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AHC Media

Natural Disasters: Hospital Management

Fortunately, I have never been part of a medical response to a natural disaster. I have had my share of drills and activations, but no real disaster experience. But I have friends who have been in the middle of natural disasters where their hospitals and surrounding communities were rendered nonfunctional. The stories they tell. Of disaster plans that did not work. Of supplies not accessible. Of circumstances unanticipated. We all have great plans that we think will carry us through these difficult situations, but as Mike Tyson is quoted to have said, "Everyone has a plan 'till they get punched in the mouth."

So while plans are important, a more useful concept is resilience, the capacity to recover quickly from difficulties. Often, we cannot prevent the damage from occurring, but we can plan to recover quickly. This often involves redundant resources and processes. Centralization of supplies and unity of command may be efficient during normal circumstances, but during disasters, decentralization of resources and direction can be the key to quick recovery.

This issue of Emergency Medicine Reports *provides an overview of natural disasters that can and do occur in North America, along with links to more information about specific events. I close my introduction with a quote from Daryn Kagan, former CNN News anchor, "Bad things do happen in the world, like war, natural disasters, disease. But out of those situations always arise stories of ordinary people doing extraordinary things." If called, may you do extraordinary things.*

—J. Stephan Stapczynski, MD, Editor

Introduction

Natural disasters are large events that disrupt infrastructure and result in population-wide death, injury, and displacement,[1] and, correspondingly, mass casualty incidents occur when casualties overwhelm local resources. Nature's calamities have affected humankind throughout the history of our civilization[2] and continue to plague us in the 21st century. (*See Table 1.*) Disaster does not affect all populations equally. Geography, climate, structural and political resources, and socioeconomic status all contribute to or mitigate morbidity and mortality, with individuals at age extremes and lower socioeconomic class typically suffering worse outcomes.[3,4] Unlike man-made disasters[5], natural disasters often affect health care infrastructure, also placing health care workers in harm's way.[3] Disaster is episodic, and many hospitals are inexperienced and unprepared to manage the mass casualties that result,[6] especially when the hospital or its staff are affected.

The focus of this review article is natural disaster hospital management when a mass casualty situation occurs. Using contemporary examples and the current literature, what follows is a primer on the causes, injury patterns, triage,

EXECUTIVE SUMMARY

- A natural disaster has the potential to create multiple casualties, but the greatest need for medical care after the initial event is for low-acuity routine care of patients with minor illnesses and chronic conditions where the existing health care infrastructure has been incapacitated.
- Of all natural disasters, volcanic eruption is unique in that the number of fatalities usually exceeds the number of injuries.
- Hospital planning for natural disaster response should stress anticipation of potential damage to the physical plant and preparation to limit its effect on the ability of the hospital to function after the event.
- Resilience should be sought in a natural disaster response plan; develop multiple redundant options so that vital functions can be maintained after the initial damage.

preparation, and special considerations for natural disaster mass casualty events that could occur in the United States. These include: earth (earthquakes, mudslides, and volcanoes); wind (hurricanes and tornadoes); fire (wildfires); temperature extremes (heat waves and winter storms); and water (tsunamis, storm surges, and floods). Natural disasters also pose unique medical and public health response challenges,[7] which will be discussed below.

Earth

Earthquakes. Earthquakes primarily occur when the earth's tectonic plates "slip" along a fault, resulting in the shaking of the ground and the radiation of seismic energy; earthquakes may also be caused by volcanic or magmatic activity, among other sudden stress changes.[8] Many densely populated areas lie in earthquake-prone zones, including the American West Coast, the Middle East, and Southeast Asia.[9] Table 1 provides a summary of deaths, injuries, and displacement resulting from major earthquakes since 2000.

Earthquake size can be described in terms of magnitude and intensity. Magnitude, a measure of the energy released at the earthquake's source, is based on the logarithmic moment magnitude scale; a difference in magnitude of 1.0 reflects a 10-fold difference in ground motion change and about a 32-fold difference in energy release.[10] The moment magnitude scale has refined and replaced — but is largely aligned with — the more popularly known Richter scale.[11] Intensity, a measure of an earthquake's effects on the earth's surface at a given location, is based on the 12-level Modified Mercalli Intensity Scale.[12] Because intensity is assigned based on observed effects on buildings, people, and natural features, it is more closely related to the level of local destruction than magnitude.[12] Table 2 describes the annual frequency of earthquakes of varying magnitudes, as well as typical intensity ranges near their epicenters.

Casualty rates are usually determined by: the size of the earthquake (*see Table 2*); the mental health, physical health, and socioeconomic status of the exposed victim or community; location within or outside a building; the seismic integrity of affected buildings; and the population density.[13] The majority of event casualties result from crush, entrapment, and falling debris.[14,15,16]

Widespread damage to infrastructure often results in a disorganized response both in the field and in the hospital, overwhelming local resources. Federal and international aid often takes 48 to 72 hours to arrive.[16] This is especially problematic for victims of entrapment, of whom less than 50% survive more than six hours;[17,18] 85-95% of those who survive are rescued within 24 hours. Many of the entrapped individuals who initially survive their injuries and finally succumb could be saved if they receive timely first aid.[16]

The injured often outnumber the dead in a ratio of 3:1,[14] stressing limited local resources. The 2001 Gujarat earthquake in India provides a good example of common survivor injuries. The earthquake on January 26, 2001, which had an epicenter northeast of Bhuj, affected 8792 villages, 171 governmental administrative units, and 21 districts, and resulted in the structural failure of most of the health care facilities in the district of Kutch. There were 20,005 deaths, 166,812 injuries (20,717 serious), and countless population displacements.[14] Phalkey et al[14] describe one hospital's experience over a 10-week period. Fractures were the most common injuries sustained in survivors (55%), and 15.5% of injured patients had wound infection on admission, presumably due to delayed care.

On the morning of December 26, 2003, a Richter scale 6.5 earthquake struck Bam, Iran, destroying 87% of all buildings and nearly every health care facility, killing more than 40,000 people (one-sixth of Bam's population), injuring 30,000, and leaving 75,000 homeless. The international response included humanitarian assistance from 60 countries, exemplifying the enormity of a significant seismic event.[15]

Even moderate events in the First World can devastate local health care capacity. On January 17, 1994, an earthquake of magnitude 6.7 on the Richter scale struck Northridge, Los Angeles County, CA. Nine of 81 hospitals were damaged and required evacuation. Six hospitals evacuated immediately and three after secondary inspection, all for structural damage.[19] The six hospitals that evacuated immediately did so without power or elevators, leading to a number of creative solutions.[19]

The most important opportunity in reducing earthquake morbidity and mortality is preparedness:[20]

1. Local, state, and federal preparedness plans;
2. Seismic-resistant new construction or retrofit of existing buildings;
3. Timely reinforcement of local emergency medical services (EMS);
4. Careful attention to critical medical infrastructure, such as hospitals;
5. Planned and practiced evacuation plans, which take into account the possible loss of utilities.

Mudslides. Mudslides are fast-moving masses of rock, earth, and

Table 1. Selected Categories of Natural Disaster, 2000-2015

Disaster Type	Occurrences	Total Deaths	Injured	Homeless	Affected	Total damage ($)
Earth	**527**	**466,222**	**1,330,901**	**11,544,655**	**96,728,766**	**270,821,063,000**
Earthquakes	415	464,872	1,329,635	11,279,440	94,765,491	269,846,594,000
Mudslides	24	685	125	149,215	87,417	506,600,000
Volcanic activity	88	665	1,141	116,000	1,875,858	467,869,000
Wildfires	**180**	**911**	**5,234**	**60,262**	**2,155,883**	**30,065,867,000**
Extreme Weather	**503**	**160,315**	**2,059,711**	**348,617**	**109,051,279**	**65,249,550,000**
Avalanche	34	1,517	276	6,640	12,593	50,000,000
Cold waves	190	10,447	1,833,672	233,000	8,867,912	5,101,134,000
Heat waves	99	143,076	113,390	0	112,842	13,382,859,000
Severe winter conditions	62	3,569	16,029	5,247	80,782,153	23,960,200,000
Winter storm/blizzard	118	1,706	96,344	103,730	19,275,779	22,755,357,000
Water	**2,572**	**334,846**	**311,492**	**17,070,727**	**1,404,106,697**	**628,796,808,000**
Tsunami	22	247,836	49,343	1,033,559	1,804,657	220,605,500,000
Flood and storm surge	2,550	87,010	262,149	16,037,168	1,402,302,040	408,191,308,000
Wind	**920**	**183,946**	**192,010**	**5,271,188**	**365,099,629**	**592,140,453,000**
Hurricanes	799	182,232	176,671	5,094,208	364,324,640	514,595,117,000
Tornadoes	121	1,714	15,339	176,980	774,989	77,545,336,000
Total	**4,702**	**1,146,240**	**3,899,348**	**34,295,449**	**1,977,142,254**	**1,587,073,741,000**

Note: "Affected" category includes individuals who were affected but not left injured or homeless by disasters.
Source: Guha-Sapir D, Below R, Hoyois PH. EM-DAT: International Disaster Database. Université Catholique de Louvain, Brussels, Belgium. Retrieved Sept. 24, 2014, from http://www.emdat.be.

debris (landslide) that typically flow in channels. Mudslides typically occur on steep slopes made unstable by a variety of environmental factors (rain, drought, destroyed vegetation, and seismic events). The Centers for Disease Control and Prevention (CDC) estimate that 25 to 50 deaths occur yearly in the United States from landslides and mudslides.[21]

On March 22, 2014, a mudslide in Oso, WA, the deadliest single landslide event in U.S. history, destroyed 36 homes, killed 43 people, and injured nine more.[22] More than 900 personnel and volunteers were involved in search and rescue efforts.[23] Despite these efforts, the final victim was not retrieved until July 22 of that year.[24] Injuries to survivors of the mudslide included: a skull fracture (to a 5-month-old infant); a broken arm, broken ankle, and foot laceration; and a crushed pelvis.[25,26] Although the initial public stance was that event was unforeseen and unpredictable,[27] multiple previous events and a number of warnings preceded this disaster.[28]

Volcanoes. Volcano eruption is also related to the shifting tectonic plates that allow the earth's enormous pressure to be released in a cataclysm of dangerous gases, ash, lava, steam, and rock.[29] Destruction, death, and injury are common, especially when a volcano erupts with little warning. Unlike in earthquakes, the number of dead greatly outnumber the injured.[30] Local destruction is often total, but the environmental consequences can be global and persistent.[31] Table 3 provides a summary of fatalities for the most destructive volcanoes since 2000.

The majority of deaths occur from a dense avalanche of hot concentrated particles (pyroclastic flow) and/or dilute turbulent particles suspended in superheated air and gas (pyroclastic surges).[30] The survivors typically sustain burns, inhalation injuries, and blunt force trauma.[30]

The Mount St. Helens eruption in Washington state on May 18, 1980, is a good example of volcanic disaster in a rural area. Early warning and eruption prediction allowed the evacuation of most of the at-risk population.[30] However, at the time of the eruption, 160 people remained in the vicinity, and 58 died.[30] A number of survivors were airlifted to safety. The nine seriously injured patients were primarily burned, and two of these died.[30]

The 2010 eruption of Mount Merapi in Jakarta, Indonesia, is a good example of the devastation possible in a densely populated area. The cone-shaped volcano located between Central Java and Yogyakarta, Indonesia, has erupted regularly since 1548. Smoke can be seen emerging from the mountaintop at least 300 days a year, and several recent eruptions have caused multiple fatalities. In the 2010 eruption, some residents in the vicinity of the volcano were initially reluctant to obey evacuation orders; Mei et al report that 35 people were killed in Merapi's first explosion as the result of their refusal to evacuate.[32] Ultimately, 367 people lost their lives, and the number of internally displaced persons peaked at 400,000.[32]

Table 2. Earthquake Magnitude, Intensity, and Frequency

Magnitude	Typical Maximum Modified Mercalli Intensity	Average Annual Frequency
< 2.0	I. Not felt except by a very few under especially favorable conditions.	—
2.0 - 2.9		1,300,000
3.0 - 3.9	II. Felt only by a few persons at rest, especially on upper floors of buildings.	130,000
	III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.	
4.0 - 4.9	IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.	13,000
	V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	
5.0 - 5.9	VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.	1,319 (magnitude 5.0-5.9)
	VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.	134 (magnitude 6.0-6.9)
6.0-6.9	VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.	
	IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.	
7.0 and higher	X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.	15 (magnitude 7.0-7.9) 1 (magnitude 8+)
	XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.	
	XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.	

Sources: • Adapted from U.S. Geological Survey. (Sept. 29, 2014). Magnitude/Intensity Comparison. Retrieved from http://earthquake.usgs.gov/learn/topics/mag_vs_int.php.
• Adapted from U.S. Geological Survey. (Jan. 13, 2015). Earthquake Facts and Statistics. Retrieved from http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php.

Early warning is often possible. The dead dramatically outnumber the injured, and the majority of post-event effort is spent on recovery and reconstruction. Preparation should focus on careful attention to evacuation plans for populations at risk, resources for search and rescue, reconstruction, and hospital preparation for the surviving victims.

Wind

Hurricanes. Hurricanes are spiraling tropical storms that can reach sustained wind speeds of more than 160 miles per hour and dump more than 2.4 trillion gallons of rain daily. In the northern hemisphere, they spin clockwise around a low-pressure area (the eye); in the southern hemisphere, they circle counterclockwise and are known as cyclones. The winds generate an enormous destructive force; however, the storm surges that accompany landfall are responsible for 90% of the storm fatalities.[33] In the United States, the entire seaboard from the Gulf of Mexico to New England is susceptible, usually during summer and early fall. Table 4 provides a summary of tropical cyclone classification, strength, and common patterns of destruction, and Table 5 provides a summary of the worst hurricane disasters of this millennium.

On August 24, 1992, Hurricane Andrew made landfall at Homestead, FL, as a Category 5 event with wind gusts more than 200 miles per hour. More than 100,000 homes and businesses were destroyed, including essentially all of the mobile homes; 700,000 people were evacuated, and 250,000 were left homeless.[34] Mortality estimates vary, but range from 32 to 44, with the majority of deaths indirectly related to the storm.[34] Twenty-one hospital emergency departments (EDs) and five coroners' offices reported a total of 462 hurricane-related injuries or illnesses. The majority (79%) occurred after the event. Of those affected, 445 (96%) had nonfatal outcomes: 383 (86%) were injured, and 62 (14%) were ill. The most common nonfatal injuries were soft-tissue wounds (41%), followed by a strain/sprain (11%).[35]

An interesting report form Alson et

Table 3. Volcano Eruption Fatalities, 2000-2014

Year	Volcano	Location	Fatalities
2014	Ontake	Japan	48
2010	Merapi	Indonesia	324
2010	Merapi	Indonesia	34
2008	Nevado del Huila	Colombia	10
2006	Raoul	Kermadec Islands	1
2002	Nyiragongo	Democratic Republic of the Congo	147
2002	Toliman	Guatemala	31
2001	Mt. Cameroon	Cameroon	23
2001	Merapi	Indonesia	2
2001	Kilauea	Hawaii, United States	2
2001	Stromboli	Italy	1
2001	Mt. Etna	Italy	1
2000	Semeru	Indonesia	2

Source: Seach J. Volcano Eruption Fatalities. Retrieved from http://www.volcanolive.com/fatalities.html.

al[36] chronicles a field hospital response immediately following Andrew by a North Carolina-based special operations team. There were 1544 patient encounters: five (0.3%) were treated for minor hurricane-related injuries, 285 (18.5%) were treated for injuries sustained during cleanup operations, and the rest were provided routine medical care not available due to the loss of offices and clinics.

On August 29, 2005, Hurricane Katrina made landfall along the Mississippi coast, resulting in the costliest and third deadliest hurricane disaster in American history.[37] The hurricane peaked at Category 5, with winds up to 175 miles per hour. However, most of the devastation in New Orleans resulted from a combination of inadequate levees and a 20-foot storm surge, which overwhelmed an underprepared city. Compounded by a less than adequate local, state, and federal response,[38,39,40] the resulting disaster was amplified.

The storm surge, in combination with the breached levees, flooded 80% of the city in up to 10 feet of water. While the business and tourist centers were relatively undamaged, many New Orleans neighborhoods were inundated. At least 986 Louisiana residents died, and half of these were older than 74 years of age. The majority of deaths were from drowning (40%), injury (25%), and heart conditions (11%).[41] An accurate injury count is not possible; however, a number of post-event injuries occurred from search and rescue, clearance of debris, and unique problems of displacement, such as carbon monoxide (CO) poisoning from portable generators and burns from alternative cooking sources.[33]

Robust evacuation plans did not adequately address those who could not or would not leave: the sick, the frail, the poor, and the elderly. While many hospitals had enough supplies, materials, and in-house generators to be self-sufficient, the majority were rendered nonfunctional by flooding.[42] Help was slow to arrive for a number of reasons that, while illustrative for planning purposes, are beyond the scope of this paper. A number of after action reports on the Hurricane Katrina response are enlightening.[38,39,40] In 2006 the Health and Social Services Committee of the Bring New Orleans Back Commission provided a number of recommendations to help hospitals prepare for future disasters.[42] A few are listed below:

1. Development of community-driven systems of health care;
2. Provision of hospital-linked community health centers;
3. Implementation of resilient communication systems;
4. Portable health care data;
5. Necessarily equipped and managed temporary shelters;
6. Evacuation planning.

To this list, we add hospital resilience planning to assure that contingency plans go more than one deep in the event of unforeseen circumstances.

Tornadoes. Tornadoes are the most violent wind-related storms, with relatively narrow violent funnels of rotating air that extend from a thunderstorm to the ground. Tornado strength is rated after the fact by the damage caused using the Enhanced Fujita (EF) Scale. (*See Table 6.*) Tornadoes occur worldwide, including in Australia, Europe, Africa, Asia, South America, and the United States.[43,44] In the United States, the most violent storms typically occur in the Southern Plains, Gulf Coast, and Midwest in the spring and summer months. North American tornadoes accounted for 4115 deaths and 70,063 injuries from 1950 to 1994, and account for some of the most significant tornado disasters worldwide.[45]

In the United States, tornado deaths averaged 86.8 per year during the past 15 years; 2011, however, was particularly violent, with 553 deaths.[46] The majority of deaths occur when victims become airborne, are wounded by airborne objects, or are crushed by building collapse.[45] Soft-tissue injuries, often with foreign body contamination, account for half of the reported injuries. Fractures and severe head injuries account for the majority of hospital admissions.[45] Table 7 provides a summary.

Although tornadoes are episodic, they can be predicted. The National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center meteorologists track weather conditions across the entire United States and issue a watch when weather conditions favor a potential tornado. The local NOAA Weather Service Forecast Office issues a warning when a tornado has been spotted in the area.[44] These alerts allow some early warning.

A study of risk factors for death during the March 1994 tornadoes in Georgia and Alabama is illustrative.[47] On March 27, 1994, six major tornadoes touched down during an eight-hour period. Forty people died: 20 in

Table 4. Classification of Hurricanes, Tropical Storms, and Tropical Depressions

Category	Sustained Winds	Types of Damage Due to Winds
Tropical Depression	< 38 mph	—
Tropical Storm	39-73 mph	—
Category 1 Hurricane	74-95 mph	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
Category 2 Hurricane	96-110 mph	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
Category 3 Hurricane (major)	111-129 mph	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
Category 4 Hurricane (major)	130-156 mph	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
Category 5 Hurricane (major)	157 mph or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Sources: • Adapted from National Weather Service - National Hurricane Center. (May 24, 2013). Saffir-Simpson Hurricane Wind Scale. Retrieved from http://www.nhc.noaa.gov/aboutsshws.php
• National Weather Service - National Hurricane Center. (Sept. 1, 2015). Glossary of NHC Terms. Retrieved from http://www.nhc.noaa.gov/aboutgloss.shtml

a church roof collapse in Alabama; and 15 in mobile homes, two in frame houses, two outside, and one as an unrestrained motor vehicle occupant in Georgia. In addition, there were 304 injuries. These authors and others point to the high mortality associated with mobile home touchdown.[43,45,47-50] However, this apparent risk is not borne out with a larger analysis of multiple tornado events; there is a relatively even distribution of mortality between mobile and permanent homes. Powerful tornadoes may overwhelm any structure; for example, in the Joplin tornado, almost all of the deaths occurred in permanent structures.

The single deadliest tornado to hit the United States occurred on May 22, 2011, in Joplin, MO, killing 162 and injuring more than 1000 victims.[51,52] Paul and Stimers[51] used a post-event survey methodology to evaluate the probable reasons for the large fatality rate. The authors suggested five reasons:

1. The sheer magnitude of the event: an EF 5 tornado with a six-mile path;
2. Tornado path encompassing a densely populated urban area;
3. A relatively large affected area;
4. Physical characteristics of the buildings: While there were few mobile homes and the majority of deaths occurred in buildings, 78% of Joplin homes are estimated to not have a basement;
5. Failure to heed tornado warnings: While 88% of respondents had five or more minutes of lead time following a warning, only 77% heeded these warnings.

Saint Johns-Mercy Medical Center in Joplin sustained a direct hit, resulting in: serious structural damage; loss of water, electricity (including generator backup), and oxygen tanks; destruction of 86 medical staff offices; and the destruction of the helicopter and disaster trailer.[53] In addition, 183 patients and 200 staffers were evacuated from the building and transferred to other local hospitals. Eight months after the disaster, the hospital was demolished.[54]

Hospital preparedness includes planning, equipping with emergency supplies, training, and drilling. Planning for tornadoes includes identifying shelter, understanding the community's warning system, and establishing a tracking method for individuals in the building.[55] The most appropriate shelter is typically in the basement of a solid structure or an interior space on the lowest floor away from windows and corners. Hospitals typically shelter in place by moving patients to interior spaces away from windows and exterior walls. Training and education should include the basics of sheltering and evacuation, updated plans based on lessons learned, and regular drills. The disaster in Joplin emphasizes how important preparation and planning can be. The Advisory Board provides more detail on the lessons learned from the Joplin Saint

Table 5. Selected U.S. Hurricane Fatalities, 2000-2012

Year	Hurricane Name	Direct Deaths	Indirect Deaths*
2012	Sandy	73	82
2008	Ike	20	44
2005	Katrina**	1200	—
2005	Rita	7	101
2004	Ivan**	25	—
2004	Frances	6	49
2004	Charley	10	29
2003	Isabel	16	36
2001	Allison**,***	41	—

Notes: * "Indirect" deaths are those not directly attributable to the physical forces of a storm, but which would not be expected in the storm's absence (e.g., due to power problems, cardiovascular failure, evacuation, or vehicular incidents).
** Data for these storms are from Blake and Gibney and do not account specifically for indirect deaths. For Katrina, Rappaport and Blanchard reported 520 direct deaths, 565 indirect deaths, and 307 deaths indeterminate for direct or indirect cause.
***Allison was classified only as a tropical storm.
Sources: • Rappaport EN, Blanchard BW. Fatalities in the United States indirectly associated with Atlantic tropical cyclones. *Bulletin of the American Meteorological Society* [In press]. 2015. http://doi.org/doi:10.1175/BAMS-D-15-00042.1
• Blake ES, Gibney EJ. (2011). The Deadliest, Costliest, and Most Intense United States Tropical Cyclones from 1851 to 2010 (and Other Frequently Requested Hurricane Facts) (NOAA Technical Memorandum No. NWS NHC-6). Miami: National Weather Service, National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf.

Table 6. The Enhanced Fujita (EF) Scale

EF Rating	3-Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

Note: National Weather Service evaluators provide "official" EF ratings based on observed damage to buildings and natural features.
Source: National Weather Service Weather Forecast Office. (Jan. 15, 2014). The Enhanced Fujita Scale (EF Scale). Retrieved from http://www.srh.noaa.gov/oun/?n=efscale.

Johns-Mercy Medical Center tornado response.[56]

Fire

Wildfires. The United States Forest Service reports an average of 73,000 wildfires yearly, clearing about 7.3 million acres and burning about 2600 structures.[57] However, because of robust planning, education, early warning, tracking, and evacuation systems, wildfire is rarely a cause of death. There are, however, four notable exceptions in modern history, and they all involve firefighters:

- The 1949 Mann Gulch Fire in Helena, MT, overran 16 firefighters, and only three survived.[58]
- The 1994 South Canyon Fire in Glenwood Springs, CO, overran 12 firefighters and two helitack crew members who perished.[59]
- The 2001 Thirtymile Fire in Chewuch River Canyon, WA, asphyxiated four firefighters who sheltered in place; their deaths were thought to have been preventable.[60]
- The 2013 Yarnell Hill Fire near Yarnell, AZ, killed 19 members of the Granite Hills Hotshots.[61]

Lessons learned from these disasters are beyond the scope of this paper, but are well-known to the men and women who risk their lives to fight these fires.

Temperature Extremes

Heat. Heat waves generally do not overwhelm local resources, but are nonetheless an all-too-common cause of urban mortality, disproportionately affecting the old, the infirm, and the poor.[62]

Three events provide examples of contemporary heat wave disasters.[63-65] In the summer of 1995, a record-setting heat wave in Chicago led to 700 heat-related deaths.[63] The medically frail, elderly, and socially isolated, especially those without air conditioning, were at greatest risk. Semenza et al[63] thought that the single biggest impact on mortality reduction is the provision of air-conditioned facilities to those at risk.

The summer of 2003 was unusually hot in Europe. Reports from Italy confirmed 3134 heat-related deaths,[64] and from France a catastrophic 14,947 heat-related deaths.[65] Deaths occurred in urban settings in the elderly and isolated, often with preexisting medical conditions. In Italy, 92% of the deaths were in those aged 75 or older.[64] Other European countries also reported excess mortality (Britain 16%, Portugal 26%); however, these pale next to France's 60% excess mortality. In France, the greatest increase in mortality resulted from heat-related events: dehydration, hyperthermia, and heat strokes. Secondary increases were related to medical conditions such as urinary and respiratory conditions.[65]

Climate change and potential solutions are still the source of public debate.[66] However, it is clear that heat is a preventable cause of excess mortality. Identifying those at risk and providing them with heat relief is the key to prevention. Hospitals should work in their communities to assist public health as appropriate.

Winter Storms. Winter weather — including cold, heavy snow, ice, and flooding — is another cause of morbidity and mortality in the United States. Winter storms include blizzards, which have winds of 35 miles per hour or more, along with blowing snow reducing visibility to less than 0.25 miles for three hours or more.[67]

Measurement of cold-related mortality can be inconsistent, in part due to a lack of uniform diagnostic criteria.[68] For

Table 7. Specific Injuries from Tornadic Storm Reports from 1962 to 1994

	Type of Injury with Number of Cases Reported					
Literature Report	Soft Tissue Laceration	Fracture	Head Injury	Blunt Trauma	Minor Strains	Medical Diagnoses
Beelman	193	129	—	3	9	—
Mandelbaum	24	13	14	3	—	—
Ivy	78	69	16	2	—	—
Glass	42	39	8	12	—	3
Leibovich	17	3	1	5	7	1
Morris	113	10	16	16	—	—
Duclos	31	24	6	11	—	—
Harris	25	40	9	5	—	2
Rosenfield	160	50	19	21	—	—
CDC	66	29	10	24	15	—
Frequency	**53.6%**	**29.1%**	**7.1%**	**7.3%**	**2.2%**	**0.4%**

Source: Adapted from Bohonos JJ, Hogan DE. The medical impact of tornadoes in North America. *J Emerg Med* 1999;17:67–73.

example, from 2000 to 2014, NOAA identifies 773 deaths related to extreme cold and winter weather in the United States, an average of 51.5 deaths annually.[69] The CDC, meanwhile, reports that 6660 deaths in 2006-2010 alone, an average of 1332 per year, were attributable to excessive natural cold, hypothermia, or both.[68] Older adults, males, and non-Hispanic black individuals are at higher risk for cold-related mortality than other groups.[68]

Among the primary conditions associated with cold weather are hypothermia and frostbite. Accidental hypothermia (a core temperature of 35˚C or less) causes more than 650 deaths per year in the United States.[70] Hypothermia can lead to thermoregulatory, cellular, and systemic responses, including: increased sympathetic nervous system activity; cellular membrane damage, altered electrolyte concentrations, thrombosis, and injury to the endothelium; and shock, arrhythmia, and neuromuscular dysfunction.[71] Susceptibility can be increased by conditions (e.g., alcohol intoxication) that impair sensation, autonomic responses, or the judgment necessary to retreat from cold weather.[71] The effects also vary depending on a patient's comorbidities, but survivors frequently struggle with lasting disorders of the kidney, liver, and pancreas.[67,70] Treatment depends on the severity of the patient's condition, ranging from passive rewarming (e.g., use of blankets), to external active rewarming (e.g., use of heating blankets or heated forced air), to active internal warming (e.g., warmed intravenous fluids or oxygen, or invasive techniques).[71]

Frostbite is tissue freezing as a result of crystal formation in the extracellular space.[70] The nose, ears, hands, and feet are particularly susceptible.[70] Superficial frostbite involves the skin and subcutaneous tissues, and leads to clear blisters when the skin is rewarmed.[71] Deep frostbite additionally affects the bones, joints, and tendons, leading to hemorrhagic blisters upon rewarming.[71] Rapid rewarming in a warm water bath can reduce tissue loss from frostbite, but the extent to which tissue remains viable may not be known for several weeks.[71] Elevation and splinting can minimize edema and support tissue perfusion in the affected area.[71]

Another cause of morbidity and mortality in winter storms is CO poisoning. In a systematic review, Iqbal et al identified 75 deaths and close to 2000 nonfatal cases of disaster-related CO poisoning from 1991 to 2009; 46% of the articles in their review were related to winter storms.[72] The effects of CO poisoning can range from virus-like symptoms to neurological impairment, coma, and death.[72] Power outages during winter storms are responsible for the major sources of patient exposure: generators (placed inside or improperly placed outside); propane, kerosene, and gas-fueled stoves or heaters; and charcoal grills used indoors.[72]

Of injuries that occur due to ice and snow, just 25% affect individuals caught in a storm, while about 70% result from vehicle accidents.[67] For more information on chain-reaction motor vehicle collisions, see Falcone and Detty.[5]

Avalanches (masses of snow that slide, tumble, or flow down an incline) are an infrequent cause of mass casualties but lead to an average of 29 deaths per year in the United States, most from asphyxia and a smaller number from trauma.[73] The majority of victims are participating in winter recreation. For information on other mass movement events, such as mudslides, see the "Earth" section.

Water

Tsunamis. Tsunamis are ocean waves caused by seismic activity such as earthquakes or underwater landslides. A tsunami is a series of waves that can propagate at speeds up to 600 miles per hour in the open ocean. Waves that hit land can be up to 100 feet high, and can inundate and destroy the affected coastline several hundred feet inland. Because waves propagate outward in any direction, essentially any coastline facing the epicenter is at risk. According to NOAA, there have been 41 major tsunami events since 2000.[74]

Although there have been no recent events on American soil, aside from a small non-seismic tsunami on the East Coast in June 2013, the coastal areas remain at risk. In the 20th century, tsunamis affected Hawaii, Alaska, the West Coast, Gulf Coast, and Puerto Rico. In Hawaii, tsunamis accounted for more deaths (221 people) than all other natural disasters combined. Although the East Coast is typically not at risk, the 1929 Grand Bank earthquake near Newfoundland resulted in a wave that reached as far south as South Carolina.[75]

The most destructive tsunami in this century, which killed more people than any other tsunami in recorded history, occurred on December 26, 2004. A massive earthquake (Richter 9.1) off the coast of Aceh, on the Indonesian island of Sumatra, affected more than 10 countries on two continents, killing more than 200,000 people and displacing many more.[76,77]

Lee et al[77] provide an illustrative experience of a Singapore Humanitarian Assistance Support Group (HASG) mobile medical team's efforts in the Aceh province's town of Meulaboh, which was essentially ground zero. There were two pre-event hospitals in the area, of which one was destroyed and the other left functional; however, the disaster shrank the supply of medical personnel from 130 doctors and nurses pre-event to 30 post-event. Because of the destruction and limited access, this HASG was the first medical team deployed to the area a week following the event. The team treated 1814 patients and performed 24 surgeries. Approximately 40% of patients were walking wounded, and the majority of the others had minor injuries or required routine medical care. The team anticipated a large number of trauma patients and sent a staff of five surgeons, two anesthesiologists, and a mobile field operating room; however, only 9% of the patients seen had traumatic injury, and most of that was minor. The few severe trauma patients who survived long enough to reach care could not be successfully treated due to a lack of blood and critical care resources. Gastrointestinal disease was anticipated but did not occur. Tetanus, on the other hand, was not anticipated but occurred in five patients.[76]

Although the property destruction cannot be prevented, it can be anticipated, especially on coastlines more remote to the event, providing an opportunity to prevent mortality. In the United States, a robust system of watches and warnings can provide time to evacuate.[75]

Storm Surge and Flood. Storm surge associated with tropical storms is discussed in the section about hurricanes. Floods often result from excess rain or snowmelts, as well as breaches of man-made structures. They are a common and often cyclic cause of death and disaster worldwide.[78] In the United States, the 30-year flood loss average is $7.96 billion in yearly damages and 82 deaths annually.[79]

The second costliest flood in U.S. history (after Katrina) occurred on the Mississippi River July 15 to August 2, 1993. The flooding caused more than $15 billion in damage and resulted in 50 flood-related deaths.[80,81] While critical resources such as hospitals were generally protected, the widespread devastation included more than 1000 breached levees, nine affected states, 75 completely destroyed communities, and 54,000 displaced people. Much of the health care work force must have been affected either directly or indirectly.[82] Despite the devastation, from July 16 to September 3, only 524 flood-related conditions were reported during regular CDC audits: 250 (47.7%) were injuries, 233 (44.5%) were illnesses, and 39 (7.4%) were listed as "other." Local hospitals saw a total of 516 patients, and almost half were treated and released. Of the 250 reported injuries, the most common were soft-tissue injuries, sprains and strains, and "other injuries." Of the 233 reported illnesses, the most frequently reported were gastrointestinal, rashes, heat-related, and "other conditions." Only 32 patients from this cohort were admitted for hospital care.[83]

The Federal Emergency Management Agency (FEMA) and others provide some insight for public health mitigation strategies;[81] however, it is clear from the Katrina experience that hospital resilience in the face of direct impact to its resources and staff is integral to preparation. This concept will be discussed in greater detail below.

Special Considerations

Rural hospitals pose a special circumstance. Their often isolated geography, limited capacity and reserve, and reduced availability of services typical in urban settings can make these institutions vulnerable. Unfortunately, a recent national survey of rural hospitals by Manley and colleagues[7] points to a number of weaknesses. While 37% of respondents indicated a mass casualty incident occurred during the preceding two years, only 9% had assisted with a state-declared disaster, 5% had worked with a Disaster Medical Assistance Team (DMAT), and only 3% had worked with a Civil Support Team. Clearly there is an opportunity to integrate regional, state, and federal response with special attention to the rural hospital.

Infectious epidemics following a natural disaster are common. The risk for communicable diseases is related to the size of the population displaced, the availability of safe water and sanitation, the level of immunity to vaccine-preventable diseases, and access to basic health care.[84] Injured survivors may also present with multi-resistant organisms. Uçkay et al recommend preemptive isolation for repatriated infected victims until cultures become available.[85] Ivers and Ryan[86] provide an excellent primer for further reading.

Natural disaster is not only physically stressful, but socially and psychologically stressful. The mental health consequences for health care providers often go beyond their personal loss during the disaster. Mild transient distress may manifest as sleep disturbance, fear, anger, sadness, and an increase in tobacco and alcohol use.[87] More serious consequences range from a persistence of these symptoms to actual post-traumatic stress disorder and clinical depression.[87,88,89] Disaster preparation should include access to psychological resources not only for the general population, but also for the health care worker.

Triage

Effective triage is essential to

optimize limited resources.[90,91,92,93] There are five standard triage categories: immediate, delayed, minimal, expectant, and dead. The immediate category of patients requires prompt institution of life support and resuscitative measures. The delayed group of patients has emergent injuries, which can wait. Minimal patients often reach the hospital first because they are not transported by EMS and are typically not scene triaged. They can quickly overwhelm valuable ED and hospital resources. The expectant patients have signs of life, such as spontaneous breathing or pulse, but have sustained such severe injuries that survival, even with advanced measures, is not expected. The dead category is self-explanatory. These last two categories require the greatest adjustment from routine care, because they should be given minimal treatment (comfort care) or quickly pronounced dead.[5]

There is an unavoidable tension between standard of care and sufficiency of care.[94] Universal standards cannot be applied to all hospitals and all circumstances. A frank discussion at the hospital level of the nature and quality of care to be provided in the case of a disaster should occur as part of the planning process.

Under normal circumstances, trauma triage is performed at the scene and hospital with a low threshold for provision of advanced assessment. This is done to have a high sensitivity for serious injury and to reduce the chance of missing a patient who would benefit. This over-triage, by design, typically has only a modest specificity, and a number of patients without serious injury are processed through the high-resource utilization pathway.

In a disaster situation with more victims than can be handled with the available resources, the triage level for high-resource utilization should be raised to preserve their availability for the more seriously ill and injured.

Despite efforts to reduce scene and hospital over-triage, the walking wounded, who typically arrive before functioning triage is in place or may bypass it once it is set up, can rapidly overwhelm a facility, and broad geographic disruption, search and rescue, and cleanup activities, combined with the loss of basic health care services, result in an increase in non-trauma post-disaster ED volume.[36]

Hospital triage should be provided by the most experienced clinicians available. Initial interventions should include only lifesaving procedures, and the victims moved in one direction to successive hierarchies of care.[91] Secondary triage along the line of patient flow is essential, and the minimal category of patient may be segregated to a space away from the ED and carefully re-triaged.[5]

The triage officer(s) should also understand the facility's and region's resources: Patients and staff may need to be evacuated, the ED full of existing patients cleared, elective surgery delayed or cancelled, elective admissions delayed or cancelled, intensive care units (ICUs) cleared, and secondary critical care units established.[5]

All of the surgical and medical specialties may eventually be needed, depending on the type of disaster; however, Alson et al,[36] in describing their response as a field hospital during Hurricane Andrew, found that most of their time and resources were spent on general medical care, and not injury. This experience is mirrored in multiple reports following earthquakes, tornadoes, hurricanes, floods, landslides, and wildfires. Once a disaster is identified in the community or by the media and volunteer staff begin to arrive to assist, establishing a staging area to vet these volunteers and assign them to appropriate tasks may be beneficial.

Preparedness

Natural disasters are uncommon and episodic; multiple competing priorities often usurp precious resources, and as a consequence, disaster planning may suffer. Published after action reports credit education, planning, training, and drilling with saving lives.[93] The National Incident Management System (NIMS) mandates: the preparation of Hazardous Vulnerability Analysis (HVA) plans; an Incident Management System (IMS); a Hospital Emergency Incident Command System (HEICS); a tabulation of local, regional, state, and national resources; and ongoing education and simulation.[93]

The Incident Command System (ICS) provides a standardized hierarchy, logistic scaffold, operational units, and job assignments necessary to manage a disaster and should be part of any regional disaster plan. This plan must be flexible, as natural disasters have a geographic scale that often encompasses health care facilities and health care workers.

The HEICS uses ICS methodology at the hospital level. The coordination of terminology and infrastructure between ICS and HEICS allows for a more seamless hospital and system-wide response. When this coordination fails, the results are a natural disaster compounded by the man-made disaster of system failure.[38,39,40]

Farmer et al[94] outline five common shortfalls in hospital disaster preparedness:

1. Insufficient coordination between hospitals and civil and governmental agencies;
2. Insufficient onsite critical care capacity;
3. A lack of "portability" for acute care processes and patient transport;
4. Education;
5. Competing hospital priorities preventing adequate preparation.

Attention to these shortfalls is essential in preparedness activities.

Planning and preparedness for natural disasters needs to be resilient.[95-98] Existing plans should be interrogated by "what ifs" so that multiple levels of contingency are accounted for. Supplies must be stored out of harm's way, and alternate power must be carefully planned for, depending on the most likely disaster. For example, storage in a basement is very appropriate for a tornado-prone area, but not for a flood-prone area. The New Orleans hospitals were well supplied in preparation for Hurricane Katrina, but flooding rendered most of those supplies (stored in basements) useless, and the backup generators inoperable. In addition, communication beyond line of sight was almost impossible, and interagency cooperation difficult.

The Memorial Medical Center experience following Katrina is especially illustrative. The hospital leased space on the seventh floor to a long-term acute care (LTAC) facility for critically ill elderly patients. These patients were sheltered in place; however, flooding led to the loss of electricity, communications, cooling, sanitation, water, and supplies. A small staff stranded and isolated by the storm surge worked for four days in this primitive environment to care for critically ill patients. More than 34 of these patients died.[99] Shortly after the disaster, reports of "euthanasia" began to circulate, leading to a criminal investigation of the health care staff on site during those four days. A grand jury declined to indict, but civil claims persist.[99]

Evacuation planning should include the evacuation of difficult patients with limited personnel and services. Alternatives for complex machinery needed for life support must be identified and prepared. Robust communication trees need to account for the possibility of the total absence of communication networks and power. Mutual aid, state, and federal aid resources should be understood and the logistics of deployment developed well in advance of a disaster.

Because natural disaster is geographic in distribution, many health care workers will often be directly affected. Staff who are injured, homeless, or searching for family and friends may not be willing to report for work. For example, wildfires in the San Diego area in 2007 burned almost 400,000 acres and displaced 500,000 people. A report from one hospital documented that on the first day of the disaster, there was a 10.6% no-show rate for staff, which was 17 times greater than the hospital's average daily absence.[100]

Preemptive education has been cited as the single most important tool to mitigate the effects of disaster,[94] and multiple authors advocate for formal education and simulation.[93,102-104] However, the effectiveness of current disaster planning and training paradigms remains to be proven.[105] Disaster plans often do not unfold as they were designed, and despite multiple reports on lessons learned, those lessons are learned over and over. The assumptions on which disaster planning is predicated need to be interrogated to explore the multitude of effects that may occur.[106] Each possibility should have a mitigation strategy, and those strategies need to be resilient.

Resilience in preparing for natural disaster[95-98] seeks to mitigate risk with natural and human resilience to catastrophe. For example, natural resilience to a water event might include porous soil to allow drainage or vegetation to absorb it; and human resilience might include cohesive social networks that can provide resources and support. From a hospital perspective, resilience implies flexibility and preparedness that accounts for multiple levels of possibility. The reader is referred to Keim for further information.[97]

The science of disaster preparedness and education is still evolving. However, there are a number of good educational activities available to the health care community: the National Disaster Life Support™ (NLDS™) course from the National Disaster Life Support Foundation (http://www.ndlsf.org/); EMS and Disaster Preparedness from the American College of Emergency Physicians (http://www.acep.org/Content.aspx?id=30194); Disaster Management and Emergency Preparedness (DMEP) course from the American College of Surgeons (https://www.facs.org/quality%20programs/trauma/education/dmep); and a number of postgraduate degree courses on disaster management at universities throughout the United States. International courses are also available from the Red Cross and Red Crescent (https://www.ifrc.org/Global/Documents/Secretariat/201501/DM%20Course%20Brochure.pdf), the World Health Organization (WHO International Diploma Course in Vulnerability Reduction and Emergency Preparedness),[103] and the United Nations Office for Disaster Risk Reduction (an Online Certificate Course in Disaster Management, http://www.unisdr.org/we/inform/events/45458).[5]

Lessons Learned

1. Scene triage is often hectic: The enormity of these events and the multitude of different responders often leads to confusion early on.

2. Notification is unusual, and normal channels of communication may be disrupted, which often leads to zero-notice events and difficult coordination of efforts.

3. The majority of survivors will not be injured, but will often need general medical care.

4. Effective hospital triage is essential, but hospitals should prepare for illness in addition to injury.

5. Natural disaster is typically geographic in distribution and may directly affect hospitals and health care workers.

6. Outside help may take several days to mobilize, emphasizing the need for local resources and resilience.

7. First responders and health care workers may be prone to physical and psychological injury.

8. Preparation helps: Disaster planning and drills save lives and are essential components for any hospital or ED. However, it is essential that planning is resilient and flexible.

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EMERGENCY MEDICINE REPORTS

CME Objectives

Upon completion of this educational activity, participants should be able to:

- recognize specific conditions in patients presenting to the emergency department;
- apply state-of-the-art diagnostic and therapeutic techniques to patients with the particular medical problems discussed in the publication;
- discuss the differential diagnosis of the particular medical problems discussed in the publication;
- explain both the likely and rare complications that may be associated with the particular medical problems discussed in the publication.

CME Questions

1. In a mass casualty earthquake, the injured typically outnumber the dead.
   A. true
   B. false

2. In a mass casualty volcanic eruption, the injured typically outnumber the dead.
   A. true
   B. false

3. The geographic nature of a natural disaster often leads to:
   A. widespread property destruction.
   B. displacement.
   C. loss of utilities and services.
   D. direct impact on health care workers and facilities.
   E. all of the above.

4. The safest place to shelter during an EF 5 tornado is:
   A. outside in a ditch.
   B. against an interior wall.
   C. a car driving away from the storm.
   D. a basement.
   E. none of the above.

5. Preparation for a natural disaster should include primary care resources to care for the displaced and ill.
   A. true
   B. false

6. Prevention strategies for heat waves should include:
   A. a system to identify and support isolated individuals.
   B. community facilities for cooling.
   C. careful follow-up of potentially vulnerable patients.
   D. all of the above.
   E. none of the above.

7. Hospitals and staff are usually spared in natural disasters.
   A. true
   B. false

8. The hospital response to a natural disaster should anticipate:
   A. regional and federal assistance within 24 hours.
   B. no loss in staff availability.
   C. the availability of emergency power.
   D. the rapid establishment of communication networks.
   E. the need to provide basic medical care for the displaced community.

9. Most natural disasters can be anticipated.
   A. true
   B. false

10. Wind is the most common cause of death during a hurricane.
    A. true
    B. false

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EMERGENCY MEDICINE REPORTS

Natural Disasters: Hospital Management

Selected Categories of Natural Disaster, 2000-2015

Disaster Type	Occurrences	Total Deaths	Injured	Homeless	Affected	Total damage ($)
Earth	**527**	**466,222**	**1,330,901**	**11,544,655**	**96,728,766**	**270,821,063,000**
Earthquakes	415	464,872	1,329,635	11,279,440	94,765,491	269,846,594,000
Mudslides	24	685	125	149,215	87,417	506,600,000
Volcanic activity	88	665	1,141	116,000	1,875,858	467,869,000
Wildfires	**180**	**911**	**5,234**	**60,262**	**2,155,883**	**30,065,867,000**
Extreme Weather	**503**	**160,315**	**2,059,711**	**348,617**	**109,051,279**	**65,249,550,000**
Avalanche	34	1,517	276	6,640	12,593	50,000,000
Cold waves	190	10,447	1,833,672	233,000	8,867,912	5,101,134,000
Heat waves	99	143,076	113,390	0	112,842	13,382,859,000
Severe winter conditions	62	3,569	16,029	5,247	80,782,153	23,960,200,000
Winter storm/blizzard	118	1,706	96,344	103,730	19,275,779	22,755,357,000
Water	**2,572**	**334,846**	**311,492**	**17,070,727**	**1,404,106,697**	**628,796,808,000**
Tsunami	22	247,836	49,343	1,033,559	1,804,657	220,605,500,000
Flood and storm surge	2,550	87,010	262,149	16,037,168	1,402,302,040	408,191,308,000
Wind	**920**	**183,946**	**192,010**	**5,271,188**	**365,099,629**	**592,140,453,000**
Hurricanes	799	182,232	176,671	5,094,208	364,324,640	514,595,117,000
Tornadoes	121	1,714	15,339	176,980	774,989	77,545,336,000
Total	**4,702**	**1,146,240**	**3,899,348**	**34,295,449**	**1,977,142,254**	**1,587,073,741,000**

Note: "Affected" category includes individuals who were affected but not left injured or homeless by disasters.
Source: Guha-Sapir D, Below R, Hoyois PH. EM-DAT: International Disaster Database. Université Catholique de Louvain, Brussels, Belgium. Retrieved Sept. 24, 2014, from http://www.emdat.be.

Earthquake Magnitude, Intensity, and Frequency

Magnitude	Typical Maximum Modified Mercalli Intensity	Average Annual Frequency
< 2.0	I. Not felt except by a very few under especially favorable conditions.	—
2.0 - 2.9		1,300,000
3.0 - 3.9	II. Felt only by a few persons at rest, especially on upper floors of buildings.	130,000
	III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.	
4.0 - 4.9	IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.	13,000
	V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	
5.0 - 5.9	VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.	1,319 (magnitude 5.0-5.9)
6.0-6.9	VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.	134 (magnitude 6.0-6.9)
	VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.	
	IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.	
7.0 and higher	X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.	15 (magnitude 7.0-7.9) 1 (magnitude 8+)
	XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.	
	XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.	

Sources: • Adapted from U.S. Geological Survey. (Sept. 29, 2014). Magnitude/Intensity Comparison. Retrieved from http://earthquake.usgs.gov/learn/topics/mag_vs_int.php.
• Adapted from U.S. Geological Survey. (Jan. 13, 2015). Earthquake Facts and Statistics. Retrieved from http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php.

Volcano Eruption Fatalities, 2000-2014

Year	Volcano	Location	Fatalities
2014	Ontake	Japan	48
2010	Merapi	Indonesia	324
2010	Merapi	Indonesia	34
2008	Nevado del Huila	Colombia	10
2006	Raoul	Kermadec Islands	1
2002	Nyiragongo	Democratic Republic of the Congo	147
2002	Toliman	Guatemala	31
2001	Mt. Cameroon	Cameroon	23
2001	Merapi	Indonesia	2
2001	Kilauea	Hawaii, United States	2
2001	Stromboli	Italy	1
2001	Mt. Etna	Italy	1
2000	Semeru	Indonesia	2

Source: Seach J. Volcano Eruption Fatalities. Retrieved from http://www.volcanolive.com/fatalities.html.

Classification of Hurricanes, Tropical Storms, and Tropical Depressions

Category	Sustained Winds	Types of Damage Due to Winds
Tropical Depression	< 38 mph	—
Tropical Storm	39-73 mph	—
Category 1 Hurricane	74-95 mph	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
Category 2 Hurricane	96-110 mph	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
Category 3 Hurricane (major)	111-129 mph	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
Category 4 Hurricane (major)	130-156 mph	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
Category 5 Hurricane (major)	157 mph or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Sources: • Adapted from National Weather Service - National Hurricane Center. (May 24, 2013). Saffir-Simpson Hurricane Wind Scale. Retrieved from http://www.nhc.noaa.gov/aboutsshws.php
• National Weather Service - National Hurricane Center. (Sept. 1, 2015). Glossary of NHC Terms. Retrieved from http://www.nhc.noaa.gov/aboutgloss.shtml

Selected U.S. Hurricane Fatalities, 2000-2012

Year	Hurricane Name	Direct Deaths	Indirect Deaths*
2012	Sandy	73	82
2008	Ike	20	44
2005	Katrina**	1200	—
2005	Rita	7	101
2004	Ivan**	25	—
2004	Frances	6	49
2004	Charley	10	29
2003	Isabel	16	36
2001	Allison**,***	41	—

Notes: * "Indirect" deaths are those not directly attributable to the physical forces of a storm, but which would not be expected in the storm's absence (e.g., due to power problems, cardiovascular failure, evacuation, or vehicular incidents).
** Data for these storms are from Blake and Gibney and do not account specifically for indirect deaths. For Katrina, Rappaport and Blanchard reported 520 direct deaths, 565 indirect deaths, and 307 deaths indeterminate for direct or indirect cause.
***Allison was classified only as a tropical storm.
Sources: • Rappaport EN, Blanchard BW. Fatalities in the United States indirectly associated with Atlantic tropical cyclones. *Bulletin of the American Meteorological Society* [In press]. 2015. http://doi.org/doi:10.1175/BAMS-D-15-00042.1
• Blake ES, Gibney EJ. (2011). The Deadliest, Costliest, and Most Intense United States Tropical Cyclones from 1851 to 2010 (and Other Frequently Requested Hurricane Facts) (NOAA Technical Memorandum No. NWS NHC-6). Miami: National Weather Service, National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf.

The Enhanced Fujita (EF) Scale

EF Rating	3-Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

Note: National Weather Service evaluators provide "official" EF ratings based on observed damage to buildings and natural features.
Source: National Weather Service Weather Forecast Office. (Jan. 15, 2014). The Enhanced Fujita Scale (EF Scale). Retrieved from http://www.srh.noaa.gov/oun/?n=efscale.

Specific Injuries from Tornadic Storm Reports from 1962 to 1994

	Type of Injury with Number of Cases Reported					
Literature Report	Soft Tissue Laceration	Fracture	Head Injury	Blunt Trauma	Minor Strains	Medical Diagnoses
Beelman	193	129	—	3	9	—
Mandelbaum	24	13	14	3	—	—
Ivy	78	69	16	2	—	—
Glass	42	39	8	12	—	3
Leibovich	17	3	1	5	7	1
Morris	113	10	16	16	—	—
Duclos	31	24	6	11	—	—
Harris	25	40	9	5	—	2
Rosenfield	160	50	19	21	—	—
CDC	66	29	10	24	15	—
Frequency	**53.6%**	**29.1%**	**7.1%**	**7.3%**	**2.2%**	**0.4%**

Source: Adapted from Bohonos JJ, Hogan DE. The medical impact of tornadoes in North America. *J Emerg Med* 1999;17:67–73.

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