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Healthcare Hazard Control

Analysis

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Natural Disasters

Abstract: Healthcare facilities are affected by natural disasters in two ways: facilities must treat people injured by the disasters, and the facilities themselves may be damaged. Potential damage includes structural damage to the building, spilling or release of hazardous materials or gases, and functional damage to the facility through loss of some or all vital plant requirements, such as power, water, gas, sewage disposal, and communication. This Analysis discusses earthquakes, tsunamis, volcanoes, flooding, blizzards, hurricanes, tornadoes, and wildfires in terms of their causes and their impact on the surrounding environment.

A natural disaster can be defined as a sudden, calamitous, and usually unexpected natural event that causes widespread damage, destruction, and loss of life. The magnitude of the disaster is usually calculated by its effect on humans, including lives lost, injuries sustained, and human property destroyed or damaged. The importance of being educated about and prepared for natural disasters is apparent. Note that a variety of federal agencies and voluntary organizations, such as the National Fire Protection Association and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), have their own specific definitions of disaster.

There are two general categories of natural disasters. One includes disasters that are a result of the movements of the earth's tectonic plates, which make up its outer shell. When the plates collide, pull apart, or slide past each other, mountains are built, earthquakes occur, and volcanoes erupt. These internal geologic processes can in turn trigger external events such as landslides, mud slides, fires, and tsunamis. Other disasters are caused by the global climate system, which creates hurricanes, flooding, tornadoes and winds, conditions conducive to fires, and temperature and precipitation extremes (e.g., blizzards, monsoons).

This Analysis describes several types of natural disasters and, where applicable, shares insights learned by healthcare facilities that have experienced various natural disasters. It is worth noting that in many cases, insights learned from one type of natural disaster (e.g., lessons learned regarding evacuation and power outages) can apply across the spectrum of disaster preparedness. This Analysis discusses the following natural disasters:

- Earthquakes
- Tsunamis
- Volcanic eruptions
- Floods
- Hurricanes (including cyclones and typhoons)
- Tornadoes
- Blizzards
- Wildfires

JCAHO's Emergency Management Standards

JCAHO's Environment of Care standards set forth many requirements for preparing for emergencies—which, according to JCAHO's definition, include natural disasters—that accredited healthcare facilities should ensure are addressed in their plans.[1] (See "Emergency Preparedness Management: Overview" in this section of the *Healthcare Hazard Control* [*HHC*] *System* for more information on this topic.) One of the first steps in developing a disaster response plan is assessing the types of natural disasters that may strike the individual healthcare facility. Those with a role in emergency planning must be aware of the types of natural disasters most likely to occur near the facility. Several resources addressing planning for natural

For more information about this topic and other related topics, go to *HHC* Members' Web site at http://www.ecri.org.

disasters are available elsewhere in this section of the *HHC System*.

As required by standard EC.4.10, healthcare facilities must conduct a hazard vulnerability assessment to identify the types of natural disasters for which the facility is at risk. Once this is done, it must be ensured that the facility's emergency preparedness plan outlines response procedures for these types of natural disasters. The facility should incorporate natural disaster scenarios into its drills.

Effect of Natural Disasters on Healthcare Facilities

The impact of natural disasters on healthcare facilities is manifold. First, facilities must treat an influx of patients injured by natural disasters, attending to the long-term health risks caused by disruption of community water and sanitation services as well. They may also end up providing emergency shelter for many people.

Second, the facilities themselves may be directly or indirectly affected by the disaster. Direct effects from being "hit" could include structural damage to the building, injury to the occupants of the building, spilling or release of hazardous materials or gases, and functional damage to the facility, including loss of some or all plant functions, power (backup emergency generators may not work if they are underwater or have been blown off the roof), water, gas, sewage disposal, and communication lines. The loss of power and water also affects such things as the heating and ventilation systems and the production of steam for sterilization.

Indirect effects on a healthcare facility include the destruction of the entire infrastructure surrounding it, which may not have been taken into account when the emergency response plan was created. The hospital should be prepared to think of itself as an isolated island for some time. In retrospect of 2005's Hurricane Katrina, many healthcare facilities along the Gulf Coast emphasized the need to be prepared to operate in disaster mode for longer durations than may be expected. Roads and bridges may be out, making it impossible for staff to get in and out or for standing orders for tanks of water or other necessary supplies to be delivered. Refuse and hazardous/medical waste pickup may not be possible. Fire and police departments, which might normally be part of a facility's emergency response plan, will have their attention elsewhere.

Finally, a natural disaster with wide-reaching impact may force healthcare facilities to set up temporary clinical unit locations, temporary triage areas, temporary morgues, and support services.[2]

Earthquakes

Issues for Healthcare Facilities

The 6.7-magnitude earthquake that occurred in 1994 in Northridge (near Los Angeles), California, resulted in the evacuation of eight healthcare facilities; four of these facilities sustained such extensive damage that they eventually were demolished. Interestingly, two facilities resumed full operation before they were ultimately condemned for being unsafe due to previously unidentified structural damage,[3] highlighting the need for careful, expert evaluation of structural safety before occupancy is resumed.

Facilities that evacuated patients cited the following reasons:

- Water damage from burst pipes, fire sprinklers, and ruptured rooftop water tanks
- Loss of electrical power
- Inability to provide medical care because of inoperative ventilation and fire-suppression systems and destruction of medical supplies or equipment

What Is an Earthquake?

An earthquake is a sudden shifting of the earth, usually at a fault—a fracture or fracture zone where displacement of the crust occurs. Faults commonly form due to forces created by tectonic plate collisions, divergence, and sliding. While faults often occur at plate boundaries, these forces can also cause faults to form far from boundaries. As movement occurs, the pieces of the crust press against each other, causing stress and strain. This in turn is thought to cause the actual length of the rock to change by causing it to bend and store energy, almost like a stretched elastic band. At some point, the stress level overcomes the frictional resistance, the rocks crack, and there is a sudden slip.[4]

Not all geologists agree with this elastic-rebound theory of earthquakes; nonetheless, all models agree on one point: something comes between the sides of the fault and lubricates them, making the fault weak.[5] Action at the faults produces vibrations called seismic waves or tremors, which radiate out in all directions. Not all rocks rebound immediately, so slippage is not always associated with an actual earthquake.

Measuring Earthquakes

The size of an earthquake is usually measured by its magnitude (which is measured using the Richter scale), which relates to the amount of energy released. The shaking of the earth is recorded by a seismograph and is converted to magnitude using logarithms, meaning that an increase of one in magnitude translates to a tenfold increase in amplitude of shaking. Magnitude also relates generally to the damage expected; a 5-magnitude earthquake can cause moderate damage, a 6-magnitude earthquake can cause considerable damage, a 7-magnitude earthquake is a major earthquake capable of causing widespread damage, and an earthquake of magnitude 8 or greater is considered to be catastrophic. Also, a higher-magnitude earthquake will last longer and produce more shaking than a lower-magnitude one. Other factors that may affect the damage caused by an earthquake include the location of the quake's epicenter, which is at the surface of the earth directly above the focus of the earthquake, and the type of rock that is involved.

Effects of Earthquakes

It is sometimes said that "earthquakes don't kill people; buildings do."[6] The primary effect of earthquakes is vibration and shaking of the ground, including permanent displacement of ground. This displacement, in turn, causes the most damage to buildings, bridges, dams, tunnels, pipelines, and other structures. Long, lower-frequency shock waves lasting several tens of seconds cause more damage to buildings than short, sharp waves with higher frequencies because even though a building may withstand the initial quake, the longer shaking causes the ground to liquefy, making it unable to support the structure.[7]

Liquefaction usually occurs on silty or sandy soils with a high water content or where the groundwater table is near the surface, usually within 30 feet. The younger and less consolidated the soil and sediments and the shallower the water table, the greater the liquefaction risk. The continuing vibrations move the water through the soil toward the surface, ultimately making the soil more liquid and often, in effect, boiling the sand and shooting fountains of water and sediment out. The land no longer has the strength to support buildings, and they collapse. Unfortunately, many of the major cities of the world are partly built on such sediment.[8]

Secondary effects associated with earthquakes include broken gas and water lines, fires (which are often started from damaged gas lines and may be even harder to put out than usual because water mains may also be broken), chemical and radioactive material releases, landslides, tsunamis, and floods. Landslides occur when rocks fall and slides of rock fragments occur on steep slopes. Electrocution, drowning, and respiratory disease from exposure to dust, rubble, and asbestos are among the health hazards associated with earthquakes.

Location of Most Earthquakes

The areas in the United States that fall within the Ring of Fire—that is, the West Coast, particularly sections of southern California and western Nevada—account for 90% of all seismic activity in the United States.[9] However, 39 states are considered to include areas that face a moderate to major threat of a major earthquake.[10] (See "Figure 1. Earthquake Risk Areas in the United States.") Furthermore, a set of maps released by the U.S. Geological Survey (USGS) also shows an increased awareness of the high threat of earthquakes in the Pacific Northwest, the central United States (near the New Madrid Fault Zone), and regions affected by the Yellowstone hot spot (Idaho, Montana, and Wyoming).[11] Other lesser-known areas east of the Rockies that USGS considers to be at risk include Connecticut, Massachusetts, New York, and South Carolina, near Charleston.

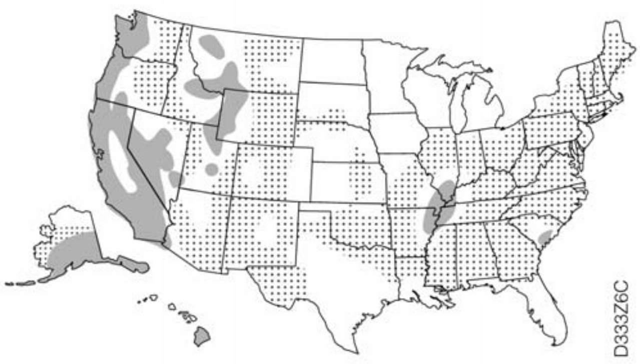
Tsunamis

Issues for Healthcare Facilities

Indonesia, the southern coastline of India, and several Southeast Asian countries experienced one of the most devastating tsunamis ever recorded on December 26, 2004. The tsunami, triggered by an earthquake in the Indian Ocean measuring 9.0 on the Richter scale, claimed more than 231,000 lives.

A 440-bed healthcare facility in India's hard-hit Nagapattinam District was able to maintain operation following the tsunami. Several units of the hospital—located just 800 meters from the ocean—were inundated with silt and mud deposits, which clogged sewer pipes and damaged x-ray machines, electrocardiogram equipment, autoclaves, and baby warmers. Despite the limited infrastructure, physicians worked around the clock to treat injured patients and to perform identification procedures for dead bodies received at the facility. After the initial phase of emergency response, the hospital served as a coordination center for sending medical teams to outlying affected areas and monitoring any public health threats related to the tsunami.[12]

Figure 1. Earthquake Risk Areas in the United States



Key: Shaded areas are at highest risk (16-32+), stippled areas are at moderate risk (4-16), and blank areas are at lowest risk (0-4). Risk is calculated by the U.S. Geological Survey based on the level of horizontal shaking that has a 1-in-10 chance of being exceeded in a 50-year period.

Source: VanDecar J. Earthquakes; shaking in the USA. *Nature* 1997 Mar 27;386(6623):328.

What Is a Tsunami?

Tsunamis are sea waves produced by earthquakes, usually undersea earthquakes or earthquakes with their epicenters near the ocean, that cause a *vertical* displacement of the ocean floor. Tsunamis are potentially the most serious consequence of earthquakes.

Tsunamis can reach speeds of up to 300 to 500 mph in the open ocean. But speed depends on water depth, and since the ocean floor is not smooth, the wave soon becomes highly irregular. The height of the wave also gets smaller as it spreads out in relation to the distance traveled. Soon the tsunami changes from one tremendously high wave to a series of very long waves that are as much as 100 to 400 miles from crest to crest, although the crests are not more than a few feet high. Ships at sea probably do not even notice them.

Effects of Tsunamis

Usually, but not always, the first visible sign that a tsunami is approaching is a withdrawal of the sea to far below the low-tide mark. The water may return in a few minutes, or it may retreat several miles out to sea and return half an hour later. Although tsunamis have been known to grow into towering walls of water up to 200 feet high, most are only 20 to 40 feet high, more like a solid wall of water or a very fast-rising tide. A succession of surges may occur.[13]

Tsunamis with violent, breaker-like waves can crush buildings and ships. Gentler tsunami waves simply float buildings off their foundations. In either case, a violent backwash can cause problems: great damage can be inflicted when it drains back (e.g., by undermining foundations, by uprooting trees).

Location of Tsunamis

Ninety percent of all tsunamis occur in the Pacific Ocean,[14] where an early-warning system has been in place since the mid-1960s. However, the Asian tsunami of December 2004 exposed the need for an Indian Ocean tsunami warning system.

Coastlines or islands where the sea floor rises gradually are less likely to have violent tsunamis than places surrounded by very deep water or deep submarine trenches because much of a tsunami's energy will be dissipated before it hits the shore.[15]

Volcanoes

Issues for Healthcare Facilities

In January 2006, southeast Alaska's Augustine Volcano issued a series of minor eruptions. Staff at a Homer, Alaska, healthcare facility placed extra filters in the facility's air-handling system as a precaution, and area residents had to don dust masks.[16] Ash and steam released by erupting volcanoes can affect air quality, posing health hazards for people with respiratory problems and even damaging vehicle engines. In addition to dealing with air quality concerns, healthcare facilities located in close proximity to an erupting volcano may need to evacuate.

What Is a Volcano?

The simplest definition of a volcano is that it is a vent, fissure, or chimney in the crust through which molten rock (magma) rises to the surface to form a mountain. As with earthquakes, most active volcanoes are at the margins of the tectonic plates.

Volcanoes occur when tectonic plates do one of two things. Unlike earthquakes, they do *not* occur where tectonic plates collide or slide past each other. However, when one plate subducts under another, the crust melts and rises toward the surface in giant blobs of magma. The molten rock subsequently feeds magma chambers lying below active volcanoes. Subduction-zone volcanoes are among the most explosive volcanoes. Their violent nature is due to large amounts of volatiles consisting of water, gases, and magma. The Cascade Range in the Pacific Northwest is a chain of volcanoes associated with subduction zones.

The second way plate movement causes volcanoes is when plates separate. These rift volcanoes account for 80% of all *oceanic* volcanism.

A third form of volcanism, hot-spot volcanism, is *not* related to plate tectonics but occurs within the interiors of plates, sometimes thousands of miles from the nearest plate boundary.

Effects of Volcanoes

Although oceanic volcanoes produce only lava, most land volcanoes *do not,* with the exception of the Hawaiian volcanoes (which produce 99% lava) and the rift volcanoes of Iceland and East Africa, which produce 60% lava. The typical land volcanoes, the subduction type, produce only 10% lava.[17] When there is lava, it usually moves very slowly, so while it can cause great destruction, people (other than seismologists who are right in the crater studying it) are not usually killed by it.

Far more common than lava eruptions are ejections of ash, pumice, and other fragments, called pyroclastic debris, such as that ejected by Mount St. Helens and Mount Vesuvius.[18] In a volcanic ash eruption, huge amounts of rock fragments, natural gas (including carbon dioxide, carbon monoxide, and hydrogen sulfide), and ash are blown high into the air, sometimes as high as the stratosphere. The ash may cover hundreds or even thousands of square kilometers. The lateral blasts of gas and ash are powerful explosions and can travel faster than the speed of sound. The ash flows are extremely hot avalanches of ash, rock, and glass fragments mixed with gas. They may reach speeds of 62 mph and temperatures of up to 1,000°C. They incinerate everything in their path.[19]

Secondary effects from volcanoes include mudslides and fires. For example, if Mount Rainier, lying 150 miles southeast of Seattle, were to erupt, even gently, the glaciers that cover it would melt and the resulting mud, rock, and ice slide would bury the city of Orting, Washington, in less than an hour.[20]

Predicting Eruptions

Forecasting the eruption of a volcano is extremely difficult; however, trained volcanologists can make these predictions based on the geologic history as well as the vital signs of a volcano, including surface deformation, occurrence of microearthquakes, temperature, gas emissions, and volcano tilt. Often, an earthquake is the first sign that a dormant volcano is getting ready to erupt.[21]

Floods

Issues for Healthcare Facilities

Flooding poses numerous hazards to healthcare facilities, including damage to equipment and building structures, electrical hazards, loss of power, and mold growth and poor indoor air quality after floodwaters recede. Texas Medical Center (Houston, Texas) suffered severe flood damage in the summer of 2001 after getting more than 40 inches of rain in one weekend from Tropical Storm Allison. Among the many lessons learned in the aftermath was the medical center's realization that recovery of medical devices and equipment was as much a key issue as crisis management during an emergency.[22] (See the Resource List for information on a report from ECRI's Health Devices group that addresses recovery of water-damaged medical devices.)

Other preparedness lessons learned from the Houston floods include the following (note that many of these points are applicable to preparing for other types of natural disasters):

- During the recovery phase, it is helpful to establish a centralized service center where all service staff are assigned to repair jobs. Service staff are instructed not to handle direct requests for "quick fixes" from other hospital staff; all repair requests must flow through the centralized location, allowing the facility to track exactly how much work and material is needed for each repair (proving beneficial for future planning and for insurance purposes).
- When bringing equipment back online after a sudden power outage—regardless of whether the equipment suffered water damage—the facility must be aware that machines may reboot in a default mode, requiring that settings programmed before the power outage be reentered.
- It is important for healthcare facilities to understand how their vendors operate and know the location of vendor warehouses and how the vendor will transport emergency supplies.

- Facilities must be prepared to use all communication tools at their disposal, from the Internet, walkie-talkies, and two-way radios to megaphones and runners, and must provide communication mechanisms to staff who are on-site at the time of the emergency, staff who come to the facility to respond, the media, and vendors.
- An off-site location must be established where temporary operations can be set up—for example, the primary command center at the Houston medical center was flooded, necessitating relocation of operations to an alternate site. The off-site location should be equipped to manage an emergency situation.[23]

Types of Floods

There are three major types of floods: flash floods, river floods, and tidal floods. Flash floods are local floods of great volume and short duration, generally resulting from torrential rains over a relatively small drainage area. They can also occur after a break in a dam or levee, the sudden breakup of ice jams, or, more unusually, the rapid melting of glaciers or icecaps due to volcanic eruptions. River floods are caused by heavy precipitation over large areas, by the melting of winter snow, or by both. They may last for weeks, slowly growing to their highest levels (known as cresting). Tidal floods are overflows in coastal areas, usually caused by hurricanes, high tides, waves from high seas, storm surges, tsunamis, or a combination of these. Their duration is usually short and depends on the tides, which rise and fall twice a day.

Floods are the most anthropogenic of all natural disasters, in that people settle in floodplains[24] or coastal areas, destroy natural runoff areas and vegetation that might absorb the water, and divert or channel rivers. Moreover, since many floods can be predicted (due to heavy rains or snowfall), flooding is the disaster that causes humans to make the most heroic efforts to save an area by, for example, sandbagging extensively or diverting water from reservoirs that will receive the floodwater. Unfortunately, focusing on trying to save an area very often leaves people unprepared to evacuate if they are ultimately unsuccessful.

River flooding* is a function of the total amount of precipitation, the rate at which it seeps through rock or soil, and the topography of the land. River floods commonly occur in spring as a result of long spring rains, often combined with the rapid melting of ice and snow.

The severity of a flood depends on the lay of the land, how much moisture is already in the ground, and whether the land is frozen. For example, steep topography increases runoff water velocity and debris flow, while abundant vegetation tends to decrease water runoff. Other factors that contribute to the damage caused by flooding include the velocity or "energy" of moving water, the debris carried by the water, the existence of levees (which speed up the river and may break), and the extended duration of flood conditions.

Rapid accumulation of runoff or surface water is perhaps the most common way floods occur. It can be caused by increased urbanization, which gives land an impervious cover (e.g., of paved streets), or by land that is too dry to absorb the water or, alternatively, is already so thoroughly saturated that it can absorb no more. Drains, the river itself, and accompanying wetlands cannot accommodate the water (rain or melted ice), and the river overflows its banks or levees.

Effect of Floods

The primary effect of major flooding is often the complete destruction of an area's entire infrastructure. Even minor flooding can cut off major highways, cause sewage system overflows, and contaminate potable-water supply systems. Other direct flood effects include injury, loss of life, and damage to buildings and other man-made structures caused by swift currents, debris, and sediment. In addition, sediment erosion and deposition on the landscape can involve a considerable loss of soil and vegetation.

Indirect flood effects include short-term pollution of rivers, the disruption of food supplies, the spread of diseases, and the displacement of people who have lost their homes. Floods can even cause fires due to short circuits in power lines or breaks in gas mains and electrocution when people return to their homes.

*Flood Control***

Flood prevention involves constructing levees and flood walls to serve as barriers against high water, building reservoirs to hold excess runoff until it is safe to release, expanding channels to move water quickly off the land, and diverting channels to route

* Unless otherwise noted, all information on river flooding comes from Erickson J. *Quakes, eruptions and other geologic cataclysms.* New York: Facts on File; 1994:96-8.
**All references to flood control come from Erickson J. *Quakes, eruptions and other geologic cataclysms.* New York: Facts on File; 1994:99-151.

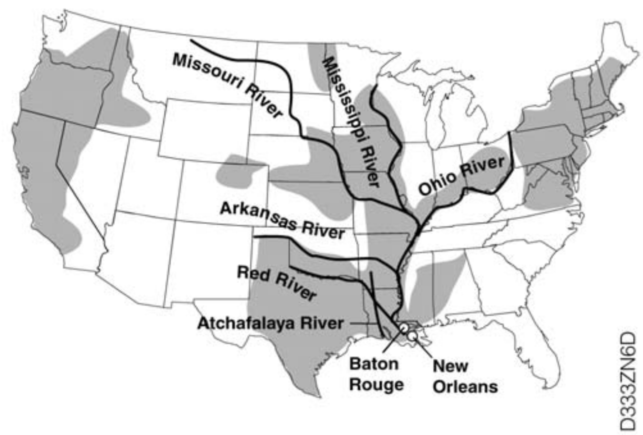
floodwaters around areas that require protection. These engineering controls should be combined with adherence to floodplain regulations.

Location of Floods

There are 22,000 flood-prone communities in the United States, spread throughout the states and territories. (See "Figure 2. Flood-Prone Regions of the United States.") Seven major water resource regions—the Great Basin, California, Missouri, Arkansas, the Texas Gulf, the area around the Rio Grande, and lower Colorado—are considered the areas most vulnerable to flood.

Thirty-five northern states face flooding problems associated with ice jams, a kind of natural damming process. In the spring, ice breaks and collects at constriction points in rivers and streams (e.g., bends, shallows, areas of decreasing slope, bridges). By trapping water behind it and then later giving way, an ice jam heightens flood levels both upstream and downstream. Ice jams occur in the fall because of "frazil" ice (when a swift current permits formation of an ice cover but ice is carried downstream and attaches to the underside of the ice cover there) and in winter when channels freeze solid.

Figure 2. Flood-Prone Regions of the United States



Hurricanes

Issues for Healthcare Facilities

Recent highly active hurricane seasons in the United States have caused hundreds of deaths (Hurricane Katrina alone was responsible for more than 1,100 deaths) and billions of dollars in destruction but have also led to some important insights for healthcare facilities regarding disaster preparedness.

Among the myriad challenges healthcare facilities faced in the days and weeks following Hurricane Katrina were dire circumstances caused by long-term power outages and generator failures. Affected facilities conclude that the following strategies can increase the chance that power will be sustained:

- Have a power circuit layout that allows critical power circuits to be run on one generator and the elevators and the heating, ventilating, and air-conditioning systems to be run on a separate generator, allowing the facility to run the second generator only when necessary.[25]
- Locate at least one generator on a higher floor of the facility (i.e., not in the basement) to reduce the possibility that all generators on a lower level would be flooded.[26]
- Determine a preestablished location out of harm's way for any temporary backup generators. Ensure that there is a means to safely connect temporary generators into appropriate parts of the existing wiring systems.[27]
- Construct a retaining wall around emergency generators to protect equipment.[28]

Healthcare facilities must also plan for the need to evacuate due to approaching hurricanes. Evacuation may be mandated by public officials; other times, facilities will need to use their own judgment. One of the most devastating lessons that 2005's Hurricane Katrina imparted is that when an evacuation order is in effect—or if conditions warrant an evacuation according to a healthcare facility's own policies and procedures—the evacuation absolutely must be implemented. The deaths of 34 residents of a New Orleans-area long-term care facility were allegedly caused by the facility administrators' decision to defend in place despite having agreements with local transportation services for evacuating residents. For further information on evacuation planning, see the *HHC* Analyses "Evacuation" and "Disaster Drills" and page 1 of the February 2003 *Healthcare Hazard Management Monitor*. See page 1 of the February 2006 *Healthcare Hazard Management Monitor* for further information on lessons learned by healthcare facilities affected by Hurricanes Katrina and Rita.

What Is a Hurricane?

Hurricanes, also known as typhoons or cyclones depending on what part of the world they form in, are severe tropical storms of sustained rotating winds of 74 mph or more, up to a maximum speed of about 200 mph. Storms with winds of 38 to 73 mph are called tropical storms, and those with winds of less than 38 mph are called tropical depressions.[29] (Tornadoes, discussed below, are smaller, shorter-lived, more intense storms with wind speeds of up to 300 mph.) The Saffir-Simpson scale is used to estimate the destructive forces associated with hurricanes and to provide warning to residents of threatened areas. (See "Table. Saffir-Simpson Scale of Storm Intensity.")

Hurricanes form during the hot, humid late summer; the threshold temperature for hurricane formation appears to be 26°C (79°F). Because hurricanes are typically slow-moving storms, sufficient warning time is usually available to allow people at risk to evacuate and find a safe place to stay before the storm reaches land. When a hurricane does strike land or reaches cool waters, it usually dies because it does not have the heat it needs for movement.

Table. Saffir-Simpson Scale of Storm Intensity

Storm Category	Wind Speed (mph)
Tropical Storm	38 to 73
Hurricane	
1 (Weak)	74 to 95
2 (Moderate)	96 to 110
3 (Strong)	111 to 130
4 (Very strong)	131 to 155
5 (Destructive)	156+

Source: National Oceanic and Atmospheric Administration. Saffir-Simpson hurricane scale [online]. 2005 Aug 22 [cited 2006 Feb 7]. Available from Internet: http://www.nhc.noaa.gov/aboutsshs.shtml.

Effects of Hurricanes

When a hurricane hits land, it causes death and destruction in four principal ways: wind, tornadoes, rainfall, and storm surge. Wind speeds are regularly more than 100 mph and may be as much as 200 mph. Few buildings remain undamaged; many are stripped of their roofs. In fact, loss of the roof is one of the most devastating hurricane-related consequences to healthcare facilities, experts say, emphasizing that proper design, construction, and inspection of a facility's roof is one of the most important defenses against hurricane damage.[30] High winds can impose significant loads on structures, by both direct wind pressure and drag, and tend to propel loose objects at high velocities. Hurricanes can also spawn tornadoes.

Hurricanes can cause several types of flooding. In coastal areas, the flooding may occur from storm surge, wind-driven water in estuaries and rivers, or torrential rain. The flooding can be still-water flooding or velocity flooding caused by wave action associated with wind-driven water along the coast.

Hurricanes may generate waves up to 25 feet high.* These can batter the coastline, devastating the shoreline itself and structures near the shore. The force of the water moving back and forth undermines the foundations of buildings and piers by removing the soil from around them. Debris driven inland by the waves can also cause severe structural damage. People directly exposed to the swiftly moving water and debris are likely to sustain severe injuries.

However, it is the storm surge that is most lethal, causing over 90% of hurricane deaths. Storm surge is caused by the drop in atmospheric pressure at sea level inside the hurricane, which sucks up the sea; at the same time, winds ahead of the hurricane pile up water against coastlines. The first effects of the latter can be felt nearly a week in advance of the hurricane, when the weather is often otherwise fine: the "calm before the storm." When the hurricane arrives, the surge is estimated to diminish in depth by one to two feet for every mile it moves inland.

Hurricanes can also cause numerous secondary hazards—for example, electrical power outages, contamination of water supplies, flooding of sewage treatment facilities, and even dam failure may occur during or after a hurricane. The most damaging effects of Hurricane Katrina in New Orleans occurred in the storm's wake, when levees gave way, allowing water to deluge the city.

Location of Hurricanes

Hurricanes usually arise in the west Atlantic; the east, south, and northwestern Pacific; and the Indian Ocean between 5° and 30° latitude north and south of the

* All information on sea surges is from Robinson A. *Earthshock: hurricanes, volcanoes, earthquakes, tornadoes and other forces of nature.* London: Thames and Hudson; 1993:128-30.

equator and seldom move closer to the equator than 4° to 5° latitude.[31] They occur in all oceans, with the possible exception of the south Atlantic and the Pacific east of 140° W longitude. The northwestern Pacific region has the most hurricanes, or as they are known there, typhoons.

Tornadoes

Issues for Healthcare Facilities

In May 1999, a series of tornadoes that produced winds of more than 260 mph struck the Oklahoma City, Oklahoma, area, injuring hundreds and damaging or destroying more than 7,000 homes. Area healthcare facilities faced an onslaught of storm victims, family members inquiring about patients, and community residents seeking shelter. Some facilities, after determining that they were in the path of an approaching tornado, prepared for a direct hit, evacuating patients away from windows into hallways and lower building levels and directing visitors to interior lobbies.[32]

Oklahoma City healthcare facilities cited many challenges related to accommodating the influx of patients, visitors, and shelter seekers, including tracking emergency department patients, controlling traffic in parking areas, and dealing with security issues such as access control. One facility found that its efforts to keep employee lists up-to-date with current contact information proved to be invaluable when it came to calling in additional security staff.[33]

In addition to causing physical trauma, tornadoes—as well as the other natural disasters discussed in this Analysis—can have devastating psychological effects on both staff members and patients. In the aftermath of a severe tornado that hit Forth Worth, Texas, in 2000, a healthcare facility spokesperson stated that the psychological components—fear, grief, and anxiety—were the most difficult to cope with.[34]

What Is a Tornado?

A tornado is a rotating air mass with speeds of up to 300 mph and a short life span (10 minutes to 2 hours).[35] Tornadoes are funnel shaped, but the funnel may be long and thin or short and fat. Tornados contain a vortex or vacuum that sucks things up as it passes over.

Most tornadoes are created in large, wild storms called supercells. In a supercell, cool, dry air lies on top of warm, moist air that is about one mile thick over the earth's surface.[36] An air rush at ground level converges with the natural spin of air masses generated by the turning of the earth. The converging air masses tighten into a spiral, and the speed of the air movement increases. As the spiral rotates, additional warm air is sucked into the rising column with enough force to create updrafts of up to 100 mph for thousands of feet to the top of the thunderstorm. This condition is known as a mesocyclone. Only about one-half of mesocyclones form tornadoes, and scientists are not sure what the additional trigger is.[37]

In the northern hemisphere, the Coriolis effect of the earth's rotation causes tornadoes to turn counterclockwise; in the southern hemisphere, they turn clockwise and almost always move northeasterly across land.

Effects of Tornadoes

Most tornadoes leave a damage path 150 feet wide, move at about 30 mph, and last only a few minutes. Extremely destructive tornadoes may be over a mile wide, travel at 60 mph, and stay on the ground for more than an hour. Even the strongest tornadoes, however, are not thought to generate winds in excess of 275 mph, and the highest wind speeds are located in the lowest 300 feet of the funnel.[38] The force of these winds can blow gravel or sand into a person's flesh with the force of a bullet or stick a piece of straw into a telephone pole, although the more likely explanation for the latter is that the wind forces open the grain of the wood, which then snaps shut, trapping the straw.

Wind is not the only damaging force that accompanies a tornado. The pressure at the center of the storm is very low, and when that part of the storm passes over a building, the pressure outside the building is far lower than the pressure inside. This may cause the building's walls to blow out. However, since the Institute for Disaster Research in Texas noted that the windward walls of buildings almost always fell inward—implying that the buildings were more often damaged by the force of the wind than by the sudden drop of pressure—residents are no longer advised to open windows to reduce pressure. This suggestion had caused many people to be hurt by flying glass as they hurried to open the windows. People are also no longer advised to hide in the southwest corner of a building, where they were actually at the most risk of having the walls fall in on them; now they are advised to seek shelter in a central closet because of the added protection of interior walls.[39]

Updrafts from a tornado can be powerful enough to lift large objects off the ground, killing or injuring livestock and severely damaging other heavy items. A 160 mph wind will produce a lifting force of over 30 tons on a typical house; if the speed doubles to 300 mph, the lifting force is 100 tons.[40]

The largest variable of destruction associated with tornadoes is the degree of contact between the tornado and the ground. It is not uncommon for a tornado's tail to barely (if at all) touch ground. It is when the tail does touch down that destruction occurs.

Tornado season runs from March to August in the United States, with peak activity from April to June; however, tornadoes can occur year-round.

Locations of Tornadoes

Tornadoes occur worldwide, although they are rarely reported in Africa. The United States has more tornadoes than any other country, averaging 700 to 1,150 each year, causing 80 deaths and 1,500 injuries annually. Twenty percent of these storms are strong, and 1% are violent storms, which cause 70% of deaths attributed to tornadoes.[41] One-third of all tornadoes in the United States occur in just three states (Texas, Oklahoma, and Kansas) in an area called Tornado Alley, a 460-mile-long, 400-mile-wide swath (see "Figure 3. Tornado Activity in the United States"). This may have to do with the warm, moist air from the Gulf of Mexico meeting the cool, dry air from Canada, which is channeled by the Rockies.[42] However, more than 50% of the land mass in the United States is within the area of significant tornado risk.

Blizzards

Issues for Healthcare Facilities

Power failures may be the most common threat to healthcare facilities associated with blizzards. Consider the following nurse's description of how her Denver, Colorado, facility coped with a blizzard-related power failure:[43]

> To complicate matters, the heavy snow had knocked out the electricity. Backup generators would provide power for only six more hours. We began planning who'd ventilate which patients. We also informed patients of the situation and reassured them that we could handle any problems. . . . When our large generator failed, only a small generator was still running. . . . We shut down all nonessential electrical use and gave patients bells to use to call the staff. We distributed every available blanket in case the inside temperature started to fall. We administered medication by flashlight; hallways, patient rooms, and nurses' stations were pitch black.

Other potential problems associated with a blizzard (or with any significant snowfall) include structural damage to the facility's roof and staffing issues (i.e., because roads may be impassable). Of course, blizzards and winter weather in general raise concerns regarding safety of staff and visitors walking through parking lots and outdoor paths around the facility campus.

What Is a Blizzard?

The start of a blizzard may be deceptive. There may be a slow drop in barometric pressure, snow may fall, and the day before the storm may be unusually warm. Then, winds shift to the north and the temperature drops by as much as 50° to 60°F. Snow starts to fall more heavily, and wind gusts pick up. To qualify as a blizzard, a storm must have sustained winds or frequent gusts of wind that reach at least 35 mph for at least three hours, with considerable snowfall and/or blowing snow that reduces visibility to less than one-quarter of a mile.[44]

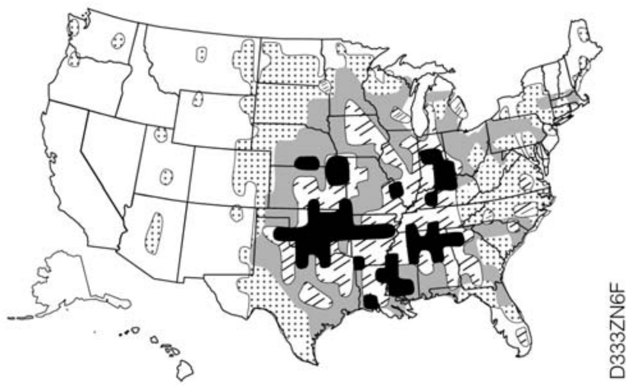
Blizzards can be differentiated from large snowfalls by the type of snow, temperatures, and wind. Snow that falls when the wind is light is soft because of the air contained in it, but when the weather is very cold, the snow is dry. Snow can also form into ice pellets when buffeted by strong winds that break off the points of crystals and pack them into small balls. Add this snow to fierce winds, and the conditions are ripe for a blizzard. During a blizzard, visibility is close to zero and wind may create snowdrifts many feet high. With the wind and snow blowing, a condition called a whiteout often occurs. During a whiteout, it is impossible to distinguish the ground from the sky, and many people get disoriented. Cases have been reported of people freezing to death just a few feet from their front doors. During a blizzard, the snow is so fine and blows so fiercely that cases have been reported of people suffocating from snow inhalation.

Effects of Blizzards

The primary effects of blizzards are, of course, snow and extreme cold.

Secondary effects are that power lines are often down and may take days to repair, pipes may freeze, people may become stuck and unable to move their cars, temperatures are often dangerously cold, and if the temperature rises too fast, severe flooding may occur. Snow or blizzards also give rise to another

Figure 3. Tornado Activity in the United States



Key: This map shows the number of F3 (severe), F4 (devastating), and F5 (incredible) tornadoes recorded per 3,700 sq. mi. from 1950 to 1998. White portions of the map represent areas where no tornadoes were recorded per 3,700 sq. mi.; dotted portions, 1 to 5 tornadoes; light gray portions, 6 to 15 tornadoes; lined portions, 16 to 25 tornadoes; and black portions, more than 25 tornadoes.

Source: Federal Emergency Management Agency. Taking shelter from the storm: building a safe room inside your house [online]. 2004 Mar [cited 2006 Feb 10]. Available from Internet: http://www. fema.gov/pdf/fima/fema320.pdf.

hazard—ice. During the day, when the temperature rises, snow begins to melt; if the temperature dips below freezing at night, the water then freezes into ice. Transportation routes are often completely cut off, and public transportation (e.g., trains, trolleys) may not run.

Location of Blizzards

In North America, blizzards occur most frequently in the northern Great Plains, the northeastern metropolitan states, North Dakota, Iowa, Minnesota, the prairie provinces of Canada, the upper Mississippi Valley, and the eastern Arctic.

Wildfires

Issues for Healthcare Facilities

Wildfires in southern California in the fall of 2003 prompted several healthcare facilities to evacuate patients and invoke internal disaster protocols, which entailed rescheduling nonessential surgeries and calling essential personnel back to work.[45] Facilities also had to deal with an influx of patients seeking care due to poor air quality; some healthcare workers were also affected by smoke and ash that infiltrated hospital ventilation systems.[46]

Two large facilities serving special patient populations were forced to quickly implement total evacuation in the face of fast-approaching fires.[47] According to the Health Care Association of San Diego and Imperial Counties, adequate preparedness—from conducting periodic fire drills and having in place procedures for handling fires, for example—resulted in a successful response for affected facilities.[48] (For information on fire safety and preparedness, see the *Fires* section of the *HHC System*.)

What Causes Wildfires?

The four major factors necessary for a wildfire are a long drought, plentiful fuel, strong winds, and abundant ignition sources.[49] Conditions equivalent to drought can be created by draining swamps or marshlands, killing vegetation, or altering microclimates. Ignition sources include fire from earthquakes, volcanic eruptions, careless handling of lit material, and arson. Lightning is another prevalent wildfire igniter. The most effective fire starters are dry lightning storms—thunderheads from which little precipitation reaches the ground—which commonly occur after droughts or dry seasons.

Fuel sources are also important. For example, the moisture content of dead logs and branches is usually 15% to 20%, which is usually too moist for large fires to start; during drought conditions, the moisture content can drop to 7% and in small, dead twigs, it can drop to 2%.[50]

Southern California faces particular problems. First, it has the Santa Ana winds and other winds that drive out moisture and fan flames once fires are started. Second, it has a particularly pyrophilic fuel supply. Chaparral, a common brush in the area, is highly flammable, and rather than clear it, people like to keep it around their homes as landscaping. Worse yet, homes have wooden roofs. Eucalyptus trees, common in California, also constitute a serious fire hazard.

The South provides a different example of the role of fuel supplies. In the South, there are three different geographic provinces, each with its own fuel supply. The coastal plains have pines and pocosins, Appalachia has hardwoods, and the Piedmont area has pines and hardwoods.

A wildfire grows from a steady state to an accelerating one when there is a tremendous accumulation of

Resource List

California Emergency Medical Services Authority
1930 9th Street
Sacramento, CA 95814
(916) 322-4336
http://www.emsa.cahwnet.gov/default.asp

- Hospital Emergency Incident Command System

ECRI
5200 Butler Pike
Plymouth Meeting, PA 19462
(610) 825-6000
http://www.ecri.org

- Disaster planning and response [guidance article]. *Health Devices* 2005 Sep;34(9):294-310.
- ECRI Hurricane and Disaster Planning Resources (https://members.ecri.org/members/_elements/HDOnline/content/docs/HDDisasterResources.htm)
- Recovering medical devices after water damage [special report]. Accession No. S0093. *Health Devices Alerts* 2005 Oct 7;29(40):4-5.

Federal Emergency Management Agency
500 C Street SW
Washington, DC 20472
(800) 621-3362
http://www.fema.gov

- National Incident Management System (http://www.fema.gov/nims/index.shtm)

Joint Commission on Accreditation of Healthcare Organizations (JCAHO)
One Renaissance Boulevard
Oakbrook Terrace, IL 60181
(630) 792-5000
http://www.jcaho.org

- Management of the environment of care. In: *Comprehensive accreditation manual for hospitals*. Oakbrook Terrace (IL): JCAHO; 2005.

National Oceanic and Atmospheric Administration
14th Street and Constitution Avenue NW
Room 6217
Washington, DC 20230
(202) 482-6090
http://www.noaa.gov/index.html

- Provides information on weather and climate conditions throughout the United States

Occupational Safety and Health Administration
200 Constitution Avenue NW
Washington, DC 20210
http://www.osha.gov

- Keeping Workers Safe during Clean Up and Recovery Operations following Hurricanes (http://www.osha.gov/OshDoc/hurricaneRecovery.html)

Additional listings can be found in ECRI's Healthcare Standards Directory, *a comprehensive source of healthcare standards, guidelines, laws, and regulations. The* Directory *is available from ECRI.*

heat and a heavy fuel load. It is so hot that it actually affects the surface wind field, and ultimately, the fire responds to the convective wind system generated by the fire itself and not to the ambient wind. Then, if a triggering mechanism occurs, such as a spread into heavier fuels or a breakup of an evening air-inversion layer, the fire is said to have begun a run. Wildfires may stay in a steady state for weeks, or transition can occur within moments after the fire has achieved a steady state. Once in the transitional phase, however, fire propagation becomes discontinuous. Fire whirls and showers of aerial firebrands create new heat sources that can spread the fire.

Wildfires acquire a self-sustaining momentum; as more heat is generated, the volume of hot air in the immediate vicinity of a fire increases, in turn creating air-pressure gradients that generate local winds. Burning tufts of twigs and conifer needles are then swept into the air by the wind and transported as much as a mile and a half away, where they ignite more fires. The manner in which a fire spreads can not always be predicted, since it is based on such factors as soil moisture and fuel and also wind and weather.[51]

Effects of Fires

The direct effects of fires are destruction of property and occasional loss of life. Indirect effects may include destruction of communication lines, pipelines, and roads.

Location of Most Wildfires

Wildfires most likely to threaten populated areas usually occur in southern California. However, wildfires may occur anywhere. For example, from late 2005 into 2006, several wildfires raged in Texas and Oklahoma as a result of very dry conditions and strong winds, destroying thousands of acres and hundreds of homes and businesses.

CHEM RECOMMENDATIONS

- Educate yourself and others involved in emergency preparedness efforts on the types of natural disasters your facility may experience.
- Review emergency preparedness plans to ensure that they address each type of natural disaster that could affect the region.
- Conduct periodic drills that incorporate natural disaster scenarios.
- Refer to this Analysis and other resources on disaster planning throughout the *HHC System* while developing or reviewing emergency preparedness plans.

Notes

1. Joint Commission on Accreditation of Healthcare Organizations (JCAHO). Management of the environment of care. In: *Comprehensive accreditation manual for hospitals*. Oakbrook Terrace (IL): JCAHO; 2005.
2. Stymiest DL. Lessons learned: recent disasters give reason to rethink emergency management strategies. *Health Facil Manage* 2005 Dec;18(12):21-4.
3. Schultz CH, Koenig KL, Lewis RJ. Implications of hospital evacuation after the Northridge, California, earthquake. *N Engl J Med* 2003 Apr 3;348(14):1349-55.
4. Levy M, Salvadori M. *Why the earth quakes.* New York: W.W. Norton and Co.; 1995:21-2.
5. Robinson A. *Earthshock: hurricanes, volcanoes, earthquakes, tornadoes and other forces of nature.* London: Thames and Hudson; 1993:8.
6. *Id.* at 60.
7. Erickson J. *Quakes, eruptions and other geologic cataclysms.* New York: Facts on File; 1994:1.
8. *Id.* at 71.
9. Levy M, Salvadori M, *supra* note 4.
10. Erickson J, *supra* note 7:42.
11. VanDecar J. Earthquakes shaking in the USA. *Nature* 1997 Mar 27;386(6623):328.
12. Surjit V. Tsunami-hit hospital rises to the occasion [online]. The Hindu 2005 Jan 16 [cited 2006 Jan 30]. Available from Internet: http://www.thehindu.com/2005/01/16/stories/2005011603461000.htm.
13. Erickson J, *supra* note 7:34.
14. *Id.* at 31.
15. Ibid.
16. Eruptions put Alaskans on volcano alert [online]. 2006 Jan 15 [cited 2006 Jan 16]. Available from Internet: http://www.msnbc.msn.com/id/10843021.
17. Robinson A, *supra* note 5:105.
18. Ibid.
19. Keller EA. *Environmental geology*. 5th ed. Columbus (OH): Merrill Publishing; 1987:200-1.
20. Adler J. Magma force. *Newsweek* 1997 May 5;129(18):67.
21. Erickson J, *supra* note 7:43.
22. Healthcare emergency preparedness: is the facility ready? *Risk Manage Rep* 2002 Jun;21(3):1, 3-9.
23. Ibid.
24. Erickson J, *supra* note 7:94.
25. ECRI. Lessons learned from the 2005 hurricane season. *Risk Manage Rep* 2006 Feb;25(1):7.
26. Ibid.
27. Stymiest DL, *supra* note 2.
28. Hurricane shows faults in hospital planning and potential liability. *Healthc Risk Manage* 2005 Nov;27(11):121-3.
29. Robinson A, *supra* note 5:125.
30. Zurich North America. When disaster strikes: how hospitals respond. *Perspectives* 2005;11(1):1-4.
31. Robinson A, *supra* note 5:123.
32. Oklahoma City's killer tornadoes: how local hospitals responded to yet another extreme disaster. *Hosp Secur Saf Manage* 1999 Sep;20(5):5-9.
33. Ibid.
34. Sussman D. The center of the storm: Fort Worth still picking up the pieces from March's tornado [online]. NurseWeek 2000 May 1 [cited 2006 Jan 27]. Available from Internet: http://www.nurseweek.com/features/00-05/twister.html.
35. Robinson A, *supra* note 5:136.
36. Davies-Jones R. Tornadoes. *Sci Am* 1995 Aug;273(2):51.
37. Robinson A, *supra* note 5:143.
38. Davies-Jones R, *supra* note 36:57.
39. *Id.* at 52.
40. Robinson A, *supra* note 5:144.
41. *Id.* at 136.
42. Ibid.
43. Jennings Y. Lessons from a blizzard. *Nursing* 2005 Dec;35(12):32cc5.
44. Murrell B. What are the conditions that cause a blizzard? [online]. 2004 Mar 30 [cited 2006 Jan 13]. Available from Internet: http://www.srh.noaa.gov/shv/Past_Questions_SIX.htm.
45. Silva C. SoCal fire caused some hospitals to evacuate patients [online]. AHA News Now 2003 Nov 3 [cited 2006 Jan 13]. Available from Internet: http://www.aha.org.
46. Hoyt KS, Gerhart AE. The San Diego County wildfires: perspectives of healthcare providers. *Disaster Manag Response* 2004 Apr-Jun;2(2):46-52.
47. Ibid.
48. Silva C, *supra* note 45.
49. Pyne SJ. *World fire: the culture of fire on earth.* New York: Henry Holt and Co.; 1995:37.
50. Romme WH, Despain DG. The Yellowstone fires. *Sci Am* 1989 Nov;261(5):37.
51. Ibid.