrupt the unique balance necessary for a successful harvest. In cases where farmers are able to control for some of these factors (for example, irrigation to compensate for lack of rain or fertilizer to enhance poor soil fertility), negative effects leading to a poor harvest can be mitigated. Subsistence farmers are often more susceptible to the risks associated with natural hazards as they have limited access to costly inputs to mitigate natural disasters. In some cases though, mitigation measures are not an option for any farmers, especially if the hazard is not predicted. Hazards include events such as storm surges, volcanic eruptions, droughts, and floods. The impact of natural hazards on agricultural production can be evident immediately following a disaster and recovery can take many years. Both subsistence agriculture and commercial agriculture can be damaged by extreme events. While some small-scale farmers may lose their seed stocks and their food stores for the coming season, commercial farmers may face disruption or destruction of local market and market chains for their crops and for access to agricultural inputs. Widespread damage to a region or a particular crop can affect the price of agricultural products in international markets. The extent of the damage caused to agricultural systems will depend on a variety of factors, including topography, weather, crop selection, and stage of crop growth when the hazard strikes. The speed of recovery for affected farmers will be influenced by all of those factors as well as the general resilience of the farming population.

Rainfall irregularity and drought

Many parts of the world have experienced great climatic variability over the past few decades. In parts of Africa, which depend primarily on rain-fed agriculture, these changes have had a negative impact on food security of subsistence farmers. Droughts can both decrease food security in the near term, whereas in the longer term, successive droughts can erode the ability of farmers and pastoralists to recover as recurrent shocks lead to loss of assets and erosion of coping capacity for vulnerable populations. Throughout Africa, drought has contributed greatly to large magnitude food security crises. Some examples include the famine in Ethiopia (1984), and the food insecurity in Niger (2005). These countries and many others affected by drought are still struggling with food insecurity, highlighting the need to address emergency needs related to current hazards while at the same time examining the agricultural system, farming methods, and underdevelopment related to the agriculture sector as a whole with sustainability of the system as a major objective (Trench et al., 2007).

Subsistence farmers who depend on rain-fed agriculture are often challenged by the inability to determine when rains will begin. For example, in Southern Sudan in 2010, rains began later than anticipated (WFP CFSAM, 2010). Farmers quickly planted once rains began, yet subsequently they lost the seed when the rain stopped soon after, leading to crop failure. With a shortened planting season, a short cycle crop variety may have produced a decent harvest, yet it is difficult to anticipate this prior to planting. Deciding what varieties to plant is difficult for farmers who lack reliable information on what the rainy season may bring, when it is likely to arrive, and how long it will last. Even with knowledge of weather predictions, access to or availability of preferred seed varieties to respond to the altered weather patterns can be limited.

Choosing alternative crops, irrigation, soil management, and improved information and early warning are common approaches to mitigating drought effects, yet these strategies are not simple to implement. Crop and varietal preferences develop over many years and are reflective of cultural preferences – complicating efforts to simply trade out crops for drought-resistant alternatives. For example, although orange fleshed sweet potato is vitamin rich and can withstand periods of drought, The International Potato Center (CIP) is working diligently to breed varieties that meet consumer preferences and that can compete in local markets with less resilient but preferred varieties (http://cipotato.org/research/sweetpotato-in-africa). Irrigation can be costly for automatic pump models, and labor intensive for human powered models. Additionally, if there is a drought, there may already be competing needs for water resources. Soil and watershed management for improved moisture retention can enhance water availability but they are longer-term programs that are not suited for the short time frame of many emergency programs. Early warning systems such as the Famine Early Warning System Network (FEWS NET) (www.fews.net) can be used to understand food security and weather trends by sharing information on rains, planting, market data, and general climate trends such as the presence of an El Niño or La Niña phenomenon. Ideally, by using early warning information of low rainfall or soil moisture, farmers can be proactive in selecting and implementing their mitigation strategies.

The views expressed in this chapter are those of the author and do not necessarily reflect the views of the United States Agency for International Development or the US Government.

While there are many easily predicted effects of irregular rainfall, such as crop failure and food insecurity, there can also be social effects of reduced water availability in the form of conflict over scarce resources. Climate variability can increase friction between different livelihood groups. For example, in parts of West Africa where farmers and pastoralists have established a system of resource sharing over time which is mutually beneficial, scarcity of water can stress this relationship. When the relationship is optimally beneficial, the pastoralists arrive with their animals in their seasonal migration just after the farmers harvest their crops. In exchange for the benefit the animal manure contributes to their fields, the farmers allow animals to graze on the stover from the harvested crops. In years where water and fodder are scarce, pastoralists begin moving early, and may even arrive prior to harvest. This can lead to land and resource conflict between the farmers and the pastoralists. Competition for scarce water resources and the potential for the livestock to consume the not-yet harvested crops heightens tensions, as do larger issues related to land tenure and resources (Shettima and Tar, 2008).

Water events: storm surges, floods, tsunamis

Agricultural areas bordered by rivers or oceans are at risk when weather and hazards bring too much water too quickly to be utilized by crop production or inundate areas with water that is not suitable for crop production, such as saline water.

Farmers in southern Africa are regularly challenged with growing conditions that include long periods of limited rainfall or drought, followed by inundation with rain leading to *floods*, an overflow that comes from a river or other body of water and causes damage, or any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream (http://ks.water.usgs.gov/waterwatch/flood/definition.html). Floods within the Zambezi River basin have become so common as to be almost an annual event. These floods regularly claim lives and submerge crops and assets, reducing food security and resiliency to future droughts. In response, humanitarian agencies are promoting a combination of early warning and early action. Early warning against floods has proven very effective and potentially reduces the loss of human lives (http://www.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/publications/prep_mit/files/fy2012/mozambique_pounds_of_prevention.pdf). Early action involves developing response and mitigation plans with local communities.

Not all floods adversely affect food security. In many riverine areas, seasonal flooding can bring much needed soil moisture, nutrients, and organic material to the banks. As the water subsides, farmers then plant on the banks of the river, taking advantage of the extra soil moisture. This recessional planting can provide an additional short season for crop production.

Storm surges involve a rise in sea level due to a hurricane or similarly intense storm. The increase in water level over the normal tide then combines with wind and waves and finally, water is forced ashore, and may proceed to infiltrate agricultural areas. December 2008 brought one such storm surge to the Federated States of Micronesia (FSM) and resulted in sea water washing over taro fields on several of the islands. Taro is a starchy tuber and a major food security staple for FSM islanders. Salt water can inflict varying degrees of damage on the taro patches depending on the length of time the water stands on the patch and the timing and duration of rainfall afterward to flush out the salt. Damage can result in total loss where the taro rots in the ground (Figure 1). Storm surges can sometimes be anticipated but island nations often have limited area to use for agricultural production. Some mitigation strategies include moving agricultural production to higher ground where possible, planting reserve plots of taro seedlings to ensure healthy planting material, planting in concrete beds or forming other barriers to prevent salt water intrusion, and diversifying crop production. Many months can pass on the island without rains which in turn does not allow recharging of the groundwater supplies, making the thin freshwater lens vulnerable to contamination by salt water. Storm surges can also hamper agricultural production by displacement of the population, destruction of crops or agricultural land through erosion or salinization, or destruction of infrastructure (docking areas, bridges, boats).

Tsunamis can wreak havoc on agricultural systems. Unlike storm surges, tsunamis are generally not caused by surface weather but rather, by earthquakes, submarine landslides, volcanic eruptions, explosions, or meteorites. The Indian Ocean Tsunami which sent a wall of water to Aceh Indonesia is estimated by FAO to have caused damage to more than 61,000 ha of agricultural land. The most common damages to agricultural land reported for this event were: "(a) Crop destruction by waves, salt poisoning, and uprooting; (b) de-surfacing of landscape as a result of erosion and sedimentation; (c) deposition of salt sediment; (d) trash and debris accumulation; (e) salt infiltration; and (f) fertility depletion." (FAO, 2005a). Ample rainfall washed away much of the surface salt in the weeks and months following. What remains is a high concentration of salts in layers of clay and silt that were deposited during the event. These layers are fairly impermeable to water, making the removal of salt through leaching when rainwater passes through, very slow.

Volcanic eruptions

In many countries agricultural production takes place in the shadow of quiescent and active volcanoes. Volcanic eruptions can lead to the displacement of populations due to the threat of various volcanic hazards, including ash fall. Displacement can last until the immediate threat of an eruption has passed, or it can persist until infrastructure and services that were damaged by the eruption are

Challenges to Agriculture, Figure 1 Rotten taro root following a storm water surge.

repaired. Damage to roads and infrastructure can affect future market access for agricultural products and inputs.

Early warning and monitoring of potential volcanic activity can help farmers take some mitigative actions, such as moving animals or choosing alternative locations for planting. Once ash falls, irrigation to settle the ash, as well as mixing the ash into the soil is a key rehabilitation strategy to aid in topsoil development. Other methods such as selecting appropriate varieties and adding lime to modify soil acidity can help reduce the negative impacts on production (http://www.maf.govt.nz/environment-natural-resources/funding-programmes/natural-disaster-recovery/volcanic-eruptions).

In addition to lava flows, volcanic activity can yield lahars, a moving fluid mass composed of volcanic debris and water, (e.g., 1993 Mt. Pinatubo eruption) and pyroclastic flows – a surface-hugging cloud of very hot gas and volcanic particles that moves rapidly across the ground surface, (http://www.geonet.org.nz/volcano/glossary.html), as well as volcanic ash falling for many months. All of these can cause extensive agricultural destruction. The effect of ash fall on agriculture and livestock can be significant and depends primarily on thickness of the ash cover, composition of the ash (the presence of soluble fluoride), weather following the eruption, and availability of feed and water for livestock.

The thickness of the ash fall can largely determine whether soil will be completely deprived of oxygen and "sterilized" or not. Ash fall thicker than 10–15 cm typically results in a complete burial of soils (Folsom, 1986). Chances of plant survival after ash fall can be improved if rain follows within 2–3 days of an eruption as the rain will wash ash from plants, compact the thickness of the ash fall, and facilitate recovery. Complete burial for several days often results in the death of the plants. Because ash composition and ash pH varies between volcanoes, the effects of ash mixing into the soil cannot be predicted. In some cases, soils will have a pH post eruption that no longer supports the crops which were previously grown. In addition to causing crop loss, livestock loss can be high when available water and fodder resources are contaminated with ash. This is especially true if fluorine is present in the ash in high concentrations, causing fluorine poisoning and death. Interestingly, the majority of livestock deaths following a major eruption are due to starvation (Wilson et al., 2011). Provision of emergency fodder and feed from unaffected areas might be a strategy for maintaining herds after an eruption.

Ash can also affect agricultural production by changing the amount of sunlight hours, altering soil properties, or damaging leaves or other crop parts. Finally, when rain mixes with volcanic gas, there is the potential to produce acid rain, which is also detrimental to crop production.

Plant pests and diseases

Some hazards directly target the crops being produced. Two examples of this type of hazard include crop pests (e.g., insects) and plant diseases. Crop pests are responsible for tremendous amounts of crop loss both in the field and during storage (post-harvest.) Monitoring of the occurrence and movement of both plant pests and diseases is an important step in controlling damage to agricultural production. In most cases, damage due to these two categories of hazard is not restricted to one farmer's field as pests do not respect property boundaries when multiple fields are planted in their preferred food source. Plant pests and diseases can wreak havoc at the local production level and potentially on an international scale unless effective control mechanisms are identified and utilized.

Some plant pests are confined at a household garden, farm or local level, restricted by available food sources, climate, and mobility. Then there are those such as the Desert Locusts, which have sufficient mobility to follow crop development and the weather pattern. Locusts travel in swarms which can vary in size from the small (hundreds of square meters) to enormous, covering 1,000 km^2. Desert locust swarms can damage 100% of the crop in a field where they land and they can fly hundreds to thousands of kilometers between their breeding sites (FAO EMPRES). The desert locust has made its way across Africa, Asia, the Middle East, and Europe and has been decimating crops and vegetation since biblical times. Control mechanisms include ground and aerial spraying with insecticides. This method must be done by trained personnel at a significant cost, and local population may not consume the locusts once sprayed. Other methods include digging trenches around fields to catch marching bands of nymphs or hoppers as they head in the direction of crops. Techniques have improved over the last decades. Emphasis on tracking the swarms increases efficiency of spraying programs, and supports a shift toward a combined approach of barrier spraying and use of less persistent and more environmentally friendly pesticides, including biological pesticides. The goal is to reach the gregarious locust populations before they reach their reproductive stage. Ideally, preventing gregarization would be the best control intervention, but this phenomenon often occurs in hard-to-reach areas. There is much support in the early warning sector for monitoring and identifying potential areas of outbreaks and subsequent invasions. Where possible, satellite imagery, field surveys, and monitoring are coordinated to predict and report the path of the swarms, providing advance notification to launch control interventions and where relief might be needed to meet food needs should the enormity of the pest invasion override control attempts.

Plant pathogens are organisms that cause a disease on a plant. As they spread and infect plants, they can significantly reduce yields. Major pathogenic outbreaks in the past include the fungus *Phytophthora infestans*, responsible for "potato blight" which culminated in the potato famine in Ireland (1845–1849). Potato blight was eventually controlled with a chemical mixture to kill the mold. More recent examples include cassava mosaic virus or cassava mosaic disease (CMD), affecting cassava crops in many African countries including Burundi, Uganda, and Democratic Republic of Congo. Cassava decimation is especially dangerous as it is a major food security staple for vulnerable populations; it is both drought resistant and able to remain in the ground for the duration of conflicts. CMD is currently managed by planting resistant varieties identified in the 1990s and, in many cases, distributed to vulnerable farmers through both emergency relief and development programs.

International agricultural research centers worldwide are challenged with new or modified pathogens. For instance, wheat stem rust can cause losses of 50% of a wheat harvest when conditions for its development are optimal. Losses of 100% are possible with susceptible cultivars. Although the Green revolution brought with it the identification of a gene with resistance to wheat stem rust, this gene was subsequently bred into most commonly grown wheat varieties over the past several decades, providing a single line of resistance against wheat rust. Then, in 1999, a strain of wheat rust arrived in Uganda (named Ug99). This strain was able to overcome the inbred resistance, attacking and decimating plants as it spread, windborne, through fields. This dispersal method facilitates spread to the many fields of wheat across the world, the vast majority of which carry no resistance to this new strain. The fungus has already made its way across Africa, Asia, and the Middle East and is particularly virulent, resulting in 100% crop loss. Scientists from more than 17 agricultural research centers and offices worldwide, including the Borlaug Global Rust Initiative, are currently committed to find new resistant varieties.

The ability of a pathogen to change and thereby render a single line of defense ineffective highlights the value of preservation of landrace and traditional crop varieties worldwide rather than conversion to one or two high performing varieties. Preservation of agro-biodiversity is a strategy for reducing the impact of pests and pathogens. When one variety is planted, a pathogen that is particularly virulent may be able to move quickly through the susceptible cultivar. When there is a wide diversity of cultivars, levels of resistance will differ, potentially slowing the spread and subsequent crop destruction. Additionally, planting multiple crops and varieties is a risk mitigating strategy for farmers against all of the hazards mentioned.

Looking forward and conclusions

Throughout history agricultural systems have faced challenges from natural hazards. Being able to anticipate hazards through monitoring or early warning systems may allow farmers to better prepare for and withstand disasters which affect agriculture. Farmers regularly employ a variety of mitigative strategies to avert disaster or enhance the speed with which they recover from disasters. These include diversification of their farms or plots and modification of planting methods to enhance sustainability and increase resiliency to hazards.

Diversification spreads risk in several ways. It provides more chances of crop survival against a particular threat. For example, if climate is not favorable for one type of crop, perhaps a different type of crop with different light, nutrient, and water requirements will survive, ensuring some measure of food security. On a global scale, crop diversity and a large genetic pool for any given crop can slow the spread of pathogens and pests. Being able to choose from a variety of characteristics provides the greatest chance to meet demands of climatic trends and pest and pathogen threats. The same is true for attack by pests or pathogens. Within crops, maintaining genetic diversity is tremendously important to long-term agricultural sustainability. Maintaining many local varieties of a given crop such as maize provides a ready supply of genetic material to better respond to evolving hazards. When only one variety is planted, the resistance to pathogens/climate stress/insect damage is limited to what is contained in that one variety. If that particular variety is susceptible to the hazard presented, a complete loss is possible.

In addition as world population growth continues and pressure on land, water, and soil resources intensifies, farmers and agricultural scientists are increasingly interested in methods such as conservation agriculture which maintain soil and water resources, and a more holistic approach to farming which considers crops as one component of the larger agricultural system. This may mitigate against many of the challenges presented by increased climate variability. The goal of this approach (ideally) is a more integrated and efficient system with less cost and waste and, hopefully, more production.

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Cross-references

Climate Change
Coping Capacity
Drought
Early Warning Systems
Flood Hazard and Disaster
Insects Hazards
Mitigation
Storm Surge
Tsunami
Volcanic Ash

CIVIL PROTECTION AND CRISIS MANAGEMENT

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Definitions

Civil protection is a term used in several countries to indicate the institution that coordinates emergency and crisis management. This apparently simple definition hides in fact organizational complexities which in most cases stay beyond the comprehensive term "civil protection." The latter refers in several countries to a single agency which holds the responsibility of coordinating the many others which interact and intervene on the scene of a mass calamity, ranging from firemen to emergency medical doctors, to health-care departments, and several others. The coordination agency is generally lacking own resources and means while being in a strategic governmental position, close enough to the prime minister or to similar key political levels, so to have enough authority to take the lead of otherwise independent bodies and organizations.

At the European level, for example, the Community Mechanism for Civil Protection is in charge of activating aid and assistance whenever requested both inside and outside the Community's borders on a voluntary basis.

This means that member states activate their own resources to make part of a European international team or to assist another country in need of help, according to the subsidiarity principle. The latter refers to the fact that external communitarian assistance has to be asked in case national forces are overwhelmed by the crisis and cannot cope satisfactorily with their own means.

In Australia, Emergency Management (EMA) is a division of the Government Attorney General's Department, which pursues an "all agencies, all hazards" approach, with the aim of encouraging disaster preparedness, supporting states in developing their own emergency management policies and providing help in case of crises that overwhelm individual states' coping capability. Nevertheless, no national law clearly defines what the legally binding mandates of EMA are.

In Canada, in 2003, responsibilities for emergency management were assigned to Public Safety Canada, a department which coordinates other departments, through the Government Operations Center, constituting a "hub of a network of operation centers run by a variety of federal departments and agencies, including Health Canada, Foreign Affairs," the police, and others (see the website of Public Safety Canada in the references). Despite this apparently operationally centered goal, the Center holds also responsibilities regarding planning, mitigation, response, and recovery (see *Mitigation*; *Recovery and Reconstruction After Disaster*).

In the USA, FEMA (the Federal Emergency Management Agency) is in charge of coordinating the various activities necessary to face a federal emergency as well as to set guidelines, plans, and preparedness programs. Since its inclusion into the Department of Homeland Security, FEMA lost its direct contact with the White House, that is, its crucial key position that had permitted in the past the fast deployment of forces and resources. Perrow (2007) describes rather clearly the severe shortcomings and difficulties of the newly created department, as mentioned also by several observers on the occasion of the Katrina disaster. An interesting comparison among different emergency management models around the world can be found in the Fema website (see references below).

The term "civil protection" is sometimes used also to indicate in a general, comprehensive way the entire set of organizations, agencies, and forces intervening in a disaster. Following this philosophy, the public itself is part of civil protection for a number of reasons. First because peoples' coping capacity (see *Coping Capacity*) is deemed to be important in enacting self-protection. The active role the public may play in a crisis is then fully recognized and encouraged instead of condemning it to the passive role of a spectator, defying the willing to react. Second because many times laypeople are the first respondents: it is well known, for example, that in the immediate aftermath of earthquakes, those who try to rescue relatives and friends under the debris are the same escaped victims. Last but not least, the public intervenes in the form of associations of volunteers that range from rather professionalized bodies (like volunteer firemen or members of the Red Cross and International Red Crescent Movement) and NGOs to individuals who participate in various forms to emergency response (including the more recent movement of volunteers of the technical community providing free web services as described in Harvard Humanitarian Initiative, 2011).

However the term is intended, what clearly emerges is the complexity and articulation of any institutional and organizational form of emergency crisis management. The latter being an activity that significantly challenges several of the mentioned agencies, particularly those that do not tackle emergencies on an everyday basis, as will be discussed in the following part of the text.

A last consideration regarding civil protection reflects upon the boundaries of its activity. Among the functions that are generally attributed to the civil protection, when the latter identifies a specific agency or organization, besides crisis management, prevention and mitigation are contemplated as well. Problems arise when the latter must be clearly defined. In fact, the civil protection does not have an ordinary budget specifically allocated for the structural and nonstructural measures necessary for achieving risk reduction in the short and long term. Therefore, the idea of mitigation is rather broadly used to encompass the need for risk assessment and mapping as well as training and risk communication. Still, the boundaries remain somehow vague, leaving room for controversies and institutional overlapping.

Crisis management is the set of activities aimed at facing a complex, unexpected situation originated by an accident, a war, a terrorist attack, or a natural calamity. The two words actually represent almost an oxymoron, as by definition crises are characterized by high levels of uncertainty, disruption of normal life, chaotic environment, that make them hard to "manage." Nevertheless, there are better strategies than others to cope with crises, to respond to the challenges they pose, eventually to exit them in ways that not only permit a return to normalcy but exhibit high levels of resilience (see *Resilience*). In this respect, the term management refers to a set of general rules, deriving from past experience and understanding of how complex organizations behave under severe stress, that deserve to be analyzed by those whose responsibility is to provide help, rescue, and aid during emergencies.

The word "crisis" derives from the Greek verb "krino" which means "to judge." In fact, the most crucial thing during a "crisis" is the ability to judge the situation, estimate available resources, and make decisions on how to act and respond to problems. Actually, this is the most difficult task to fulfill, making decisions under the pressure of the stress provoked by crises. Lagadec (1993), for example, suggests that whenever decisions are not taken, the chaotic situation originated by the event takes over and simply annihilates the reaction potential of exposed systems and organizations. Weick (1988) observes that action itself helps in finding interpretations to the crisis condition while reshaping its feature in the meantime. Nevertheless “there is a delicate trade off between dangerous action which produces understanding and safe inaction which produces confusion.”

There are many types of crises, which are classifiable also with respect to the initial event that triggers them. Actually some crises occur without any identifiable triggering event, or in circumstances where there are many events to which the crisis can be linked to, while no one stands out in a clear cut way. In this respect, some blackouts can be cited as an example, or some political breakdowns. In this contribution, only crises originated by natural hazards are discussed.

It should be noted that the term “crisis” may be considered close to others, for example, “disaster” (see *Disasters*). In fact, in the UNISDR Glossary, the term crisis is missing, whereas the term disaster has many connotations that are attributed here to “crisis.” It may be held though that in the common use, the term “disaster” is broader in its covering the entire event, from impact to longer term consequences, whereas “crisis” refers more to the initial phases, and in this respect, it gets closer to “emergency” and “contingency.” The term crisis expresses the type of disruption that one is faced with, the situation in which it is necessary to decide under significant stress and disruption of normal life. Following this reasoning, while the term “disaster” depicts the overall condition for the entire affected community, the term “crisis” is the disaster seen from the eyes of the interveners, of those who have responsibilities and are attributed the means and the resources to intervene and respond.

This brief discussion points out that even though terms like “crisis,” “disaster,” “calamity,” and the like seem obvious, they cannot be accepted in an uncritical way. As an example, the book by Quarantelli (1998) titled *What Is a Disaster?* convincingly shows how difficult it may be to provide satisfactory and universally agreed upon definitions. Actually, different organizations, including EM-DAT or Munich-Re, or various national legislations set rather different thresholds to distinguish between what can be considered a disaster and what cannot. Not any landslide nor any ground shaking produces a level of damage and devastation so as to call for a disaster declaration. Furthermore, what makes a disaster in one region of the world may not in another, a death toll is considered high in one country and negligible in another.

Similarly, it is not that easy to attach the definition of a crisis due to some natural hazards to the level of disruption and losses that a specific event may provoke. In the following paragraphs, some crucial elements and factors generating a crisis and requiring specific actions for its control and management in the aftermath of a natural extreme will be discussed.

Here, it will suffice to list some specific conditions that can be considered as specifically characterizing crises linked to natural events. The verb “linked” and not due to or provoked by is used because the assumption here is that not only large magnitude events provoke crises, the latter can arise also as a consequence of somewhat medium or even minor environmental stress, depending on the weaknesses of exposed systems. In fact, a crisis may be originated either by a severe natural event, for example, a high magnitude earthquake, a fast landslide mobilizing large volumes, a strong volcanic eruption, or be the consequence of highly vulnerable exposed systems (see *Vulnerability*).

Therefore, in investigating the types of crises that may occur as consequence of some natural event be it very severe or not, both the characteristics of the threat and of exposed systems must be identified and described.

Types of crises

Following what has been stated above, types of crises will be classified according to hazard and vulnerability aspects.

With respect to the first, spatial and time factors should be considered. From a spatial point of view, hazards may generate local, regional, or multisite events. Local events, like landslides, avalanches, or tornadoes, are such that they hit a given place, provoking concentrated damages and losses. In this case, even though the event can be very severe and provoke significant local disruption, it is possible to delimitate an area, an event core, around which a corona and a periphery from which help may come and to which victims can be temporarily or permanently evacuated can be clearly drawn. In terms of crises management, a local unit to tackle the event from a close post is generally sent so as to check needs and demands arising from the field and then control the situation from a safe place at the shortest possible distance from the core area. Concentration of rescuers, teams, and support goods must be managed and organized so as to avoid congestion that may end up getting the opposite result to the intended.

Regional events, on the contrary, involve large areas, comprising different types of settlements and infrastructures, from rural/natural areas to highly urbanized to metropolitan. Large regional events may be transboundary, across several administrative borders, including regional and national. In this case, several teams will be sent to the area; a number of advanced units must be forecasted and positioned in strategic zones. Challenges are clearly larger than in the case of local events, because of the extent of territories and the expectedly larger numbers of affected people. Whenever regional events affect different jurisdictions or even nations, a complex issue of coordination among levels of government, different governments, and authorities arises, making the crisis easily escalate beyond the

Civil Protection and Crisis Management, Table 1 Issues arising in crises that are differently characterized in terms of spatial and temporal scales. Self-elaboration. Concepts in this table can be found in Chaps. 2 and 4 of Menoni and Margottini (2011)

Space Time	Local	Regional	Multisite
Slow onset	Crisis may not be recognized by early signs	Crisis may escalate and involve large areas and more than one country	Similarities among events in different localities may not be recognized
Fast onset	Potential indirect consequences at larger scales may not be adequately foreseen	Crisis requires significant coordination in the area without any/enough prealerting time to make first common decisions	Challenge of recognizing the crisis' actual spatial extent
Long duration	Attention by the media and even by governmental offices may fade away as time passes	Turnation of a large number of officers and workers is required Large amount of resources Temporary solutions (like shelters) for partial return to normalcy	Problems in assuring resources to all affected sites
Short duration	When the most critical phase is over, the local community may be left alone even in cases when it does not have the resources to fully recover	Difficulties may arise to guarantee coordination particularly in cross-border and interregional crises Long-term effects may not be adequately considered or treated differently across borders	Challenge to assess the needs in multiple locations Challenge in dispatching forces to a variety of places simultaneously

control and management capacity of any of the involved authorities or agencies.

The adjective multisite can be attributed to otherwise local events that occur simultaneously in different places, for example, forest fires in the dry period or a storm affecting several places in the same days. Even though events like a fire or a landslide or a storm hit individual places, their contemporary occurrence puts a much stronger pressure on intervention agencies and teams. In fact, while local events, even though very severe, permit to concentrate response forces, multisite events challenge response teams, in that resources and means must be dispatched at the same time to a variety of places. The fires which occurred in Southern Europe in the summer of 2007 are a clear example of such events that distressed significantly the Community Mechanism of the European Union and required the rapid displacement of fire fighters from France to Portugal to Italy to Greece.

As far as time factors are concerned, as shown in Table 1, two criteria must be borne in mind. The first refers to the time of onset of an extreme event and the consequent crisis. Some natural events can be sudden and rather unexpected, not so much in general as for the actual circumstance, the hour and the day in which they occur. In other words, as commented by Hewitt (1983) in his *interpretation of calamities*, there is the possibility to forecast most natural hazards, such as earthquakes, floods, and landslides which occur in areas that are prone to them and historical evidence exists of their occurrence in the past. Nevertheless, the exact moment when they will occur may not be predictable, as premonitory signals are either weak, or inexistent, or highly uncertain.

Events characterized by fast onset may generate sudden, unexpected crises, particularly when mitigation has not or has been poorly carried out. Early warning and prealert is either impossible or possible with only few seconds to minutes in advance, so that crises start when most damages and losses have already occurred. Events like earthquakes, debris, and mud flows are not only sudden but also rather rapid in their development; in a short or very short time, they deploy all their destructive potential, leaving to rescuers only the possibility to respond to losses and death toll.

Events characterized by slow or relatively slow onset, like plain floods or droughts, may be predicted in advance and actions can be taken to protect people and goods as well as to secure the most critical and strategic facilities and places (see *Early Warning Systems*).

Even though examples have been provided for slow and rapid onset events, it is noteworthy that they are only indicative and cannot be considered as fully exhaustive or satisfactory. In fact, there are large earthquakes that are announced by a series of minor tremors months ahead; there are ash crises that can or cannot be followed by a big explosion; some types of landslides do show clear signals of movement, others do not. What can be said therefore is that monitoring devices, complete warning systems, comprising besides the technical component also the social and logistic aspects, may significantly change the type of crisis, from largely unexpected to highly anticipated. The ability to generate event scenarios, previous training, exercises and simulations permit to be ready for a given event in large advance, so as to downscale the magnitude of the consequent crisis.

What is crucial in most if not all instances described above is the capacity to deal with uncertainties and make decisions despite scientific and other types of uncertainties (including legal, institutional, societal, see De Marchi 1995). In fact, the classification of crises, as mentioned above, cannot be strictly associated to the characteristics of the threats. The interface between the latter and the exposed systems, considered not only as physical but also organizational and social, is equally important to determine how a crisis will look. As suggested by Sarewitz et al. (2000), not only by reducing the scientific uncertainty associated with some natural hazards one may improve the coping capacity (see *Coping Capacity*), but also by lowering all other types of uncertainties, particularly legal, institutional, and societal. By making timing and good decisions, the catastrophic potential of some events may be lowered by reinforcing the response capacity of likely to be affected systems.

In this respect, clearly, the vulnerability of the latter plays a key role.

It would be too long and perhaps beyond the scope of the present contribution to list the variety of conditions that may shape crises, according to the characteristics of the physical built environment, land use patterns, and the mode of use of buildings in exposed areas. Clearly, all those factors influence some logistics of the crises, in terms for example of accessibility to damaged zones and to resources and facilities (Ceudech and Galderisi 2010); they also strictly influence the extent of physical damage, which in turn translates into number of affected people and extent of resources to be deployed (for partial or total evacuation, etc., see also *Evacuation*).

Another vulnerability facet determining the level of crisis can be labeled as systemic or functional. How well and how long strategic facilities like lifelines can provide service is crucial to sustain help, search, and rescue activities and therefore directly influence the level of control that can be sustained by crisis managers.

Among the variables identifying communities' vulnerability and resilience, the response capacity of established organizations, like the firemen, the army, and the medical doctors, is essential. The response system constitutes a sort of standardized and predetermined body, whose preparation and training is independent from the specific features of the crisis at stake. According to the practical experience gained in the field within an operational organization like the firemen, a fundamental lesson that can be suggested refers to the importance of being able to rely on established rules and standardized procedures at least for the most repetitive tasks, for those operations and to use those devices that are most common. Formalized crisis management models may significantly improve the performance of teams, as they permit to achieve a good level of response at least for the most repetitive and trivial operations while devoting due energy to what really stands out (Wybo et al. 2001). Without standardization and preparation, coupled with strategic management, it would be extremely difficult to even recognize exceptions and surprises.

Last but not least, as for time factors, duration of crises must be accounted for. Most plain floods, for example, may affect very large portions of a given territory but are not likely to last for long. After days, people will be able to return to their houses unless severely affected or contaminated and start reconstruction (see *Recovery and Reconstruction After Disaster*). Earthquakes would require long-term stay in temporary shelters, whereas the crisis itself may last for a number of weeks. In this case, turnover among rescuers must be carefully planned and mechanisms for exchange of solutions and information must be set up.

Models of crisis management

According to common sense, crisis management requires the presence of a strong subject able to lead the team working on the disaster scene so as to achieve the best solutions in the shortest time. While this idea holds certainly some truth, particularly when the necessity to make decisions and to lead the event instead of just being at its mercy are considered, in general, some authors (Lagadec 1995; Reason 1997) contradict the idea that centralizing decisions and actions as well as making coping organization hierarchical actually improve response. In fact, the opposite has been demonstrated. Highly hierarchical organizations are not able to respond fast to changes and be flexible enough to react to surprises and unexpected situations. They require a long chain of orders and decisions to be followed and do not allow for much initiative to those in the field, who nevertheless have the direct grasp and perception of events, even though they lack a supervision of the entire scene and of the many interconnections among areas, resources, and systems.

A good balance must be sought between one person or restricted groups' ability to control and be in charge of the situation on the one side and the personnel who are at site and have a direct vision of the event on the other, so as to guarantee decisions and leadership and, in the meantime, allow for sufficient flexibility.

Often recalled in the crisis management field is also the opposition between improvisation and preparation. To a certain extent, this opposition is linked to the one discussed above between hierarchical and "democratic" organizations. In fact, hierarchical organizations tend to rely heavily on established plans, whereas local cells guaranteed enough autonomy may take fast decisions more tailored to the upcoming situation.

One way of combining the two needs, that is, take control of the entire crisis scene, particularly when the latter is complex and extended over large areas, and the need to be "close" to the site, where the incident or the natural event occurred, is constituted by a model of operation called "Incident Command System." The latter makes part of the recently reorganized "National Incident Management System" promoted within the US Homeland Security (2008) as a model for managing large emergencies. Such a model, already well established since the 1970s, has spread beyond the USA and is currently adopted, though under different names, in many countries worldwide.

"The NIMS is based on the premise that utilization of a common incident management framework will give emergency management/response personnel a flexible but standardized system for emergency management and incident response activities. NIMS is flexible because the system components can be utilized to develop plans, processes, procedures, agreements, and roles for all types of incidents; it is applicable to any incident regardless of cause, size, location, or complexity. Additionally, NIMS provides an organized set of standardized operational structures, which is critical in allowing disparate organizations and agencies to work together in a predictable, coordinated manner" (Homeland Security 2008, p. 6). According to the model, local cells are sent to the scene with the capability to guarantee information exchange among those in the disaster scene and among the various organizations present on site and their respective operation centers. The incident command system is therefore constituted by an advanced group of technically skilled personnel who are also granted the capability to decide some immediate actions on site, coordinate the various organizations, and guarantee information and exact request of resources to each operational center and to the main emergency control room.

In the case of natural disaster, this organizational mode has to be adapted to the environmental and social contexts and to the characteristics of the hazard, particularly as far as the spatial features described above are concerned. Several challenges have to be met in adapting the NIMS to individual countries' characteristics and previous mode of operating. For example, the system requires the extensive use of technical terms and standardized documents. Both have to be "translated" linguistically and also semantically in newly produced documents and then a period of extended training must be foreseen. The transition from previous models to the new, even though more efficient structure, requires planning and the provision of additional resources.

In the case of a local hazard, an advanced command post may be enough; the same cannot be held for regional or multisite events, where clearly a net of advanced command posts must be coordinated so as to guarantee the correct treatment of each site where an event has occurred.

Civil protection and crisis management in a nutshell

In the previous section, the model of intervention, whether highly centralized or distributed, whether hierarchical or flexible, has been shortly discussed. In this section, the much more complex issue of how civil protection, as initially defined, manage crisis will be addressed.

Drawing upon Cherns and Bryant's (1984) work on the construction industry, it can be held that also crisis management requires inevitably the coordination of a complex temporary multiorganization that must achieve a unique goal (facing and exiting the crisis condition) in the shortest time and reducing as much as possible losses and errors. First, because crisis management requires the presence and the action of various agencies and organizations, ranging from the firemen, to the police, to the army, to the agencies in charge of environmental assessments, health indicators, etc. Those agencies and organizations share (or should share) a common objective, solving the crisis, but are characterized by their own culture, by their political and social mission, by their means and resources. Some of the organizations involved in the crisis are dealing with "minor" or "normal" emergencies everyday on a routine basis, for example, firemen or emergency doctors. Others are involved in crisis management only occasionally, depending on the event to be tackled, for example, lifelines managing companies, public health agencies, etc.

Those organizations do not generally meet on a routine basis, hardly know each other, both as organizations and as individuals, which makes coordination and management particularly challenging, among other reasons because the one who will be in charge of coordinating must get the approval and respect of all involved parties. What Cherns and Bryant (1984) say about the construction industry perfectly fits also the crisis management arena: "Relationships [among the various bodies] are formally governed by the contract [in the case of crisis management the contingency plan or other formal governmental arrangements and protocols can be considered], but are supplemented and moderated by informal understandings and practices which have evolved to cope with the unforeseen, sometimes unforeseeable difficulties that characterize [disasters]."

Unfortunately, few studies have been devoted to analyzing the difficulties and the solutions found by the temporary multiple organizations in charge of crisis management in given circumstances and under different crisis duration. Some work that can be quoted refers to organizations under stress, how they cope and how they can be brought to react better and even with success. A recent relevant work in this direction is provided by Comfort (2007) who suggests that beyond control, coordination, and communication capabilities, the real challenge "is to build the capacity for cognition at multiple levels of organisation and action in the assessment of risk to vulnerable communities." In her contribution, Comfort stresses the importance of cognition, as the capacity of multiple organizations to build a common understanding and interpretation of the evolving emergencies and act accordingly.

In general terms, it can be said that much more research has been carried out with respect to what happens within the same organization under stress, whereas little has been done with respect to the intercorporate dimension, that is, among distinct organizations. In general it can be said that difficulties encountered within the same organizations, for example, relatively to information exchange, decision making, identification of available resources, are exacerbated when a number of organizations must work together, particularly when such circumstance is temporary and not too frequent.

A specific point should be raised with respect to international crisis management, when aid is given to poor and developing countries. In fact, such intervention often sees the convergence of massive forces from a variety of countries in the affected place. Recent examples are the intervention on the occasion of the devastating tsunami hitting Southern Eastern Asia in 2004 (see Christoplos 2006) and of the earthquake in Haiti, January 2010. As it is already very complex to achieve coordination and cooperation among different organizations of the same country, one may easily imagine the almost insurmountable difficulties when the latter must be achieved among organizations pertaining to different countries. In this case, lack of coordination may be dramatic, producing overredundancy of some goods, complete lack of others, mismanagement in the form of goods supplied where and when they are least needed, tragic delays where they are urgent, etc. In addition to the multiple temporary organizations of different countries and speaking different languages, problems of logistics, understanding of the social, political, historic, and cultural context are also crucial, leading to a variety of mistakes, sometimes severe. There are not simple solutions to those problems; nevertheless, some elements may be considered to improve current practices. On the side of aiding countries, what can be asked is a higher understanding of the social and cultural context before providing help, building on experience to avoid errors already committed in the past, avoiding putting too much emphasis on fast results to be shown to donors, in favor of deeper analysis of actual needs, and identifying where resources can be invested so as to obtain the best results for the victims. On the side of recipients, what would be clearly ideal is the training of local responsible personnel able to direct materials and goods, to dispatch help to the most affected areas, and to provide guidance to international and external agencies. At the very least, local authorities should be able to interface with international agencies so as to avoid to be completely overridden, with the uncomfortable but almost inevitable outcome of money and resources spent haphazardly.

Main characteristics of crises today and potential challenges of tomorrow

Challenges can be grouped according to whether they are intra- or interorganizational, that is, whether they refer to problems arising within the same organizations involved in crisis management or among different agencies and organizations.

Within the same organization, the following can be mentioned:

- Ability to transfer information timely and effectively among the various members and subparts. Studies have shown that organizations relying on formal systems of communication are more likely to manage effectively crises particularly when technical disturbances in communication devices may occur (see McLennan et al. 2006).
- Level of preparation and preplanning. Regarding this particular point, a rather interesting literature exists (Lagadec 1993, 1995; Roux-Dufort 2000), depicting what works well, poorly, and not at all prepared organizations. Among other criteria, the most important is the behavior and attitude of responsible managers in facing crises, as in prepared organizations the latter tend to take the lead, whereas in the least prepared they tend to retire in their own shell and protect themselves from criticism. Equally relevant is the ability of organizations to learn from experience and to successfully interface with the public and the media.
- A specifically mentioned aspect refers to decision making, that is, the ability to make decisions (possibly sound ones) in the urgency of a disaster, under the tremendous pressure of the evolving event and the concerned public(s). Lagadec, Roux Dufort, and Weick all share the conviction that crisis management is a strategic not a reactive activity.

An example of decision which is particularly hard to make in the face of natural disasters is early warning in case of large uncertainties (see *Early Warning Systems*). Specific examples are in the field of seismic risk, where early signals may be particularly difficult to interpret correctly and, in any case, leave large room for false alarm (see *Earthquake Prediction and Forecasting*). Even though other hazards, like volcanic eruptions or floods, are in general more predictable than earthquakes, they all share some basic common aspects, like the sources of uncertainty, deriving from the quality of available data, the quality of scientific explanations and models. Other types of uncertainty intertwined with the latter refer to the societal and institutional backgrounds where the decision must be taken. As Sarewitz et al. (2000) convincingly showed, sometimes improvement in scientific understanding of a given natural phenomenon may even lead to larger and deeper uncertainties. Instead, the latter may be reduced by means of strong and sound decision making rather than better science or better data.

Larger difficulties arise when multiple organizations intervene in the same crisis scene:

- Communication among different organizations which does not only imply issues of language, jargon, secrecy, willing to keep information inside each organization, but also technical aspects, for example, different radio frequencies assigned to every agency and organization, a simple fact holding heavy consequences.
- Communication with the media, when multiple actors are in theory eligible to provide information. How to agree among the police, firemen, medical doctors, etc., about the opportunity to dispatch a unique information bulletin, particularly when stakes are high and uncertainty large?
- Need to share not only material resources but also the information about the actual availability of those resources and the way to obtain them from legitimate owners. Even though the civil protection is entitled to

ask for resources, conflicts among ministries and governmental agencies must be avoided; furthermore knowledge about existing resources must preexist if they are to be practically managed during the crisis.

A final word in this section must be devoted to the so-called lay or general public. Some of the latter may actually be part of the population who may be potential victim of the disaster. Social scientists have been producing thousands pages of studies describing and reasoning about the response of "people" to disasters under different circumstances and in different contexts (just as a reference, Barton 1970; Drabek 1986; Fischer 1996). Time has come to make those studies part of active crisis management, avoiding treating the public as pure recipients of somebody else's thoughts and decisions, recognizing the essential active role that the affected population actually plays in the majority of cases. Attempts to elude this reality have often turn crisis management into failure even in the presence of substantial means and well-prepared organizations. In this respect, the issue of informing the population before and during crises is clearly crucial. As Parker (1999) stated, there is often a contradiction between the requirement to keep it secret, in the fear of "panic," and the need to have the public act in an informed way (see *Risk Perception and Communication*). Considering again the example of early warning, Parker and Handmer (1998) have shown how any information, advice, or input from official sources undergoes a process of verification and analysis of costs and benefits implied in the suggested or required actions. The decision to comply with the latter depends, among other factors, on the familiarity with the hazard, on the familiarity with the authority issuing the alert, on the correspondence between the given message and the perceived threat, and, last but not least, on the tone and wording of the message itself.

Inter- and intraorganizational challenges mentioned above are limited to what is already known about past crises, emerging from experience and thinking about what happened in past events.

This is just one part of the problem at stake for today's crisis managers, the other one being future challenges, tomorrow's problems, and constraints that are not always that easy to identify and detect in advance. Scenarios of future and emerging hazards and risks must be first depicted in order to be able to answer the just asked question of how future crises will look like (see *Global Change and its Implications for Natural Disasters*).

In their book, *La fin du risqué zero*, Guilhou and Lagadec (2002) addressed those issues, pointing at two main concerns, referring to the emergence of surprises on the one hand and to the need to develop specific scientific expertise on the other. As for the first, the Authors hold that future crises will imply larger surprises and unexpected outcomes, the only way to be prepared for is training on scenarios and simulations, not because the future will be as drawn in the scenario, but because the latter helps those dealing with crises to prepare for the unexpected. As for the second, there is an increasing demand for scientific experts able to provide guidance on the basis of poor quality (and sometimes also quantity) data, making a guess informed by their knowledge and past experience in the field of concern (for example earthquakes or floods). This may be considered as a particular case of scientists advising policy makers (Jasanoff 1990), in a condition which is particularly stressful and delicate for both. As an example of tragic problems that may arise in the aftermath of a catastrophy one may recall the ongoing trial in Italy after the l'Aquila earthquake, in which scientists who worked as consultants for the civil protection are under trial for their failure in correctly communicating the risk and/or uncertainties implied in risk estimation and assessments capabilities (see Hall 2011).

In this contribution, little room has been devoted to technology, despite its omnipresence in all arenas of modern life, certainly in the field of emergency management. Computers, satellites, and cellular phones have changed substantially the conditions under which officers and civil protection servants are working (Harvard Humanitarian Initiative 2011). The increasingly extensive use of Internet has changed also victims' ability to get informed, to exchange feelings, problems, and sometime crucial information. Many technologies, starting from the GIS to several communication devices, have slowly shifted from military to civilian applications. In spite of such major influx of modern technologies, which certainly must be used to manage crises at best, a number of warnings must be raised, not with the aim to contradict the obvious potential of technologies, but rather to promote their most effective usage.

Quarantelli (1998) suggested for example that overreliance upon modern technologies should not divert attention from the need to provide backups, including manual backups, in case of technologies' failure; in any case, technologies should be looked for and developed to address actual needs rather than reshape crisis management to fit the technical features of existing devices offered in the market. Finally, the rather trivial but nonetheless important reminder of the fact that problems of interpretation and meaning cannot be solved by "more technology" (nor by more science as suggested by Sarewitz et al. 2000).

Conditions for successful crisis management: lessons learnt from successful and unsuccessful cases

There are a number of conditions that are commonly considered as keys to positive outcome of crisis management, including ability to govern complex and highly dynamic contexts and situations, ability to select the crucial information in the midst of flouring data and uncontrolled rumors, and ability to anticipate on the basis of understanding of the situation and thanks to a prior effort in designing scenarios and simulations helping to identify weak points and fragilities of both the exposed environment and communities.

One of the most crucial aspects refers to the capacity to learn upon experience, to capitalize past mistakes and successful results, and to rethink strategy and form of organizations. Well-organized agencies are able to face even failures so as to learn and question basic assumptions in an effort to be much more prepared for the next occasion; unprepared organizations do not even have the tools to analyze what went wrong and lack human, technical, and financial resources to recover in a resilient way. A resilient organization in this sense is not only able to recover after a failure but also to restructure itself so as to become stronger and take advantage of the lessons learnt. This is clearly a very demanding achievement, while most organizations tend to restore pre-event patterns, aiming at surviving, keeping the attention all focused on the specific aspects of the just occurred crisis, without questioning the entire set of organizational assumptions and fundamental beliefs.

Still the problem that remains open is how temporary multiple organizations can accomplish such learning which should not be only individual but also collective, that is, related to the entire set of different agencies, private companies, groups, and organizations making part or coordinated by civil protection and contributing to the solution of a crisis for the best or for the worst.

And even more challenging is the question of how to keep the memory of such learning, of the conditions that led to positive as well as to negative outcomes. Who should be responsible for keeping such memory and what form such memory can take. It can be suggested as a partial solution that emergency plans (see *Emergency Planning*) may be one of the material places where such memory can be kept, in the sense that the plan should constitute both a reminder of activities and procedures that proved to work well under given scenarios and may as well provide room for learning lessons from real events and simulations so as to revise the plan whenever the latter is being felt obsolete or requiring any kind of updating.

One unfortunate observation made by some authors (De Marchi 1996; Murphy 2009) is regarding the large amount of information, expertise, and know-how that is lost after some time has passed since the last crisis and several lessons must be learnt again and solutions found again, whereas they had already been achieved but not successfully transmitted in the past. In this regard, reports of emergencies that have been tackled in the recent past, in various developed and developing countries, are worthwhile reading and analyzing with the aim to build a reference archive at least for those problems and obstacles that arise over and over, which would deserve to become a common patrimony of all those in charge of crisis management at different stages and with varying levels of responsibility.

Summary

Civil protection is a term used in several countries to indicate the institution(s) that coordinates (or tackle) emergency and crisis management.

Crisis management is the set of activities aimed at facing a complex, unexpected situation originated by an accident, a war, a terrorist attack, or a natural calamity.

Crisis management is a particularly complex activity, which requires a number of qualities from those who are in charge of its solution. It is stated that crisis management as a definition holds an intrinsic contradiction in that crises are unmanageable by their very nature. They are characterized by a number of aspects, like difficulties in getting the right picture and extent of damage, disruption and resource needs, problems in communication at all levels, among stakeholders and with the public, rapid development, strong pressure on decision makers, and significant uncertainties about potential outcome of alternative decisions and consequent actions. Those and other features make the solution of crises particularly troublesome and questioning fundamental beliefs and procedures of the established organizations which are expected to deal with them effectively. Those organizations are generally grouped under the label of civil protection. The latter term may either refer to an individual organization which is in charge of coordinating the activity of the many others who intervene on the scene of a disaster or to the entire set of organizations entering in a disaster field. In both cases, crisis management often implies the establishment of a complex temporary multiorganization, comprising a variety of different agencies and organizations that meet on the occasion of a disaster and have to cooperate despite cultural, language, and mission differences. Findings of recent literature and deriving from practical cases are proposed to discuss what are the most agreed upon conditions that may lead to satisfactory crisis management solutions.

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CLASSIFICATION OF NATURAL DISASTERS

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Introduction

The question of how to define a disaster and which criteria should be applied to classify it has been the subject of vigorous debate among practitioners of the field (MunichRE, 2006; Perry and Quarantelli, 2005; Quarantelli, 1998). For example, Berren et al. (1980) offer an independent and comprehensive classification that is not limited to natural disasters and is based on type and duration of disaster, magnitude of impact, potential for occurrence, and ability to control the impact. Other classification schemes consider the differentiation by magnitude of event or consequences, by the different scales (such as individual, family, community, and region), or by speed of onset and predictability. Hence, numerous classification schemes have been proposed, and little would be gained from reviewing them all here.

Despite these reservations, there is broad consensus that a disaster is an event or situation that severely disrupts normal socioeconomic activities and causes damage and possibly casualties. Attempts to quantify the definition, for example, in terms of monetary losses and numbers of people killed (Foster, 1976; Keller et al., 1992; Munich Re, 2006), have not met with universal acceptance. Nonetheless, it is clear those disasters there is a qualitative difference between disasters and lesser events, in that they require extraordinary responses in terms of resources and organization (Kreps, 1983). A common definition of a disaster is that the coping capacities of the affected individual, group or unit (local, regional or national governments, public institutions, social groups, etc.) are exceeded and external support is likely to be required. Hence, it may be appropriate to base the classification of the magnitude of emergencies and contingencies upon ability to cope with and respond to events of a given size (Table 1).

Three global data sources for natural disasters are available. Two are data catalogs compiled by insurance companies: the Sigma database of SwissRe and NatCatService of MunichRE. However, the most widely used data bank on disasters is the OFDA/CRED International Disasters Database (EM-DAT, refer also to www.em-dat.net), maintained at the Centre for Research on the Epidemiology of Disasters (CRED) of the Catholic University of Louvain in Belgium. Besides temporal information, all entries are arranged by continent, country, and theme, as requested by the UNISDR Secretariat.

It has long been noted that the term "natural disaster" is not particularly apt (O'Keefe et al., 1976). For example, although most earthquakes are entirely natural phenomena, the root cause of seismic disasters could be regarded

Classification of Natural Disasters, Table 1 A size classification of emergencies and contingencies (Partly after Tierney, 2008)

	Incidents	Major incidents	Disasters	Catastrophes
Impact	Very localized	Generally localized	Widespread and severe	Extremely large
Response	Local efforts	Some mutual assistance	Intergovernmental response	Major international response
Plans and procedures	Standard operating procedures	Emergency plans activated	Emergency plans fully activated	Plans potentially overwhelmed
Resources	Local resources	Some outside assistance	Interregional transfer of resources	Local resources overwhelmed
Public involvement	Very little involvement	Mainly not involved	Public very involved	Extensively involved
Recovery	Very few challenges	Few challenges	Major challenges	Massive challenges

as poor construction of buildings rather than the occurrence of ground shaking. Hence, there is a motive for regarding earthquakes as human-made disasters. In fact, because so much of the impact of disasters depends upon vulnerability, a predicament that mainly depends on human decision making, "natural" disaster can be regarded as a convenience term which distinguishes one class of phenomena from others. In this case the generating mechanisms stem directly from events in the geosphere, biosphere, atmosphere, and hydrosphere.

"Natural" disasters are caused by extreme events, in the sense of large departures from long-term mean values. For instance, sudden excesses of precipitation can cause floods, whereas long drawn-out shortages can result in drought. In this respect, *speed of onset* and *duration* are important criteria in classifying events. Earthquakes and rapid debris avalanches are examples of sudden-impact disasters, whereas drought and desertification or soil erosion are examples of slow-onset events. Most earthquakes have a main shock that will last from a few tens of seconds to a couple of minutes, but the sequence of aftershocks can stretch the emergency period to hours or days. This contrasts with a drought that may be prolonged for months or years and desertification that is essentially a permanent condition, i.e., one that is technically challenging and expensive to reverse. The typology suggested by the U.S. National Research Council's Committee on Disaster Research in the Social Sciences. (US NRC, 2006) is similar to the discussion presented here, but also includes the scope of impact.

Among extreme natural phenomena there is a wide variety of speeds of onset and duration, and in turn a large variation in predictability and potential for warning. For example, tsunamis are generated abruptly by the sudden displacement of a column of ocean water. Triggers may be earthquake activity, submarine landslides, or meteorite impact. However, the very long distances that tsunamis travel allow monitoring to take place and warnings to be issued to distant coastal areas in their path. This has been successfully applied, for instance, in the tsunami generated by the Chile earthquake on February 27, 2010, and the respective precautionary response along the Western Pacific coasts including Japan and New Zealand. For the Pacific basin warning lead times may exceed, at most, 17 h, but the main problems occur with "near-field" tsunamis (those that are generated locally) in which even instant detection does not allow more than a few minutes' warning to be issued to local communities. However, one should never forget that the population at risk from a local tsunami can often recognize earthquake shaking as an environmental cue indicating a need to evacuate to higher ground (McAdoo et al., 2009).

The prospect of short-term prior warning of earthquake main shocks has long been a goal for seismologists, but has proved consistently elusive, mainly because each earthquake involves some degree of complex uniqueness. Hence, most seismic disasters occur without prior warning, other than the long-term identification of areas at risk and recurrence intervals of earthquakes of a particular maximum size.

The predictability and warning potential of volcanic eruptions is highly variable. Heat fluxes, harmonic tremor, and gas emissions all indicate the rise of molten magma close to the Earth's surface, but the exact timing of eruptions tends to defy prediction. In the mid-1980s volcanic emergencies occurred in the Caribbean and southern Italy that lasted months without any actual eruptions. In contrast, many extreme events of an atmospheric or hydrological origin have a higher degree of predictability. The preparatory phenomena can be observed by direct measurement (e.g., rain gauges and streamflow monitoring) or remote sensing (synoptic views of storms), and numerical modeling can give forecasts of pending events.

Drought is the archetype of a slow-onset, or "creeping" disaster, a category that includes desertification (the degradation of land productivity) and accelerated soil erosion. This sort of phenomenon tends to be insidious. It may go undetected until the impact is chronic, and thus the state of disaster is defined by the cumulative sum of effects.

Recurrence interval and regularity are two further elements in the classification of natural disasters. Although many anthropogenic phenomena are nonrecurrent (for example, transportation crashes and catastrophic pollution episodes), most extreme natural events are repetitive. The degree of regularity, or cyclicity, depends on the type and origin of the phenomenon. Meteorological and hydrological events tend to be the most cyclical on account of seasonality. In South Asia, monsoon-induced rains cause summer flooding; in the eastern central Atlantic Ocean the general circulation of the atmosphere leads to a hurricane season that extends from May to November; in the Pacific basin the El Niño-Southern Oscillation (ENSO) causes a 4-year cycle of floods and storms; and in the European Alps, large magnitude snowfalls often associated with temperature changes cause snow avalanches that tend to have their peak occurrence in particular months of the year (e.g., slab avalanches in deepest winter and slush avalanches in spring).

Many extreme atmospheric phenomena recur on complex cycles. Annual seasonality provides the shortest of these, whereas sunspot occurrence, fluctuations in the Earth's ionosphere, and trends in climate change provide others. Earthquakes tend to have definable cycles based on the gradual accumulation and sudden release of strain in the Earth's crust. On the San Andreas Fault the occurrence of high-magnitude earthquakes has been established by carbon dating of exposed faults, and other indications, as averaging once in 160 years. However, variations in the recurrence of seismic events can require confidence intervals that may be more than 50% as large as the cycle itself. The situation is even more indeterminate for volcanic eruptions, where the intervals between events may be very much longer than human timespans, in some cases as much as 10,000 years.

Regarding earthquakes, the picture may be complicated by other contributory factors. For instance, some research indicates that precipitation events may trigger large earthquakes (see Huang et al., 1979). The large amount of water made suddenly available adds weight to the earth's surface over a relatively short-time span. The stress–strain field in the Earth's crust can thus change very rapidly. If there are stable conditions, precipitation will have no influence on earthquakes, but if a region is already weakened then additional loading through precipitation may very well have an influence. The same is true of marine tides and "Earth tides" the pull of the Sun-moon system on the Earth's crust.

The case of river flooding illustrates the difficulty of using recurrence intervals in planning and preparedness. Following the practice in the USA, many countries use the 100-year flood as a benchmark. This is an event that has a probability of occurrence of 100% in a century and 1% in any single year. It usually corresponds to a defined floodable area and a set of depths of inundation, both of which can be expressed on maps. Convenient as the 100-year flood is, there is no guarantee that it will be the most significant or most disastrous event. Neither will it necessarily occur after a 100-year interval without major floods. The dilemma for land-use and emergency planners is what size of event should be used for preparation.

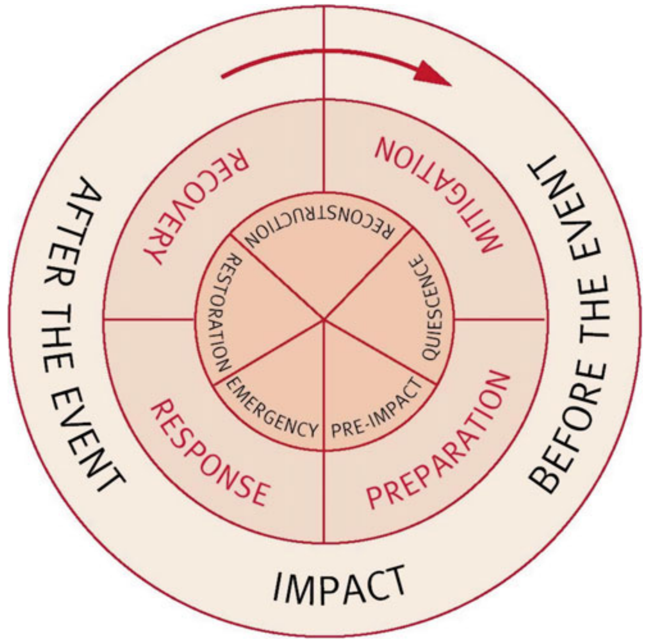
Probability distributions of diverse kinds of natural events were given by Hewitt (1970). Most of them were deemed to follow the magnitude-frequency rule, in which the larger the event, the smaller its probability of occurrence during any given interval of time. With normalization using logarithms, this can be reduced to a straight-line on a graph. However, the degree of predictability tends to fall with larger events for which there are limited or no data because the time spans are longer than those of existing measurements. Current thinking (Blöschl and Zehe, 2005) suggests that larger, less frequent events may be more significant than recognized in the past. This is the so-called "fat-tailed distribution" problem, in which large events are overrepresented in probability distributions, inducing major disasters to be more common than expected. This may be reinforced by the future tendency of climate change to increase the intensity, if not the frequency, of extreme meteorological events.

To some extent the complexity of extreme natural events defies classification. A good example of this is furnished by landslides (mass movements). Classifications (e.g., Cruden and Varnes, 1996) have commonly been based on the mechanism and speed of movement, with particular attention to flowing, sliding, falling, toppling, gliding, and creeping, and to a range of speeds that extends from infinitesimally slow to hundreds of kilometers per hour. Other classifications have considered the morphology of the phenomenon or its lithological setting, although perhaps with less success, and yet others have taken into account whether movement is primary, dormant, reactivated, or relict. Clearly, a perfect classification, if such were possible, would have to utilize sets of information on a wide variety of geological, mechanical, kinematic, and environmental factors. The first difficulty is to define boundaries on continuous phenomena, for instance, in speed of movement, which in most cases can only be arbitrarily divided up. Additionally, speed may vary within one large landslide body. The second, and overwhelming, problem is that the majority of mass movements in natural slopes are composite events, for example, flow-slides or avalanche-slide-falls. Slumps, in particular, may be reactivated paleolandslides, which further adds to the complexity. Moreover, many mass movements result from the underlying lithological complexity, particularly the juxtaposition of permeable and impermeable strata and the inclination of the respective layers. These factors tend to make classification somewhat artificial and to prevent it from being definitive.

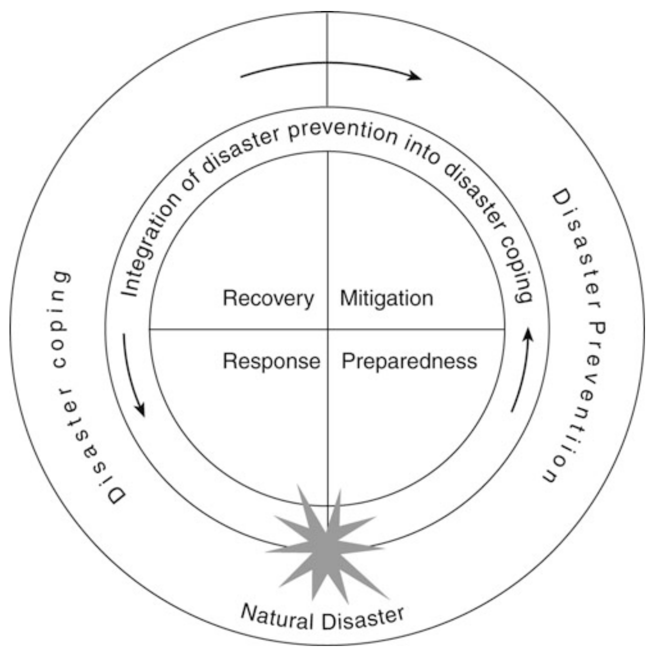
In classification perhaps the broadest distinction is between natural disasters such as earthquakes and floods, technological disasters such as transportation crashes and toxic spills, social disasters (e.g., riots and crowd crushes), and intentional disasters (conventional and CBRN terrorism – see Showalter and Myers, 1994 and Steinberg et al., 2008). There is, of course, plenty of opportunity for overlap, as in the so-called "NaTech" disasters, which have natural origins and technological effects. For instance, reservoir dams can be affected by floods, earthquakes, landslides, avalanches, or siltation. Indeed, as human impact is a prerequisite for an event to become a disaster, all natural catastrophes are to some extent NaTech events.

Like other forms of disaster, recurrent natural events can be considered in terms of the "disaster cycle" (Figure 1), with its phases of mitigation, preparation, emergency response, recovery, and reconstruction. The cycle has been criticized on various grounds. Not all events are cyclical, not all cycles are regular, and the phases may overlap or be superimposed, rather than be sequential (Neal, 1997). Three major issues are involved when dealing with the cycle. Firstly, mitigation and preparedness should be concurrent, not sequential as indicated in the figure. Secondly, some parts of the community may enter the recovery phase while others are still in response, leading to geographical discrepancies in the application of the cycle. Thirdly, mitigation is more likely to be undertaken if it is integrated into the recovery rather than constrained to follow it (Lindell et al., 2006). But despite these criticisms, the cycle has proved to be a robust and useful model, both in training and in the organization of disaster risk reduction (DRR) activities. Clearly, the duration of the cycle, and also the relative length of its phases, depends on the duration, geographical extent, and seriousness of the disaster impact. A major catastrophe may affect tens of thousands of square kilometers and hundreds of thousands of people. Recovery from it may take decades.

The "disaster cycle" has been lightly revised by Dikau and Weichselgartner (2005 – see Figure 2). In the new version countermeasures taken either in terms of supporting structures or land-use planning may alter or change the effects of the disaster impact.



Classification of Natural Disasters, Figure 1 The disaster cycle.



Classification of Natural Disasters, Figure 2 The revised disaster cycle (Revised by Dikau and Weichselgartner, 2005).

Summary

A natural disaster is an extreme event, caused by a natural phenomenon that has severe adverse impacts on human lives and livelihoods. Such events result from natural processes in the atmosphere, hydrosphere, biosphere, or geosphere. They can be characterized by their type of process, speed of onset (from instantaneous to long drawn-out), duration (from seconds to years), predictability, potential for warning, and scope of impact. A further element in classification is cyclicity and recurrence: events vary from unique to highly cyclic depending on their origin and on factors such as seasonality or the buildup of crustal strain.

The global sequence of natural disasters is irregular, but it shows a trend toward increases in the number and size of events of all kinds. It is dominated by natural processes such as floods, storms, and earthquakes, while others such as tsunamis or landsliding are increasing in importance as the vulnerability to them of human settlements and activities increases. Clearly, the impact of a natural event cannot be a disaster unless humans are affected. If a high-magnitude natural process develops into a disaster, this is not only an expression of its event characteristics, but also a reflection of the social context. Hence, any classification scheme for natural disasters should consider both the natural environmental and social dimensions.

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Cross-references

Casualties Following Natural Hazards
Civil Protection and Crisis Management
Disaster Risk Management
Disaster Risk Reduction (DRR)
Disaster Relief
Historical Events
Integrated Emergency Management System
Resilience
Risk Assessment
Risk Governance

CLIMATE CHANGE

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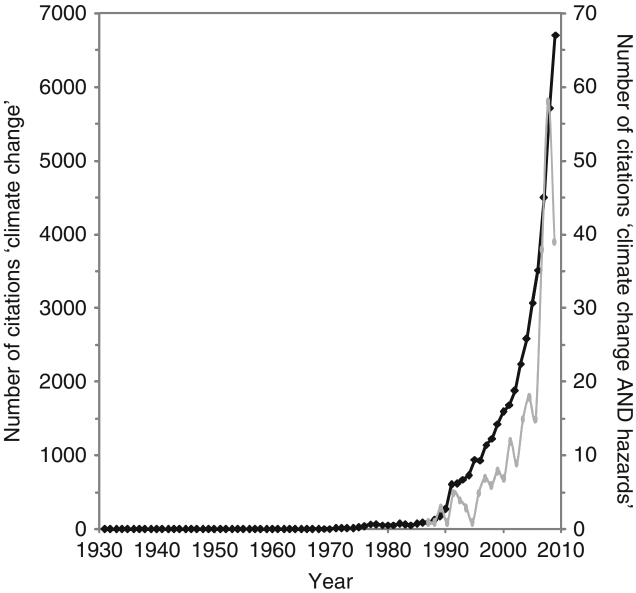
Definition

Climate change. (1) A statistically-significant change in the state of a particular climatic variable (commonly, mean annual air temperature; MAAT) that can be detected at a given place over a given timescale, and based on observed, instrumental data. (2) Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as that "which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." (3) The Intergovernmental Panel on Climate Change (IPCC) has a slightly wider definition, inasmuch as it sees climate as a totality of different variables (precipitation, temperature etc.) and states that climate change can take place by a combination of natural and anthropogenic forcings (IPCC, 2007, p. 78).

Introduction

"Climate change" is an important and quickly-developing research area of the twenty-first century. It has spread from a relatively narrow and defined base in numerical modelling, meteorology and atmospheric physics to an all-embracing topic that spans the social and physical sciences, arts and humanities, and touches all areas of academic and applied research (Hulme, 2009). Figure 1 illustrates the increase in growth of research related to climate change. Moreover, "climate change" is now synonymous in the public sphere and mass media with "anthropogenic global warming," which fits with the UNFCCC (definition 2, above) but which is significantly different to its scientific meaning as given by the IPCC (definition 3, above). It is important to distinguish between these definitions because they imply the roles of different forcing factors on, in the context of this report, natural hazards. Although the IPCC definition of climate



Climate Change, Figure 1 Graph showing the increase in number of recorded citations on Web of Knowledge to year end 2009 (http://apps.isiknowledge.com, accessed January 23, 2010) with the keywords "climate change" (*black line*, left axis, $n = 43,297$) and "climate change AND hazards" (*grey line*, right axis, $n = 257$). Note the very marked recent increase in research on climate change and hazards although this is consistently two orders of magnitude smaller than work on climate change generally.

change is favoured over that of the UNFCCC because it considers both natural and anthropogenic processes, this contribution discusses the role of climate change in natural hazards within the context of specific climatic variables (definition 1, above) that correspond to present day climate change attributed to anthropogenic global warming. This approach is adopted because, in the real world, most natural hazards typically result from a particular type of climatic or meteorological forcing (such as very high precipitation or very strong winds), rather than from the sum of different climatic variables working together. Other direct measures of climate change that are related to MAAT include changes in albedo; sea surface temperature; seasonality of temperature range; radiative and sensible heat flux; and insolation receipt. These measures are in addition to changes in atmospheric composition (mainly CO_2) that is explicit in the UNFCCC definition, but also need to be considered within the wider context of climate change. Such alternative measures also suggest that "climate change" cannot simply be defined or parameterised using single measures alone: it can also be measured indirectly using other meteorological and associated climatic variables. These include, for example, relative humidity (which reflects latent heat flux); wind strength, direction and duration (which reflects the disposition of atmospheric pressure cells and gradients); sea ice area (which reflects sea surface temperature and freshwater flux patterns); and phenology and senescence of land plants (which mainly reflects MAAT).

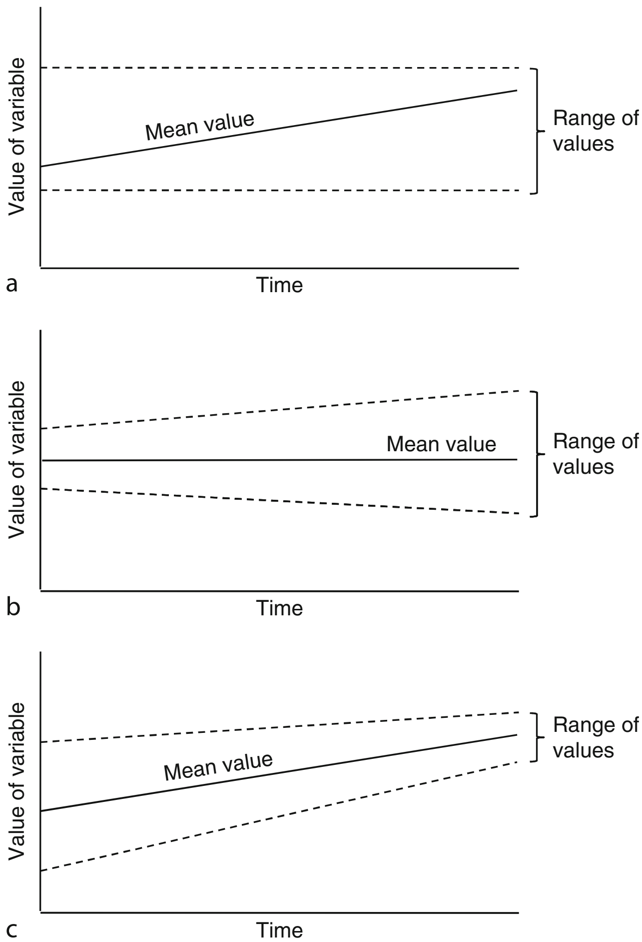
In addition to the direct and indirect measures, climate also defines the context and boundary conditions within which geomorphological and ecological processes operate. Climate change can therefore also be evaluated indirectly through the dynamic behaviour of processes and landforms in different physical environments, including those occupied by rivers, glaciers and coasts. For example, increased precipitation usually results in increased river discharge, and it can also drive increased river bank erosion and sediment transport through the river system (see *Flood Hazard and Disaster*). These effects can be seen through the behavior of rivers at the present time, which enables relationships between precipitation, river discharge and sediment transport to be established. Furthermore, these processes can be linked directly to the dynamic behaviour of landforms and sediments, particularly on river floodplains, that evolve in response to changing river regimes over different spatial and temporal scales (Thorndycraft et al., 2008). Landforms and sediments that are preserved within river floodplains, at river mouths, and within river terraces provide evidence for past river responses to climate forcing.

Analysis of past climate change deduced from proxy biological or geological evidence is best undertaken where this evidence has a stratigraphic (time) context, and where it unambiguously reflects a specific climatic forcing factor such as temperature or precipitation. Reconstruction of past climate change is the concern of the scientific discipline of palaeoclimatology (Cronin, 1999), and is not discussed in herein.

Climate change and climate variability

Both present-day instrumental and past reconstructed records of meteorological measures (mainly MAAT and precipitation) show that there is variability in these measures over all spatial and temporal scales. This variability arises as a result of both natural (including Milankovitch and sunspot cycles, El Nino, North Atlantic Oscillation, thermohaline circulation) and anthropogenic (including fossil fuel CO_2 and NO_x emissions, landuse change) factors in combination (O'Hare et al., 2005).

Much debate focuses on the degree to which present-day and projections of future climate change can be attributed to anthropogenic rather than natural factors (cf. Braganza et al., 2004). Fundamental to this debate, and its impact on natural hazards, is the relationship between climate change and climate variability. The term "climate variability" refers to the scatter or "spread" of values of certain meteorological variables (such as MAAT and precipitation) when they



Climate Change, Figure 2 Illustration of various scenarios of changes in the mean value and data range of a meteorological variable. (**a**) Mean value changes but the data range is the same, i.e., the distribution changes in skewness. (**b**) Mean value stays the same but the range increases, i.e., the distribution increases in variability with increased likelihood of extreme values. (**c**) Mean value increases but the data range changes (here, becomes narrower, indicating less variability and decreased likelihood of extreme values).

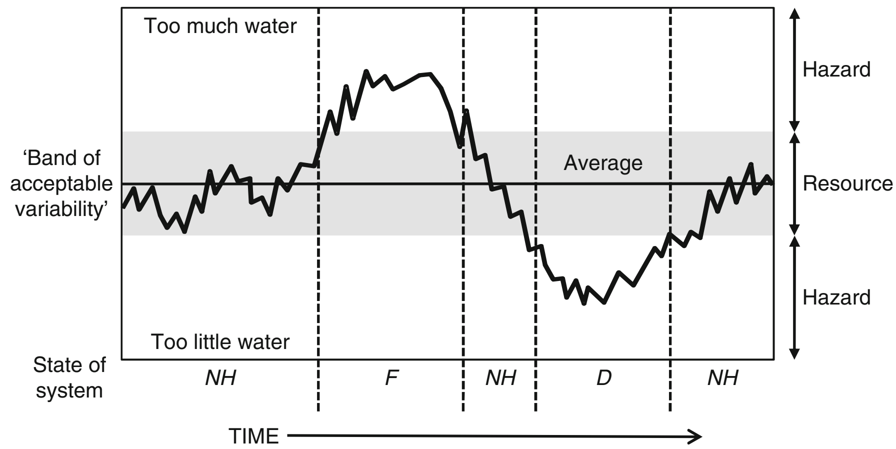
are measured systematically at a certain place over a certain time period. Measurement of these variables over time allows for a dataset to be constructed, which can then be examined statistically by calculation of its mean, standard deviation, trend etc. Change in the mean value over time is taken to be indicative of "climate change," which refers to a consistent directional trajectory (either upwards or downwards) of values of a certain meteorological variable that is measured at a particular place and over a particular time interval.

The IPCC (2007) uses specific terminology in order to help quantify the robustness of predictions of future climate changes. For example, the terms "likely" and "virtually certain" are used where there is a >66% and >99% probability of future occurrence, respectively. The distinction between climate variability and climate change is significant because it is related to the likelihood of occurrence of meteorological extreme values. For example, Figure 2a shows a consistent increase in mean value through the time period of the dataset, yet climate variability (given here by data range) has not changed. This suggests there is a change in shape of the frequency distribution from negatively to positively skewed. Figure 2b and c illustrate contrasting examples of changes in climate variability. In Figure 2b, the mean value is not changing but the variability is increasing over time, suggesting that the frequency of occurrence of more extreme values (relative to the mean) is also increasing (e.g., Schneider et al., 2007; Allan and Soden, 2008). Climate variability and climate change therefore have to be considered together in their implications for hazards.

Climate, resources and hazards

Many meteorological phenomena are associated with hazards that have the potential to impact directly on human activity. These commonly include floods and droughts (caused by variations in precipitation); heatwaves and cold snaps (variations in temperature); and hurricanes, tornados and typhoons (variations in wind speed). The unifying characteristic of these hazardous events is that they tend to occur most often when anomalously high or low values of the climate variable are received; for example, most lowland river floods take place when very high precipitation is received across the catchment. Floods can also occur, however, under conditions of more "average" precipitation but where other local environmental factors contribute, such as the ground surface being pre-saturated and unable to absorb any more water (see *Flood Hazard and Disaster*). This situation enhanced the devastating impacts of the August 2005 floods in the European Alps when prolonged rain reduced water storage capacity in high alpine areas, leading to very rapid water transfer into lowland basins with accompanying debris flows and landslides (Hilker et al., 2009).

Figure 3 illustrates the relationship between the amount of a meteorological variable, such as precipitation, and its value to human activity as a resource or a hazard. In the case of precipitation, a certain amount of precipitation is required over different time scales in order to sustain human activities, as for domestic, industrial and agricultural use, and to maintain the workings of land surface systems, including rivers and ecosystems. The amount required to sustain these activities is here termed the "band of acceptable variability." The width of this "band" is determined by the resilience of human and land surface systems to accommodate the natural variability in precipitation. As dams and irrigation schemes on river systems are developed, the capacity of the system to buffer temporary changes in precipitation amount is improved, and so the "band of acceptable variability" in precipitation amount will therefore increase in width. Outside of this



Climate Change, Figure 3 Schematic illustration of how changes over time in a meteorological variable (here, precipitation) are related to changes in perception of that variable as a resource or as a hazard (see text for detailed explanation). *NH* no hazard, *F* flood, D drought.

band, however, lies the flood (drought) hazards that are associated with precipitation amounts that are far above (below) the capacity of human and land surface systems to accommodate this variability (see *Drought*; *Flood Hazard and Disaster*). Changes in precipitation amount over different time and space scales therefore mean that hazard periods (as defined by meteorological factors alone) are episodic and evolve in intensity, location and impact over time (Schneider et al., 2007). In most real-world situations, a combination of natural and human factors contribute to the development of hazards, and are strongly conditioned by local scale factors and antecedent conditions.

The foregoing discussion highlights the fact that hazards may not always be identified or predicted based solely on statistical (e.g., standard deviation of a normal distribution) or magnitude-frequency relationships of time series of meteorological variables. This means that, by itself, a meteorological extreme may not be sufficient to produce a hazardous event, and that localised and/or antecedent conditions are often also required (Fuchs, 2009). As a result, future patterns of hazards may be difficult to predict based upon the distribution or timing of meteorological forcings alone.

Regional perspectives of climate change and hazards

The types of climatic hazards that impact most strongly on different physical environments or latitudes are shaped by prevailing synoptic-scale climate conditions related largely to atmospheric circulation patterns, including the vigour of the hydrological cycle (Hastenrath, 2007). For this reason the term hydrometeorological hazards is used (e.g., Lawford et al., 1995). Due to variations in atmospheric circulation patterns, there are therefore similarities between the hazards that affect different locations within the same latitudinal belt, and climate change is also having similar effects within these latitudinal belts. This enables locations within the same latitudinal climate zone to be compared to one another.

Low-latitude areas

Climate change in low-latitude areas is associated with changes in the hydrological cycle over both land and ocean (Lorenz and DeWeaver, 2007). At present, spatial variations in sea surface temperatures (SSTs) over low-latitude oceans drive atmospheric pressure gradients, leading to the seasonal development of deep low-pressure systems (cyclones) including hurricanes (Atlantic) and typhoons (Pacific). Shifts in hurricane intensity in the Azores-Caribbean region reflect climate changes over decadal to centennial scales (Mann et al., 2009), which are also recorded by spatial changes in hurricane tracks (Reading, 1990) (see *Hurricane (Typhoon, Cyclone)*). These variations reflect changes in open-Atlantic SSTs and positions of the intertropical convergence zone (ITCZ) and subtropical jet stream.

Temperature gradients between land and sea also drive seasonal monsoon circulation that is of critical importance in SE Asian agriculture (see *Monsoons*). Switch between summer and winter monsoon states is controlled strongly by heat balance over the Tibetan plateau. Presently, climate change is causing large-scale changes in snowcover extent and duration, glacier meltwater production, and vegetation distribution in the Tibetan plateau region (Bhutiyani et al., 2008; Kehrwald et al., 2008). These effects have major implications for the strength and duration of the blocking high pressure cell that controls the winter monsoon phase (Duan and Wu, 2005). Climate change is already affecting the strength, timing and location of monsoon rains, and leading to greater climatic variability, which has potential to decrease food security in the region (Mall et al., 2006). High precipitation in low-latitude areas, coupled to steep and tectonically-active slopes and high rates of chemical weathering, also leads to slope weakening and high incidence of landslides, as in Hong Kong (Peart et al., 2009). These climatic conditions are also important in the transformation of mass movements and volcanic debris into highly dangerous landslides and mudflows (see *Mass Movement*).

More widely, significant future changes in low-latitude climates will be closely associated with changes in the position and dynamics of the ITCZ, which marks the equatorial convergence of trade winds. Changes in land-sea surface temperatures and moisture availability, particularly over large forest areas such as Amazonia (Huntington, 2006; Cook and Vizy, 2008), will have significant impacts on meridional energy fluxes, resulting in widening of the ITCZ and tropics with accompanying shifts in precipitation patterns and ecosystems (Seidel et al., 2008).

Mid-latitude areas

Mid-latitude areas tend to have high levels of urbanisation and population density, developed over long time periods, and as such are characterised by significant modification of landuse and water resources. Climate change impacts on the activity of the mid-latitude Ferrel cell are closely related to changes in the strength of surface ocean currents (including the North Atlantic Current (Gulf Stream), Kuroshio Current, Humboldt Current, Benguela Current etc.) that are important in meridional heat transport (Herwiejer et al., 2005). Mid-latitude oceans are also sensitive to changes in thermohaline circulation (deep water) and freshwater input from rivers and melting sea ice (surface water). As such, hazards that impact on mid-latitude coasts are linked very closely to variations in the dynamics of adjacent oceans. Strengthening zonal circulation in the North Atlantic region is associated with changes in frequency of strong westerly winds and wind gusts (Kaas et al., 1996) and with increase in mean wave height (Bacon and Carter, 1991). The net result of these is increased frequency and/or magnitude of coastal storm, storm surge, and related flood events, which is a likely outcome of climate change along these coasts (IPCC, 2007).

Other coastal impacts are a consequence of the Pleistocene glacial inheritance of many mid-latitude areas (see *Paraglacial*) which means that many of these coastlines are sediment-rich with well-developed sandy beaches, sand dunes and estuaries that are vulnerable to coastal erosion (Hansom, 2001). Enhanced coastal erosion can be related directly to climate change effects of sea-level rise and increased storminess (see *Coastal Erosion*). Coastal and river management has, in many areas, decreased sediment supply to nourish these coasts, thereby making them more vulnerable (Stive, 2004).

Inland, river engineering and management and the presence of historic settlements on floodplains make river systems vulnerable to variations in precipitation input and storage that may lead in turn to increased lowland flood frequency. This is seen clearly in some managed rivers worldwide (e.g., Wilby et al., 2008).

High-latitude areas

Climate change in high-latitude areas is causing increased glacier melt (Greenland, Antarctica) and permafrost warming (Eurasia, Canada), both of which are driven mainly by increased MAAT (Camill, 2005; Osterkamp, 2005). As a result, meltwater availability in these environments is increasing, with increasing volumes of fresh water being stored within proglacial or subglacial lakes (see *Jökulhlaups*). Increased glacier melt and ice retreat can also lead to slope instability, mass movement and land surface rebound that can contribute to increased seismicity (Hampel et al., 2010). To date, hazards associated with glacier retreat and permafrost melt in high-latitude areas have been relatively isolated in location, and subdued in magnitude (Gude and Barsch, 2005). For example, roads, buildings and oil pipelines in many high-latitude and high-altitude areas have been adversely affected by land surface subsidence as a result of permafrost melt, although some of this can be attributed directly to poor engineering practice (Harris et al., 2001; Khrustalev, 2001) (see *Cryological Engineering*). On shallow slopes, however, increased depth of the seasonally-thawed permafrost leads to meltwater pooling and mass flow hazard (including bog bursts) that decrease the stability of the land surface. More widely, permafrost melt is associated with secondary effects of increased CH_4 (methane) and CO_2 degassing where peatlands are undergoing aerobic decomposition (Schuur et al., 2009). Increased subsurface water mobility can also lead to increased contaminant transport through thawed substrates (see *Permafrost*). Hazards associated with ice retreat in mountain areas are more commonly observed (see *Paraglacial*).

Studies show that, as a result of changes in freshwater input and sea-surface warming, sea ice cover in the Arctic Ocean has decreased dramatically in recent years, continuing a trend that began in the 1970s (Serreze et al., 2007). Increased exposure of arctic coastlines due to sea ice retreat, and warming and destabilisation of coastal outcrops of permafrost, has led to a dramatic increase in coastal erosion rates across the entire Arctic Ocean, including northern Russia and Canada (Jones et al., 2009). In turn, sediment release into the nearshore zone increases turbidity and heat capacity of the water, leading to additional warming. This positive feedback effect is the basis for the arctic amplification of climate (Serreze et al., 2009). Long-term implications of climate change in the high-latitudes are likely to be significant but as yet are poorly understood, including CH_4 and CO_2 release (Schuur et al., 2009). More widespread permafrost warming will also increase the geographical area over which mass movement hazards operate, which will in turn become far more common than at present. This will be a major outcome of climate change in high-latitude areas over the next decades.

Driving factors linking hazards in different latitudes

Interrelationships between hazards that are most common in different latitudes are driven, largely, by the strength of the hydrological cycle (Huntington, 2006). This is manifested by both the vigour of macroscale atmospheric circulation patterns, including the strength and positioning of the low-latitude Hadley cell and high-latitude polar cell, and the detailed dynamical processes that take place within the atmospheric part of the hydrological cycle. This includes, critically, the role of latent heat effects which are related directly to the amount of energy (heat) moved through the system, and thus to climate change.

Water within the hydrological cycle can exist in solid, liquid and gaseous phase states. A change in phase between any of these stable states by processes of melting/freezing and evaporation/condensation is associated with the exchange of latent heat, as given by the Clausius-Clapeyron relation. Based on this relation, an airmass with a higher water vapour content and therefore associated with very vigorous evaporation/condensation processes generates a large amount of latent heat that, in turn, fuels atmospheric convection and instability (Willett et al., 2007). Increased SSTs particularly in low-latitude regions are actively contributing to increased rates of evaporation, leading to higher relative humidity and higher meridional heat flux as a result of macroscale atmospheric circulation (Lorenz and DeWeaver, 2007; Seidel et al., 2008). This process, driven largely by low-latitude warming, provides an atmospheric bridge to higher latitudes, and contributes to increased convective rainfall (thunderstorms) within the Ferrel cell. Furthermore, increased moisture content is also associated with changes in cloudiness, aerosols and atmospheric optical depth (Santer et al., 2007).

Surface and subsurface circulation patterns within the oceans are important in macroscale heat transport, and their paths depend on the three-dimensional evolution of density gradients within the oceans. As such, increased low-latitude SSTs have impacts on global temperatures: the globally-warm year of 1998 was due in large part to the strong El Nino event of that year associated with positive SST anomalies in the equatorial Pacific. Warmer surface waters have less capacity to draw down atmospheric CO_2, and are associated with lower levels of dissolved oxygen, reduced productivity where upwelling is suppressed by water stratification, and reduction in water quality, with impact on fisheries and other ecosystems. Studies of thermohaline circulation dynamics show that subsurface ocean current strength in the North Atlantic is variable spatially and temporally, which has implications for meridional heat transport (Cunningham et al., 2007). It also suggests that multiple factors can affect thermohaline circulation strength, with multiple outcomes for higher-latitude regions. Several studies discuss possible future changes in thermohaline circulation strength, including the likelihood of reversal or collapse (e.g., Vellinga and Wood, 2008), but most modelled predictions suggest that thermohaline circulation is likely to weaken rather than collapse fully (IPCC, 2007).

Impacts of climate change on the vulnerability of human systems to hazards

Climate change and climate variability give rise to changes in the frequency and magnitude of extreme events that can lead to hazards, as previously discussed. This relationship alone, however, cannot explain the impact of those hazards upon human systems (including agricultural production, socioeconomic impacts, cultural impacts, human health and wellbeing, etc.) (Hulme, 2009). The future climate changes that will frame the environmental conditions under which future hazardous events and processes will take place are considered explicitly by the IPCC (2007) (Table 1). These hazards operate over spatial and temporal scales that mean their impacts will be diverse, unpredictable, and multidisciplinary in nature. Table 1 shows that future climate change will impact in many different ways on almost all areas of human activity. Of particular concern is the role of climate change in the sustainability of food production. For example, Peng et al. (2004) show that, despite increased CO_2 which generally promotes plant growth, increased night-time temperatures will cause a decrease in rice yields.

Many natural hazards, where they impact upon human activity, have the capacity to lead to environmental or humanitarian "disasters" (see *Disasters*). The World Health Organisation-linked Centre for Research on the Epidemiology of Disasters (CRED) defines a disaster as "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (Below et al., 2009, Annex II) (see *Casualties Following Natural Hazards*). The interlinkage of this definition to the capacity of local systems to deal with environmental variability is very similar in basis to that presented in Figure 3. CRED collates information on disasters of all types, but one such disaster category is hydrometeorological disasters that are related to floods, droughts, storms and storm surges, and landslides and avalanches (see *Hydrometeorological Hazards*).

Analysis of spatial and temporal trends in disasters and their impacts shows a very clear relationship to hydrometeorological variability (ISDR, 2009). In the period 1950–2007, two thirds of all disaster-related deaths and economic losses were caused by hydrometeorological disasters. Due to the dependence of floods, droughts and other events on atmospheric circulation patterns and local-scale factors, the disaster risk from hydrometeorological hazards is highly concentrated spatially, and disaster impacts are very variable depending on an individual country's infrastructure and wealth. For example, 75.5% of all expected global mortality from tropical cyclones (1975–2007) was in Bangladesh, but the entire south Asia region represents only 2.7% of total economic losses from these events over this time period. Patt et al. (2010) use a numerical model to predict how vulnerable developing countries will be to future climatic hazards. They show

Climate Change, Table 1 Summary of some of the major outcomes of future climate change for different aspects of earth systems (Summarised from IPCC, 2007), and their implications for hazards

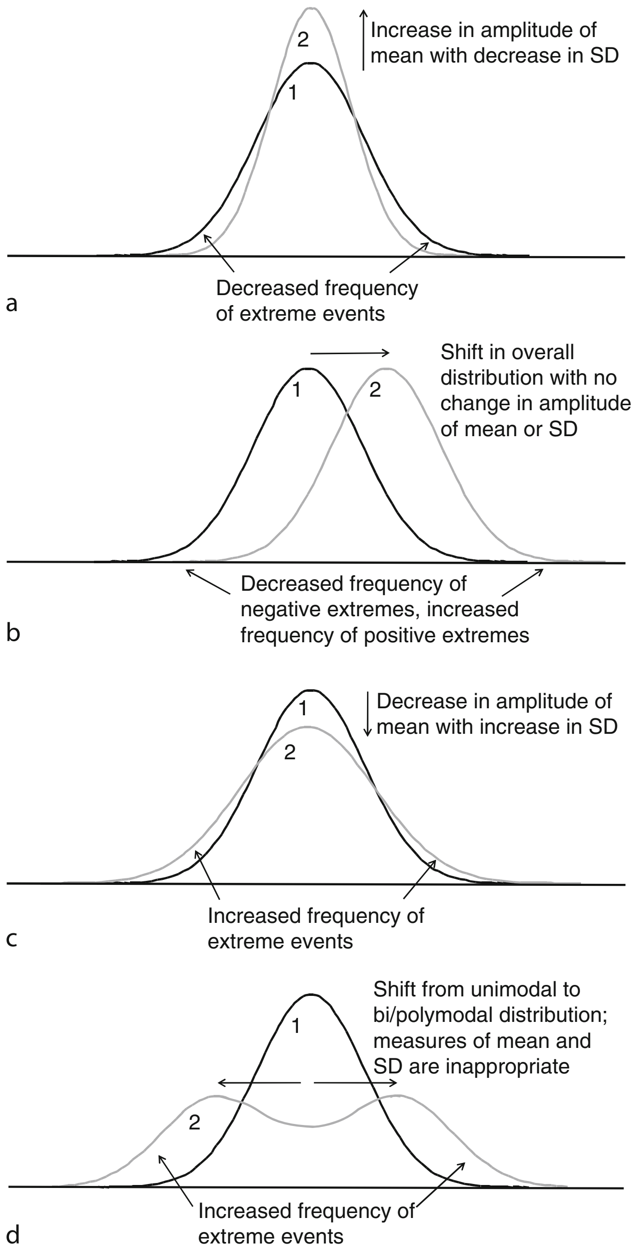
IPCC subheading	Summary of likely changes (from IPCC, 2007)	Implications for hazards
Ecosystems	• Ecosystems will become more sensitive to environmental disturbance under future climate change • Ecosystems will contribute to changes in net carbon storage (to about 2050) and then outgassing (thereafter) • Increased risk of species' extinction under future climate change • Changes in ecosystem functioning, structure and biodiversity as a result of future CO_2 increase	• Risk of invasive species and pathogens that contribute to biodiversity loss and/or crop failure • On mountains, increased forest cover that will stabilise slopes • Increased CH_4/CO_2 outgassing from warming permafrost and desiccation of wetlands and peatlands
Food	• Spatial changes in agricultural productivity, with likely increase in mid-latitude areas and decrease in low-latitude areas, with impacts on food security in many regions	• Increased uncertainty in food and fibre production, particularly in agriculturally marginal areas in semi-arid regions and mountain slopes • Increased soil erosion and salinisation, loss of soil fertility • Reliance on irrigation in many areas, impacts on potable water quality; increase in water contamination/ pollution and eutrophication
Coasts	• Increased risk of coastal erosion and flooding	• Increased frequency and height of flooding along coastal fringes, river estuaries and floodplains • Increased likelihood of storm surges and increased height of storm waves • Increased coastal erosion along all coastline types (including rock and sandy coasts) • Increased sediment mobility in some areas, implications for port/harbour access and navigation channel infilling
Industry, settlements and society	• Increasing vulnerability of industry, settlements and society to hydrometeorological events, particularly in low-lying and coastal regions	• Increased risk to all aspects of economic activity in coastal and low-lying areas from sea and river flooding • Increased risk of built and natural heritage loss in low-lying and coastal regions due to flood inundation and warmer sea temperatures, e.g. Venice, Great Barrier Reef
Health	• Increased risk of malnutrition and hunger as a result of variations in food production and hydrometeorological events • Increased risk of infectious and respiratory diseases and heat-related deaths, but fewer cold-related deaths	• Mass movement and flood events can cause groundwater and river water contamination
Water	• Increase in water-stressed regions, particularly in areas with high urbanisation • Reduced water availability from retreating mountain glaciers • Increased precipitation in mid-latitude areas, decreased precipitation in some low-latitude and semi-arid areas • Increased precipitation variability and seasonality, decreased water quality	• Increased mass loss from retreating glaciers, increased risk of downstream floods, jökulhlaups, landslides, mass and debris flows, rockfalls • Increased variability of precipitation at all latitudes with impacts on domestic, agricultural and industrial water supply and water quality, eutrophication

that increasing the country's resilience and adaptive capacity to such events, through socioeconomic development, is the most effective means by which hazardous impacts can be minimised (Figure 4).

Figure 5 shows that hydrometeorological disasters have increased disproportionate with respect to other types in recent decades, and are dominated by floods (30.7% of all disasters in the period 1970–2005) and wind storms (26.8%). This overall pattern is broadly similar irrespective of geographical region. The IPCC (2007) also confirms that hydrometeorological extremes are more likely under future climate change, therefore hazards of these types are likely to increase in frequency. Responses of the physical environment and human activity to these challenges are uncertain but are likely to be multidimensional and wide-ranging (McBean, 2004).

Hazards and the normal distribution

Present and future climate, in its totality, is headed on an upward trajectory, in which anthropogenic global warming is causing a directional shift in standard statistical measures of climate, for example in increased MAAT (IPCC, 2007). Other meteorological variables, however, are unlikely to show a comparable simple statistical response. For example, precipitation impacts are



Climate Change, Figure 4 Schematic distribution plots of a meteorological variable showing four possible changes in the nature of the distribution from time 1 to time 2. (**a**) Where the mean value stays the same but where standard deviation (SD) decreases. This leads to decreased frequency of extreme events. (**b**) Where the distribution stays the same but shifts to a higher (or a lower) value with no accompanying change in SD. In the example of precipitation this results in a decreased probability of droughts (floods) and increased probability of floods (droughts). (**c**) Where the mean value stays the same but where the SD increases, giving an increased probability of both positive and negative extreme events. (**d**) Where the distribution plot changes from unimodal (normal distribution) to a bimodal or polymodal distribution. In this case there may be an increased probability of extreme events, and that standard measures of mean and SD are inappropriate descriptors of the distribution.

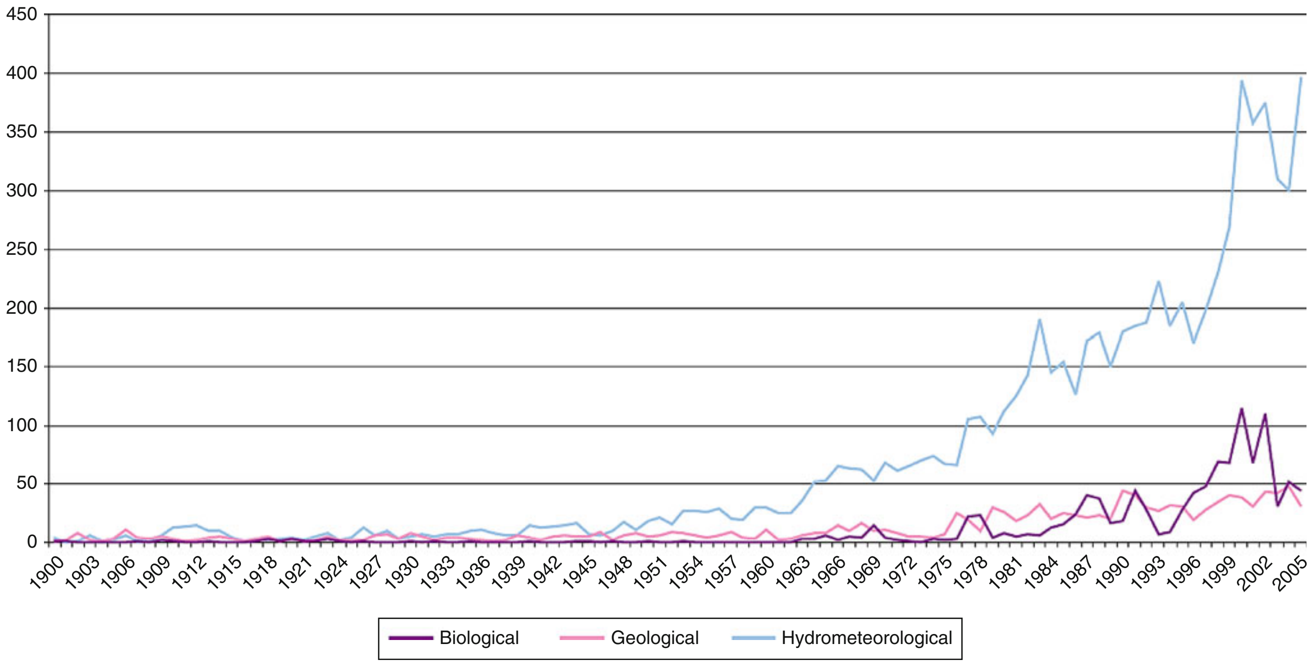
more complex spatially and temporally, because they involve important feedback processes via ecosystems, humidity, and latent heat (Allen and Ingram, 2002). As a result, it is unlikely that under projected climate change precipitation will follow a normal distribution but rather will show a polymodal distribution in which the likelihood of both flood and drought hazards will increase (e.g., Figure 4d). Recent patterns of precipitation changes by latitude, season, and intensity suggest that these events are now beginning to take place (Zhang et al., 2007; Müller et al., 2009). Further evidence for the inapplicability of the normal distribution to some climatic variables comes from studies of changes in strength of thermohaline circulation over time that suggest this circulation can switch between one of two modes ("on" and "off") and over very short time scales and in response largely to changes in high-latitude freshwater input (Rahmsdorf, 2002). If this dynamic behaviour characterises thermohaline circulation under conditions of rapid climate change, then it confirms the importance of non-normality, nonlinear responses, and hysteresis (Rahmsdorf, 2002). These properties are not associated with simple shifts in the normal distribution, and highlight the role of spatial and temporal climate variability.

Changes in internal properties of the normal distribution, and shifts to other distributional types, show the importance of climate variability, for two reasons. First, it reveals the internal dynamical processes that are associated with changes in individual meteorological variables. Second, it impacts on the likelihood of occurrence of the extreme events that are most often associated with hazards.

Summary and outlook for the future

Anthropogenic climate change is causing unprecedented changes in physical and human systems that, together, are converging on increased frequency and magnitude of hazardous events related explicitly to changes in meteorological processes on different spatial and temporal scales. This suggests that earth systems are experiencing unprecedented rates of change and systems' organisation is responding dynamically to meteorological drivers.

One of the major areas of uncertainty in the prediction of future climate is related to climate sensitivity. This is defined as the equilibrium temperature response to a doubling of pre-industrial values of atmospheric CO_2 (Gregory et al., 2002) and is calculated, based on climate models that consider radiative forcing only, to be in the range +1.5–4.5°C (IPCC, 2007). Climate sensitivity is relevant to climate hazards because, if temperature reaches and maintains an equilibrium value, it can be inferred that other climatic variables such as precipitation must also be at equilibrium. However, much of the uncertainty associated with the calculation of climate sensitivity is due to the role of nonlinear feedbacks in the climate system, in particular atmospheric moisture content and cloudiness (Zickfeld et al., 2010). There will also be time lags and



Climate Change, Figure 5 Graph showing changes in number of disasters of different types, 1900–2005 (from http://www.unisdr.org/disaster-statistics/occurrence-trends-century.htm). Note the recent increase in hydrometeorological hazards relative to other hazards types, and individual peaks that correspond to strong El Nino events in 1982 and 1998.

feedbacks associated with the long-term response of earth surface processes (Lunt et al., 2010). In combination, these factors mean that long-term climate sensitivity could well be higher than predicted by radiative forcing alone (e.g., Pagani et al., 2010). There are a number of important implications of climate sensitivity for climatic hazards. The role of feedback processes means that future patterns of precipitation are unlikely to show the same speed or magnitude of change as that of temperature. It may also mean that temperature reaches equilibrium at a different time to other meteorological variables.

Many meteorological hazards yield secondary impacts which are predominantly negative, can be long-lasting, and which affect many earth systems and the human environment. Secondary impacts include, but are not limited to, changes in fluvial sediment budgets; coastal erosion; biogeochemical cycling; chemical weathering; biodiversity; food production; and renewable energy production. The precise nature and timescale of these impacts are often poorly-defined, and although they often arise from individual hazardous events such as a single flood, such events in themselves cannot be attributed with certainty to anthropogenic climate change. Rather, the events represent one aspect of climate variability that arises out of a set of ongoing directional changes to earth and human systems that have cumulative effect (i.e., climate change). Climate change therefore provides the hydrometeorological setting from which individual hazardous events can arise. In this way, climate change (sensu lato) has potential to impact in unexpected, complex and unpredictable ways on both human activity and the physical environment (Hulme, 2009).

Individual hazardous events cannot be predicted. General circulation models (GCMs) can, however, predict global to regional scale changes in some meteorological variables (temperature, precipitation etc.) that can in turn provide input to regional ecological, geophysical and geochemical models. None of these model types downscale very well to the local level where issues of land surface stability, earth surface processes and human activity are most significant, and where real hazards take place. As such there is a mismatch between our knowledge of future climate and our knowledge of future climate responses. Impacts of future climate change on hazard characteristics (type, location, magnitude) are therefore still unknown and, as such, cannot be predicted with any certainty. This is an important area for future research.

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Cross-references

Casualties Following Natural Hazards
Coastal Erosion
Cryological Engineering
Disaster
Drought
Flood Hazard and Disaster
Hurricane
Hydrometeorological Disasters
Jökulhlaups
Mass Movement
Monsoon
Paraglacial
Permafrost

CLOUD SEEDING

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Synonyms

Precipitation enhancement; Rain making

Definition

Cloud seeding is the practice of intentionally adding aerosols (e.g., silver iodide, common salt) or even ice itself (or dry ice) with the intent of changing the development of a cloud.

Discussion

Specifically the aim is to change either the phase of the cloud droplets/crystal (e.g., convert supercooled liquid water to ice for glaciogenic cloud seeding) or the size distribution (e.g., produce largely droplets that will coalesce more rapidly for hygroscopic seeding). Primarily cloud seeding has been used with the intent of enhancing the precipitation of a cloud, although efforts have been made to prevent precipitation, suppress hail, and burn off fog. The principles of cloud seeding have even been attempted for the suppression of hurricanes. Cloud seeding is perhaps the most common/vivid example of the practice of weather modification or weather engineering.

While cloud seeding is practiced in dozens of countries around the globe, it still remains a highly controversial practice primarily because of the lack of evidence supporting its effectiveness outside of fog dispersal. As stated in the World Meteorological Organisation Weather Modification Statement and Guidelines (2007): "Evidence for significant and beneficial changes in precipitation on the ground as a result of seeding is controversial and in many cases cannot be established with confidence." This lack of statistically significant evidence is even more apparent for the intent of hail suppression. These are the same conclusions reached the by committee established by the US Academy of Sciences in 2003.

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Cross-references

Doppler Weather Radar
Fog Hazard Mitigation
Hurricane
Lightning

COAL FIRE (UNDERGROUND)

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Synonyms

Burning coal; Coal combustion; Coal fire; Underground coal fire

Coal Fire (Underground), Figure 1 Surface manifestation of an underground coal-mine fire includes ground subsidence and smoke, as shown here along a former section of Pennsylvania Route 61 at the Centralia mine fire (Stracher et al., 2006). The asphalt road through the town of Centralia is subsiding into abandoned coal-mine workings, where anthracite is burning underground. A detour was constructed around this section of the highway. Coal fires emit dozens of toxic gases into the atmosphere including carbon monoxide, benzene, and toluene, in addition to green-house gases. Minerals and creosote (coal tar) that nucleate at the surface from coal-fire gas may serve as vectors for the transmission of bio-accumulated pollutants, including Hg and As, from water, soil, and wind-blown dust (Stracher, 2004; Stracher et al., 2005, 2009) (Photo by Janet L. Stracher, 2006).

Definition

An underground coal fire is defined as the combustion of coal below the Earth's surface accompanied by heat-energy transfer and the emission of gas, but not necessarily flames and consequently, the emission of light. Although "fire" implies flames, coal burning underground is seldom observed, and peer-reviewed publications about underground burning or even coal burning at the surface (Stracher, 2004, 2007; Stracher et al., 2010, 2012) do not consider flames and light as a necessary criterion when describing coal fires. When a coal fire is not accompanied by flames, the terminology "smoldering" is sometimes used in reference to such fires (Hadden and Rein, 2010).

Discussion

Underground coal fires may occur just beneath, many meters below, or as is commonly the case – at an unknown depth below the Earth's surface. They may occur in association with active or abandoned coal mines (Figure 1) and also in coal seams that were never mined. Combustion is supported by the circulation of atmospheric oxygen underground to the burning coal via joints, faults, intake vents, and coal-mine portals.

Origin: Underground coal fires are started by either anthropogenic or non-anthropogenic processes. The causes include (Stracher and Taylor, 2004; Stracher et al., 2009) (1) lightning strikes; (2) forest, grass, or brush fires; (3) landfill, coal-gob pile, or coal-storage-facility fires transmitted to underground coal seams; (4) mining activities such as the use of explosives, welding or electrical work, and short circuits; (5) arson; (6) spontaneous combustion promoted by "self heating" of the coal during exothermic oxidation of sulfide minerals in the coal (e.g., pyrite); (7) the illegal distillation of liquor in underground coal-mine tunnels; and (8) smoking or other activities that may accidentally ignite hydrogen or methane gas in an underground mine.

Extinguishing: Any attempt to extinguish or contain an underground coal fire is based on available funding, and some fires are cost-prohibitive to extinguish. Fire-fighting technology includes the use of compressed-air foam, inert-gas injection, fly-ash grout, water and mud or water and fly-ash slurries, fire breaks, burial of gas vents and fissures at the surface beneath soil, remote sensing technology, and excavating the fire either by hand or mechanical digging.

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Cross-references

Forest and Range Fires
Land Degradation
Land Subsidence
Lightning

COASTAL EROSION

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Definition

Coastal erosion. The net landward retreat of the shoreline, as measured relative to a given datum, over a given temporal scale that is longer than cyclic patterns of coastal variability.

Introduction

Coastal erosion is the net landward retreat of the shoreline, where the shoreline is represented by a datum such as mean high water spring or a mapped feature such as a cliff, beach or road (Figure 1). The landward retreat is persistent through time as distinct from shorter term (e.g., weeks, months) fluctuations in the position of the shoreline associated with storm erosion and recovery, typical of beaches. On cliffed coasts there is no recovery from erosion events because such landforms are wholly erosional in origin. Coastal erosion is a common condition of coastlines globally, with 70% of the world's beaches thought to be eroding (Bird, 1987, 1996) and 80% of the world's total shoreline composed of eroding cliffed and rocky morphologies (Emery and Kuhn, 1982). Coastal erosion is also associated with coastal hazards when infrastructure is built on an eroding shore, coastal erosion overtakes human use systems, or when erosion increases the exposure of infrastructure to processes such as inundation or direct wave attack.

Whilst coastal erosion is considered to be a hazard and is a significant issue for coastal managers, it is also a natural geomorphic process representing the adjustment of shorelines toward a new equilibrium, often in response to sea level rise, changes in sediment supply, wave climate, or a combination of these factors. Much of the world's shoreline is configured the way it is because of erosional processes. Coastal landscapes valued for their intrinsic beauty are often erosional in origin (e.g., cliffs, arches, stacks) and contribute to economic activity, particularly tourism. Paradoxically, coastal erosion management may involve allowing erosive processes to take place in order to maintain landscape values.

Causes

There are three first order controls of coastal erosion applicable to all coastal landforms, a rise in relative sea level, a deficit in the local sediment budget, and a change in wave climate. In addition to these fundamental causes, human activities introduce a myriad of interactions that can generate coastal erosion where there was none before or make existing coastal erosion worse. Human activity usually involves interference with local sediment budgets but can also change processes such as wave energy or wave driven longshore currents that transport sediment.

Sea level rise since the last glacial maximum is one of the most important long-term causes of coastal erosion, and many shorelines are still responding to this rise. The melting of glaciers and continental ice sheets since the last glacial maximum added vast volumes of water to the world's oceans causing very rapid sea level rise. The broad configuration of the world's coastlines and coastal erosion observed over historical time frames is in response to sea level changes that have occurred over the last 6,000–7,000 years. In addition to eustatic (changes in ocean water volume) causes of sea level rise, isostatic processes can also cause a relative rise in sea level through subsidence of land masses. Isostatic processes include the addition or removal of mass from the Earth's crust, such as ice sheets, sediment, or water, and cause the crust to sink under loading and rebound after the load is removed, such as when ice sheets melt during warm phases of Earth's climate. Tectonic processes may also cause subsidence of land masses giving the appearance of sea level rising. When there is no eustatic change in sea level in this scenario, the shoreline will respond as if sea level is rising. However, a rise in sea level does not always result in coastal erosion, and in some instances, shorelines can respond by advancing when there is a supply of sediment eroded from elsewhere or transported onshore from the continental shelf, generating a positive sediment budget.

Sediment budgeting offers a useful management approach to coastal erosion by accounting for inputs and losses of sediment from a defined length of coast known as a littoral cell (e.g., Komar, 1996; Bray et al., 1995; Patsch and Griggs, 2008; Mazzer et al., 2009). Sediment budgets are usually expressed as a volume of sediment gained or lost annually from a littoral cell. A negative sediment budget (where a littoral cell loses sediment over time) equates to coastal erosion whereas a positive budget results in shoreline progradation. Littoral cells are often delimited by natural features such as headlands, river mouths, and cliffs, or artificial structures such as harbor breakwaters. Some boundaries are fixed (e.g., headlands) while others can be transient such as river mouths that migrate alongshore or the seaward limit of sediment transport that changes as wave conditions change. Cell boundaries can also be absolute, in that no sediment crosses them, or partial in that they allow some leakage of sediment.

Importantly, a properly accounted sediment budget with well-defined boundaries allows the cause of sediment loss to be identified and the amount of sediment loss to be quantified. Determining why a cell is losing sediment and the amount of the deficient in the budget allows for a better assessment of appropriate mitigation techniques (e.g., Cooper and Pethick, 2005; Bezzi et al., 2009).

Coastal Erosion, Figure 1 Coastal erosion occurring on the North Otago coast of South Island, New Zealand. The management strategy has been to abandon the road after attempts to build protective rip-rap structures failed (source of debris on the beach) (Photo: Wayne Stephenson).

Increases in wave heights have been observed in the North Atlantic (Wolf and Woolf, 2006) and the northwest Pacific over recent decades and have been linked to evidence for enhanced beach erosion (Allan and Komar, 2002, 2006). Increases in wave height and frequencies of storms are also expected to increase the incidence of coastal erosion and shoreline retreat under climate change scenarios (Zhang et al., 2004).

In addition to natural changes in sea level, sediment budgets, and wave patterns, human activities can also cause or exacerbate coastal erosion. Sea level rise from global warming will in many instances contribute to coastal erosion. Coastline development can remove, slow, or stop sediment delivery to coastal systems and prevent transport within or between littoral cells. The effect is often to shift neutral or positive sediment budgets into negative ones. Shorelines respond by eroding in order to restore the supply of sediment that has been lost. Dams on or extraction of sediment from rivers can cause coastal erosion by reducing sediment supply to the coast (Patsch and Griggs, 2008). Sediment extraction from dunes, beaches, reefs, or the nearshore for the purposes of construction may also cause coastal erosion. Seawalls built to stop cliff erosion may prevent sediment delivery to the coast and, where cliffs are important local sources of sediment for beaches, coastal erosion can result (Bird, 1987). Beach loss following the construction of a seawall is a widely recognized consequence. Wave energy is reflected by the wall, causing scour in front of the wall rather than dissipating wave energy as a beach would. Structures perpendicular to the shoreline such as groynes, built to intercept longshore sediment transport or retain sediment, may well accumulate sediment on one side (the up-drift side) but also cause erosion on the down-drift side, or farther along the shoreline by preventing sediment transport alongshore. Thus, many actions taken to prevent coastal erosion can make the situation worse or simply transfer the problem elsewhere along the coast. Breakwaters built for harbors can also inadvertently act as groyne and produce the same effects.

Measuring coastal erosion

Erosion rates are useful for planning and hazard mitigation purposes since they determine the amount of time remaining before infrastructure is overtaken or the rates at which land is being lost. Coastal erosion rates can be measured using a wide range of techniques, from regularly surveying of cross shore transects to aircraft using lasers known as LiDAR (Light Detection And Ranging). Maps, charts, and aerial photographs can be used to analyze shoreline change over longer historical time scales. Regardless of the method used, knowing the rate of shoreline retreat and/or the volume of sediment being lost from a coastal cell is critical for, first, determining that there is a real erosion problem and, second, deciding on the appropriate management response. Furthermore, the analysis needs to be over a sufficiently long timescale to remove short-term fluctuations associated with storm erosion and recovery in the case of sedimentary coasts, or noise associated with episodic failures common on cliffed coasts. Published rates of coastal erosion vary greatly, depending on shoreline type and geology and exposure. Erosion is also an episodic process both spatially and temporally. While erosion is commonly reported as a rate per year, this belies the highly episodic nature of the process.

Impacts

An obvious impact of coastal erosion is the permanent loss of land and infrastructure (Figure 1). Erosion of land can lead to loss of economic activity such as where beaches provide tourist amenity. Ecological function can also be lost as erosion progressively removes mangroves or salt marshes, and this is a significant issue when the coastal erosion is caused by human activity. Community vulnerability is increased as coastal erosion reduces the ability of shorelines to dissipate wave energy or to withstand barrier breaching. Vulnerability may also increase when artificial defenses (e.g., seawalls) are lost or damaged.

Response and mitigation

Approaches to erosion mitigation generally take one of two forms: retreat or defend. In the case of retreat, assets or activities can be abandoned or relocated to a safer position farther inland from the shore. However sociopolitical considerations work often to make this option difficult to employ. In many situations, this option is not viable because accommodation space behind the coast is unavailable to allow relocation. Defensive mitigation involves building a wide range of structures such as seawalls, breakwaters, groynes, and beach nourishment, where sediment is placed to recreate the natural buffer provided by beaches and dunes. Beach nourishment has become a popular and widely used method of erosion mitigation and is a useful approach since it addresses one of the fundamental causes of erosion – a deficit in the sediment budget. Psuty and Pace (2009) illustrate the use of sediment budgeting to better inform a beach nourishment approach to coastal erosion at Sandy Hook, New Jersey, USA. However, as with any response, it is not without problems, such as economic high costs, technical difficulties such as a lack of suitable sediment and negative ecological impacts (Grain et al., 1995; Speybroeck et al., 2006). For example, sand is often dredged from the sea floor disrupting or destroying benthic habitat and organisms. Sea turtle nesting success is known to be impacted when renourished sand is different to the original sand on the beach or when beach geometry is significantly altered (Brock et al., 2009). Alternatively well-designed beach nourishment could potentially improve nesting success by replacing lost beaches and nesting sites and restoring ecological opportunities. In situations where there is economic dependence on beach tourism, the cost (financial and ecological) of nourishment may be justifiable. Defensive structures are also expensive to build and maintain and often have detrimental impacts on shorelines, such as beach loss following seawall construction or down-drift erosion after a groyne is built. However, for high value assets, defensive structures are often necessary and beach loss is accepted. Importantly, there is no single response that is suitable for all coastal erosion problems and each case must be assessed on its own merits. The variety of responses to coastal erosion was reviewed by Pope (1997).

In situations where development has not occurred or is proposed, careful assessment of future erosion trends (based on measured or projected erosion rates) is necessary to avoid creating a new hazard. In such cases, planning schemes and zoning can be used to avoid creating erosion hazards. Predicting the position of future shorelines as sea levels rise is another approach and a wide variety of models are available for different shore types. A commonly used model to predict shoreline retreat in the face of sea level rise is the Bruun Rule, but the title is misleading since it is not a rule in a strict scientific sense but a rather simple model. The model requires a strict set of conditions to be met to successfully predict shoreline erosion, and more common than not these conditions are seldom meet (Cooper and Pilkey, 2004).

A common problem for coastal management is the view that shorelines should be rendered stable by erosion mitigation techniques, but this view is at odds with an environment that is naturally dynamic. Mitigation techniques that are also dynamic provide against current erosion problems and future climate change and sea level rise. Shoreline structures can be modified to return to dynamic behavior or built in such a way so as to allow dynamic behavior. For example, groynes can be constructed so as to be permeable to allow some sediment to continue to move alongshore (Nordstrom et al., 2007). Restoration of ecological function of mangroves, salt marshes, and coral reefs also provides protection from sea level rise, cyclones and tsunami, and hence coastal erosion. Such methods may be a more sustainable approach to erosion management than engineered structures.

Conclusions

Coastal erosion will continue to be a major hazard on coastlines into the future and in the face of projected climate change and increasing population pressure on coastal resources, it is likely to become an even more important hazard for coastal managers. Hazard management will need to come from adaptive strategies utilizing a wide range of mitigation techniques focused on managing human use systems.

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Cross-references

Beach Nourishment (Replenishment)
Breakwater
Climate Change
Coastal Zone, Risk Management
Erosion
Sea Level Change
Tsunami
Zoning

COASTAL ZONE RISK MANAGEMENT

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Definition

A coordinated strategy to cope with risks in the context of environmental, sociocultural, and sustainable multiple uses of the coastal zone.

Discussion

Risk management in the coastal zone requires an understanding of the evolving trends, particularly the desire for Integrated Coastal Zone Management (ICZM). A thorough understanding of the biophysical and ecoclimatic systems, using scientific principles and methods of investigation, is required. Socioeconomic concerns and maritime traditions must be incorporated into any management initiative. Management strategies must be practical, reflecting and respecting socioeconomic systems, demographic differences, existing political and regulatory systems, and biophysical conditions. They must also simultaneously respect the principles of conservation, stewardship, and sustainable development, and must acknowledge the human contribution to management.

In theory, ICZM requires:

- *Comprehensiveness* – all components of all systems must be included; all affected (or potentially affected) groups and individuals must be consulted and their views incorporated.
- *Coherence of elements* – the management plan as designed must "fit together," with individual components intermeshed; no overlapping jurisdictions or responsibilities, but perfect coordination between units with adjacent responsibilities; resource partitioning completely accomplished.
- *Consistency over time* – the plan remains in effect, not subject to political or regulatory change.
- *Cost-effectiveness of results* – the plan is economically (or socioeconomically) feasible, within the ability of the community or political jurisdiction to pay for its implementation.

In practice, this is unattainable. Not only is it impractical, but it also ignores the real nature of coastal systems: most significantly, by demanding consistency over time, it tacitly assumes that systems can reach a condition of stability. This is demographically and physically impossible. Although some degree of political consistency is desirable, any good plan must be suitably flexible to adapt to changing circumstances.

Applied specifically to risk management, this means that the hazard must be considered in the context of the coastal community or region. Coastal communities develop because they are adjacent to resources, such as fish species, convenient for transportation, attractive locations for humans to live and play, or for combinations of these reasons. Risks associated with waves and storms are inherent in any coastal setting. Some localities are also vulnerable to tsunami, slope failures, or terrestrial flooding. Communities are rarely settled in the complete absence of any perception of the hazards: although tsunami events may be rare, wave activity is a daily occurrence and is well known to maritime residents. The communities develop despite the known hazards, because the tangible benefits outweigh the hazards, both in visibility and frequency of occurrence.

Rather than thinking strictly of "cost-effectiveness" in terms of money, it is better and more productive to consider "effort-effectiveness." Does the risk management initiative make sense not only from a financial viewpoint but from the viewpoint of the amount of human effort required? Is the effort required to enforce a new regulation proportionate to the benefit? A risk management strategy in the coastal zone may affect demographic, sociocultural, or biophysical returns, in addition to fiscal ones.

These practical and conceptual issues and difficulties suggest that flexibility is the key to successful risk management in the coastal zone. The principles or theoretical ideals of Integrated Coastal Zone Management can be applied in a realistic way within the particular biophysical, political, and socioeconomic systems and subsystems.

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Cross-references

Beach Nourishment (Replenishment)
Breakwater
Coastal Erosion
Critical Infrastructure
Disaster Risk Management
Erosion
Erosivity
Flood Protection
Hazard and Risk Mapping
Hazardousness of Place
Ice and Icebergs
Indian Ocean Tsunami 2004
Marine Hazards
Pacific Tsunami Warning and Mitigation System (PTWS)
Red Tide
Rip Current
Sea-Level Change
Storm Surges
Storms
Tidal Bores
Tsunami
Waterspout

COGNITIVE DISSONANCE

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Synonyms

Contradictory beliefs; Misperception

Definition

Cognitive dissonance is an unpleasant sensation that appears when someone is confronted with two contradictory facts or ideas at the same time. People usually tend to keep consistency internalized and thus reduce the dissonance.

Overview

The cognitive dissonance theory is one of the most influential theories in social psychology. It was proposed and developed by Leon Festinger (1957). It states that people have some persistent beliefs about their physical and social environment, and try to behave in a self-consistent manner. When they encounter two cognitions (attitudes, beliefs, behaviors), which are relevant to each other, but dissonant at the same time, it generates an uncomfortable psychological tension. People are then motivated to reduce the dissonance by altering one of the causative cognitive elements. Consequently, it results in changing their attitudes, beliefs, and behaviors, or in attempts to justify or rationalize some of these. Dissonance reduction explains attitude and behavior changes of people, but fails in predicting what changes will happen in a particular situation (Glassman and Hadad, 2009). This human reaction can be interpreted as a kind of an irrational behavior as it prevents one from discovering real facts or in taking more appropriate decisions. From the psychological point of view, this mechanism serves to defend people's ego and keep a positive image of themselves (Aronson, 1979).

Cognitive dissonance processes help to understand the perception of natural hazards and disasters, and they especially explain why people living in hazardous areas tend to underestimate the risk and resign from undertaking appropriate mitigation actions. It results from misperception of natural hazards, particularly their frequency and intensity. People generally have difficulties in assessing the probability of rare phenomena and they usually think of disasters as something exceptional. They also feel they have limited control over such phenomena (National Research Council of the National Academies, 2006).

People living in hazardous areas may be confronted with dissonant ideas having both positive and negative consequences. On the one hand, they fear the eventuality that a disaster will happen that can cause losses and casualties. On the other hand, they may appreciate their living conditions or feel strongly attached to their neighborhood. Moreover, they might not have sufficient resources to move to a secure area. For example, inhabitants of volcanic slopes perceive higher benefits of living in a clean environment with opportunities to develop agriculture and tourism over the risk of eruptive and seismic activity (Chester et al., 2002). Understanding people's perception of natural hazards, particularly cognitive dissonance reduction, helps to improve hazard mitigation policies in cooperation with local population.

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Cross-references

Insurance
Perception of Natural Hazards and Disasters
Risk Perception and Communication
Social–Ecological Systems
Sociology of Disasters

COLLAPSING SOIL HAZARDS

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Synonyms

Hazards of collapsible or metastable soils

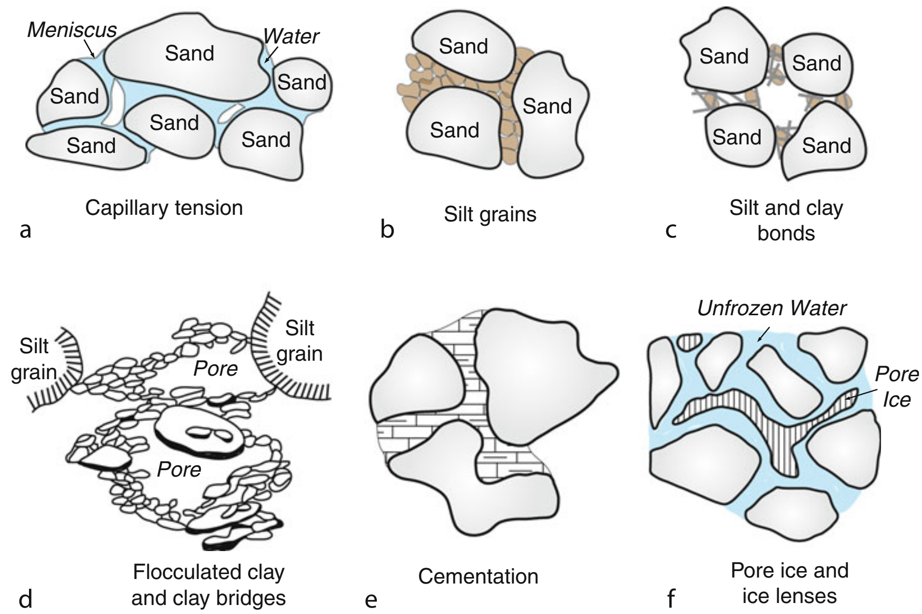
Definition

Collapsing soil hazard. A major hazard to natural land, disturbed ground, or engineered structures worldwide resulting from the structural collapse of constituents in soil. In most cases, collapse occurs following the wetting and loading of unsaturated materials (unconsolidated sediments), but soils with higher moisture content such as quick clays may undergo collapse as well. Collapsible soils also include those sediments that contain perennial ice or permafrost that has subsequently melted.

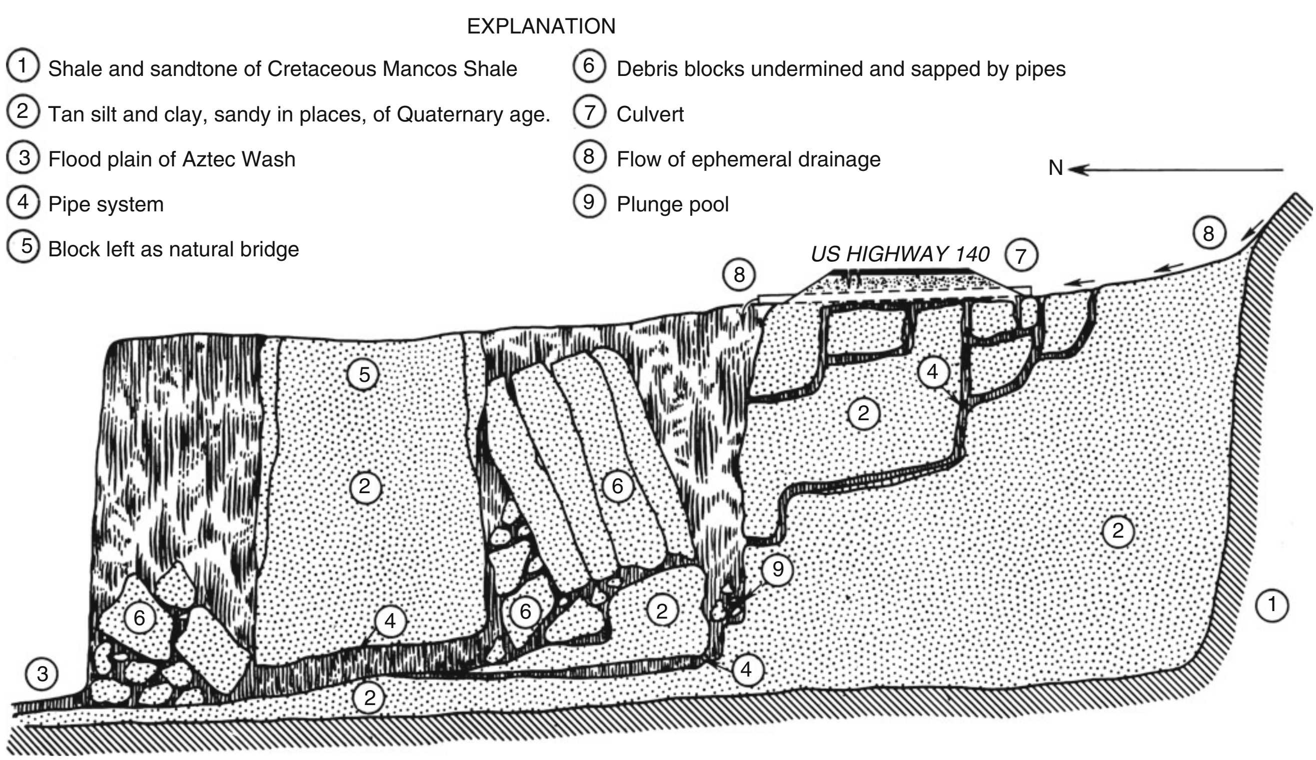
Introduction

Collapsing soils are not a local problem, but rather a worldwide phenomenon occurring on a variety of landscapes under different subsurface conditions. Soils may collapse catastrophically, but often signs of impending failure remain undetected especially in remote areas or on land modified by humans. The rate of collapsibility in soils depends on a number of factors such as their internal structure, moisture content and wetting history, degree of weathering or alteration, age, landscape position and mode of deposition, climatic conditions, mineralogy and shape of soil particles, presence of cementation, and compaction history due to loading (Dudley, 1970; Barden et al., 1973; Darwell and Denness, 1976; Rogers, 1995).

Alone, soil collapse annually results in hundreds of millions of dollars in damage to private and public property in the USA (Prior and Holzer, 1991). These collapse events may cause significant instability that engineers and



Collapsing Soil Hazards, Figure 1 Typical internal structure of collapsible soils. Soil particles and minerals are held together by: (**a**) capillary tension, (**b**) silt grains, (**c**) bonds containing silt and/or clay, (**d**) flocculated clay or clay aggregations, (**e**) mineral cements, and (**f**) pore ice or ice lenses (Modified from Collins and McGowan, 1974; Pavlik, 1980; Clemence and Finbarr, 1981; Holtz and Kovacs, 1981).



Collapsing Soil Hazards, Figure 2 Idealized north to south cross-section of Aztec Wash alluvium in southwestern Colorado, USA showing incipient piping system beneath US highway 140 (Figure 18 in Parker and Jenne, 1967). As a result of culvert-concentrated drainage, a system of gullies developed by piping and subsidence that has undermined the roadbed (Reproduced with permission from the United States Geological Survey).

scientists must address in the design, construction, and maintenance of water distribution systems, pipelines, low gradient canals, power transmission lines, highways, railroads, buildings, and various aspects of land development and use (Curtin, 1973).

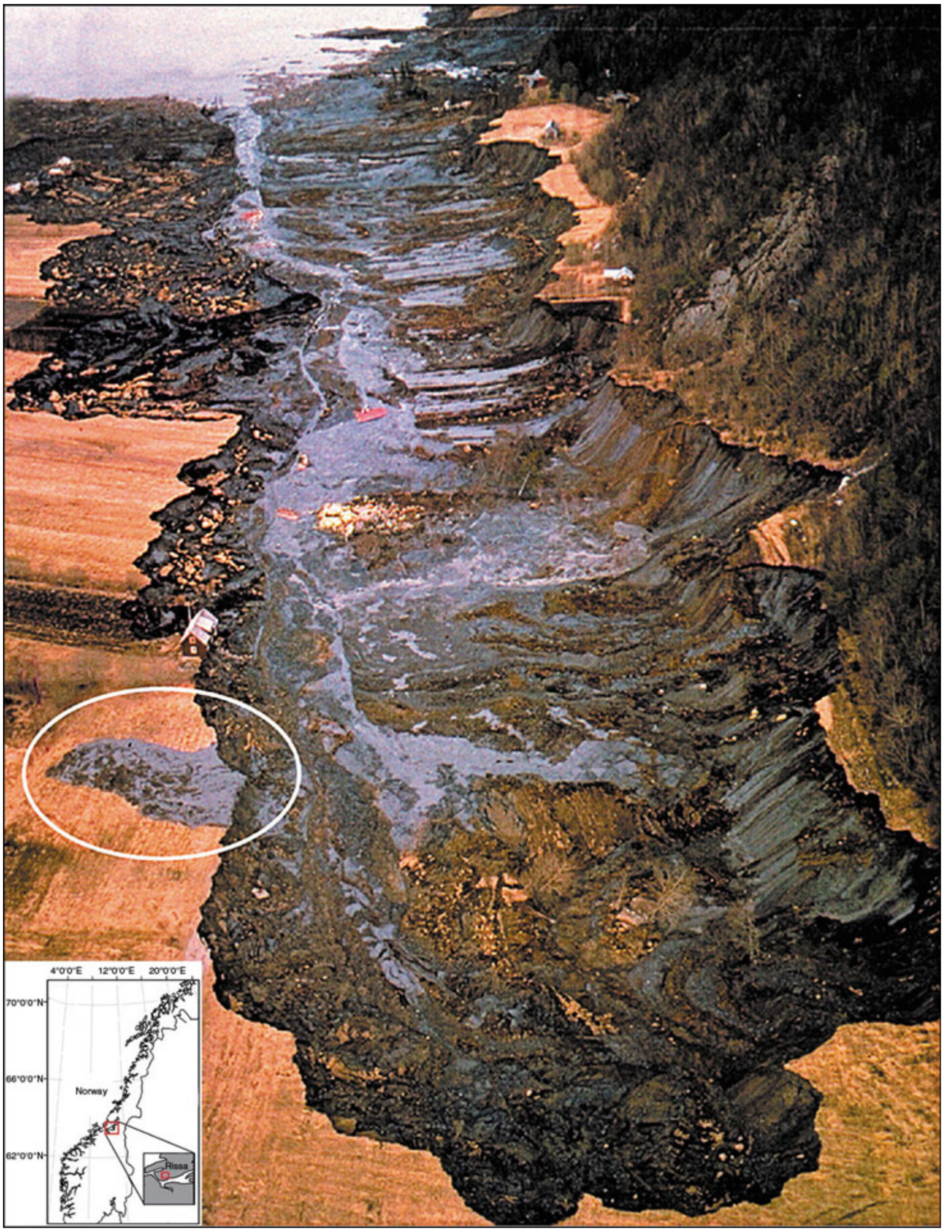
Properties of collapsible soils

Soils develop over a long period of time through a combination of physical, chemical, and biological processes that install distinctive internal structures and arrangement of soil particles. In situ compaction and wetting can further alter these soils. Collapsible or metastable soils are generally described as hard, dry, or partially saturated materials that have a low dry density and high porosity and will undergo an appreciable amount of volume change upon wetting, loading, or a combination of both (Sultan, 1969; Dudley, 1973; Handy, 1973; Jennings and Knight, 1975; Booth, 1977). These soils tend to be relatively young or recently altered, and have an open structure, a high void ratio, high sensitivity, and low interparticle bond strength (Derbyshire et al., 1995). Additional studies by Rosenqvist (1966), Czudek and Demek (1970), Mackay (1970), Torrance (1983), and MacKechnie (1992) provide additional information that show collapse may also occur in saturated soils, in transported or residual soils, dispersive soil, dispersive soil, and soils containing perennial ice. Soils overlying karst qv "*Karst hazard*" and soft bedrock may also collapse (Waltham et al., 2005), but these failures require the underlying rock be dissolved or fractured, processes not directly controlled by the overlying materials.

At the microscopic scale, collapse occurs when bonds between soil particles are broken and their internal structure weakened. Through this process, soil particles become further compacted producing subsidence that can be substantial and nonuniform (Barden et al., 1973; Clemence and Finbarr, 1981; Hunt, 2007). A soil is relatively stable when made up of uniform spherical particles that readily pack together to a near stable configuration reaching an optimum density (Rogers, 1995), whereas soils that contain much larger interparticle spaces between irregularly shaped grains, often of silt or fine sand size, are more prone to collapse (Clemence and Finbarr, 1981). Certain deposits containing flocculating clays may also collapse if the mineralogy and ion bonding are altered qv "*Dispersive soil hazard*" (Quigley, 1980).

Temporary strength in partially saturated, fine-grained cohesionless soils is provided through bonds between particles maintained by capillary tension, interlocking silt grains, silt and clay films and bridges, flocculated clay and clay agglomerations, chemical precipitates of iron oxide, calcium carbonate and gypsum, or pore ice and ice lenses as illustrated in Figure 1. Collapse in soil occurs once the bonds are broken particularly when: (a) water is applied increasing the degree of saturation; (b) loading exceeds the maximum strength; (c) cementing agents and salts are dissolved; and (d) permafrost is melted (Hunt, 2007; Muller et al., 2008).

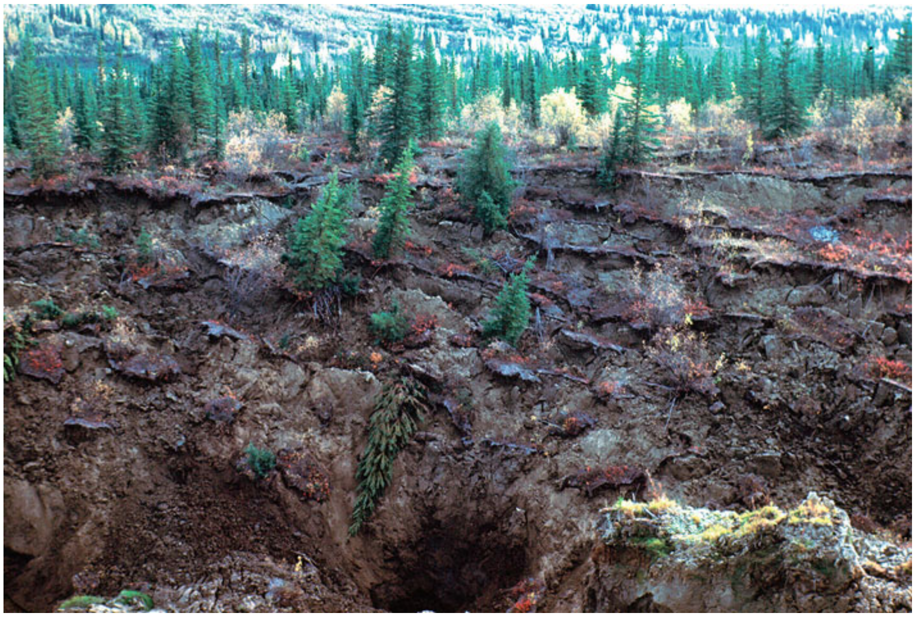
Collapsing Soil Hazards, Figure 3 Complex retrogressive block collapse in thick loess on the fourth terrace of the Yellow River (Huang He) at Heifantai, ca. 60 km southwest of Lanzhou city, Gansu Province, China. Soil collapse has been accelerated by rapid growth of human settlement and resulting widespread irrigation of the terrace for agriculture. The river in the distance is the Huang Shui, here just above its junction with the Huang He. Photograph taken in 2006 (Reproduced with permission from E. Derbyshire).



Collapsing Soil Hazards, Figure 4 Photograph of the quick-clay slide at Rissa near Trondheim occurring in 1978. The largest quick-clay slide in Norway in the twentieth century, it covered a 330,000 m^2 area. The event began as a small failure in fill by a lake, but in a few hours approximately 6,000,000 m^3 of soil had collapsed by retrogressive sliding (Gregersen, 1981). The deposits of liquid clay that spilled over the edge of the scar during failure are encircled. Note the houses for scale (Reproduced with permission from Elsevier Limited).

When the support is removed, particles are able to move and slide past one another to fill the vacant pore space (Clemence and Finbarr, 1981).

Wetting that penetrates deeply into unsaturated, low-density soils often causes interparticle bonds to be broken and washing out of silt and clay particles. This creates open pore space that promotes the denser packing of grains that can result in subsidence. This process, hydrocompaction qv "*Hydrocompaction subsidence*", is commonly observed in fine-grained soils of arid and semiarid environments (Rogers et al., 1994). Some of these soils, once wetted, are prone to significant subsurface erosion by piping qv "*Piping hazards*", which may lead to further subsidence (Paige-Green, 2008). Water entering the soil through fractures formed by desiccation or subsidence carries suspended clay particles to discharge points on slopes or permeable layers at depth. Over time, the fractures enlarge, undercutting the overlying materials (Figure 2). Piping is most prevalent in dispersive



Collapsing Soil Hazards, Figure 5 Slumping at Ester Drain on Gold Hill near Fairbanks, Alaska, USA. Following the melting of permafrost in loess, a large piping system developed causing rapid subsidence. Photograph taken by T. L. Pewe on September 14, 1949 (Reproduced with permission from the United States Geological Survey).

soils qv "*Dispersive soil hazards*"; soils that have a higher concentration of soluble salts that are developed in alluvial clays, windblown fine sand and silt (loess qv "*Loess*"), flood plain deposits qv "*Flood deposits*", and residuum on marine claystone and shale (Sherard et al., 1977). Knight (1963) and Holtz and Hilf (1961) have shown that collapse occurs in saturated and unsaturated soils following loading, particularly when the moisture content exceeds the liquid limit of the soil.

Soils containing weakly cemented particles or dispersive clays are highly susceptible to collapse after wetting (Figures 3 and 4), especially when exposed at the surface or interstratified with higher permeability sediments (Handy, 1973; Torrance, 1987). Reports by National Research Council (1985) and Wang et al. (2006) suggest that ground motions from earthquakes and underground explosions may produce enough energy to trigger collapse in these soils.

At high latitudes and altitudes, melting of perennial ice in both fine-grained and permeable soils may cause significant subsidence of the ground surface (Figure 5). In finer textured soils where drainage is poor, the melting of ice creates supersaturated conditions causing the sediment to liquefy (Andersland and Ladanyi, 2004). In more permeable soils, however, subsidence of the ground surface occurs by consolidation after the loss of excess water by drainage or evaporation (Murton, 2009).

Distribution of collapsible soils

Collapse in partly saturated or saturated soil is a phenomenon recognized throughout the world posing significant problems to engineered structures and land management. As noted previously, collapse soils are geologically young and have not undergone significant compaction or weathering by natural processes. Collapsible soils are most commonly found in Upper Pleistocene loess of the North America, central Europe, China, Africa, Russia, India, Argentina, and elsewhere (Rogers et al., 1994 and therein; Trofimov, 2001) however other soils considered prone to collapse are developed in:

1. Weathered bedrock (Brink and Kantey, 1961; Rao and Revanasiddappa, 2002; Pereira et al., 2005)
2. Aeolian sand (Knight, 1963; Amin and Bankher, 1997)
3. Glacial lake silt and clay (Clague and Evans, 2003; Kohv et al., 2009)
4. Glaciomarine and marine clay (Egashira and Ohtsubo, 1981; Geertsema et al., 2006: Hansen et al., 2007)
5. Alluvial and flood deposits (Parker and Higgins, 1990; Psimoulis et al., 2007; White and Greenman, 2008)
6. Organic deposits (Wösten et al., 1997; Haeberli and Burn, 2002)
7. Perennially frozen sediment (Demek, 1996; Jorgenson and Osterkamp, 2005)
8. Volcanic ash and dust (Wright, 2001; Iriondo and Kröhling, 2007)
9. Cemented soil (Ola, 1978; Petrukhin and Presnov, 1991)
10. Saline soil (Loveland et al., 1986; Azam, 2000)
11. Man-made materials (Booth, 1977; Herbstová et al., 2007)

Summary

The large number of studies undertaken worldwide to identify and predict the distribution of collapsing soil suggests that their presence in geologic and man-made materials is more common than originally presumed (this point is set forth in Derbyshire et al., 1995). There has been much debate between the soil scientists, geologists, geomorphologists, and geotechnical engineers on definition of collapsible soils. It is expected that with continued discussion between these academic disciplines, along with additional characterization studies of soils prone to collapse, a comprehensive criteria for identifying collapsible soils will assist local- and regional-based practitioners in determination and mitigating their hazards.

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Cross-references

Dispersive Soil Hazards
Flood Deposits
Hydrocompaction Subsidence
Karst Hazards
Land Subsidence
Loess
Piping Hazards

COMET

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Definition

Cometary nucleus – The solid, icy-conglomerate body that is the heart of the comet and the source of its activity.

Cometary coma – The freely outflowing atmosphere of dust and gas around the nucleus.

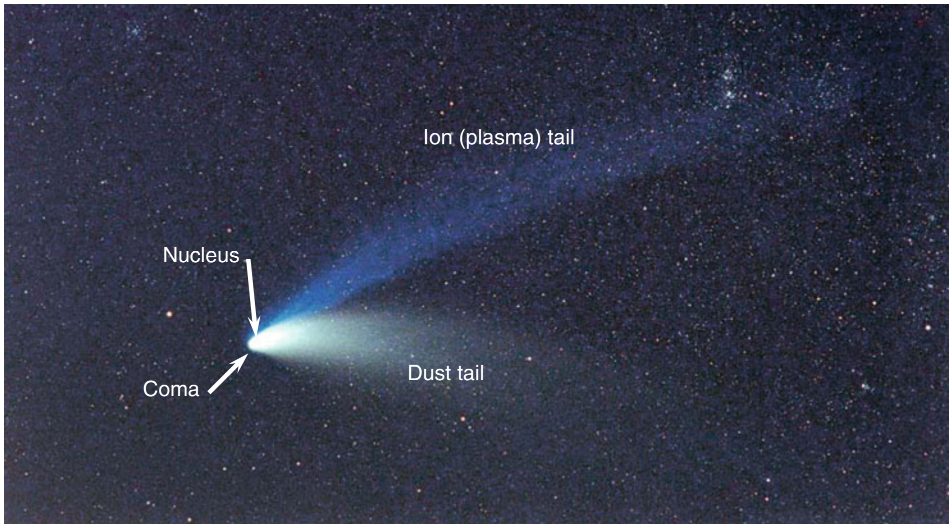
Comet tails – The coma materials separate and form two tails trailing behind the nucleus, one composed of dust and one composed of ionized gas molecules (see Figure 1).

Introduction

Comets are primitive bodies left over from the formation of the solar system. They were among the first solid bodies to form in the solar nebula, the collapsing interstellar cloud of dust and gas out of which the Sun and planets formed. Comets formed in the outer reaches of the planetary system where it was cold enough for volatile ices to condense. This is generally taken to be beyond 5 AU (astronomical units), or beyond the orbit of Jupiter. Because comets have been stored in distant orbits beyond the planets, they have undergone little of the modifying processes that have melted or changed most other bodies in the solar system. Thus, they retain a physical and chemical record of the primordial solar nebula and of the processes involved in the formation of planetary systems.

Cometary nuclei

Cometary nuclei are small bodies, typically only a few kilometers in diameter, and composed of roughly equal parts of volatile ices, silicate dust, and organic materials. The ices are dominated by water ice (~80% of the total ices) but also include carbon monoxide, carbon dioxide, formaldehyde, and methanol. The silicate and organic mix is similar to that found in the most primitive meteorites, carbonaceous chondrites. These materials are intimately mixed at micron scales. Images of the five



Comet, Figure 1 Comet Hale-Bopp in 1997, showing the major components that make up a typical comet. The nucleus is embedded deep within the bright coma and is too small and dark to see in this image.

cometary nuclei visited so far by interplanetary spacecraft are shown in Figure 2.

The nuclei formed in the solar nebula as dust and ice particles settled to the central plane of the nebula. When these particles collided they tended to stick. Micron-sized particles grew through this process of agglomeration and accretion to meter-sized and then kilometer-sized bodies.

When cometary nuclei come close to the Sun, the ices in them sublimate, transforming directly from the solid to the vapor phase. The evolving gas molecules flow off the nucleus surface, carrying with them silicate and organic dust particles embedded in the ices. This outflowing mix of materials then forms the cometary coma, the comet's atmosphere. Because cometary nuclei are small, their gravity is too weak to retain this atmosphere and it flows freely out into space.

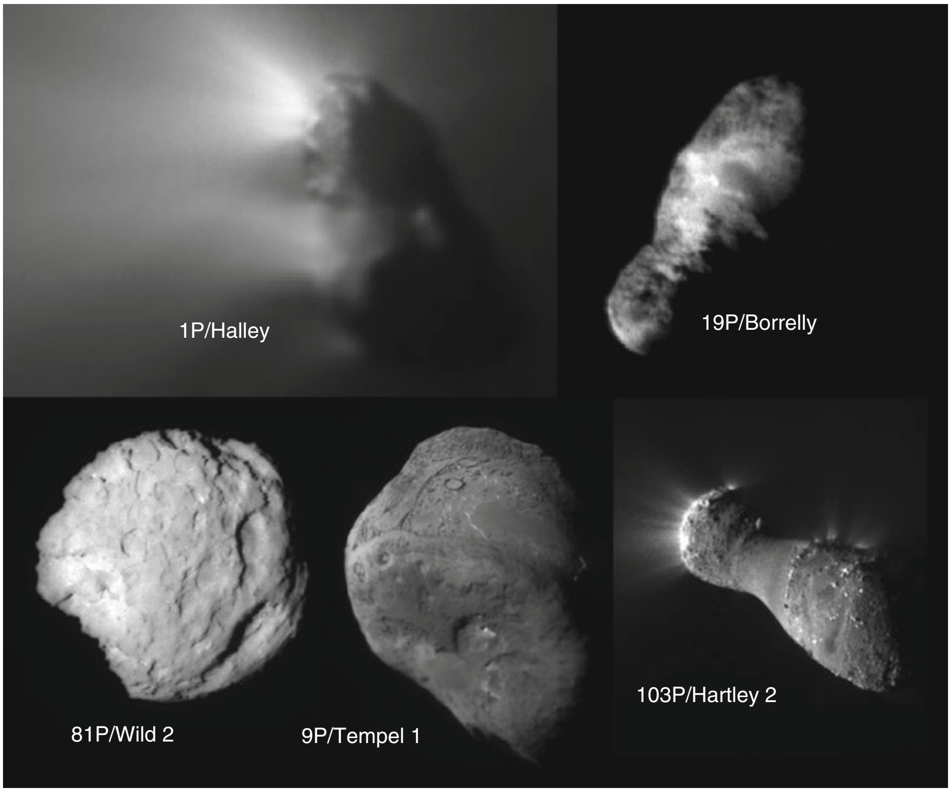
Because the different ices sublimate at different temperatures, gases are liberated from different depths below the surface as the solar heat wave penetrates into the surface. So the layers closest to the surface become progressively depleted in the most volatile ices. Also, a lag deposit of nonvolatile dust develops on the surface. These are typically particles too large to be lifted by the escaping gases. This nonvolatile layer can become so thick that it effectively insulates the icy component below it, preventing further sublimation.

Another feature of cometary activity is driven by the fact that the water ice in comets condensed at very low temperatures, <100 K. At these low temperatures, ice forms in the amorphous state, a random ordering of molecules. As the amorphous water ice is warmed above $\sim$115 K, it begins to transform to crystalline ice, first in the cubic form and then the normal hexagonal ice that we are most familiar with. This transition is complete at $\sim$153 K. It is an exothermic reaction, that is, it releases energy. This energy further sustains the reaction as it warms the ice around it, but dies out because it must also heat the nonvolatile dust components of the nucleus. The amorphous-crystalline ice transition may be one source of cometary outbursts, sharp increases in cometary activity that appear to occur randomly.

The internal structure of cometary nuclei is still an area of speculation. It is generally believed that as icy planetesimals came together at low velocity in the solar nebula, there was not enough energy to melt or compress them into a single solid body. The two leading explanations suggest that cometary nuclei are "fluffy aggregates" or "primordial rubble piles" with low binding strength and high porosity. Key data supporting these models are estimates of nucleus bulk density, ranging from 0.2 to 1.5 g/cm^3, with preferred values of $\sim$0.3–0.6 g/cm^3. This suggests a combined microscopic and macroscopic porosity of $\sim$64% or more, a very high value.

Additional evidence for the rubble pile model for cometary nuclei comes from observations of split (disrupted) cometary nuclei. Observations show that nuclei can randomly break apart, shedding a few or many pieces. These pieces have typically been estimated to be between 8 and 60 m in diameter. In some cases, the entire nucleus disrupts. Disruption can also occur if the nucleus passes too close to the Sun or to a large planet like Jupiter, where gravitational tidal forces tear the weakly bound nuclei apart. This has been observed for Sun-grazing comets, comets with perihelia within one solar radius of the Sun's photosphere.

A particularly interesting case of a tidally disrupted nucleus is that of comet Shoemaker-Levy 9. This comet was discovered in 1993 as a string of 21 separate but comoving, active nuclei. Observations showed that the



Comet, Figure 2 The five cometary nuclei imaged to date by flyby spacecraft: comet Halley (1986 by Giotto), comet Borrelly (2001 by Deep Space 1), comet Wild 2 (2004 by Stardust), comet Tempel 1 (2005 by Deep Impact), and comet Hartley 2 (2010 by EPOXI). The nuclei range in size from 16 × 8 km for Halley, down to 2 × 1 km for Hartley 2. Note the considerable differences in topographic features on each of the nuclei. These may be due to the surface features evolving as each comet makes more returns close to the Sun.

comet had been captured into orbit around Jupiter, and had passed so close to Jupiter on its last perijove passage, 1.3 Jupiter radii, that it was tidally disrupted. The nucleus appeared to have broken into thousands of separate “cometesimals.” As this swarm of bodies moved away from Jupiter, their own self-gravity caused them to clump together. Interestingly, the number of final clumps was shown to be a function of the bulk density of the original nucleus, and the best fit was obtained for densities of $\sim$0.6 g/cm^3. Thus, comet Shoemaker-Levy 9 is another of the proofs of a low-density, rubble pile or aggregate structure for cometary nuclei.

Cometary atmospheres

Because of the small size and low gravity of the cometary nuclei, the evolving gases from sublimating ices expand freely into the vacuum of space. Entrained in the outflowing gas are fine dust particles, typically a micron in size, composed of both silicates and organics. Because the molecules are exposed to sunlight and the solar wind they begin to disassociate, breaking up into radicals and individual atoms. The most common case of this is the water molecule, which disassociates into H and OH. Organic dust grains appear to also release radicals into the outflowing coma, most common of which are CN, C_2, and C_3. These are known as “daughter” molecules and cometary spectroscopy is used to study the chemistry that goes on in the coma as the parent and daughter molecules, radicals, and individual atoms react with each other.

The observed composition of volatiles in cometary comae is very similar to that seen in dense, cold interstellar clouds where stars and solar systems are being formed. This reinforces strongly the belief that comets are frozen remnants of the primordial solar nebula, preserving unmodified volatiles from the formation of the planetary system, 4.56 billion years ago.

Cometary comae often show geyser-like structures, or “jets,” which are taken as evidence of individual active areas on the surfaces of the nuclei. As noted above, lag deposits of large dust grains can shut down sublimation on the surface. Because the nature of the source vents for the cometary activity is as yet unknown, there is no good explanation as to why some areas remain active and others do not. It is known that this is likely an ageing effect, as the “active fraction” on the nucleus is large for long-period and Halley-type comets (see below), which have made relatively few approaches close to the Sun, and very low, typically only a few percent, for Jupiter-family comets, which have made hundreds of returns, on average.

Comets also can display "outbursts," which are large, sudden releases of dust and gas. The most famous of these is comet Holmes in 2007, which brightened by 15 magnitudes (one million times brighter) in less than a day. The explanation for outbursts, and their larger cousins, disruption events, is as yet unknown, though rotational spin-up due to torques from coma outgassing, has been suggested, and the amorphous-crystalline ice transition (see above) is also likely a factor.

Comet tails

The outflowing dust and gas in the coma also interacts with the solar wind and sunlight. The fine dust is blown away from the Sun by radiation pressure on the tiny grains. This forms a broad, curved sometimes yellow-colored tail following the comet in its orbit and pointed generally away from the Sun. This is known as a Type I tail. The molecules suffer a different fate as they are ionized by charge exchange with the solar wind. Once ionized, they are caught up in the Sun's magnetic field and flow away at high velocity in the solar wind. This process forms long, narrow, straight trails that glow blue in color due to the presence of CO^+ molecules. These tails point sharply away from the Sun and are known as Type II tails. Well before the first spacecraft observations of the solar wind in 1959, the existence of the solar wind was inferred from the appearance of cometary ion tails.

Dynamics

Comets are typically in more eccentric and more inclined orbits than other bodies in the solar system. In general, comets are classified into three dynamical groups: the Jupiter-family comets with orbital periods less than 20 years, the Halley-type comets with orbital periods between 20 and 200 years, and the long-period comets with orbital periods greater than 200 years. A more formal definition involves a quantity called the Tisserand parameter:

$$T = a_J/a + 2\sqrt{(a/a_J)(1 - e^2)}\cos i \qquad (1)$$

where a, e, and i are the semimajor axis, eccentricity, and inclination of the comet's orbit and a_J is the semimajor axis of Jupiter's orbit. Jupiter-family comets have Tisserand parameters between 2.0 and 3.0 and Halley-type and long-period comets have T values less than 2.0. Asteroids have T values greater than 3.0. However, there are both some comets whose orbits have evolved to T values slightly greater than 3, and some asteroids with T values slightly less than 3.

Another important difference in the dynamical groups is their orbital inclination distributions. Jupiter-family comets typically have orbits that are modestly inclined to the ecliptic (the plane of the Earth's orbit), with inclinations up to about 35°. The Halley-type comets have much higher inclinations, including retrograde orbits that go around the Sun in the opposite direction, though not totally randomized. The long-period comets have totally random inclinations and can approach the planetary system from all directions. As a result, the Jupiter-family comets are also known as "ecliptic comets," whereas the long-period comets are also known as "isotropic comets."

The inclinations of the cometary orbits provide important clues to their origin. Dynamical simulations show that the great concentration of Jupiter-family orbits close to the ecliptic can only originate from a flattened source of comets. This source has been identified as the Kuiper belt, a flattened disk of icy bodies beyond the orbit of Neptune and extending to at least 50 AU from the Sun. The Kuiper belt is analogous to the asteroid belt and is composed of ice-rich bodies that never had enough time to form into a larger planet.

The exact source of the Jupiter-family comets is called the Scattered disk, Kuiper belt comets that are in more inclined and eccentric orbits with perihelia close to Neptune. Neptune can gravitationally scatter comets from the Scattered disk inward to become Jupiter-family comets, or outward, to the Oort cloud (see below).

The origin of the long-period comets with their random inclinations was a mystery until 1950 when Dutch astronomer Jan Oort proposed that these comets came from a vast cloud of comets surrounding the solar system and stretching to interstellar distances. The key to recognizing this was the distribution of orbital energies, which showed that a large fraction of the long-period comets were in very distant orbits with semimajor axes of ~25,000 AU or more. The orbits of comets in the "Oort cloud," as it is now known, are so distant that they are perturbed by random passing stars and tidal forces from the galactic disk. Again, dynamical simulations show that the Oort cloud is the only possible explanation for the number of comets with very distant orbits, but still gravitationally bound to the solar system.

But where did the Oort cloud comets come from? The solar nebula was too thin at those large distances for comet-sized bodies to form. Current thinking is that the Oort cloud comets are icy-planetesimals that formed in the region of the giant planets, between 5 and 30 AU, and were gravitationally ejected to distant orbits by the growing giant planets. This process is fairly inefficient and most icy planetesimals were ejected to interstellar space by the giant planets. If other forming solar systems are doing the same thing, then there is a vast swarm of comets in interstellar space. However, no comet has ever been observed entering the planetary system that was on an obviously interstellar orbit.

It is also possible that if the Sun formed in a cluster of stars, as most stars do, then it might have exchanged comets with the growing Oort clouds of those nearby stars. This could be a significant contributor to the Oort cloud population.

The source of the Halley-type comets, with their intermediate inclinations and eccentricities, is still a matter of debate. Both the Scattered disk and the Oort cloud have been suggested as sources. It may be that the explanation lies with a combination of the two cometary reservoirs.

The comet impact hazard

Comets pose a natural hazard to the Earth. This is because many of them are in orbits that cross the Earth's orbit and may collide with the Earth. Approximately 10 long-period comets, on the order of 1 km in diameter (or larger), cross the Earth's orbit each year. Because the Earth is a relatively small target and space is vast, the impact probability per comet is, on average, very low. A random long-period in an Earth-crossing orbit has an average impact probability of 2.2×10^{-9} per perihelion passage. This means that, on average, one long-period comet will strike the Earth for every 454 million comets that cross its orbit. Given the estimated rate of 10 long-period comets crossing the Earth's orbit per year, this results in a mean time between long-period comet impacts of 45 Myr.

However, because the long-period comets move on highly eccentric and highly inclined orbits, their mean impact velocities are much higher than for other celestial bodies, that is, asteroids. The average long-period comet will strike the Earth with a velocity of 51.8 km/s. If we weight the impact velocity by the probability of impact for a particular orbit, then the weighted mean impact velocity increases to 56.4 km/s. These values are much higher than that for Earth-crossing asteroids, which are typically only ~15 km/s.

An interesting case is that of Earth-crossing long-period comet Hale-Bopp (Figure 1), which passed closest to the Sun in 1997. Hale-Bopp was an unusually large and active comet, easily seen with the naked eye in evening skies. With a perihelion distance of 0.914 AU (the point in the orbit closest to the Sun), Hale-Bopp's orbit crossed inside the orbit of the Earth. Hale-Bopp was believed to have an unusually large nucleus, estimated to be 27–42 km in diameter. Taking a median value of 35 km and assuming a mean bulk density of 0.6 g/cm^3 results in an estimated mass of 1.3×10^{19} g.

The impact probability for Hale-Bopp on the Earth is 2.54×10^{-9} per perihelion passage, fairly typical for a long-period comet. Because of the comet's high orbital eccentricity, 0.9951, and inclination, 89.43°, the impact velocity would be 52.5 km/s. The resulting impact energy is equivalent to 4.4×10^9 megatons of TNT. This is ~44 times the estimated energy of the asteroid impact 65 Myr ago that killed the dinosaurs. Such an energetic impact may have the capability to completely sterilize the Earth, resulting in the extinction of all life on the planet! Fortunately, Hale-Bopp passed through the plane of the Earth's orbit on the far side of the Sun from the Earth, so there was never any possibility of an impact. Also, the average time between impacts of cometary nuclei as large as Hale-Bopp far exceeds the age of the solar system.

This illustrates an important point about the cometary impact hazard. Although asteroid impacts are far more frequent than comet impacts, some comets crossing the Earth's orbit are considerably larger than any of the known near-Earth asteroids. Thus, the largest and most devastating impacts on the Earth are likely to be of comets. Other known Earth-crossing comets with large nuclei include comet Halley, ~16 × 8 km in diameter, and comet Swift-Tuttle, ~23–30 km in diameter.

Also, the flux of long-period comets can vary over time. If a star comes close enough to the Sun to pass through the Oort cloud, in particular at distances less than 10,000 AU, then the star can cause a "shower" of comets to enter the planetary system. The rate of long-period comets crossing the Earth's orbit could increase by a factor of ~200 and the complete shower would last for about 2.5 Myr. Fortunately, such close stellar passages are rare, about one every 300 Myr.

For Jupiter-family comets, whose returns are predictable (once discovered), only 22 Earth-crossers are known (excluding the many small fragments of disrupted comet 73P/Schwassmann-Wachmann 3). Of these, four are lost, eight have only been observed on only one return, and one is no longer Earth-crossing. Their mean impact probability is 7.3×10^{-9} per orbit or 1.3×10^{-9} per year, and their mean encounter velocity with the Earth is 22.9 km/s, with a most probable encounter velocity of 19.9 km/s. The mean time between Jupiter-family comet impacts is 35 Myr

For Halley-type comets, whose returns are also predictable, another 16 Earth-crossers are known, of which 1 is lost and 6 have not yet made a second observed appearance. Their mean impact probability is 7.0×10^{-9} per orbit but only 0.16×10^{-9} per year because of their longer orbital periods. Their mean encounter velocity is 45.4 km/s, with a most probable encounter velocity of 52.3 km/s. The mean time between Halley-type comet impacts is 390 Myr. Note that the impact frequency for both Jupiter-family and Halley-type comets may be higher if there are yet undiscovered members of each group.

Summary

Comets are among the most interesting bodies in the solar system because they retain a cosmochemical record of the physical and chemical conditions at the time the planets formed. They have been kept in "cold storage" far from the Sun, during most of the solar system's history, and thus are essentially unmodified from their primitive state 4.56 billion years ago. Comets pose a small but significant part of the impact hazard to the Earth, and probably can account for the largest impacts on our planet over the last 3 billion years.

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Cross-references

Asteroid

COMMUNICATING EMERGENCY INFORMATION*

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Definition and introduction

The empirical study of public communications in emergencies has been ongoing for almost 50 years (Perry and Mushkatel, 1986, 1984; Leik et al., 1981; Quarantelli, 1980; Baker, 1979; Mileti and Beck, 1975; Drabek and Stephenson, 1971; Lachman et al., 1961). These studies, when viewed collectively, have compiled an impressive record about how and why public behavior occurs in the presence of impending disaster or threat. For example, it is well documented that emergency warnings are most effective at eliciting public protective actions like evacuation when those warnings are frequently repeated (Mileti and Beck, 1975), are confirmatory in character (Drabek and Stephenson, 1971), make specific recommendations, and are perceived by the public as credible (Perry et al., 1981). Informal warning mechanisms (friends or relatives) are also at times very effective. In many evacuations, people leave the area at risk before an official warning is announced. Evacuation behavior is also influenced by other factors such as personal or family resources, age, and social relationships including social networks, level of education completed, experience with previous emergencies, social and environmental cues of immediate hazard, physical or psychological constraints to evacuating, as well as other more specific circumstances (such as time of day, weather conditions, etc.). Table 1 provides a list of those factors and how they have covaried with decisions to respond (Mailman School of PH @ Columbia, annual preparedness survey, focuses on why parents may not heed evacuation orders).

Studies that have used surveys of random samples of people living in or near-disaster areas have been conducted for a variety of hazard events. For hurricanes, these include Elena and Kate (Baker, 1987; Nelson et al., 1988), Eloise (Windham et al., 1977; Baker, 1979), Camille (Wilkinson and Ross, 1970), David and Frederick (Leik et al., 1981), Carla (Moore et al., 1964), Floyd (Dow and Cutter, 2002; HMG, no date), Andrew (Gladwin and Peacock, 1997), Bertha and Fran (Dow and Cutter, 1998), Georges (Dash and Morrow, 2001; Howell et al., 1998), Brett (Prater et al., 2000), Bonnie (Whitehead et al., 2000) Ivan (Howell and Bonner, 2005), and Lily (Lindell et al., 2005).

Studies of flood include Denver, CO (Drabek and Stephenson, 1971); Rapid City, SD; (Mileti and Beck, 1975); Big Thompson, CO (Gruntfest, 1977); Sumner Valley, Fillmore, and Snoqualmie, WA (Perry et al., 1981); Abilene, TX (Perry and Mushkatel, 1984); Clarksburg and Rochester, NY (Leik et al., 1981); and Denver, CO, and Austin, TX, (Hayden et al., 2007).

Studies of chemical accidents include Mississauga, Ontario, Canada (Burton, 1981); Mt. Vernon, WA; and Denver, CO (Perry and Mushkatel, 1986); Confluence and Pittsburg, PA (Rogers and Sorensen, 1989); Nanticote, PA (Duclos et al., 1989); and West Helena, AR (Vogt and Sorensen, 1999). Graniteville, SC (Mitchell et al., 2005).

Other protective action studies include the Hilo, HI, tsunami (Lachman et al., 1961); the Mt. St. Helens, WA, volcanic eruption (Perry and Greene, 1983; Dillman et al., 1984); the Three Mile Island nuclear accident, PA (Cutter and Barnes, 1985; Flynn, 1979); the World Trade Center bombing, NY, in 1993 (Aguire et al., 1998); the World Trade Center collapse, NY, in 2001 (Averill et al., 2005); SoCal wildfires in 2003 and Australian bushfires in 2005 (Proudley, 2008, AJEM) and in particular 2009 (Haynes et al., 2008, *J. Volc. Geotherm. Res.*, on volcanic risk perception; Wray et al., 2008, *Am. J. Pub. Health*, on communicating with

Communicating Emergency Information, Table 1 Factors associated with warning response

As factor increases	Response	Level of support
Characteristics of the warning		
Channel: Electronic	Is mixed	Low
Channel: Media	Is mixed	Moderate
Channel: Siren	Decreases	Low
Personal warning vs. impersonal	Increases	High
Proximity to threat	Increases	Low
Message specificity	Increases	High
Number of channels	Increases	Low
Frequency	Increases	High
Message consistency	Increases	High
Message certainty	Increases	High
Source credibility	Increases	High
Fear of looting	Decreases	Moderate
Time to impact	Decreases	Moderate
Source familiarity	Increases	High
Characteristics of People		
Physical cues	Increases	High
Social cues	Increases	High
Perceived risk	Increases	Moderate
Knowledge of hazard	Increases	High
Experience with hazard	Is mixed	High
Education	Increases	High
Family planning	Increases	Low
Fatalistic beliefs	Decreases	Low
Resource level	Increases	Moderate
Family united	Increases	High
Family size	Increases	Moderate
Kin relations (number)	Increases	High
Community involvement	Increases	High
Ethnic group member	Decreases	Moderate
Age	Is mixed	High
Socioeconomic status	Increases	High
Being female vs. male	Increases	Moderate
Having children	Increases	Moderate
Pet ownership	Decreases	Low

public about health threats). The National Env. Health Assn published an excellent review of risk comm., risk perception, and loss of trust in "authorities" re post-collapse risk (Lyman, 2003, *Messages in the Dust*).

Excellent summaries of this research currently exist (Lindell and Perry, 2004; Drabek, 1986; Mileti and Sorensen, 1990; Tierney et al., 2003; National Research Council, 2006) and will not be repeated here.

Summary

Empirical studies and summaries have done much to further social scientific understanding of how people process and respond to risk communications in emergencies; it has also served to inform practical emergency preparedness efforts in this nation and abroad. Relevant research on human response to risk communications derived from the empirical research record can be summarized as follows.

Research indicates that people's decisions to respond to emergency communications are influenced by:

- The frequency and channel of communication of the warning. The most important dimensions of the warning frequency/channel are the number of different channels people hear the warning from, hearing from personal channels, and the frequency that people hear the warning.
- The content of the warning message. The most important dimensions of content are a description of the hazard and impacts, the predicted location of impacts, what actions to take, and when to take those actions.
- Observing cues. These include social cues (i.e., seeing neighbors evacuating) and physical cues (i.e., seeing flames or a smoke cloud).
- Aspects of individual status. These include socioeconomic status (i.e., income level and education completed), age, gender, and ethnicity.
- The role(s) an individual holds in society. These include having children at home, family size (i.e., larger vs. smaller), extent of kin relations, being a united family at time of the event, and greater community involvement.
- Previous experience with the hazard. People are inclined to do what they did in a previous situation.
- People's belief in the warning. Belief is not determined by the credibility of the source issuing the warning but by the frequency the message is heard.
- People's knowledge about the hazard. This includes previous information and data gained in the event or by cues.
- People's perceptions of risk. This includes perception of the threat before the event and perception of risk from the specific event.
- The extent of social interactions during the event. This includes efforts to contact others about the event, being contacted by others, and being able to confirm the message as accurate and credible.

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COMMUNITY MANAGEMENT OF NATURAL HAZARDS

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Definition

Community management of natural hazards. Community-based participation in identification, mitigation, preparedness, response, and recovery and reconstruction activities related to potential and/or experienced natural hazards.

Introduction

Natural hazard management strategies typically include several broad categories of management. They include hazard identification and mitigation, preparedness (or planning), response, and recovery and reconstruction. These strategies can be viewed as a continuum, with recovery and reconstruction activities ideally resulting in increasingly effective mitigation strategies in advance of the next hazard event.

Historically, the management of natural hazards has been viewed primarily as one of response and recovery, with the responsibility resting largely on state or national government, and with direct planning and participation at the community level largely neglected (e.g., Laughy, 1991). However, as the Organization of American States has noted in its policy series on managing natural hazard risk, natural hazard risk management efforts are most effective when they are explicitly addressed at every level, including at the community level (OAS, 2004). The strengthening of stakeholder and community involvement is viewed by some as the greatest need in the evolving area of hazard management and mitigation (King, 2008). It has become increasingly clear that there is an ongoing shift from a response and recovery approach toward a mitigative approach in the management of natural hazards, which requires the integration of management practices at the community level in order to be successful and sustainable (Pearce, 2003).

There are many challenges to implementing successful community-based participation in the management of natural hazards. Among them is the influence of previous experience with a specific hazard (or lack thereof) on how local government and community members perceive risk from that hazard, which can determine the level of public participation in preparedness and mitigation strategies (Tierney et al., 2001). The effect of previous experience on how an individual responds to future participation in mitigative programs can often be counterintuitive, and has implications for the management of hazards (McGee et al., 2009). Another challenge is the difficulty of conveying concepts of hazard risk to the public, given the often very imprecise nature of the business of hazard prediction (Alexander, 2007). Additionally, individuals may not participate in mitigative strategies due to a lack of accurate information, or the perception that a hazard is a political or ideological creation rather than a reality. They also may be moved to nonparticipation as a means to avoid unpleasant emotions about the issue or in the belief, especially in the case of global threats such as climate change, that there is really nothing they can really do about it (Norgaard, 2006). Studies showing relationships between individuals' risk-taking propensity and attitudes toward preparation for natural hazards (e.g., McClure et al., 1999), as well as the role that media portrayal of natural disasters has in influencing future social behavior and attitudes (e.g., McClure et al., 2001) have significant implications for how community management strategies may help alleviate fatalism and improve hazard preparedness. Drawing on community empowerment and engagement strategies can significantly enhance the ability of communities to promote and sustain participation in hazard preparedness (e.g., Frandsen et al., 2011).

Those living in the developing world as well as those living in poverty are particularly vulnerable to the effects of natural disasters (World Bank, 2001), largely as a result of the combination of underdevelopment, poor building construction and siting, and economic inability to adequately respond to and recover from a major disaster. The earthquake that struck the impoverished nation of Haiti on January 12, 2010 provided a stark example of the confluence of these attributes in the face of a major natural disaster. Well over 200,000 people had lost their lives as a result of this event, and at least 1.5 million were homeless. In the face of warnings from scientists as recently as 2008 that Haiti was at significant risk for a major earthquake (Manaker et al., 2008), mitigative measures to prepare were lacking, with economics likely a major factor in the lack of community preparedness for such a disaster.

Hazard identification and mitigation

Mitigation includes activities that eliminate or reduce the chance of occurrence or the effects of a disaster. Identification of potential hazards and potential vulnerabilities to hazards is the first step in this process. Communities' response to recommendations for mitigative measures may be predicated on previous personal experience with specific hazards (McGee et al., 2009). Community mitigation and preparedness for hazards that are perceived to be of low risk may not be implemented, in spite of the fact that occurrence of such hazards can result in very high consequence events (e.g., 2004 Indian Ocean Tsunami). Pre-hazard mitigation programs such as those offered by the Federal Emergency Management Agency (FEMA) in the United States have shown that, while communities may not necessarily be able to prevent disasters, they can take many proactive steps that can reduce the effects of hazards upon communities and their residents (e.g., Volunteer Florida, 2004). For example, requiring structural reinforcements to homes in areas prone to seismic activity will reduce property damage and loss of life from earthquakes. Similarly, the implementation of Early Warning Systems (e.g., Zschau and Küppers, 2003; Momani and Alzaghal, 2009) at the community level has the potential to save hundreds of thousands of lives in extreme cases, such as that which occurred as a result of the 2004 Indian Ocean Tsunami. Haque (2005) provides a range of experiences in the mitigation and management of natural hazards from an international perspective. It is important to distinguish between mitigation strategies themselves and a community's capacity to respond to them in a timely and effective manner. Assessing a community's ability to adapt and respond favorably to these strategies is key to effective implementation, whether in advance of or in response to a natural hazard (e.g., Paton and Tang, 2009).

Preparedness

Preparedness, the next aspect of hazard management, involves planning how to respond in the advent of a natural hazard, and how to activate community resources to respond effectively. Careful advance planning can help save lives and minimize property damage by preparing community members to respond in a prescribed manner when a hazard occurs. In a community-based approach, this phase involves significant public informational and educational components.

Ensuring public participation in the process of hazard management planning can be problematic at times for a variety of reasons (e.g., Chen et al., 2006). However, the importance of continued public involvement throughout the entire management cycle has direct bearing on whether or not mitigative strategies can be sustained until they are needed (e.g., Tanaka, 2009). Promoting community involvement in all aspects of preparedness can result in greater post-disaster resilience, particularly in segments of the population who are likely to be most affected by the occurrence of a natural disaster, such as children and their families (Ronan and Johnston, 2005). However, it is important to note the need to distinguish between providing information on hazards preparation and people's general ability to interpret and use such information. For example, Lindell et al. (2009) note that hazard experience, risk perception, and population demographics, among others, all can have effects on attributes related to hazard preparation adjustments. Additionally, community risk management strategies are to some extent socially constructed, and how people may act to manage their risk often encompasses both social and cultural issues (e.g., Paton et al., 2010). Finally, trust in the purveyor of the information related to hazard mitigation can influence how effective resultant strategies are (e.g., Paton, 2008).

Response

Response covers the period immediately prior to (if the hazard can be predicted in advance), during, and immediately following a disaster. Responders typically include entities such as the fire and police departments, and medical services. Depending on the magnitude of the event, however, the usual responders and local government may be ill-equipped to manage the response phase without significant assistance from the state or national government, or the international community. Involvement of local community members in the aspects of disaster awareness training can influence hazard-related cognitions and preparedness behaviors (Karanci et al., 2005), resulting in the ability of the general community to participate in the response actions completely and in more beneficial effects (e.g., Paton et al., 2001).

Recovery and reconstruction

Recovery and reconstruction represent the final part of the management cycle, though it can also be viewed as the precursor to the improvement of mitigation procedures. Recovery and reconstruction continue until community functions have returned to normal. In the early part of this phase, critical community services are restored to minimum operating conditions. Depending on the severity of the hazard's impact, recovery may go on for months or even years, as in the case of disasters with major loss of life or property. Ironically, the impact of a major disaster on a community presents the opportunity for significant improvement of infrastructure and construction practices, resulting in the incorporation of features that are less likely to be affected by future events. While the process of recovery can provide opportunities to mitigate future disasters, successful implementation of such strategies requires an understanding of changes in community contributions to recovery and rebuilding efforts over time (Paton, 2006).

The recovery and reconstruction phase following a significant natural disaster often requires significant economical resources in order to succeed, and the resilience of a community may depend largely on the strength of pre-hazard mitigative strategies that are already in place at the time of the event. Just as important as the resources that contribute to the physical recovery of a community are the services that are in place to address emotional health needs, which can often be quite severe following a natural disaster. Psychiatric disorders such as post-traumatic stress disorders can be common, and while most people are resilient and will recover, some populations may be at higher risk for more serious mental health problems (Watanabe et al., 2004; Wickrama and Wickrama, 2008). A critical aspect of community management of hazards involves planning for both physical and emotional injury that could potentially result from a natural hazard, and communities can use methods such as the formation of innovative self-help groups to ensure recovery in both areas (e.g., Kuppuswamy and Rajarathnam, 2009). While the enabling of participatory planning after the occurrence of a natural disaster bears some beneficial aspects, earlier involvement of stakeholders in the mitigation process is indicated, since many may be ill-equipped emotionally immediately following a disaster (e.g., Ganapati and Ganapati, 2009).

The role of internet technology in community management of hazards

Just as radio and television in the earlier days, the Internet has become an increasingly important resource for communities marching toward active engagement in hazard management. The ability to provide near-real-time hazard-related data (Dimitruk, 2007) and interface with Geographical Information Systems (GIS) (Raheja et al., n.d.), Global Positioning Systems (GPS), and other communications technologies aid in all areas of hazard management. As early as 1998 following the advent of Hurricane Mitch's landfall in Central America, the Internet was used intensively to post regular updates on information such as epidemiological reports and public health guidelines on topics ranging from household water quality to the prevention of measles (Bittner, 2000).

For the community in the early stages of hazard management planning, the Internet is a tremendous source of ready information on all aspects of hazard management, with some sites functioning as warehouses for relevant links, such as a site hosted by Keele University in Britain (http://www.keele.ac.uk/depts/por/disaster.htm). The added benefit of being able to store relevant information and databases on computer servers far removed from the community that they will serve in the advent of a natural disaster means that the information will still be potentially accessible to communities, responders, and other critical parties even if communications infrastructure is initially disabled or destroyed at the site of the event. In the aftermath of Hurricane Katrina's landfall near New Orleans on the south coast of the United States in 2005, and also following the earthquake that struck Haiti in early 2010, the Internet was a critical resource in aiding community members at home and abroad to track down information on the status of missing loved ones (http://guides.library.msstate.edu/content.php?pid=16013&sid=107538; http://www.google.com/relief/haitiearthquake/). Finally, the Internet has become a critical component for the affected communities in the conduct of outreach to the global community to raise funds during the response and recovery phases following the advent of a natural hazard.

Selected examples of community management of hazards

The following are examples of different types of strategies of community management of various natural hazards:

Earthquakes

Tokai Earthquake Preparedness in Shizuoka Prefecture, Japan http://www.e-quakes.pref.shizuoka.jp/english/earthquakepreparedness_in_shizuoka.pdf

This entry discusses in detail the history behind, formation of, and plans for implementing highly integrated management of a potential earthquake hazard in Shizuoka Prefecture, Japan, including community education and participation.

A Novel Strong-Motion Seismic Network for Community Participation in Earthquake Monitoring

(Cochran et al., 2009) http://qcn.stanford.edu/ (Quake-Catcher Network).

This is an innovative approach to passive community-based volunteer participation in seismic data gathering and analysis through use of distributed computing techniques, with a goal of increasing the awareness of various aspects of seismic activity to aid with the aspects of earthquake preparedness planning.

Hurricanes, coastal erosion, and coastal flooding

Sustainable Coastal Communities and Ecosystems (SUCCESS) http://seagrant.gso.uri.edu/ecosystems/hazards.html

Based out of the University of Rhode Island in the United States, this program works with governments, the private sector, and community organizations to ensure that coastal communities face and recover from hurricanes, floods, and coastal storms. The goal is to help communities achieve economic growth while reducing the potential impacts of natural hazards and maximizing public safety and public access to the shore. The SUCCESS program works to help develop strategies to prepare for natural disasters, educate disaster preparedness and response professionals, enhance evacuation preparations, and plan for expediting recovery efforts.

Landslides

Landslide Management by Community-Based Approach in the Republic of Armenia (Mori et al., 2007) http://www.n-koei.co.jp/library/pdf/forum16_017.pdf

Report discussing community-based approach toward landslide hazard identification and management.

Natural radioactivity, radon hazard

The Community Environmental Monitoring Program http://cemp.dri.edu/

While this program concentrates on the potential of releases of man-made radioactivity as a result of the past testing of nuclear weapons at the Nevada Test Site, an understanding of the potential hazards of natural radioactivity, including radon, as well as concepts of dose, is an important component of the program. The program provides a hands-on role for community members in the monitoring process and equips them with the knowledge to communicate information on the subject to their neighbors (Hartwell and Shafer, 2011). This program also provides an example of how the Internet can be an effective tool for communication data dissemination.

Tornadoes

Tornado Tabletop Exercise: Engaging Youth in Community Emergency Management http://www.unce.unr.edu/publications/files/cy/2009/cm0908.pdf

An example of a classroom curriculum designed to educate students about community emergency management, including training them to use geospatial technology to create maps with shelter locations and evacuation routes, and simulating a tornado event.

Volcanoes

Maximizing Multi-stakeholder Participation in Government and Community Volcanic Hazard Management Programs: A Case Study from Savo, Solomon Islands (Cronin et al., 2004). Report on attempt at multi-level integration of volcanic risk management strategies and challenges of involvement of certain sectors of the community populations.

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Cross-references

Casualties Following Natural Hazards
Climate Change
Coastal Erosion
Coastal Zone, Risk Management
Communicating Emergency Information
Community Management of Hazards
Coping Capacity
Costs (Economic) of Natural Hazards and Disasters
Damage and the Built Environment
Disaster
Disaster Relief
Disaster Risk Management
Dose Rate
Early Warning Systems
Earthquake
Earthquake Damage
Earthquake Prediction and Forecasting
Economics of Disasters
Education and Training for Emergency Preparedness
Emergency Management
Emergency Mapping
Emergency Planning
Epidemiology of Disease in Natural Disasters
Exposure to Natural Hazards
Federal Emergency Management Agency (FEMA)
Flood Hazard and Disaster
Forest and Range Fires
Frequency and Magnitude of Events
Geographic Information Systems (GIS) and Natural Hazards
Global Change and Its Implications for Natural Disasters
Global Positioning System (GPS) and Natural Hazards
Hazard
Hazardousness of Place
Hurricane
Information and Communications Technology
Integrated Emergency Management System
International Strategies for Disaster Reduction: The IDNDR and ISDR
Internet, World Wide Web and Natural Hazards
Landslide
Misconceptions About Natural Disaster
Mitigation
Monitoring and Prediction of Natural Hazards
Mortality and Injury in Natural Disasters
Natural Hazard
Natural Hazards in Developing Countries
Natural Radioactivity

Perception of Natural Hazards and Disasters
Planning Measures and Political Aspects
Posttraumatic Stress Disorder (PTSD)
Prediction of Hazards
Psychological Impacts of Natural Disasters
Radon Hazards
Recovery and Reconstruction After Disaster
Remote Sensing of Natural Hazards and Disasters
Resilience
Risk
Risk Assessment
Risk Perception and Communication
Seismology
Social–Ecological Systems
Structural Mitigation
Tornado
Tsunami
Volcanoes and Volcanic Eruptions
Warning Systems
Wildfire

COMPLEXITY THEORY

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Synonyms

Systems theory

Definition

A complex system consists of many interacting parts, generates new collective behavior through self organization, and adaptively evolves through time. Many theories have been developed to study complex systems, including chaos, fractals, cellular automata, self organization, stochastic processes, turbulence, and genetic algorithms.

Introduction

The classical approach to study natural phenomena is to model them as *dynamical systems* governed by differential equations, which allow the temporal evolution of many *linear* phenomena (e.g., motions of a planet around the Sun, laminar fluid flow, etc.) to be predicted with considerable accuracy. A linear system is deterministic because its output is proportional to the input. However, most natural phenomena involve *nonlinear* processes. Jules Henri Poincaré analyzed the stability of the solar system and in 1890 discovered chaotic behavior in a three-body dynamical system. Since then, many new concepts and tools have been developed for solving nonlinear problems – some are successful, but many raise more questions than provide answers.

Chaos in dynamical systems

In 1963, Edward Lorenz discovered that simple computer models of weather were very sensitive to *initial conditions*, such that a slight change at the start would give very different results. Lorenz used a simplified version of the Navier–Stokes equations (formulated in the mid-nineteenth century) for his computer models. Lorenz's discovery led to the realization that our ability to predict weather is limited at best to several days, because small measurement errors in the initial conditions grow exponentially with time, leading to predictions that deviate significantly from the actual weather conditions in just a few days. This requires repeated updating of initial conditions to extend a useful prediction.

Fractals in geology and geophysics

About 1/3 of major natural catastrophes are caused by earthquakes (the other 2/3 are mostly due to hurricanes and floods); hence their occurrences have naturally drawn attention for millennia. A prominent feature of seismicity is the Gutenberg–Richter relation derived empirically from observations (Gutenberg and Richter, 1954). It is given as $\log N(M) = a - bM$, where M is the earthquake magnitude, $N(M)$ is the number of earthquakes with magnitude greater than or equal to M, and a and b are constants. It can be rewritten as $N = \alpha\, A^{-\beta}$, a power law that is characteristic of *fractals*, which possess scale invariance (Turcotte, 1997). As is the case with earthquakes, faults, volcanic eruptions, landslides, floods, and many other natural phenomena also exhibit scale invariance. A fractal is commonly defined as a collection of objects that have a power-law dependence of number on size. Fractals are observed in many physical, biological, and social systems, regardless of their underlying governing processes.

Discussion

The classical, deterministic approach enjoys great success in studying some natural phenomena that can be approximated as *linear* systems. However, many natural phenomena are *nonlinear*. Complexity theory has been developing to meet this challenge, but a unified theory is not yet available for universal applications. Existing theory indicates that deterministic prediction for many phenomena (e.g., weather or earthquakes) is inherently impossible but that probabilistic forecasts are feasible. Mitchell (2009) provides a "tour" of complexity theory, and an introduction to complexity in earthquakes, tsunamis, and volcanoes is given by Lee (2009).

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Cross-references

Early Warning Systems
Earthquake

Earthquake Prediction and Forecasting
Earthquake Resistant Design
Extreme Value Theory
Fault
Tsunami
Volcanoes and Volcanic Eruptions

CONCRETE STRUCTURES

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Synonyms

Reinforced concrete structure

Definition

A structure constructed primarily of concrete reinforced with steel.

Concrete is a commonly used construction material that is locally available throughout the world. It consists of fine aggregate (sand), coarse aggregate (crushed stone), cement (usually Portland Cement), water, and air. Cement has the appropriate chemical composition as a binding material that hydrates in the presence of water, chemically binding fine and coarse aggregate particles together to form a rock-like material called concrete (Kosmatka et al., 2008; Neville and Brooks, 2008). The aggregates account for approximately 75% of total mix by volume. Air in concrete, purposely introduced through chemical admixtures, improves resistance to freeze-thaw cycles. Water-cement (W/C) ratio by weight is the single most important parameter that affects the quality of concrete. W/C ratio of 0.5 produces sufficient workability, good performance, and an average compressive strength of approximately 30 MPa. As the W/C ratio decreases, the strength and quality of concrete (durability, abrasion resistance, freeze-thaw resistance, permeability) improves drastically. Concrete mixtures may also contain chemical admixtures for improved quality and workability.

Concrete is strong in compression for use as a structural material. However, it is generally very weak in tension. Concrete cracks at approximately 10% of its compressive strength in tension, and further breaks into pieces unless properly reinforced. Therefore, concrete is often reinforced with a material that permits resistance to tension when used for structural applications. The resulting composite material is referred to as "reinforced concrete." The most commonly used type of reinforcement is a steel bar. Typical reinforced concrete structural elements consist of beams, columns, walls, slabs, and footings. The longitudinal reinforcing bars are often placed on the tension side to control cracks and resist tension, although sometimes they may be placed in the compression zone for additional compressive capacity. Transverse reinforcement is used to control diagonal tension cracks associated with shear, to laterally restrain compression bars against buckling or to confine concrete for improved inelastic deformation capacity. The resulting structural elements form a structural framing system, consisting of moment resisting frames, structural walls (shear walls), or the combination of the two. The primary objective in structural design is to provide resistance to gravity and lateral loads, including those caused by natural hazards. Concrete structures are built either as "cast-in-place" monolithic (continuous) structures, or "precast" structures that consist of prefabricated elements that can be assembled and connected on site. A special form of reinforced concrete is "prestressed concrete." This type of construction takes advantage of eliminating or reducing tension in concrete by imposing compressive stresses prior to the application of external loads (Nawy, 2006). The prestressing operation is often done by means of high-strength steel strands, cables, or bars that are pretensioned or posttensioned to compress concrete in regions of expected tension. Concrete structures are generally favored for providing resistance to natural hazards because of their inherent mass and rigidity, which provide stability and deformation control against extreme wind effects, storm surges, and tsunamis, while also providing fire resistance. They have to be designed for continuity and inelastic deformability for improved seismic resistance (Park and Pauley, 1975). Concrete structures are often designed to experience inelastic deformations under strong earthquakes to dissipate seismic-induced energy.

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Cross-references

Building Codes
Buildings, Structures and Public Safety
Damage and the Built Environment
Earthquake Resistant Design
High-Rise Buildings in Natural Disaster
Structural Damage Caused by Earthquakes
Unreinforced Masonry Buildings

CONVERGENCE

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Synonyms

Disaster tourism; Post disaster return

Definition

Convergence refers to the spontaneous movement of people, messages, and goods – organized and unorganized – towards a disaster area.

Overview

Following a disaster, a spontaneous movement towards the disaster-affected area of people for various reasons, messages bearing different forms of information, and goods including relief supplies are frequently observed. That movement combines organized and unorganized efforts. Such activity is termed "convergence" and is a topic in disaster research.

Fritz and Mathewson (1957) articulated reasons for what they termed "informal or unofficial convergers" to disaster sites within their theory of convergence behavior in disasters. They describe five categories – still relevant and used today, as they form the basis for ongoing convergence research – that are not mutually exclusive: the returnees, the anxious, the helpers, the curious, and the exploiters.

Returnees are disaster survivors, evacuees, or those who were away from home before the disaster and who come back to their homes, with or without official sanction. Reasons for returning include property recovery, property protection, grieving, and no other place to live. The anxious refers to those individuals with a close connection to the disaster-hit community but who do not live there and who converge on the disaster site out of anxiety for friends, relatives, or their previous home.

The helpers refer to volunteers or professional assisters who wish to provide post-disaster services. Examples are rescuing trapped people, body recovery, and meeting physical and psychological needs of on-site disaster survivors or other convergers. Some helpers self-deploy which is usually not recommended because that can interfere with post-disaster resources and coordination. Donations – of cash, time, goods, and services – is a form of helper convergence. Often, problems result from poorly considered donations, such as sending food or clothes that are culturally inappropriate for the affected area. The most effective post-disaster donations tend to be cash given to credible organizations that are familiar with the location.

The curious refers to people converging on the disaster site as sightseers or spectators.

The exploiters are subdivided into looters, pilferers or souvenir hunters, relief stealers, profiteers, each of which is self-defining. Although representatives of these categories are witnessed after many disasters, widespread and systematic looting, profiteering, and mob-related crime are not common. Instead, these tend to be isolated incidents that simply receive exaggerated publicity.

The Internet has permitted online convergence behavior. Examples are online memorials, scam artists trying to defraud disaster-affected people, and Web sites dedicated to specific disasters for memorials and/or voyeurism.

Research on convergence is principally, although not entirely, derived from sociological and American perspectives. Limited work covers convergence from other geographic, cultural, and disciplinary perspectives.

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Cross-references

Myths and Misconceptions

COPING CAPACITY

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Synonyms

Adaptive capacity

Definition

Coping capacity is the ability of a system (natural or human) to respond to and recover from the effects of stress or perturbations that have the potential to alter the structure or function of the system.

Discussion

The capacity of a system to cope with a natural hazard is determined by the ability of the system to adjust to a disturbance, moderate potential damage, take advantage of opportunities, and adapt to the consequences (Gallopin, 2006). The concept of coping capacity is often associated with extreme events whereas the concept of adaptive capacity generally alludes to a longer time frame and implies that some learning either before or after an extreme event or change in conditions has occurred (Smit and Wandel, 2006; Peltonen, 2010). The IPCC (2007, p. 869) defines "adaptive capacity" in relation to climate change as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences." Turner et al. (2003) describe "adaptation" as a system's restructuring after exposure to a stress or perturbation.

Some natural hazards are considered "extreme events" because they are associated with the rapid restructuring of physical, biological, and/or societal systems. Storms, fires, volcanic eruptions, floods, landslides, avalanches, tsunamis, and other extreme events are all capable of stressing systems to a point that leads to a rapid shift from one state to another. Other natural hazards, such as subsidence of the land surface and erosion of the coastline, occur over a longer time frame. The cumulative effects of such small-scale events can perturb natural and human systems, in some cases more severely than an "extreme event" such as a storm or earthquake.

The capacity of society to cope with a natural hazard is dependent upon many variables. The following factors are considered major determinants of coping capacity, based on a review of Yohe and Tol (2002), Gallopin (2003, 2006), Armas and Avram (2009), and Gaillard and others (2008):

1. The exposure and sensitivity of the system to direct or indirect impacts of the natural hazard and the related vulnerability of social systems and the environments on which they depend.
2. The ability of decision makers to manage information, the accuracy of information, the processes by which decision makers determine which information is credible, and the credibility of the decision makers themselves.
3. The range and availability of technological options.
4. The availability of resources and their distribution across the affected population.
5. The structure and efficiency of critical institutions and decision-making authority.
6. The stock of human and societal capital, including education, personal security, strength of livelihoods, and social networks.
7. The potential for risks to be shared or spread (e.g., insurance systems).
8. The public's perception of the natural hazard and the relative significance of exposure compared to other societal challenges.

Coping capacity is an attribute of a system that exists prior to the perturbation (Gallopin, 2006). In the context of human societies, changes in coping behavior can emerge spontaneously (unplanned) or proactively (planned). Proactive coping behavior is the outcome of deliberate policy decisions that are based on an awareness of the nature of the hazard and its potential impact, coupled with actions that are required to return to, maintain, or achieve a desired state. The enhancement of coping behavior is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions and socioeconomic groups (Peltonen, 2010). Human coping behaviors and factors that determine the degree to which they increase societal capacity to cope with natural hazards are illustrated in the table below.

Natural hazard	Example of coping behavior	Factors that influence how the behavior enhances coping capacity (examples)
Tsunami	Early warning system	Availability of technology; effectiveness of evacuation; availability and distribution of resources to victims
Flood	Building codes that require elevation of structures above potential flood level	Public perception of risk; efficacy of enforcement; accuracy of flood level calculation; availability of flood insurance
Earthquake	Building codes	Availability of resources needed to for compliant building construction or retrofitting; confidence in vulnerability assessments; efficiency of institutions that regulate construction
Hurricane storm surge	Business continuity planning	Public perception of risk; speed with which utilities, transportation, and other infrastructure is restored; prior experience or simulations that reveal errors or omission in planning
Wildfire	Reduction of fuel load through prescribed fire	Public acceptance of fire as a management tool; training, skill, and availability of personnel experienced in the use of prescribed fire; presence of houses and other structures that prevent the use of fire as an option for hazard reduction
Subsidence	Control of human activity that contributes to subsidence – example: reduce rate of groundwater withdrawal	Geologic setting and other antecedent conditions; availability of alternative water resources

Summary

Coping is a behavioral capacity that can reduce the adverse impacts in a system that is exposed to an extreme event or a chronic natural hazard. The capacity for coping with a natural hazard is generally inversely related to vulnerability – the higher the coping capacity, the lower the vulnerability of a system, region, community, or individual. In some cases, however, even strong coping capacities do not necessarily reduce vulnerability. For example, transportation and sewage treatment facilities constructed in a geologic floodplain by a community with high institutional and financial resources may be as physically vulnerable to the impacts of flooding as facilities constructed by a community with low coping capacity. Coping behaviors that are based on a good understanding of both the hazard and its impacts can substantially increase the resilience of human settlements, infrastructure, and economies.

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Cross-references

Adaptation
Antecedent Conditions
Coastal Erosion
Disaster Risk Reduction (DRR)
Earthquake Resistant Design
Emergency Planning
Flood Hazard and Disaster
Hazard and Risk Mapping
Hurricane (Cyclone, Typhoon)
Indian Ocean Tsunami, 2004
Land Subsidence
Planning Measures and Political Aspects
Risk Perception and Communication
Wildfire

COST-BENEFIT ANALYSIS OF NATURAL HAZARD MITIGATION

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Definition

Defined in its broadest sense, cost-benefit analysis (CBA) is a tool to estimate and sum up the equivalent monetary value of the costs and benefits of alternatives in order to establish a decision context for politicians (e.g., Mishan, 2006). CBA is used for a systematic comparison of all costs and benefits that arise over (a certain) time period; and it uses discounting to make costs and benefits that arise in future comparable. Regarding natural hazard mitigation, CBA is for the most part applied with respect to permanent technical mitigation measures such as snow-supporting structures in avalanche-prone areas or dams along rivers. Costs are usually defined as expenses needed for the respective mitigation measure, such as concrete and steel necessary to build a check dam, and the labor needed for construction works. Benefits are typically defined as prevented damage which will arise in the future due to the implementation of the planned mitigation measure. CBA allows comparing different given mitigation alternatives with each other. CBA is targeted at the socially optimum level of safety, which will be when risks have been reduced by mitigation measures up to the point where the extra cost of any risk reduction equals its benefits (Marin, 1992).

Background

Costs and benefits can be determined for any goods traded on perfect and therefore efficient markets by using existing market prices; these so-called private goods include almost everything that is available in everyday life, such as food, vehicles, realties, and flight tickets. Such private goods are characterized by rivalness and excludability (e.g., Mankiw, 2008); multiple consumers compete for the use of such goods, and if someone is not willing to pay for the good, he or she can be excluded from consumption. However, it has been repeatedly argued that some goods do not have these characteristics (e.g., Samuelson, 1954). When a person cannot be excluded from consumption even if he or she is not willing to pay (non-excludability), and the individual consumption does not detract from the ability of others to consume such goods (non-rivalry) the good is considered as a public good. Typical examples of public goods include national defense, uncongested nontoll roads, and permanent constructive natural hazard protection.

Taking the latter as an example, for an inhabitant of a settlement, the quality of hazard protection does not change by the utilization of the same good by another inhabitant (Fuchs and McAlpin, 2005; Fuchs et al., 2007). The marginal costs of the utilization of the hazard protection measure by an additional user are zero and, as a consequence, there is no market price for this good. As a result, consumption of the utility from this public good is not necessarily fully valued by the users. In turn, no user can exclude, independently of the individual willingness to pay, another user from utilization. Non-excludability creates incentives for free riding because people can attain the utility of a good without paying for it. Free riding is another source of market failure because, since people pay for less than the efficient quantity of a good, the market produces less than the efficient quantity of the good and, as a result, the private sector fails to provide this good at a sufficient level for economic efficiency (Fuchs and McAlpin, 2005). Therefore, the supply must take place via the public sector in order to meet the societal demand.

However, in some cases, due to the scarcity of protected areas for development within hazardous areas, potential users could be excluded from the utilization. This scarcity would make mitigation measures common (pool) resources, for which use by some decreases the potential utility to others (Fuchs and McAlpin, 2005; Mankiw, 2008).

To facilitate the optimal supply of mitigation measures, the public sector will need, among other information, evaluations of the costs and benefits of mitigation approaches (Musgrave, 1969). Due to the characteristics of public goods stated above, such an evaluation can be made by comparing the costs of the supply of the good with an indirect measurement of the benefit for the consumer. Whereas such an attempt is relatively robust with respect to tangibles, questions related to an evaluation of intangibles have been subject to continuous discussions for decades (e.g., Adams, 1974; Green and Penning-Rowsell, 1986; Bateman, 1992; Eade and Moran, 1996).

Methodology

It is necessary to consider all relevant costs and benefits when applying CBA, including indirect costs and those costs arising later in time. Sensitivity analysis allows coping with uncertainty by analyzing the sensitivity of the results obtained under the CBA to variations in the individual factors used. The net present value to be obtained during CBA is the discounted net benefit gained or the net cost imposed on the stream of costs and benefits over time. As a consequence, the planning horizon that is considered (e.g., with respect to a planned flood retention basin) matters for the outcome of a CBA.

From a theoretical point of view, the methodology is schematically illustrated by total cost and corresponding total benefit due to the implementation of mitigation measures in Figure 1. At the level of mitigation q^0, the marginal benefit of additional mitigation is higher than the cost. Thus, further investments produce net benefits. At q^{po}, the slope of total benefit (A) and the slope of total cost (B) are equal, the marginal benefit and marginal cost per unit of mitigation are equal, and the level of mitigation is optimal. As the level of mitigation increases beyond q^{po} up to q^{pi}, where the total costs are the same as the total benefits, the total supply of mitigation still provides positive net benefits but is greater than optimal because the marginal cost of each additional unit of mitigation exceeds the corresponding marginal benefit. Beyond q^{pi}, the total supply of mitigation produces negative net benefits (adapted from Russell, 1970, 386).

Determination of costs

Economic theory suggests evaluating the costs of mitigation measures in terms of opportunity costs, which is the alternative investment of resources in the next-best alternative available to someone who has to select between several mutually exclusive choices. These costs mirror the benefit that would have resulted from an alternative appropriation of the resources. From a practical point of view, the present value of investments in mitigation measures is taken instead since it is almost unfeasible to take into account all possible other alternatives. Apart from any material and labor force needed, the investments necessary for maintenance over the life time of the structures have to be taken into account. The present value of capital expenditures for permanent mitigation measures is calculated using Equation 1, based on the real interest rate, which takes into account inflation and therefore allows comparison of expenditures in different years. Therefore, discounting may change considerably the results of a CBA depending on the choice of the discount rate. From the perspective of society, the use of low discount rates is justified with considerations on intergenerational equity and sustainability. K_n is the present value of the total capital at the expiration of the validity in monetary units, p is the real interest rate in percent, s is the interest period, n the term, and K_0 the opening capital in monetary units. The real interest rate i_{real} is typically calculated on the basis of the nominal interest rate i_{nom} and the inflation J, using Equation 2. The corresponding nominal interest rate is derived from, e.g., the average rate of interest of government bonds in the countries were the study is located.

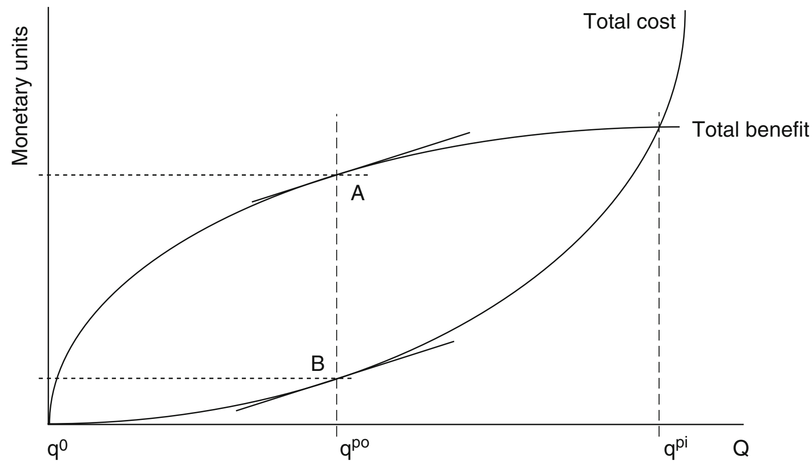
$$K_n = \left(1 + \frac{p \cdot s}{100}\right)^n \cdot K_0 \tag{1}$$

$$i_{real} = \left(\frac{1 + i_{nom}}{1 + J}\right) - 1 \tag{2}$$

Determination of benefit

The accuracy of CBA depends on how accurately benefits (and costs) are estimated and that all costs and benefits are accounted for. Principally, benefits of the impacts of an intervention are evaluated in terms of the public's willingness to pay for these impacts (benefits). The benefit related to mitigation measures can be determined in different ways. However, from a methodological point of view and focusing on the application of CBA in natural hazard risk management, the evaluation is either based on an evaluation of buildings and infrastructure lifelines exposed or with respect to protected human life. Both concepts are therefore separately described below.

- The utility can be defined in the sense of prevented damage to buildings and infrastructure, the so-called method of loss expenses. Because market processes (here for real estate within hazard-prone areas) are able to reflect the real costs, market values, from an economic point of view, are particularly suitable for the determination of possible damage. If, at the time of investigation, the market demand for the buildings is high, their current value may be above the replacement value. If, for example, due to a flood event, there is no demand on the market for those buildings, their value could be zero. The societal preferences of buildings in hazard-prone areas can therefore precisely be



Cost-Benefit Analysis of Natural Hazard Mitigation, Figure 1 Cost-benefit analysis of natural hazard mitigation.

measured, which is the overall aim of such economic methods. However, since the investigation is exactly focusing on buildings in endangered areas, there might be a bias with respect to the socially optimum level of safety. Thus, the replacement value can be used instead as an approximation, neglecting any risk-dependent change in the demand of buildings on the market. Following this method, data concerning the number of potentially affected buildings and their respective replacement value has to be collected. With respect to infrastructure lifelines, the evaluation usually takes place by multiplying their affected length by the value per unit length. These values have to be adjusted to take into account for inflation, and the obtained sums can be directly compared to the respective year of construction.

- In a second set of calculations, the benefit can be evaluated in terms of the number of lives protected (see *Economic Valuation of Life*). The number of persons in the endangered areas is thereby determined on the basis of census data, or the number of domiciles located within areas to be protected by the mitigation measure. Subsequently, a valuation of the number of persons is undertaken in order to place monetary units on human life to be able to calculate the cost-benefit ratios. This step is solely a technical necessity and does not imply that there is a however-defined "value" of human life (which would be an ethical issue that cannot be solved by CBA, compare Adams, 1974). One possibility to achieve such a value does make use of a human capital approach. This procedure can be traced back to approaches in the insurance business, where financial compensation is paid to the immediate family upon the premature demise of the policyholder. The value of human life is calculated as follows: In the study area, the annual gross earned income per working person is identified, for example, by using available statistical information. Subsequently, the average age of the population is achieved and compared to the mean average retirement age. By subtracting these two figures, a remaining average expectancy of working life and a corresponding expected gross income results. Equation 3 is applied to calculate the annuity value R_0 from the payment r, the factor q, and the term n. The factor q is derived summing up the rate of interest i with 1. The rate of interest is calculated by using information on the average rate of interest of government bonds in the countries where the study is located. Applying Equation 3, an annuity value with the interest paid at the end of the period results for the annuity value corresponding to the income of an average person during the remaining working life. This value is subsequently applied in the CBA in order to calculate the benefits resulting from a mitigation measure.

$$R_0 = r \cdot q^{-n} \cdot \frac{q^n - 1}{q - 1} \tag{3}$$

Discussion

Societal and political decisions about mitigation measures concerning natural hazards are generally based on a multiplicity of interests due to the variety of parties involved. Hence, there is a particular need for methodologies ensuring the consideration of all these interests and providing simultaneously a reliable basis for the final decision maker.

However, evaluations of the net benefits of natural hazard protection measures will vary as the local context changes. The relatively high property values in the densely populated regions of central Europe and the USA and relatively high incomes of persons produce net benefits that are higher than they would be in other areas or countries with lower property values and incomes.

Although there may be potential gains in economic efficiency from changing the supply of hazard protection in some areas, the decision to supply more or less avalanche protection is a political one (Gamper et al., 2006). CBA can only inform, rather than answer, the question of how much risk protection the public sector should provide. The choice of how much to invest in mitigation measures depends on the political determination of a standard of protection. The standard may be set in terms of societal preferences such as risk reduction, the level of expenditures, as a target for the maximum number of lives lost, or in some other way. In addition to the need to incorporate CBA into a broader context of political decision making, there are still unresolved issues involved in using CBA as information for decisions about the level of protection against natural hazards. Firstly, most cost-benefit analyses assume that effects should be evaluated with respect to the preferences of individuals (Nash et al., 1975; Adams, 1993). However, since some people benefit more directly from mitigation measures than others, the preferences for the measures may be different among the group of people who live in endangered areas and among those who live outside those areas. Therefore, CBA is affected by whose preferences are used to determine the benefits of mitigation measures. In its traditional form, CBA does not consider the distribution of benefits and costs over individuals, and any increase in net benefits is desirable, regardless of to whom they occur. Secondly, while the utility from protecting property from natural hazards can be determined with relative ease and minimal debate, as the property values are already expressed in monetary terms, the valuation of protecting people from natural hazards requires placing a monetary value on each human life in the absence of objective rules for doing so (e.g., Adams, 1993; Pearce, 1998). The human capital approach presented above raises ethical issues, as it values old people less than young or middle-aged people. Thirdly, problems may arise in the aggregation of material assets and nonmaterial assets, such as an individuals' cognition of safety. Therefore, CBA seems to be an appropriate tool for a relative evaluation of different mitigation alternatives rather than for an absolute evaluation of one individual mitigation measure. CBA is simplified considerably when different alternatives attaining the same utility are evaluated against each other. This approach would apply in the situation where a level of risk acceptance has been set by the relevant community and the question is how to most effectively meet this standard. In order to determine the most competitive alternative, only relative comparisons of cost-effectiveness are necessary, which avoids the problems associated with valuing human lives.

Conclusion

Despite its limitations, economic analyses can contribute by providing information for the political choice of a standard of protection against natural hazards and on how to achieve the socially determined standard. CBA offers a tool for policy decisions because it allows for the comparison of monetary and nonmonetary factors. The comparison of economic costs and benefits is one consideration that may facilitate decision making about protection against natural hazards.

The optimal approach to natural hazards risk reduction depends on the particular hazard, the aims of the affected community, and relevant decision processes. Minimizing human fatalities may be the main priority, with an economic efficiency – thought of as a shift in welfare – as a secondary goal. Although there may be gains in economic efficiency from changing the supply of natural hazard protection, the decision to supply more or less protection is a political one. This decision is related to the society's level of risk acceptance, and should only be discussed on a participative basis.

The potential of CBA depends on its proper integration in the decision-making process as an equitable, transparent, and flexible instrument. Transparency as to assumptions used to calculate costs and benefits and the uncertainty contained in the results will increase the ability of decision makers to use findings of CBA. Decision makers have a responsibility to understand that CBA provides only part of the necessary information for natural hazards planning. Aims other than economic efficiency, such as alternative contextual factors or constraints, provide additional, necessary information for decision making.

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Cross-references

Costs (Economic) of Natural Hazards and Disasters
Damage and the Built Environment
Economic Valuation of Life
Economics of Disasters

COSTS (ECONOMIC) OF NATURAL HAZARDS AND DISASTERS

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Definition and introduction

Given the hundreds of billions of dollars in economic losses that catastrophes have caused in the USA since 2001, it is difficult to remember that when Hurricane Hugo hit the USA in 1989, it was the first catastrophe to inflict more than $1 billion of insured losses. But times have changed and there have been numerous large-scale natural disasters in the USA and other parts of the world in the past two decades that have been far costlier than Hugo both in terms of economic losses as well as fatalities and injuries due to the increasing concentration of population and activities in hazard-prone areas.

In Southeast Asia, the tsunami in December 2004 killed approximately ¼ million people residing in coastal areas. Cyclone Nargis, which made landfall in Myanmar in May 2008, killed an estimated 140,000 people, making it the deadliest natural disaster in the recorded history of the country. During the same month, the Great Sichuan Earthquake is estimated to have killed over 85,000, injured 374,000, and left almost five million homeless (Munich Re, 2008). Deaths from the Haitian earthquake in January 2010 are estimated at 230,000 (Insurance Journal, 2010).

Data reveals that the year 2011 is the costliest year the insurance industry has ever faced with respect to catastrophic losses. The Japan earthquake, tsunami, and nuclear power plant accident in March 2011 caused over US$210 billion in economic losses (not including nuclear-related damage), and insured losses in the range of US$35–40 billion (Munich Re, 2012). This disaster highlights the interdependencies between natural and technological accidents: the 9.0 magnitude earthquake that struck the Tohoku region of northeastern Japan caused a tsunami that hit the country's coastline within half an hour, taking the lives of nearly 20,000 people and destroying over 100,000 buildings, including the cooling system and the backup power generator of the Fukushima nuclear plant. The resulting meltdown of three nuclear reactors led to high radiation levels, which required the evacuation of more than 60,000 people (World Economic Forum Global Risk Report, 2012).

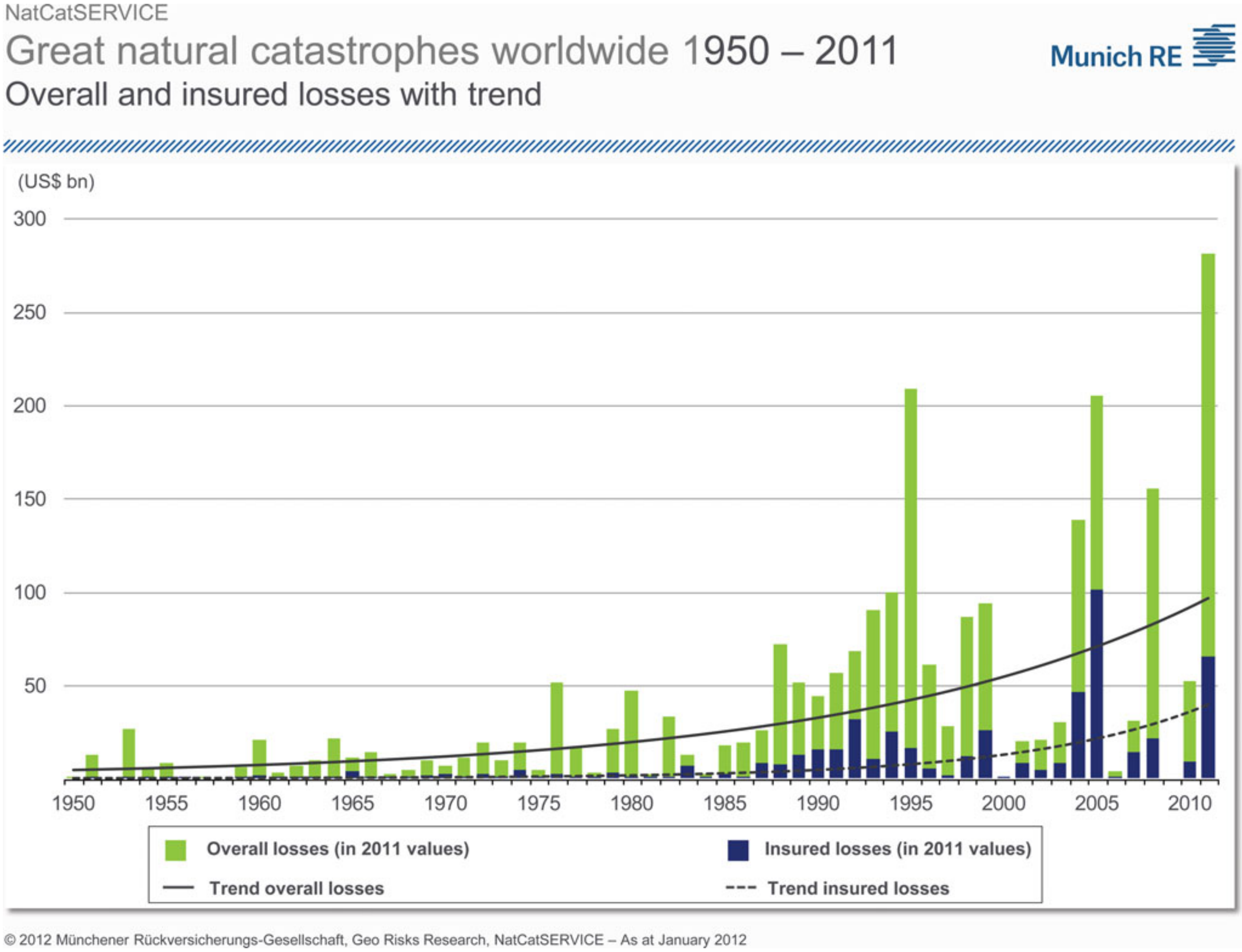
Although the USA has extensive experience with natural catastrophes and the resources to adequately prepare for them, loss-reduction measures and emergency-preparedness capacity are often inadequate to deal with large-scale natural disasters. Hurricane Katrina, which hit Louisiana and Mississippi at the end of August 2005, killed 1,300 people and forced 1.5 million people to evacuate the affected area – a historic record for the country. Economic losses from Hurricane Katrina are estimated in the range of $125–$150 billion (Munich Re, 2010).

Hurricanes in 2008 caused billions of dollars in direct economic losses along the Caribbean basin and in the USA. Hurricane Ike was the most expensive individual event in 2008, with privately insured losses estimated at $17.6 billion in addition to $2.4 billion in claims paid by the US National Flood Insurance Program for flood surge resulting from Ike (Swiss Re, 2009). Based on these figures, Hurricane Ike ranks as the third worst weather-related disaster in US history, after Hurricane Katrina and Hurricane Andrew, which hit southeast Florida in August 1992.

A new era of catastrophes

The economic and insured losses from great natural catastrophes such as hurricanes, earthquakes, and floods worldwide have increased significantly in recent years. According to Munich Re (2012), economic losses from natural catastrophes alone increased from $528 billion (1981–1990), $1.2 trillion (1991–2000) to $1.6 trillion over the period 2001–2011. During the past 10 years the losses were principally due to hurricanes and resulting storm surge occurring in 2004, 2005, and 2008. Figure 1 depicts the evolution of the direct economic losses and the insured portion from great natural disasters over the period 1970–2011.

Catastrophes since 1990 have had a more devastating impact on insurers than in the history of insurance before that time. Between 1970 and the mid-1980s, annual insured losses from natural disasters (including forest fires) were in the $3–$4 billion range. There was a radical increase in insured losses in the early 1990s, with



Costs (Economic) of Natural Hazards and Disasters, Figure 1 Natural catastrophes worldwide 1980–2011 – Overall and insured losses ($ billion) (Sources: Munich Re geo risks research).

Hurricane Andrew in Florida ($24.6 billion in 2008 dollars) and the Northridge earthquake in California ($20.3 billion in 2008 dollars). The four hurricanes in Florida in 2004 (Charley, Frances, Ivan, and Jeanne) collectively totaled almost $35 billion in insured losses. Hurricane Katrina alone cost insurers and reinsurers an estimated $48 billion, with total losses of $87 billion paid by private insurers for major natural catastrophes in 2005.

Table 1 reveals the 25 costliest insured catastrophes from 1970 to 2011 (in 2011 dollars). Of these 25 major events, 15 have occurred since 2001, 14 in the USA. With the exception of the terrorist attacks on September 11, 2001, all 25 of the costliest catastrophes were natural disasters. More than 85% of these were weather-related events – hurricanes, typhoons, storms, and floods –with nearly three quarters of the claims in the USA. Hurricane Andrew and the Northridge earthquake were the first two catastrophes that the industry experienced where losses were greater than $10 billion (designated "super-cats") and caused insurers to reflect on whether risks from natural disasters were still insurable. To assist them in making this determination, many firms began using catastrophe models to estimate the likelihood of, and consequences to, their insured portfolios from specific disasters in hazard-prone areas (Grossi and Kunreuther, 2005).

There is a very clear message from these data. Twenty or thirty years ago, large-scale natural disasters were considered to be low-probability events. Today, they not only are causing considerably greater economic losses than in the past but also appear to be occurring at an accelerating pace. In this context, it is important to understand more fully the factors influencing these changes in order to design more effective programs for reducing losses from future disasters.

The question of attribution

Several elements explain the increased costs of disasters in recent years. These include a higher degree of

Costs (Economic) of Natural Hazards and Disasters, Table 1 Twenty-five costliest insured catastrophes worldwide, 1970–2011

$ Billion	Event	Victims (dead or missing)	Year	Area of primary damage
50.1	Hurricane Katrina	1,836	**2005**	USA, Gulf of Mexico
38.2	9/11 Attacks	3,025	**2001**	USA
35–40	Earthquake and Tsunami	15,840	**2011**	Japan
25.6	Hurricane Andrew	43	1992	USA, Bahamas
21.2	Northridge Earthquake	61	1994	USA
18.5	Hurricane Ike	348	**2008**	USA, Caribbean
15.3	Hurricane Ivan	124	**2004**	USA, Caribbean
15.3	Hurricane Wilma	35	**2005**	USA, Gulf of Mexico
13.0	Earthquake	181	**2011**	New Zealand
11.7	Hurricane Rita	34	**2005**	USA, Gulf of Mexico, et al.
10.0	Floods, landslides	813	**2011**	Thailand
9.6	Hurricane Charley	24	**2004**	USA, Caribbean, et al.
9.3	Typhoon Mireille	51	1991	Japan
8.2	Maule earthquake (M_w: 8.8)	562	**2010**	Chile
8.2	Hurricane Hugo	71	1989	Puerto Rico, USA, et al.
8.0	Winter Storm Daria	95	1990	France, UK, et al.
7.8	Winter Storm Lothar	110	1999	France, Switzerland, et al.
7.3	Storms and tornadoes	350	**2011**	USA
7.0	Hurricane Irene	55	**2011**	USA, Caribbean
6.6	Winter Storm Kyrill	54	**2007**	Germany, UK, NL, France
6.1	Storms and floods	22	1987	France, UK, et al.
6.1	Hurricane Frances	38	**2004**	USA, Bahamas
5.5	Winter Storm Vivian	64	1990	Western/Central Europe
5.5	Typhoon Bart	26	1999	Japan
4.8	Hurricane Georges	600	1998	USA, Caribbean

Sources: Kunreuther and Michel-Kerjan (2011) with data from Swiss Re (2012).

urbanization, and an increase in the value at risk and insurance density. In 1950, approximately 30% of the world's population lived in cities. In 2000, about 50% of the world's population (six billion) resided in urban areas. Projections by the United Nations (2008) show that by 2025, this figure will have increased to 60% based on a world population estimate of 8.3 billion people.

In the USA in 2003, 53% of the nation's population, or 153 million people, lived in the 673 US coastal counties, an increase of 33 million people since 1980, according to the National Oceanic Atmospheric Administration. And the nation's coastal population is expected to increase by more than 12 million by 2015 (Crossett et al., 2004). Yet coastal counties, excluding Alaska, account for only 17% of land area in the USA. In hazard-prone areas, this urbanization and increase in population translate into greater concentration of exposure and hence a higher likelihood of catastrophic losses from future disasters. This new vulnerability is best understood in historical context – that is, compared to the cost of hurricanes in the past. It is possible to calculate the total direct economic cost of the major hurricanes affecting the USA in the past century, adjusted for inflation, population, and wealth normalization. Several studies have estimated how much previous hurricanes would have cost had they hit today. The most recent study by Pielke et al. (2008) normalizes mainland US hurricane damage for the period 1900–2005. Drawing on these data, Table 2 lists the 20 hurricanes that would have been costliest had they occurred in 2005. The estimate for each is a range based on the two approaches to normalizing losses used by the Pielke et al. study. The table provides the year when the hurricane originally occurred, the states that were the most seriously affected, and the hurricane category on the Saffir-Simpson scale. The data reveal that the hurricane that hit Miami in 1926 would have been almost twice as costly as Hurricane Katrina had it occurred in 2005, and the Galveston hurricane of 1900 would have had total direct economic costs as high as those from Katrina. We are very likely to see even more devastating disasters in the coming years because of the ongoing growth in values located in risk-prone areas.

There is another element to consider in determining how to adequately manage and finance catastrophe risks: the possible impact of a change in climate on future weather-related catastrophes. Between 1970 and 2004, storms and floods were responsible for over 90% of the total economic costs of extreme weather-related events worldwide. Storms (hurricanes in the US region, typhoons in Asia, and windstorms in Europe) contributed to over 75% of insured losses. In constant prices (2004), insured losses from weather-related events averaged $3 billion annually between 1970 and 1990 and then increased significantly to $16 billion annually between 1990 and 2004 (Association of British Insurers, 2005). In 2005, 99.7% of all catastrophic losses

Costs (Economic) of Natural Hazards and Disasters, Table 2 Twenty costliest Hurricanes, 1900–2005 (ranked using 2005 inflation, population, and wealth normalization)

Rank	Hurricane	Year	Category	Cost range in 2005 ($ billions)
1	Miami (Southeast FL/MS/AL)	1926	4	140–157
2	Katrina (LA/MS)	2005	3	81
3	North Texas (Galveston)	1900	4	72–78
4	North Texas (Galveston)	1915	4	57–62
5	Andrew (Southeast FL and LA)	1992	5–3	54–60
6	New England (CT/MA/NY/RI)	1938	3	37–39
7	Southwest Florida	1944	3	35–39
8	Lake Okeechobee (Southeast Florida)	1928	4	32–34
9	Donna (FL-NC/NY)	1960	4–3	29–32
10	Camille (MS/Southeast LA/VA)	1969	5	21–24
11	Betsy (Southeast FL and LA)	1965	3	21–23
12	Wilma	2005	3	21
13	Agnes (FL/CT/NY)	1972	1	17–18
14	Diane (NC)	1955	1	17
15	(Southeast FL/LA/AL/MS)	1947	4–3	15–17
16	Hazel (SC/NC)	1954	4	16–23
17	Charley (Southwest FL)	2004	4	16
18	Carol (CT/NY/RI)	1954	3	15–16
19	Hugo (SC)	1989	4	15–16
20	Ivan (Northwest FL/AL)	2004	3	15

Source: Pielke et al. (2008).

worldwide were due to weather-related events (Mills and Lecomte, 2006).

There have been numerous discussions and scientific debates as to whether the series of major hurricanes that occurred in 2004 and 2005 might be partially attributable to the impact of a change in climate. One of the expected effects of global warming will be an increase in hurricane intensity. This increase has been predicted by theory and modeling, and substantiated by empirical data on climate change. Higher ocean temperatures lead to an exponentially higher evaporation rate in the atmosphere, which increases the intensity of cyclones and precipitation. An increase in the number of major hurricanes over a shorter period of time is likely to translate into a greater number hitting the coasts, with a greater likelihood of damage to a residences and commercial buildings today than in the 1940s – a trend that raises issues about the insurability of weather-related catastrophes.

Conclusions

Since the 1990s, a series of large-scale catastrophes have inflicted historic economic and insured losses. Fifteen of the 25 costliest insured catastrophes worldwide between 1970 and 2011 occurred after 2001, and all were natural disasters except for the 9/11 terrorist attacks. The USA has been particularly challenged because 14 of these disasters occurred in this country. The growing concentration of population and structures in high-risk areas, combined with the potential consequences of global climate change, are likely to lead to even more devastating catastrophes in the coming years unless cost-effective risk-reduction measures are put in place.

The task facing the USA and many other countries is ascertaining how to prevent the natural disaster syndrome. Even when risk-reduction measures are available and are cost-effective, many people still do not invest in them because they are myopic and misvalue the upfront costs of these measures as much greater than the expected benefits in reduced damage from disasters in future years. Many victims of Hurricane Katrina suffered severe losses from flooding because they had not undertaken loss mitigation and did not have flood insurance. As a result, an unprecedented level of federal disaster assistance – $81.6 billion (2005 prices) – was provided to these victims and the affected communities (Kunreuther and Michel-Kerjan, 2011).

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CREEP

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Synonyms

Permafrost creep; Rock creep; Soil creep

Definition

Creep is defined as a semi-continuous, time-dependent deformation of solids which occurs at a low rate, under stress imposed by gravity. In Earth Sciences, creep of rock, soil, and frozen ground are distinguished. Not only are they different from the mechanical point of view, but they are associated with different types of natural hazards.

Overview

Soil creep is a very slow downslope movement of the near-surface part of the soil profile, at a rate usually decreasing exponentially with depth. At a depth > 50 cm, the effects of soil creep are hardly visible. It is a combination of different mechanisms, including pure shear, viscous laminar flow, expansion, and contraction. Frequent freeze/thaw and wetting/drying cycles contribute to the efficacy of creep. Creep rate, typically a few centimeters per year, is dependent on slope angle, cohesion of soil material, climatic conditions and biotic factors (vegetation cover, animal trampling). In the most favorable circumstances, e.g., on steep tropical slopes, rates approaching 0.5 m year^{-1} have been observed. Terracettes and bent trees (Figure 1) are noted as typical surface indicators of soil creep.

Creep, Figure 1 Bent trees are commonly viewed as an evidence of soil creep.

Rock creep is a unique behavior of solid rock and occurs under two circumstances. It may affect heavily fractured rock masses near the surface, which deform by joint opening and shearing along joint surfaces. Primary structural discontinuities bent downslope are the evidence of near-surface creep. Rock creep is also known to occur at great depths under considerable lithostatic stress, mainly in weak sedimentary rocks, particularly evaporates. Tunnel closures and excavation-wall buckling are typical manifestations of rock creep.
Permafrost creep is a term used to describe deformation of ice-saturated debris bodies, typically rock glaciers and protalus lobes, primarily under their own weight. However, doubts are expressed if this expression is correct, as permafrost is commonly understood as a thermal state of lithosphere.

Creep, being a deformation occurring at rather low rate, is rarely hazardous, although it may result in weakening of building foundations and tilting of trees and other vertical man-made structures (e.g., poles, masonry walls, gravestones) in the longer term, the latter leading to their collapse. However, creep may be a precursor to much more rapid deformations, in the form of either a mudslide (for soil creep) or rock slope failure (for rock creep). Rock creep may also cause severe problems in mine operations and transportation tunnels. Acceleration of creep usually occurs prior to a catastrophic yield. Therefore, in areas identified as potentially hazardous, the rate of creep should be monitored.

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Cross-references

Landslide Types
Mass Movement

CRITICAL INCIDENT STRESS SYNDROME

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Synonyms

Acute stress disorder; Acute stress reaction; Post-traumatic stress disorder; Traumatic stress

Definition

Experiencing trauma is an essential part of being human, yet most people who experience critical incidents survive without developing psychiatric disorders. However, traumatic experiences can alter people's psychological, biological, and social equilibrium (van der Kolk et al., 1996).

Normal reactions

Most people exposed to critical incidents or traumas do not go on to develop psychiatric disorders; in fact, there is literature to support that there is the potential for post-traumatic growth following trauma (Linley and Joseph, 2004; Joseph and Linley, 2005; Paton, 2005). Natural disaster victims and their significant others who have been exposed to a sudden event that precipitates fear of injury or loss of life can respond to the traumatic event with a wide range of physical and emotional responses. Simply witnessing such an event can also produce psychological, social, and physiological dysfunction. Natural, technological, and other types of disasters (i.e., man-made, terroristic) expose innumerable people to scenes of destruction and human loss, and they can react with a classic set of symptoms similar to an acute stress reaction. Their emotional responses to disasters may be conceptualized as progressing through a number of phases. During the impact phase within the first few days, individuals often feel stunned and in shock. In these early days, individuals may also experience disbelief, numbness, fear, and confusion to the point of disorganization (Lubit, 2008). In the crisis phase, individuals may alternate between denial and intrusive symptoms with hyperarousal and may experience any number of somatic symptoms as well as irritability, apathy, and social withdrawal. Here, persons may become angry with caregivers who fail to solve problems and/or may be unable to be organized in the chaos of dealing with the crisis (Lubit, 2008). During the resolution phase, grief, guilt, and depression may be prominent and last through the first year as people continue to cope with their numerous losses, and finally, in the reconstruction phase, reappraisal, "meaning-making," and the integration of the event into a new self-concept occurs (Lubit, 2008).

Epidemiology

Epidemiological surveys of large groups of the general public have been done to determine exposure to various traumatic events. Researchers concluded that lifetime exposure to traumatic events may be as high as 73.6% for men and 64.8% for women (Solomon and Davidson, 1997). The lifetime prevalence of those individuals who will experience post-traumatic stress disorder (PTSD) at some point in their life varies from 7.8% (Kessler et al., 1995) for all to 5% of men and 10–12% of women (Solomon and Davidson, 1997). This figure jumps from 3% to 58% for "at risk individuals" (APA, 1994). Individuals may be at an increased risk for the development of PTSD if they witness an event that involves death, interpersonal violence, grotesque sensory images, or some natural disasters. It is also important to remember that critical incident stress may affect professionals (e.g., police, fire, health-care professionals, and others) working in the field with victims of disasters (Paton and Violanti, 2011).

Complications

Two possible complications following exposure to a disaster include the development of acute stress disorder (ASD) and PTSD. Guidelines established by the Diagnostic Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM-IV-TR) remain the gold standard for diagnosing ASD and PTSD. For both disorders, the individual must have been exposed to or witnessed a traumatic event that involved actual or threatened death, serious injury, or a threat to physical integrity in addition to responding with fear, helplessness, or horror. Additional symptoms seen in both disorders include reexperiencing the traumatic event, avoidance of stimuli associated with the traumatic event, and increased arousal. Reexperiencing the trauma may occur through intrusive recollections, nightmares, flashbacks, hallucinations, and psychological distress/physiological reactivity upon exposure to cues that symbolize the trauma. Symptoms of avoidance include efforts to avoid thoughts, feelings, or conversations associated with the trauma, inability to remember certain aspects of the trauma, reduced interest in activities, feeling detached from others, and a sense of a foreshortened future. Symptoms of increased arousal include difficulty with sleep, irritability/angry outbursts, poor focus, hypervigilance, and exaggerated startle response. Lastly, in both disorders, the symptoms cause significant distress or impair the individual's ability to function (APA, 1994).

Differences between the two diagnoses include the time frame and the occurrence of dissociative symptoms. The onset of ASD must occur and resolve within 4 weeks of the traumatic event. Additionally, in ASD, the individual experiences dissociative symptoms during exposure to the trauma or immediately following the trauma. In PTSD, the duration of the symptoms exceeds 1 month. PTSD can also be classified as acute (duration of symptoms is less than 3 months), chronic (duration of symptoms is greater than 3 months), or delayed (duration of symptoms is at least 6 months after the stressor).

There is emerging evidence that there is a potential for positive outcomes following exposure to trauma. Paton (2005) and others (Tedeschi and Calhoun, 2003) have identified post-traumatic growth, enhanced professional capability, greater appreciation of family, and increased sense of control over significant adverse events as adaptive outcomes that may occur following a crisis. Factors that influence positive growth include personal resilience and vulnerability factors.

Treatment

Following exposure to a trauma, it is necessary to ensure a sense of safety. Provision of basic needs including food, clothing, and medical care must be met as well as ensuring that survivors are protected from reminders of the event, if possible; the onlookers; and the media. Mobilization of family members is critical, as social support networks may provide an important resource for coping with the aftermath of a traumatic event. It is also important to assist the survivor in reestablishing a sense of efficacy through education about stress responses and normal versus abnormal symptoms, as well as strategies to reduce anxiety.

Psychotropic medications should be used sparingly in the first 48 h following a natural disaster or trauma unless the individual is experiencing psychotic symptoms or their behavior is presenting a danger to themselves or others. If this is the case, a fast-acting benzodiazepine and/or an antipsychotic may be warranted as described in guidelines for managing agitation (Yildiz et al., 2003). Individuals who are experiencing acute panic symptoms and severe insomnia may benefit from a short-term (<1 week) prescription for benzodiazepines; however, early administration of benzodiazepines may be associated with a higher incidence of PTSD (Gelpin et al., 1996). According to the American Psychiatric Association (APA) practice guidelines, selective serotonin reuptake inhibitors (SSRIs) and serotonin-norepinephrine reuptake inhibitors (SNRIs) have shown superiority over placebo for noncombat-related PTSD (Benedek et al., 2009).

Conclusions

Exposure to a natural disaster or another traumatic event can disrupt an individual's physical, emotional, and psychosocial functioning. Besides providing emotional support, psychoeducation, improvement in coping skills, and reestablishment of a sense of resilience, a thorough assessment of the individual's symptoms and impairment in functioning is essential. There are numerous assessment scales available (Keane and Wilson, 2004; Norris, 1990) that can be utilized to assist in this process. In addition, screening the person for ASD and/or PTSD utilizing DSM-IV-TR diagnostic criteria is also necessary. Although medications should be used judiciously in the first days following a trauma, SSRIs have been found to be beneficial in the treatment of PTSD.

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Cross-references

Adaptation
Coping Capacity
Disaster Relief
Education and Training for Emergency Preparedness
Emergency Management
Federal Emergency Management Agency (FEMA)
Human Impact of Hazards
Natural Hazard
Resilience

CRITICAL INFRASTRUCTURE

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Synonyms

Lifelines; Lifeline utilities

Definition

The term critical infrastructure is used to cover physical and organizational structures that provide services that are estimated to be essential to the functioning of society. Hence it is feared that the unavailability of critical infrastructure services may have severe consequences for basic societal needs.

The functioning of critical infrastructures depends to varying degrees on personnel and resources (material as well as information resources). The provision of critical infrastructure services in many cases involves the private sector. Public interest in their availability has frequently been articulated, e.g., in critical infrastructure protection policies (for an overview, see Brunner and Suter, 2008). Conventionally, concrete sectors, such as communication infrastructure or energy infrastructure, are listed in these policies. As most critical infrastructures are characterized by a high degree of (inter) dependencies, a failure in one sector is likely to affect others.

Among others, natural hazards are held to be threats for critical infrastructures and the services they provide. Destruction of critical infrastructure and service outages may initially cause severe problems and/or aggravate the situation in the course of events, most notably when services are needed to carry out relief measures to mitigate the immediate impact, and during recovery and reconstruction. Vulnerability and risk assessments as well as safeguards and risk-management measures may either focus on the level of single infrastructure components and/or opt for a system perspective.

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Cross-references

Disaster
Disaster Relief
Disaster Risk Management
Exposure to Natural Hazards
Hazard
Hospitals in Disaster
Information and Communication Technology
Mitigation
Natural Hazard
Post Disaster Mass Care Needs
Recovery and Reconstruction After Disasters
Risk Assessment
Vulnerability

CRYOLOGICAL ENGINEERING

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Synonyms

Cold regions engineering; High mountain engineering; Northern engineering; Permafrost engineering

Definitions

Cryosphere. That part of the earth's crust, hydrosphere, and atmosphere subject to temperatures below 0°C for at least part of each year.
Cryology. The study of materials having a temperature below 0°C.
Geocryology. The study of earth materials having a temperature below 0°C.
Engineering. The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all to meet an intended function, economics of operation, and safety to life and property (cf. American Engineers' Council for Professional Development). Additionally, the planning for, and maintenance of, a sustainable lifetime performance of the design object and its environment is essential.

Introduction

Generally, *Cryological Engineering* can be considered as the application of scientific principles to any design assignment that is subjected to temperatures below 0°C. The engineering disciplines that are most likely to be related to cryological engineering are civil, geotechnical, and mining, in particular when linked with projects in cold regions, such as northern and southern latitudes or high elevations. In recent years, engineering projects and developments in these cryospherical environments gained in importance due to access required to enable mining of natural resources (e.g., in the high Andes and the Arctic), resource transportation (e.g., pipelines), or in improving infrastructure and accessibility (e.g., Qinghai–Tibetan railway and railroad). But also in the aviation and space industry and science, subfreezing conditions are of importance either for the design of aircrafts, space, Moon or Mars stations, or just for the study of extraterrestrial processes.

The cryosphere

The cryosphere may be divided into the cryoatmosphere, the cryohydrosphere (snow cover, glaciers, ice caps, ice sheets and river, lake and sea ice), and the cryolithosphere (perennially and seasonally cryotic ground). Some authorities exclude the earth's atmosphere from the cryosphere (e.g., UNEP, 2007); others restrict the term "cryosphere" to the regions of the earth's crust where permafrost, that is, perennially frozen ground, exists (Baranov, 1978). However, for engineering purposes, it is important to understand the physical differences in the materials that may be encountered and used as foundations or construction materials from the cryosphere, which include snow, firn, and ice in special forms, such as sea ice, glacier ice, pore ice, segregated ice, ground ice, ice shelves or ice bergs, just to name a few.

However, good knowledge about the special conditions that prevail in the cryosphere is required for the design of conditions that are artificially induced, such as artificial ground freezing used to increase the strength of the ground temporarily to build tunnels, caverns, or shafts (e.g., Harris, 1995).

Divisions of cryological engineering

Cryological engineering is complex and can, therefore, be seen as sub-categories in a series of engineering disciplines. Figure 1 illustrates some aspects of cryological engineering that demonstrates the variety of engineering disciplines involved. *Geotechnical* engineers design foundations and dams, and assess slope stability or general geohazards due to ground ice degradation. *Road* engineers design road surfaces that resist the harsh climatic conditions, which also affect the design of towers, buildings, and bridges that have to be designed by *structural* and *civil* engineers. *Mechanical* engineers have to consider the effect of subfreezing temperatures in their designs; in particular for moving elements where freezing water or the temperature-dependent material behavior may affect a machine's performance over its lifetime, which may also be reduced by repeated cycles of freezing and thawing. These examples are not exclusive and aspects of cryological engineering can probably be found in any engineering field.

Although the engineering problems are diverse, the main challenge is similar for most disciplines, that is, the change in the mechanical behavior of unfrozen material versus frozen materials – in other words the differences in the physical response of a material containing fluid water opposed to ice.

Engineering challenges

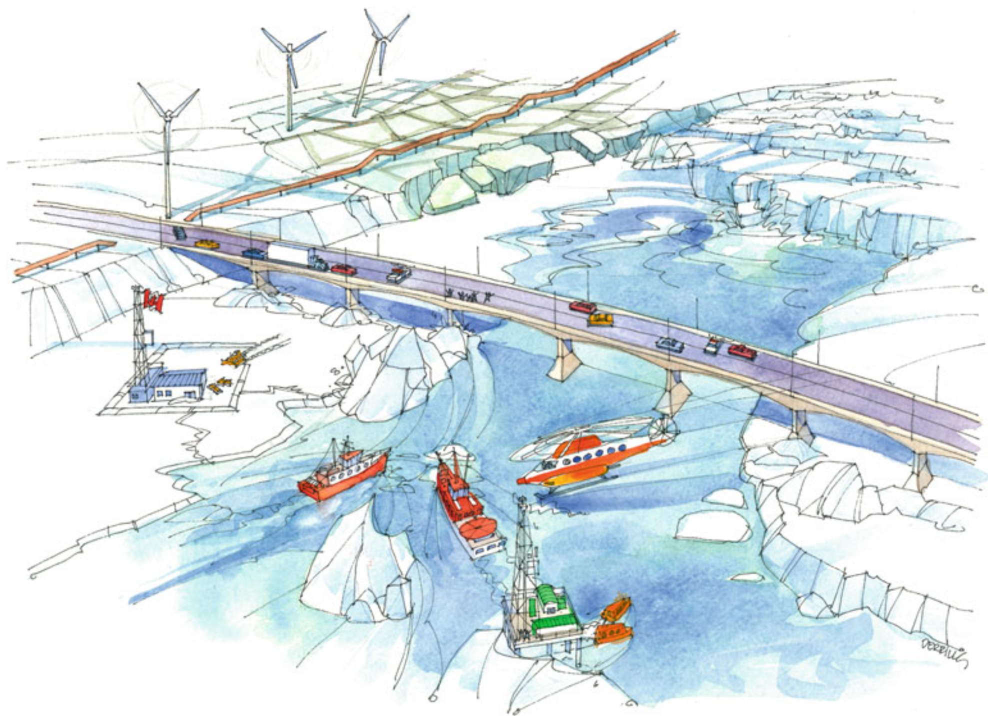
The challenges associated with cryological engineering are as diverse as the projects. A good understanding of the *material properties* is essential. Phase changes (i.e., latent heat effects), thermal expansion, viscosity of ice, fatigue, and self-healing mechanisms as well as the temperature- and loading-dependent material stiffness are only some aspects that need to be considered. Andersland and Ladanyi (2004) or Paterson (1994) provide/provides valuable overviews on frozen ground and glacier physics. Figure 2 shows a diagram that illustrates schematically how the mechanical response of a frozen soil varies as a function of the loading conditions, temperature, and ice content. The differences in the mechanical response may result in variations of several magnitudes in the strength response and are, therefore, crucial for a sustainable foundation design. In addition, spatial variations and heterogeneities in the ground conditions pose problems in creating a standard design for linear infrastructure foundations, for example, and continuous in situ adaptations are often required in the field. Therefore, flexible engineering solutions are required.

The challenges from the material properties are, however, only one element to be considered in cryological engineering designs. Often more expensive are challenges related to the *logistics*, such as the remoteness of the construction site, available resources (e.g., gravel for concrete), or access in steep and high mountain environments. But also the effect of the harsh climatic conditions with cold temperatures and dark days at high latitude, or major diurnal air temperature variations and low oxygen levels in high mountain areas, are wearing on equipment and working crews. The logistical challenges and remoteness of some construction sites often result in limited information for the design, such as site investigation or historical climate data. The latter are important in predicting and designing for future climate change effects. Generally, the cryosphere is often found in environments that are ecologically very sensitive and it is, therefore, important to understand how a planned structure affects it and what adaptation strategies are required.

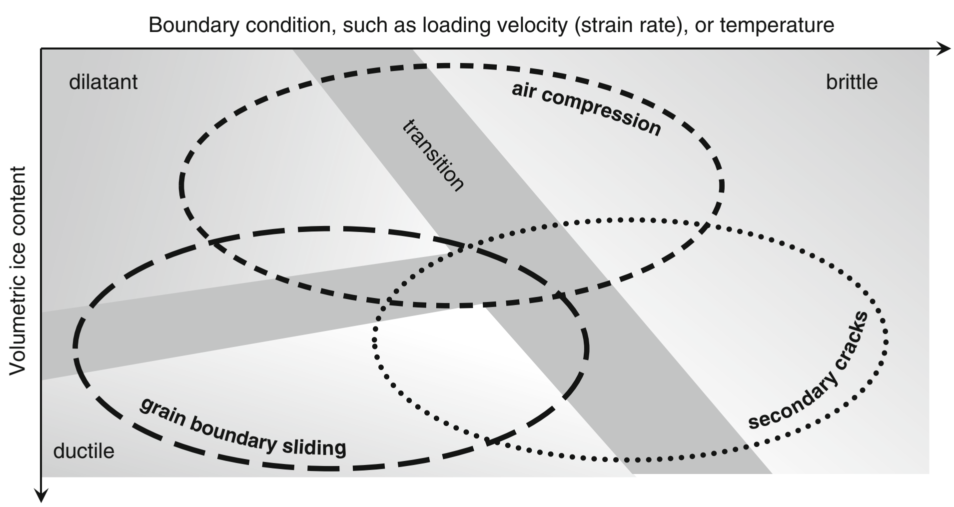
Not only local aspects are to be considered in the design process, but larger-scale effects may become important. For example, the cryogenic conditions of the surrounding landscape may change in the future, so that formerly stable, frozen slopes become unstable and transform into a potentially dangerous debris flow source zone. Hence it is important to familiarize oneself with the proximate surroundings, and with the general environment and landscape. A summary of these problems is presented in Bommer et al. (2010) for mountain permafrost environments.

Solutions

As with most engineering projects, in particular with civil projects, designs are typically prototypes, and no real testing is possible. Because of this unique situation, and the



Cryological Engineering, Figure 1 An overview of the diversity of cryological engineering (Illustration by Derrill Shuttleworth).



Cryological Engineering, Figure 2 Schematics of the dependency of the response mechanism of frozen soil on the boundary conditions (After Arenson and Springman, 2005).

challenges indicated above, special care is required during the design, construction, and operation of an engineered structure. Successful cryological engineering requires enough resources for planning in terms of time and financial means. It is important to have a good spatial representation of any data and long time series that allow for statistical trend analyses. Designs are to be favored that minimize the impact on the environment, notwithstanding the uncertainty about ongoing climate change over several decades. However, the environmental sensitivity and complex interactions between climate, foundation, and structure require designs to be adaptive, and the incorporation of an observational approach is essential. Ongoing data evaluation and updating predictions should be a crucial part in the structure's operation and maintenance plan to monitor a structure's performance effectively. Redundancies, designed and implemented in time, help in minimizing any operational interruption in the future due to unforeseen changes in the boundary conditions. An estimation of project vulnerability, hazard, and associated risks is critical for the decision-making process and should also be carefully planned ahead of time.

Cryological engineering projects are, therefore, often expensive and require more resources for project management than similar projects in unfrozen environments. The project lifetime is often to be chosen shorter, or design re-evaluations are required at regular intervals (e.g., 20–30 years) and are to be accounted for in the original design process. In particular, the effects of climate change, including second- and third-order effects that are almost impossible to predict, have to be analyzed regularly, especially for sensitive structures and locations.

While the challenges of cryological engineering are substantive, various innovative solutions have been presented in recent years or are currently being evaluated. These include adjustable foundation designs (e.g., Phillips et al., 2007) or standardized protocols are in development to account for the potential impacts of climate change (e.g., CSA, 2007). Additional resources are listed in the bibliography to assist in cryological engineering designs.

Summary

Cryological Engineering implies the adaptation of multidisciplinary engineering processes to account for cryological conditions in subfreezing environments. When liquid water turns into ice, several physical processes change and this has to be considered in the design. However, the effect of the structure on its environment or climate change may result in current cryogenic conditions changing into non-cryogenic ones with time. The structural integrity or the serviceability of the engineered structures may be affected by such changes in the boundary conditions. It is, therefore, critical to consider such potential changes adequately in an adaptable design that has been developed on the basis of thorough investigations and historical data analyses.

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Cross-references

Climate-Change
Frost Hazard
Geohazards
Glacier Hazards
Ice and Icebergs
Impact Winter
Paraglacial
Permafrost

CULTURAL HERITAGE AND NATURAL HAZARDS

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Definition

Cultural heritage is understood as the legacy of past generations which is maintained by the present one and intended to be passed on to future generations. It can be intangible (customs, beliefs) and tangible, the latter including various physical objects, from human-transformed landscapes (e.g., paddy rice fields on hillslopes) through places, buildings, monuments, to movable artifacts. The significance of cultural heritage may be local, regional, or global. The most valued places are those with the status of World Heritage granted by UNESCO.

Natural hazards may adversely impact tangible cultural heritage, but in specific instances, the remains of an inhabited place, or a building, may become a valuable component of cultural heritage because of their destruction by natural forces at some time in the past. Likewise, stories of ancient catastrophes have become a part of the intangible heritage of many societies.

Introduction

Relationships between cultural heritage of humankind and natural hazards are many and complex. Hence, many interrelating themes appear within the subject, including:

(a) Damage or destruction of cultural heritage due to natural catastrophic processes of various sorts
(b) Problems of adequate protection of cultural heritage sites against natural hazards
(c) The occurrence of globally or regionally significant representatives of ancient cultural heritage which have undergone catastrophic destruction by natural forces and have now become highly valued cultural properties because of their history of destruction
(d) The presence of natural hazards and catastrophes in oral folk traditions, hence a part of intangible cultural heritage

Natural hazards affecting cultural heritage properties do not form a specific category of hazards in terms of process or effect. Sites of cultural significance may become affected by catastrophic events of either endogenous (earthquakes, volcanic eruptions, tsunami) or exogenous origin (landslides, floods, ground collapses, wildfires, cyclones) (Smith, 1996), for which little or no warning has been received (particularly prior to the twentieth century). However, these sites may also suffer from processes which are not catastrophic in the conventional sense (i.e., have not appeared suddenly) but their cumulative effects in the long term may have a highly adverse impact. These include ground subsidence, especially in coastal settings, accelerated weathering of building stone, sandstorms, and recession of coastal cliffs.

Natural processes and loss of cultural heritage

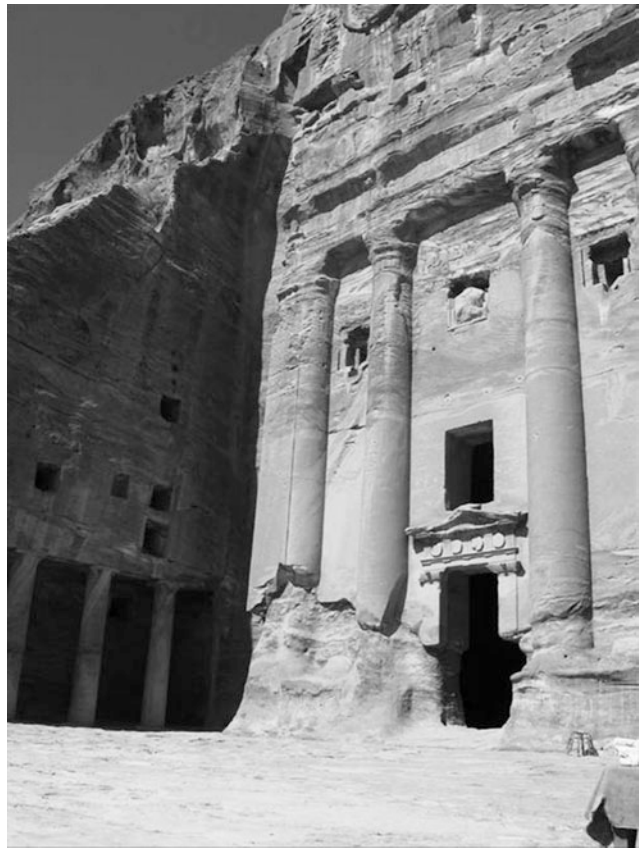
Natural catastrophes have been known to affect and occasionally destroy material evidence of human activities since prehistory. Those from the most distant past are often shrouded in uncertainty and subject to scientific debate, such as the probable destruction of Sodom and Gomorrah located in the Dead Sea Graben due to an interaction of earthquakes, natural gas explosions, and fire. Volcanic eruptions were among the most devastating, able to wipe out island populations, as on the Aegean island of Santorini in the fifteenth century BC. At a more local scale, pyroclastic flows from Vesuvius were responsible for the total destruction of Pompeii and Herculaneum in 79 AD, whereas lava flows destroyed and buried the native American ceremonial center at Cuicuilco (present-day Mexico City) in the first century AD. Likewise, deteriorating environmental conditions in the longer term, particularly droughts, are often suspected as reasons for apparent declines of once mighty societies and political entities. It is widely believed that decreasing rainfall and diminishing river flows resulted in temporary or ultimate collapses of early “hydraulic” civilizations such as the Old Kingdom of Egypt around the twenty-second century BC or the great Harappan civilization of the Indus Valley, where channel changes may also have been important. More controversially perhaps, fragmentation of the Mayan states and an apparent decline of many Mayan cities in the eighth to eleventh century has been attributed to climate changes, mainly increasingly unreliable rainfall. More recent societies may also have been vulnerable, especially those living in marginal conditions. The demise of Nordic settlements in Greenland in the thirteenth/fourteenth century was influenced by climate cooling and the advent of the Little Ice Age.

The concept of cultural heritage was apparently present among ancient societies as early as the third century BC. In the Hellenistic world, its reflection was the list of Seven Wonders of the World, which was also the list of “must-see” places for ancient travelers. It included objects and sites, from Greece to Babylon, then considered absolute masterpieces of human genius. Only one of them – the Great Pyramid of Giza – has survived until today. Among the other six, three have been damaged by earthquakes. The Colossus of Rhodes tumbled down around 227 BC, the Pharos Lighthouse in Alexandria finally in the fourteenth century AD, whereas the Mausoleum in Halikarnassos (today Bodrum), destroyed by floods and earthquakes and rebuilt several times, eventually disappeared in the fifteenth century.

In recent decades, many significant sites of cultural heritage have suffered damage, occasionally irreversible, from natural processes. Mud-brick walls of an ancient fortress in Bam, Iran, largely crumbled during an earthquake on December 26, 2003, whereas numerous components of the famous Dujiangyan Irrigation System in the Sichuan province, China, dated to 256 BC, collapsed during the Wenchuan earthquake on May 12, 2008. Earthquake-induced ceiling collapse in the basilica of Assisi, Italy, in 1997 led to the destruction of unique frescoes from the thirteenth/fourteenth century. The revered pre-Columbian site of Chan Chan in northern Peru, built of dried mud brick, greatly suffered from several floods related to El Niño years. Widespread forest fires in western Peloponnese, Greece, in August 2007, put at serious risk the site of ancient games at Olympia, destroying parts of the surrounding landscape. Subsequent to fire, soil erosion from burnt slopes became an issue and a widespread erosion control project was undertaken. Floods tend to threaten historical cities located in the valley floors, late twentieth century examples being inundation of downtown Florence (Italy) in 1966 and parts of Cologne (Germany) in 1993 and 1995.

For cultural heritage sites, slow-acting natural processes may be devastating too. However, it is useful to make a distinction between those processes which are an intrinsic part of the natural environment and those which have been induced, or accelerated, by human activities. This differentiation has considerable implications on the choice of remedial solutions toward preservation of sites under threat. Many ancient temples were located along shores, on exposed cliffs and promontories. Long-term transport of salts derived from sea-spray and its subsequent crystallization has affected building stones and caused disappearance of various fine architectonic details, particularly if these were built of easily weathered limestone (e.g., the megalithic temples of Malta, and the Poseidon temple at Cap Sounion near Athens). Salt weathering is also of considerable concern at the UNESCO site of Petra, Jordan. Both scarp-foot and mid-wall weathering, influenced by capillary rise and seepage respectively, have caused widespread damage to the finely carved facades of rock-hewn tombs (Figure 1). Rock/cave art is another highly valued legacy of past cultures that is highly susceptible to weathering and in many places suffers from rapid deterioration. In Calatayud, Spain, slow gypsum dissolution underneath the medieval city results in extensive ground subsidence and building destruction. Sea level changes affected the historic Serapis temple in Pozzuoli, Italy, as well as numerous other Mediterranean examples. In urban and industrialized areas, however, damage experienced by buildings of cultural significance can be often ascribed to anthropogenic sources of salt and air pollution (Goudie and Viles, 1997). In the context of aeolian processes, human impact has been suggested as the reason behind the damage of western sections of the Great Wall in Gansu province, China. In the last 20 years more than 40 km of this unique construction disappeared or was severely reduced by sand blasting during windstorms, and destructive farming methods with consequent enhanced dust production are considered responsible (http://www.msnbc.msn.com/id/20492488/ns/world_news-world_environment/t/sandstorms-eating-away-chinas-great-wall/(retrieved 2012-03-18)).

Coastal erosion is another process to impact building constructions located on cliffs and along beaches. Usually, the coast sections under threat are those undergoing slow long-term recession, but major damage is experienced during storm episodes, when wave energy is sufficient to induce cliff undercutting, leading to rock fall or retrogressive landslides. The southern coast of England hosts many examples of cultural heritage objects affected by cliff recession, from ancient Roman forts to remains from World War II (Bromhead and Ibsen, 2006), as do Mediterranean coasts. In Tanzania, beach erosion and wave inundation threat the integrity of ancient harbors of Kilwa Kisiwani and Songo Mnara. Coastal subsidence is of major concern too, the best known example being Venice, Italy. High floods, the famous *acqua alta*, have increased in frequency, causing weakening of building foundations and setting the stage for accelerated weathering.



Cultural Heritage and Natural Hazards, Figure 1 The unique cultural legacy of Petra in Jordan is under threat from various geomorphic processes, including salt weathering. The picture shows two zones of accelerated rock breakdown and deterioration, caused by capillary rise (near the bottom) and seepage (in the middle of the facade) (Photo P. Migoń).

Significant sites of cultural heritage: Evidence of ancient natural catastrophes

Our cultural heritage consists of objects and sites of various origin, context, and age. Many such objects are treasured because they have survived largely intact since the very distant past, occasionally even from prehistory. Their maintenance in a condition as close to original as possible is now the priority of conservation efforts and a significant constraint in access policy. Hence, any damage arising from any cause is considered highly detrimental for the integrity of a site. However, a considerable number of much valued cultural heritage sites, including many listed as UNESCO World Heritage properties, bear evidence of either natural catastrophes or slow deterioration. These natural processes once led to the abandonment of the sites, occasionally destruction, and their subsequent

Cultural Heritage and Natural Hazards, Figure 2 The ruined church tower rising from lava field north of the Paricutín volcano, Mexico, overwhelmed by lava in 1944, is already visited as a cultural heritage site (Photo P. Migoń).

disappearance from human memory. Much later archaeological work unearthed these sites as they appeared in ancient times, offering thereby unique insights into the past, not obstructed by subsequent societal and architectural developments. Examples come from different parts of the world, from the Mediterranean realm through the Middle East to the Far East, as well as from Central America.

Perhaps the best known example is Pompeii near Naples in Italy, the remains of a wealthy town buried by pyroclastic flow deposits from the eruption of Vesuvius in 79 AD. Excavations carried out since the eighteenth century, and more comprehensively since 1863, have revealed an astonishingly complete picture of daily life in the Roman Empire, with no parallels from elsewhere in the Mediterranean region. Interestingly, archaeological work has also shown evidence of earlier damage by a strong earthquake in 62 AD. Another important archaeological site is Akhrotiri on the Island of Thera (Santorini), likely abandoned just prior to the catastrophic explosion of Santorini volcano in the fifteenth century BC and then buried by many meters of pyroclastic deposits. Excavations, initiated in 1967, brought to light many details of the Minoan culture, including unique frescoes. Many ancient sites or buildings suffered from high-magnitude earthquakes, such as Kourion (Curium) in Cyprus in 365 AD, abandoned soon after. Archaeological work has not only revealed remnants of important buildings of the ancient city, but opened a window on the everyday life of this important, predominantly Christian settlement. The evidence of ancient earthquakes is common at archaeological sites in Asia Minor (e.g., Hierapolis) and along the Dead Sea Rift (e.g., Jericho). Patterns of building destruction are now used as important palaeoseismological tools (Hancock and Altunel, 1997).

River mouth siltation and channel changes have contributed to the decline and later abandonment of many important settlements of antiquity. Today many of these sites, excavated and partially reconstructed, are cherished sites of cultural heritage and important tourist attractions. They also tell instructive stories of how people interact with nature and how things can go wrong. Excellent examples are provided by ancient Greek-Roman cities in Asia Minor, along the Aegean coast, such as Miletus or Ephesus. Once important harbors and trading posts located at river/sea junctions, they declined concurrently with delta buildup, often considered a response to accelerated soil erosion in the hinterland.

Today, damage brought by natural events is usually repaired as quickly as possible. With current technological advances and international aid, the evidence of destruction may be obliterated in a few years and rebuilding sites of cultural heritage is often a priority. Very few places are left as standing memories of violent natural processes and these, over time, may join the family of cultural heritage sites. One such object is the ruined church at a site of the former town of San Juan Parangaricutiro in Mexico,

Cultural Heritage and Natural Hazards, Figure 3 The remains of a medieval church in Trzęsacz, northern Poland, atop a Baltic Sea cliff. The church was built in the fifteenth century about 1 km from the cliff edge, but long-term cliff recession resulted in a few successive collapses since 1900. Today the site is considered to be of special cultural importance and protected against further cliff erosion. However, erosion continues unabated next to the site (Photo P. Migoń).

the only survivor of a lava flow issued by the Paricutín volcano in 1944 (Figure 2). Others include sites near Pinatubo volcano in the Philippines.

Protection of cultural heritage against natural hazards

Natural hazards affecting cultural heritage properties do not form a specific category of hazards in terms of process or effect. It is the vulnerability and universal value of these properties which is decisive for the increasing risk experienced by cultural heritage sites. Mitigations and risk reduction strategies should consider characteristics of natural processes potentially affecting a site, particularly the likelihood of its occurrence in a specified period, the magnitude of expected damage, and the feasibility of preventive actions. Further, any potential human contribution to the hazard needs to be identified.

In many instances, hazards are simply unavoidable as the properties cannot be relocated to safer places. This applies to all cultural heritage sites in seismic zones and in the vicinity of active volcanoes. Many great heritage cities have been built along active fault zones and their cultural legacy is at particular risk from high-magnitude earthquakes (e.g., Istanbul, Athens, Mexico City, Kyoto). Construction strengthening is practically the only measure which can be undertaken. Others cities are located in zones prone to pyroclastic flows from volcanic eruptions (e.g., Naples, Mexico City). Large tsunamis can affect cultural heritage sites along seismogenic coasts of the Mediterranean Sea, southeast Asia, and the Pacific Ocean, as they did in Lisbon in 1755. Some sites, e.g., the Inca site of Machu Picchu, are located on hillslopes conducive to slope failures and these, if occur, may irreversibly damage the entire property.

Surface processes, such as shallow landslides, mudflows, or floods, can be predicted with more confidence and there is a choice of mitigation strategies. Landslide hazard and risk mapping is now routinely carried out and helps to identify the most vulnerable places. After these are identified, various methods of slope stabilization, depending on the type of mass movement likely to occur, may be used to protect a cultural heritage site. These include rock slope strengthening, reduction of slope angle, drainage diversion or improvement, bioengineering, and others (see Sidle and Ochiai, 2006). Flood hazard may be reduced by bank strengthening and dyke heightening adjacent to a site of concern, but these measures may not be sufficient during low-frequency, high-magnitude floods. It is also important to remember that for flood mitigation schemes to be effective, they should be designed for entire catchments and those for cultural heritage sites specifically need to be integrated within catchment-wide strategies. Valuable cliff-top sites may be protected by various coastal defenses, including sea walls, artificial boulder beaches, and concrete tetrapods (Figure 3). However, coasts are complex systems of mass transfer from one place to another and emphasis on preventing erosion and cliff recession in one locality may result in accelerated erosion in an adjacent locality. There are also different methods available to avert salt weathering and ground salinization, such as the UNESCO attempt to rescue Mohenjo Daro, Pakistan, by reducing the water table and hence the capillary rise of salt. Any preventive action is bound to be very costly (e.g., plans to build protective barriers at the entrances to the Lagoon of Venice) and often there is no guarantee that the effects will be satisfactory.

An important part of disaster prevention and risk management programs at sites of cultural significance should be adequate preparedness (Spennemann, 1999; Taboroff, 2000). Ideally, it includes components such as hazard assessments for each natural process likely to occur, individual emergency plans integrated with disaster plans for wider areas, priority lists, detailed inventories of objects, and records of past dealings with natural events, and staff specialized training. There is no doubt that cultural heritage sites will continue to suffer from natural processes, which are largely beyond our ability to control them, but accumulated knowledge from past disasters can be of considerable help to reduce negative impact of any future event.

Summary

Cultural heritage is exposed to different types of hazards and potentially devastating natural events which may result in different degrees of damage or, less commonly, total destruction. Earthquakes appear to have most serious effects and many great heritage sites are located along major fault zones in Europe, Asia, and America. Other hazards include volcanic eruptions, gravitational mass movements, flash floods, and coastal erosion. Weathering and ground subsidence are slow-acting processes whose cumulative effects may nevertheless seriously affect the stability of structures and their visual quality. Perhaps the most important aspect of relationships between cultural heritage and natural hazards is that damage or loss of properties cannot be measured in monetary units only. Their value to the humankind can be hardly expressed in this way, and some are considered of outstanding universal value, protected by international conventions. In disaster-affected areas, if objects of cultural heritage are prioritized for rebuilding, they may be used as catalysts of renewed tourism interest and, thereby, as means to improve a shaken local economy.

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Cross-references

Biblical Events
Coastal Erosion
Damage and the Built Environment
Earthquake
Flood Hazard and Disaster
Geological/Geophysical Disasters
Historical Events
Santorini, Eruption
Subsidence Induced by Underground Extraction
Vesuvius
Volcanoes and Volcanic Eruptions
Wenchuan, China