# Primary Protection: Enhancing Health Care Resilience for a Changing Climate

U.S. Department of Health and Human Services

December 2014

# PRIMARY PROTECTION: ENHANCING HEALTH CARE RESILIENCY FOR A CHANGING CLIMATE

## A Best Practices Document under the HHS Sustainable and Climate Resilient Health Care Facilities Initiative


## AUTHORS

### Robin Guenther, FAIA, LEED Fellow

Perkins+Will, Health Care Without Harm

### John Balbus, MD, MPH

National Institute of Environmental Health Sciences



## ACKNOWLEDGEMENTS

***The authors thank the following for their assistance in facilitating the stakeholder review of this document:***

- Critical Infrastructure Protection Program, HHS Office of the Assistant Secretary for Preparedness and Response
- Health Care Without Harm
- Forum on Medical and Public Health Preparedness for Catastrophic Events, Institute of Medicine
- Environmental Justice, Labor and Public Health Workshop Review Participants

***This document appeared in the Peer Review Agenda for NIH on June 16, 2014. The authors thank the following peer reviewers for their comments:***

- Mark Catlin, Service Employees International Union
- Kim Knowlton, Natural Resources Defense Council
- John Kouletsis, Kaiser Foundation Health Plan
- Hubert Murray, Partners HealthCare
- Jon Utech, Cleveland Clinic
- Jalonne White-Newsome, WE ACT for Environmental Justice

***The authors thank the following individuals for their assistance with this document:***

- HHS-OASH: Diana Cassar-Uhl, Sarah Field, Sandra Howard
- HHS-ASPR: Steve Curren, Lauren Wolf
- HHS-NIH: Joseph Hughes, Nyron Rouse, Ross Bowling
- Health Care Without Harm: Gary Cohen

The Offices of the Assistant Secretary for Administration and Assistant Secretary for Health supported this project through contracts with EnDyna, Inc. and MDB, Inc.


***Cover Photo Credits:***

**Top:** Ascension's Our Lady of Lourdes Memorial Hospital in Binghamton, New York. A flood wall was built in 2011 to keep the hospital operational during times of flooding.

**Left:** Memorial Sloan Kettering Cancer Center is a leader and early adopter for sustainable design and climate resilience initiatives. Its 74th St. location is one of the first major health care facilities to be built in a flood zone post Superstorm Sandy in New York State. It is targeted to be LEED Silver certified.

**Right:** Partners HealthCare Spaulding Rehabilitation Hospital is the first building on the Boston waterfront designed to be climate resilient. The building is LEED Gold certified and opened in 2013.

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# PART 1: INTRODUCTION

Disasters in hospitals do not have to occur to become the subject of intense planning and programming: future crises and disasters, either more or less similar to previous occasions, or never-before experienced but anticipated occasions, become part of the imagined reality of hospital staff, are considered as having the potential to occur and disrupt the functionality of the hospital, and anticipatory planning and corrective actions take place to respond to them. The planning and mitigation that take place are part of a general culture of mindfulness, a deep-seated awareness that emergencies and accidents are always lurking under the appearance of utter normality, so that disasters, either occurring or imagined, are used by hospital staff as signals of impending trouble which demand their response (Aguirre, Dynes, Kendra, & Connell, 2005).

## OVERVIEW

The Health Care Climate Resilience Guide and Toolkit, delivered through the U.S. Climate Resilience Toolkit website (*toolkit.climate.gov*), has been created as an initial component of the President's Climate Action Plan. The Plan included this recommendation for actions to promote resilience in the health sector:

"The Department of Health and Human Services will launch an effort to create sustainable and resilient hospitals in the face of climate change. Through a public-private partnership with the health care industry, **it will identify best practices and provide guidance on affordable measures** to ensure that our medical system is resilient to climate impacts. It will also collaborate with partner agencies to share best practices among federal health facilities" (Executive Office of the President, 2013).

These documents have been developed for sectors and disciplines engaged in health care facility climate resilience to assist in improving response to extreme weather events and facilitate a faster return to normal or adoption of a new normal. Climate resilience, as applied to health care, is anchored by the acute care hospital, a "high-reliability organization" that is keenly aware of, and sensitive to, broader resilience concerns. Disruptions and losses incurred by the U.S. health care sector after recent extreme weather events strongly suggest that specific guidance on managing the new and evolving hazards presented by climate change is necessary.

The Guide and Toolkit is intended to provide key tools and insights to improve the climate resilience of the full spectrum of health care delivery settings at the institution (campus or facility) level, nested within the broader context of regional and community infrastructure. This Guide is organized in three parts. Part 1 introduces the overall program. Part 2 examines the characteristics of health care delivery settings and defines the parameters of changing extreme weather risks; this part includes case studies of actual health care infrastructure responses to historical extreme weather events. Part 3 introduces a five-element planning framework for improving health care infrastructure resilience, a framework that in turn guides the Toolkit organization. Part 3 highlights case studies of emergent practices for improving health care resilience.

## GUIDE AND TOOLKIT DEVELOPMENT PROCESS

The Guide and Toolkit is an initial step in a collaborative project sponsored by the U.S. Department of Health and Human Services that will engage a broad group of public and private stakeholders.

## PURPOSE AND SCOPE

The goal of the Guide and Toolkit is to assist health care providers, design professionals, policymakers, and others with roles and responsibilities in assuring the continuity of quality health and human care before, during and after extreme weather events. The Guide is focused on ***health care infrastructure*** resilience to climate change impacts as manifested primarily by extreme weather events.

Health care, for the purposes of this Guide and Toolkit, is defined as hospitals, residential health care (rehabilitation/long-term care), ambulatory care (dialysis, drug treatment, chemotherapy), retail (pharmacies), and home care settings. The focus of this resource is institution-level infrastructure: physical buildings and campus infrastructure as well as mobile technologies.

Hazard vulnerabilities addressed in the Guide and Toolkit include:

- Planning (service locations, stormwater, site and transportation access issues)
- Structural (fixed structural elements, such as roofs and walls)
- Nonstructural (utilities, electro-mechanical systems, communications systems)
- Organizational (supply chain and staff accommodation)

***Not included:*** Municipal infrastructure/ Community health infrastructure

***Not included:*** Seismic events/ Bioterrorism/ Pandemics

***Not included:*** Emergency preparedness activities/Evacuation methodologies/ Regional health care preparedness organizing/Regional transportation

## KEY TERMS

**Adaptation:** The adjustment of our built environment, infrastructure, and social systems in response to actual or expected climatic events or their effects. Adaptation includes responses to reduce harm or capture benefits (Intergovernmental Panel on Climate Change [IPCC], 2007).

**Climate Resilience or Climate Change Resilience:** The capacity of an individual, community, or institution to dynamically and effectively respond to shifting climate impact circumstances while continuing to function at an acceptable level. Simply put, it is the ability to survive and recover from the effects of climate change. It includes the ability to understand potential impacts and to take appropriate action before, during, and after a particular consequence to minimize negative effects and maintain the ability to respond to changing conditions (Rockefeller Foundation, 2009).

**Critical Facility:** Facilities for which the effects of even a slight chance of disruption would be too great. Critical facilities include designated public shelters, hospitals, vital data storage centers, power generation and water and other utilities, and installations which produce, use, or store hazardous materials (FEMA 2014).

**Critical Infrastructures:** Includes assets, systems, and networks, both physical and virtual, that support campuses and buildings, and that are so vital their destruction or incapacitation would disrupt the security, health, safety, or welfare of the public. Critical infrastructure may be manmade (such as structures, energy sources, water, transportation, and communication systems), natural (such as surface or groundwater resources), or virtual (such as information systems) (DHS 2013).

**Disaster:** an ecological disruption causing human, material, or environmental losses that exceed the ability of the affected community to cope using its own resources, often calling for outside assistance (Centers for Disease Control and Prevention [CDC], 2014).

**Mitigation:** any sustained action taken to reduce or eliminate long-term risk to life and property from hazard events. This word has two distinct meanings: In the climate change and sustainability context, it means reduction of greenhouse gas emissions and concentrations; in the disaster preparedness and resilience context, it means any type of risk reduction.

**Resilience:** the capacity of a system to absorb disturbance and reorganize while undergoing change to still retain function, structure, identity, and the capacity for learning and adaptation (Resilience Alliance, 2014).

**Risk:** the magnitude of an impact and the probability of its occurrence. For example, the risk posed to a structure by sea level rise depends on the rate of sea level rise, the structure's existing vulnerabilities, and the rate at which the structure can be adapted. Risk is connected to vulnerability, and both terms are complicated by the lack of a common metric for assessment (Blanco et al., 2009).

**Vulnerability:** the degree to which a system is susceptible to and unable to cope with the negative effects of extreme weather or climate change. Vulnerability of a building or the built environment is the result of age, condition or integrity, proximity to other infrastructure, and level of service (Ebi, Sussman, & Wilbanks, 2008). The impact of a weather event on a system or infrastructure element is mediated by its vulnerability.

**Vulnerable Populations:** Health care professionals define this group as the segments of the general population most susceptible to some pathogen, disease, or other adverse health outcome, categorized by age, race, gender, income, or other common factors. The weather community classifies vulnerable groups in terms of geographic proximity to discrete weather events or climatic patterns. This document considers both contexts.

## BASIC ASSUMPTIONS

The following foundational concepts of health care climate resilience are the basis for this Guide and Toolkit:

1. A network of coordinated health care services must remain operational during and following extreme weather events. Acute care and emergency medical services must continue uninterrupted. In addition, essential health services must remain available to communities and individuals during and immediately following

extreme weather events, even during extended utility outages and transportation infrastructure disturbances.

2. Health care settings continue to decentralize from hospitals to a range of sub-acute settings such as long- term care, assisted living, ambulatory facilities, and home care. Public policymakers and health care providers must work together to determine the minimum and recommended infrastructure requirements for all health care delivery settings.
3. Increasing incidents of extreme weather represent complex hazards that challenge accepted baseline assumptions for infrastructure capabilities, redundancies, and disaster preparedness and response. Climate change is introducing new threats and new building design threshold conditions.
4. Health care organizations play a key role in community resilience. Health care workers are first responders; hospitals are critical facilities. For hospitals to remain operational, both to deliver essential medical care and serve as a safe haven for residential care settings (such as nursing homes) that are adversely affected by the weather event, physical infrastructure (including utilities), key personnel (both medical and support), and supply chain resilience must all be in place.
5. Today, health care facilities are often only as resilient as the communities and regions within which they are located. Resilient health care organizations must anticipate extreme weather risks and transcend limitations of regional public policy, local development vulnerabilities, and community infrastructure challenges as they site, construct, and retrofit health care facilities.
6. Community engagement is a key element of health care system resilience. Communities face unique extreme weather risks and have varying levels of resilience to those risks. Social factors affect the capacity of communities to prepare for and recover from weather related damage. Because access to health care services is a key element of disaster survival and recovery, health care organizations cannot undertake infrastructure resilience without understanding the role of particular hospitals, residential care facilities, ambulatory and home care programs in the health and wellbeing of community residents, and the social and environmental justice issues that define their communities.

## BACKGROUND

A realistic appraisal of the health care infrastructure and its vulnerability to severe weather events recognizes that weather extremes are and will remain major features of the atmosphere. Furthermore, forecasts of these extremes may often be on too short a time frame to provide enhanced protection to the health care delivery enterprise. Climate change and increasing variability will make future efforts to build resilience more difficult, while extreme weather events are likely to increase health care delivery systems' exposure to hazards and risk.

Less obvious is the fact that geographic population shifts within the United States and demographic changes as the nation ages will place additional stresses on health care infrastructure, continuing to drive significant health care real estate development and infrastructure investments. Continuing local development practices to accommodate evolving market demands, such as infilling coastal wetlands and increased impermeable paving, may also generate complex environmental changes and contribute to increased risk from extreme weather events, if they are not understood and acted upon. Sustainable and resilient development practices are unevenly applied at regional, state and local levels, resulting in variable levels of climate change preparedness in health care infrastructure. There is no acknowledged universal "baseline" with regard to the ability of health care infrastructure to withstand impacts of extreme weather events.

Finally, health care resilience relies on more than the viability of its physical facilities. What good is a hospital that withstands a 500-year storm if personnel cannot get to work? If supplies of food, water, medical supplies or fuel are depleted after 96 hours? As high-reliability organizations, hospitals understand how to organize for the unexpected, but sub-acute residential settings and ambulatory care systems have fewer infrastructure requirements and perhaps less experience in managing extreme weather risks. Health care preparedness must reflect both the increased reliance on these non-hospital settings while acknowledging their potential increased physical vulnerabilities.

## DISASTER RISK

Risk is a function of the hazard (a hurricane, an earthquake, a flood, or a fire, for example), the exposure of people and assets to the hazard, and the conditions of vulnerability of the exposed population or assets. Significant extreme weather risk drivers, according to the United Nations International Strategy for Disaster Reduction [UNISDR] (2012) include:

- Growing urban populations and increased density, which put pressure on land and services
- Increasing settlements in coastal lowlands, along unstable slopes and in hazard-prone areas
- Weak local governance and insufficient participation by local stakeholders in planning and urban management
- Inadequate water resource management, drainage systems, and solid waste management, causing health emergencies, floods and landslides
- Ecosystem decline as a result of human activities such as road construction, pollution, wetland reclamation, and unsustainable resource extraction that threatens the ability to provide essential services such as flood regulation and protection
- Decaying infrastructure and unsafe building stocks, which may lead to collapsed structures (older building stocks often contain hazardous materials, such as asbestos, in vulnerable locations)
- Adverse effects of climate change that will likely increase or decrease extreme temperatures and precipitation, depending on localized conditions, with an impact on the frequency, intensity and location of floods and other climate-related disasters

Literature emphasizes that a resilient city, development, or institution is one that improves post-disaster through adaptation. No development can expect to completely protect itself or return to normal after experiencing the effects of severe flood, hurricane, or other disaster; the most resilient communities and institutions are able to mitigate and minimize damage, provide support and emergency services, and take advantage of the post-disaster situation to improve or facilitate positive change economically, socially, and ecologically (New York City Chapter of the American Institute of Architects, 2013; The City of New York Strategic Initiative for Rebuilding and Resiliency [SIRR], 2013; UNISDR, 2012).

## SEVERE WEATHER, CLIMATE CHANGE, AND HEALTH

**"Severe weather is a necessary product of the natural environment. Storms, though sometimes powerful and deadly, are nature's temperature and moisture balancing mechanisms" (American Meteorological Society [AMS], 2010).**

Globally, the recorded number of weather-related hazard events that adversely affect human populations is on the rise. Each local and urban context is affected differently, depending on the prevailing hazards in each location and the exposure and vulnerabilities of the region or community. SwissRe (2013), the world's largest global reinsurer, reported that 2012 was the third most expensive year in recorded history for natural catastrophes and man-made disaster losses, costing $186 billion.

Large-scale weather events in the U.S. pushed total insured claims to $77 billion. Superstorm Sandy alone is estimated to have cost $70 billion with roughly half covered by the private and national flood insurance programs. Record heat and extremely dry weather conditions in the U.S. led to one of the worst droughts in recent decades, affecting more than half of the country. Severe crop failures in the U.S. corn belt resulted in insured agricultural losses of $11 billion, the highest ever recorded agricultural loss. According to the IPCC's *Special Report on Managing the Risks of Extreme Events and Disasters* (2012), the increase in impacts from extreme weather will remain largely dependent on human activity in terms of exposure and vulnerabilities.

According to the American Meteorological Society [AMS] (2010), the U.S. experiences as much or more severe weather than any other country on Earth. In a typical year, the nation experiences 10,000 severe thunderstorms; 5,000 floods; 1,000 tornadoes; and 10 hurricanes. Extreme temperatures (both hot and cold) also have a major effect on vulnerable populations—nearly 12,000 people, primarily the aged and economically disadvantaged, are hospitalized each year as a result of extreme temperature conditions. Extreme weather events create surges of demand for health care while simultaneously threatening the continuity of that care. The AMS notes that "a changing climate may intensify storms that already frequent coasts and rip through rural and urban areas on a seasonal or annual timeframe" (2010).

Extreme weather events are associated with a range of health impacts, from immediate injuries and deaths associated with high winds and flooding, to chronic depression and post-traumatic stress disorders seen in weather-related disaster survivors. Temperature extremes are associated with increased risks of death and hospitalization from heat stress and exacerbation of underlying diseases, especially of the heart, kidney, and lungs (Melillo et al., 2014). High temperatures and sunlight speed the reactions that lead to the formation of the air pollutant ozone, which irritates the lungs and causes worsening of diseases like asthma and chronic obstructive pulmonary disease as well as increased risk of death. As summer temperatures, including the hottest days of summer, become warmer as the result of climate change, the peak concentrations of ozone will be higher than they would have been if temperatures had not increased, with worsened impacts on people's health. Extreme weather events may also discourage or prevent patients on chronic medications from seeking care or accessing new supplies. Thus, extreme events in a setting of climate change may pose the double threat of stress to health care systems, including the buildings, systems and the personnel needed to deliver clinical services, as well as increased health problems in the populations served by those systems.

In addition to the health threats associated with extreme weather events, climate change is anticipated to pose threats to human health in a variety of other ways. According to the Third National Climate Assessment, threats to health from climate change include the health impacts of decreased air quality from air pollution, wildfires and aeroallergens, altered risks of infectious diseases, including waterborne, foodborne, and vectorborne diseases like Lyme Disease and West Nile Virus, and mental health impacts. People taking a range of medications, from diuretics to anti-psychotics, may be especially vulnerable to heat and other climate-related stressors. Health care systems will need to be aware of these varied threats that climate-related stressors pose to their patients as they assess their specific vulnerabilities.

The Centers for Disease Control and Prevention (CDC) have developed robust Climate and Health resources, including the BRACE Framework – Building Resilience Against Climate Effects – which can assist hospitals and public health providers in increasing understanding of and developing responses to climate-related physical and mental health stressors. Health care organizations and their local public health agencies should collaborate on understanding the likely health impacts related to climate change and extreme weather challenges for their communities.

## RESILIENCE

**"Human societies have never been more globally interconnected and technologically efficient, and less resilient: less able to handle, physically and psychologically, the disruptive changes we will likely face as we encounter planetary tipping points in the decades ahead" (Fisher, 2013).**

Ecological economist C.S. Holling (1973) developed the concept of "resilience" in his study of ecosystem health and transformation. Why did some ecosystems seem unaffected by external human development pressures while others collapsed? Through this work, resilience has been defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (Walker, Holling, Carpenter, & Kinzig, 2004). ***Resilience thinking*** is a framework applied to social- ecological systems (SESs) that considers the capacity of social systems to continue amid either abrupt disruption or gradual change. Resilience thinking examines healthy ecosystems to understand the factors that increase resilience to external challenges and their applicability to social systems.

Architect Thomas Fisher (2013) described our current ***fracture-critical*** design reality: "centralized infrastructure, including power grids and hospitals, are larger, more complex, dependent upon massive amounts of ongoing maintenance, and may be entirely incapacitated by the failure of a single element." Unlike in ecosystems, where resilience is assured through redundancy, affluent societies define efficiency by the elimination of redundancy. U.S. health care infrastructure exemplifies this notion: operable windows were eliminated once mechanical ventilation came into use; electrical lighting replaced daylight; and, ultimately, windows themselves were perceived as redundant. Now, a loss of backup emergency electrical power renders hospitals completely uninhabitable—and the size and complexity of backup systems have increased to the point that they are financially difficult to afford or maintain.

The concept of "passive survivability," coined after Hurricane Katrina, suggests that buildings should be designed to survive loss of essential services such as electricity, water, and sewage management after a natural disaster, utility outage, or terrorist attack (Wilson, 2006) in order to safely accommodate people awaiting evacuation or the restoration of utility services. For a high-reliability organization's mission-critical systems, such as acute care hospitals, passive survivability is truly the last option—when all systems fail, passive survivability extends the ability to "survive" within the structure while an evacuation process is underway. It is imperative to provide multiple independent and redundant ways of supplying necessary services and locate those services out of harm's way.

On-site renewable energy, daylight, potable water storage and passive ventilation are examples of strategies that extend the ability to inhabit buildings in the event of major ongoing utility disruptions. Hospitals that incorporate renewable power on-site, for example, have a third option to operate critical ventilation systems when grid infrastructure is unavailable and backup generators fail.

## COMMUNITY CONTEXT

In the handbook *How to Make Cities More Resilient* UNISDR notes:

**"In disasters, local governments are the first line of response, sometimes with wide-ranging responsibilities but insufficient capacities to deal with them. They are equally on the front line when it comes to anticipating, managing and reducing disaster risk, setting up or acting on early warning systems, and establishing specific disaster/crisis management structures. A review of mandates, responsibilities, and resource allocations is needed to increase the capacity of local governments to respond to these challenges" (2012, p. 7).**

Health care delivery systems are also on the front line of disaster response, and must remain operational regardless of the community context and level of preparedness in order to provide needed services to an affected population. While there is no doubt that regional health networks and independent health care organizations must participate in and work with regional governments to develop and maintain sustainable development practices, health care organizations must also provide a stand-alone level of resilience appropriate to the care delivery context and broader network capacity. For example, health care organizations may not be able to abandon low-lying coastal communities in order to avoid risk from severe storms. Because emergency services are essential in disaster events, health care organizations providing critical emergency response should instead enhance their resilience so that they may continue operations during extreme events.

The physical settings for health care delivery are not limited to the acute care hospital campus. In an era of increasing chronic disease management, health care organizations operate a broad range of care settings. These include residential care settings, such as rehabilitation, long-term care, and behavioral health; ambulatory settings that deliver critical, schedule-dependent services to chronically ill patients, such as dialysis centers and substance abuse clinics; retail settings, such as pharmacies, urgent care and outpatient diagnostic facilities; and an expanding range of home care services. In the aftermath of Superstorm Sandy, for example, dialysis patients flooded hospital emergency departments, quickly exceeding the capacity of the setting to deal with the volume. New York area hospitals, which typically act as places of refuge for residents from evacuated nursing homes, were unable to absorb more than 5,000 displaced elderly residents—particularly for an extended time following the storm—as many nursing homes sustained significant damage.

Community resilience is affected by social and economic context. Climate risk is not equitably apportioned among U.S. communities, while climate-related social vulnerability is particularly apparent in communities that experience temperature extremes and flooding. Real estate development patterns often result in economically disadvantaged populations in flood-prone settings. Income levels often determine the ability of community residents to evacuate, relocate following damage, and return to repair their homes and businesses. In the U.S., a vast majority of low-income communities of color are concentrated in urban centers in the Southern United States and along coastal regions–areas that are at high risk of flooding and major storms and that have a history of substandard air quality.

**"With rising temperatures, human lives–particularly in people of color, low-income, and Indigenous communities–are affected by compromised health, financial burdens, and social and cultural disruptions. These communities are the first to experience the negative impacts of climate change such as heat-related illness and death, respiratory illness, infectious diseases, unaffordable rises in energy costs, and extreme natural disasters" (ACJ 2014).**

In addition to the continuous provision of clinical services, hospitals and health care facilities may play an important role in broader community resilience to weather-related and other disasters. Communities may expect hospitals and major health care facilities to provide services, such as access to clean water and food, for non-injured or ill community members (Charney, Rebmann, Esguerra, Lai, & Dalawari, 2013). Such a role may be especially critical in disadvantaged communities where individuals may not have the resources or ability to flee, relocate, or access necessary energy, water, and food in a disaster.

Understanding local community climate vulnerability is essential to effective provision of health services and creates unique opportunities for community engagement. Health care organizations and facilities may contribute to disaster risk reduction and resilience in their surrounding communities through the following specific actions:

1. participating in community partnerships to engage the community in resilience planning
2. educating community members on the challenges that climate presents and how they can better prepare
3. providing community investments and health management programs that build local social cohesion and improve community health

## GLOBAL CONTEXT

While this Guide and Toolkit is intended to address the particular circumstances of U.S. health care, the quest for improved resilience of health care infrastructure is a global concern. Extreme weather is increasing around the globe and the larger ecological and health issues that changing weather patterns present affects global populations. Many of the world's major cities are within 100 kilometers of a coast, and issues related to sea level rise affect an estimated 44% percent of the earth's population. International health agencies, including the World Health Organization and the Pan American Health Organization, are developing tools and resources to improve health care resilience to climate change and extreme weather events (see, for example, The SMART Hospitals Toolkit *http://www.paho.org/disasters/index.php?option=com_content&view=category&layout=blog&id=1026&Itemid=911*). This Guide and Toolkit is intended to complement these efforts, as the assessment of risk and resilience measures are relevant worldwide.

## RESILIENCE AND SUSTAINABILITY

Many strategies that are employed to meet sustainable design goals improve resilience. Energy conservation measures, for example, reduce energy demands – a hospital that is less energy intensive can operate longer on a fixed amount of reserve fuel. Medical facilities that reduce their water needs can operate longer if they lose water service. Daylit stairwells can be used during daytime hours without need for emergency power. Increasingly, resilience is viewed as the "new sustainable design."

Whether manifested through stricter local and national energy codes (which reduce energy demand and keep buildings habitable without heat or air-conditioning for longer periods) or green building certification programs, such as Leadership in Energy and Environmental Design (LEED), many of the solutions improve the inherent resilience of health care buildings by reducing dependence on energy and water resources.

Increasingly, health care workers are receiving sustainability and environmental management training through their unions that includes consideration of emergency preparedness and resilience measures. Hence, frontline health care workers are viewing resilience and sustainability programs as complimentary and mutually reinforcing. From environmental services staff trained in the use of less-toxic chemicals (which reduces inventories of hazardous chemicals that can be exposed to floodwaters) to security staff briefed on resilience, worker training is increasingly building on the experience of workers to improve the safety, sustainability, and resilience of the health care workplace.

## HEALTH CARE'S RESPONSE TO EXTREME WEATHER

"And, going forward, good design and planning should start with the assumption that nothing will work as intended—or even at all. We should, in other words, take nothing for granted and act as if we have only those within our community and that within our control to depend on … it is the only way to achieve the real optimism of knowing that we can survive, and indeed thrive, regardless of what may happen. We are at our best when we have imagined and accounted for the worst" (Fisher, 2013).

Challenges to the functionality of health care delivery are of two broad types: supply disruptions (the loss or diminution of infrastructure, staff or resources needed for health care organizations to function and deliver care) and demand disruptions (an increase in patients, actual or anticipated, in excess of existing capacity). The invocation of the disaster plan is a complex outcome of these two processes (Haas & Drabek, 1970; Mileti, Drabek, & Haas, 1975; Aguirre, Dynes, Kendra, & Connell, 2005). The AMS (2010) notes that "despite the accumulated awareness of increasing extreme weather events, the United States' critical infrastructure, most specifically hospital infrastructure, remains unprotected against the expected movements of our natural environment." In every region of the country, unprecedented extreme weather events—from coastal storms to tornadoes, extreme rain to prolonged drought, forest fires and heat waves—have negatively affected the full range of health care delivery in all types of settings.

Five past events—Superstorm Sandy (2012), Cumberland River floods (2010), Mississippi River floods (2008), Hurricane Katrina (2005), and Tropical Storm Allison (2001)—highlight the fragility and vulnerability of America's health care infrastructure to severe weather. Hurricane Katrina, an event that captured global attention, displayed with stunning clarity the vulnerability of New Orleans to hurricanes, despite concerns that had been raised following each major storm and more significant evacuations: Hurricane Juan (1985), Hurricane Andrew (1992), and Hurricane George (1998). Katrina also triggered tremendous disruptions that overwhelmed health care delivery facilities in and around New Orleans and the Gulf Coast. In many ways, Katrina epitomized a failure to integrate available meteorological knowledge and engineering solutions on a timely basis to protect critical infrastructure, most especially hospitals, from known risks. Likewise, it was only following the devastation of Superstorm Sandy that the Federal Emergency Management Agency (FEMA) expedited the revision of flood hazard maps along the northeast Atlantic coast to reflect the surge effect related to tides and current sea level rise conditions.

Tropical Storm Allison, an extreme rainfall event that resulted in $2 billion in damage to the Texas Medical Center in Houston, revealed failures to plan for weather emergencies or connect and protect people and resources. While the infrastructure was designed to withstand flooding, the 30-40 years since the previous extreme weather event depleted institutional memory of flood-proofing measures. Both Hurricane Katrina and Superstorm Sandy highlighted not only the vulnerability of hospital infrastructure, but the disruptions to the broader continuum of health care services that take place in far less resilient and prepared but equally important residential, commercial, and retail settings like nursing homes, mental health and drug treatment facilities.

Infrastructure responses to the challenges of extreme weather have been developing for at least a decade. The American Society of Civil Engineers (2009) noted that the U.S. is beginning to acknowledge the fact that its aging infrastructure is in need of repair, a situation exacerbated by the dynamic conditions of shifting extreme weather patterns:

**"Public safety, health, and welfare are at stake. The nation's economic well-being is at stake. The investment that the nation has made in its built and natural environments is at stake. The leaders of our nation, the owners of our critical infrastructure, design and construction professionals, and the public as end-users must take these matters seriously."**

For the most part, the science, engineering, and emergency management solutions necessary to protect critical health care delivery infrastructures and to promote continuity of operations already exist. At the same time, there has been no effective way to transmit best practices and shared learnings, integrate emergent disaster infrastructure responses into public policy, integrate the potential increased risks suggested by climate models, or critically examine the implications of the market shift of health care delivery to less costly or less resilient settings. The AMS (2010) has identified the following as barriers to improvement:

- a general lack of awareness of environmental vulnerabilities on the part of local decision makers
- an absence of coordination and communication across federal agencies
- a paucity of financial resources or incentives to encourage needed structural mitigation or adaptation for current and projected weather risks

Despite progress in some regions of the US, challenges remain with health care infrastructure resilience. While the weather itself and its direct effect on the health care system are uncontrollable, some elements of the system's vulnerability can readily be improved. The difficulty lies in sharing and coordinating the information. This Guide and Toolkit are intended to bring together available tools and resources to help policymakers and institution-level decision makers improve health care resilience.

# PART 2: THE CURRENT STATE OF HEALTH CARE INFRASTRUCTURE CLIMATE RESILIENCE TO EXTREME WEATHER RISKS

## OVERVIEW

Every state in the U.S. experiences extreme weather. This section begins with an examination of the current state of resilience in each level of health care delivery, followed by specific discussion of each extreme weather risk, associated climate impacts, and case studies of health care's response to each category of event.

## CURRENT STATE OF HEALTH CARE INFRASTRUCTURE RESILIENCE

Climate change contributes to the increase in the incidence of extreme weather across the U.S. For health care infrastructure to be resilient in the face of extreme weather, adaptation measures are required. Adaptation measures that respond to climate change impacts can be categorized in the following ways:

- Increasing design thresholds to recognize more severe weather ***intensities*** (design thresholds include design temperatures, wind velocities, mean flood elevations)
- Increasing warehousing and storage capacities to recognize more severe weather ***durations*** (increasing the minimum amounts of on-site food, water, and fuel storage)
- Enacting requirements for hardening facilities in new geographic regions to respond to changing extreme weather ***frequencies and patterns*** (adopting requirements for exterior building envelope or electro-mechanical system resilience in geographic regions that have historically not required such measures but may be vulnerable in the future)
- Increasing capabilities for "islanding operation" that recognizes that on-site infrastructure, staff, and supplies may be required for extended periods of time following weather events because of ***damaged community infrastructure*** (regional electrical grid, municipal potable water supplies, roads and transportation networks, communication systems) and that facilities may need to operate for more than 96 hours without aid from the community

### Hospital Resilience

The focus of resilience in health care facilities has been historically centered on acute care hospitals. Because of the compromised health of inpatients and the complexity of evacuation and transport, hospitals are designed and constructed to "shelter in place" during and after sentinel events, including extreme weather. In general, they rely upon emergency electrical generators (fueled by diesel oil) to provide required electrical power if the municipal grid, or their internal normal electrical system, fails. Generally, thermal energy is provided by on-site boiler and chiller systems (also known as central utility plants, or CUPs), which, if undamaged and given uninterrupted fuel supply (natural gas) or sufficient on-site fuel storage (most commonly oil), can remain operational through municipal electrical grid disruptions.

According to the U.S. Energy Information Agency, the average age of a U.S. acute care hospital is approximately 31 years (USEIA 2006); most are multi-building campuses that include buildings built from as early as 1910 through contemporary time. Historically, hospitals sought land near bodies of water—rivers or the coast—for water supply and sewage discharge. Once established, they rarely moved. To this day, a large number of hospitals occupy waterfront sites in cities and towns across the country.

Hospitals are licensed by the states in which they operate. The Facility Guidelines Institute's (FGI) Minimum Standards for the Design and Construction of Hospitals and Health Care Facilities (Facility Guidelines Institute, 2014), an outgrowth of U.S. Department of Health and Human Services standards for the construction of hospitals under the post-WWII Hill Burton Act, designate minimum fuel supplies, and define mechanical, electrical and communication systems that must be supplied by on-site emergency power systems. The FGI Guidelines reference a series of National Fire Protection Association (NFPA) and National Electrical Code (NEC) standards that must be compared to local requirements; the more stringent is applied. The FGI Guidelines have been adopted by 38 state legislatures, and considered informally by 4 others. They are periodically updated using a consensus process.

In addition to these minimum requirements for facilities, hospitals comply with state and local zoning and building code requirements. These codes, collectively, define a "minimum" standard of construction. The Joint Commission (TJC) accredits hospitals, but does not set resilience criteria. In some instances, the Centers for Medicare and Medicaid Services (CMS) also require specific compliance with NFPA or NEC standards in order to qualify to serve Medicare and Medicaid populations. The Veterans Administration has its own set of design criteria. One of the confusing elements of multiple authorities is the lack of alignment between the editions of cited reference standards. Whether facility design must meet the NFPA 2000 edition, 2004 edition, or 2012 edition may not be clear, which can result in wide variations in facility standards as they relate to climate resilience.

According to The Joint Commission (TJC) (Fink, 2012), new hospitals in some U.S. coastal low-lying areas are not required to flood-proof their systems; the level of resilience is dependent upon local regulation. The result is hospitals that may be compliant, but remain unprepared. TJC and CMS require hospitals to adhere to the 2000 edition of the National Fire Protection Association's life safety code. It calls for "careful consideration" to protecting electrical components from "natural forces common to the area" such as storms, floods and earthquakes (National Fire Protection Association, 2000). The 2012 version of the NFPA code strengthens its language, saying the systems "shall be designed" to protect against these hazards, but leaves the assessment of minimum requirements for such protection to state and local jurisdiction, which results in varying requirements throughout the U.S. The conclusion, according to George Mills, director of the Engineering Department at The Joint Commission, is that "all of these systems are only as reliable as the weakest link" (Fink, 2012).

The inability of hospitals to function through extreme weather events in the last two decades can be traced to one or more of the following issues:

- External infrastructure dependence
    - Reliance upon, and compliance with, the minimum flood elevations designated by local zoning and FEMA maps (extreme weather events exceed thresholds with catastrophic results)
    - Reliance upon aging municipal flood protection infrastructure that fails, such as the levees in New Orleans or Mississippi River dikes
    - Reliance upon municipal thermal energy infrastructure (such as district steam) that fails or must be pre-emptively shut down
- Regulatory Conflicts
    - Contradictory regulations, codes and utility practices, which require diesel fuel storage and locate major utility infrastructure such as electrical switchgear at grades vulnerable to flooding (these contradictions can be at an infrastructure system level or, in major cities, at a zoning level, where limitations on above grade bulk and floor area leads to below grade infrastructure placement)
- Building envelope failures
    - Building façade and enclosure failures, along with improperly anchored equipment in high winds, resulting in equipment blowing off roofs, which compromises roofing systems and waterproofing
    - Envelope failures related to the age or condition of building enclosures that were designed prior to contemporary extreme weather considerations or building code regulations
- Building infrastructure systems failures
    - Aged and complex critical infrastructure in multi-building campuses, making hospitals highly vulnerable to "fracture-critical" failures (see Part 1)
    - Reliance on on-site diesel emergency generator plants, which have grown larger and more complex, require ongoing maintenance and testing, and are prone to failure under full load conditions (required fuel storage may be too short to allow for safe refueling in a weather emergency, when fuel shortages are acute and roads may be impassable)

Following extreme events that include hospital evacuations, local regulations often shift to redefine minimum flood elevations and revise requirements for critical infrastructure placement. However, the wide variation in established practices leads to limited cross-industry sharing of lessons learned. Regional differences between extreme weather event types and limited understanding of future hazard risks further contribute to inconsistency of best practices.

## Research Facilities

While much of the focus on hospital evacuations is on the direct impact to inpatients, there are significant impacts to research and medical education functions that can be as or more costly and disruptive. Often underreported, flooded below-grade vivaria result in the loss of years of scientific research samples; power lost to research freezers and refrigerators ruin years of grant-funded research. The cost of a tertiary academic medical center's evacuation and shutdown amounts to more than the inconvenience, relocation, and repair costs; it can alter medical research progress. Hurricane Katrina forced the Tulane Medical School to relocate to Houston for a year. Research losses at NYU Langone Medical Center have given the National Institutes of Health

(NIH) reason to consider weather vulnerability in grant funding. The Texas Medical Center story, profiled on page 64 of this guide, demonstrates the urgency for patient care, teaching, and research facilities to implement more sophisticated, resilient responses to the infrastructure challenges posed by climate-induced extreme weather events.

## Residential Health Care Settings

As health care delivery moves out from the acute care hospital setting, the resilience of the facility to extreme weather measurably decreases. Over the last 50 years, the expansion of residential care facilities has been significant, with concentrations of long-term care and assisted living facilities in more vulnerable coastal areas (particularly along the Atlantic and Gulf Coast regions). Included in this category are nursing homes, which offer skilled nursing for the elderly and very frail in need of ongoing medical attention, and adult care facilities, which primarily support residents who require help with basic daily tasks such as meals or bathing. Other residential facilities offer treatment, care, and supportive housing for individuals with substance abuse problems, developmental disabilities, or other behavioral or mental health challenges.

These facilities have complex ownership, governance, and financial structures, ranging from licensed long-term care facilities owned and managed by non-profit integrated health networks to small, individual, private for-profit endeavors that operate “below the radar” of licensure and regulatory requirements. Physically, they range from large, institutional campuses to adapted single-family homes. Regardless of the size of the facility, all residential providers must look after the health, safety, and well-being of these vulnerable populations.

Until recently, there was little focus on Residential Care facilities in the FGI Guidelines. There are limited specific requirements for emergency power systems in residential health care settings. Residential care facilities have staff training for “shelter in place” mechanisms during emergencies. They are required to meet local zoning and building codes; however, the number of states enacting the FGI Guidelines provisions for long-term care facilities is far fewer than those enacting hospital provisions (13 use nursing home requirements, 11 enforce the guidelines for assisted living facilities, and 13 consider the guidelines in hospice care settings (FGI, 2014)). Hence, there is limited consistency among minimum standards for construction. Local hospitals and spare capacity in the regional systems act as safe havens when nursing home or rehabilitation facilities are forced to close.

Kathryn Hyer, PhD, MPP, Director, Florida Policy Exchange Center on Aging, University of South Florida, and an expert on nursing home evacuations, notes:

**“Recent events have shown that disaster-related outcomes for this population, even when they survive the immediate danger, often are especially poor. Further, post-disaster studies have shown that facilities that care for the elderly, particularly those that are for-profit or privately owned, often have been excluded from or overlooked in community emergency planning … Recurring controversies in the news over the past decade have raised serious questions in the public mind about the ability of facilities that care for the elderly to make the best decisions when a disaster occurs or is imminent” (2013, p. 43).**

After Hurricane Katrina in 2005, most nursing home administrators became familiar with FEMA’s 2008 National Response Framework for communitywide emergency planning, and with federal emergency support functions. They revised their disaster plans to incorporate a nursing home-specific incident command structure. *The Emergency Management Guide for Nursing Homes* provides an example (see Resources). The National Response Framework was expanded and updated in 2013 (FEMA, 2013).

Research suggests that nursing home residents that shelter in place have better health outcomes than those that are evacuated or transferred during or following an event. During the four hurricanes in Louisiana and Texas (Katrina, Rita, Gustav, and Ike) residents who were evacuated from nursing homes had higher post-storm death rates and hospitalizations compared with residents in facilities that sheltered in place. The conservative estimate is that 94 “excess” deaths were due to evacuations resulting from those four storms (Hyer, 2013). Hence, ensuring that nursing home facilities have structural and system integrity and have the resources to self-sustain for a period during an event is certainly a best practice. Another is making sure that supplies, personnel and fuel can be replenished during the aftermath, before systems return to normal. Depending upon the severity of the event, an inability to sustain operations during recovery may compromise resident safety.

In a major regional weather event, such as Hurricane Katrina or Superstorm Sandy, the widespread destruction of residential care venues created a care dilemma that far outlived the actual event. This dilemma was captured by the New York City Strategic Initiative on Resilience and Reconstruction (SIRR) report following Sandy: nursing home patients (coupled with the hospital transfers from impacted acute care facilities) filled all available hospital beds and overwhelmed emergency departments for weeks and months following the event (The City of New York, 2013) (see special section on Superstorm Sandy beginning on page 32). Following Katrina, nursing home residents were dispersed hundreds of miles from New Orleans, losing contact with consistent medical care as well as family support. Similar experiences following Hurricane Andrew in 1992 led the state of Florida to adopt strict new building codes (see pullout).

The Post-Sandy Initiative reported that, "In Brooklyn and Queens, 29 nursing homes were severely damaged; despite receiving instructions to shelter their populations in place, they were unprepared to endure the storm and its desolating aftermath" (New York City Chapter of the American Institute of Architects, 2013). The following factors contributed to the failure of residential long-term care and rehabilitation facilities to shelter in place effectively:

- Reliance upon, and compliance with, the minimum flood elevations designated by local zoning and FEMA maps (weather events can exceed thresholds with catastrophic results for envelope and Infrastructure)
- Reliance upon municipal flood protection infrastructure that fails, such as the levees in New Orleans
- Vulnerability of building envelope, elevator machinery, stair towers, and interiors to severe damage from wind projectiles and/or water
- Lack, insufficiency, or failure of emergency power and, consequently, the loss of elevator service and water supply to upper floors

## Community-Based Ambulatory Facilities

Community-Based Ambulatory Facilities include large community clinics that provide primary care, mental and behavioral health services, and other outpatient services to the general population every week. Other community-based providers include private doctors' practices for urgent, primary and specialty care, dialysis centers, hospital-affiliated outpatient providers (such as ambulatory surgery and cancer treatment), independent clinics, and retail pharmacies. The SIRR report noted these larger stressors on the ambulatory health care delivery system following Sandy:

**"Flooding and power outages forced community clinics, doctors' offices, pharmacies, and other outpatient facilities to close or reduce services in the areas most impacted by the storm. Sandy not only put unprecedented stress on the provider system; it placed the health of medically fragile individuals at risk. There were an estimated 75,000 people in poor health living in areas that were inundated by floodwaters and an estimated 54,000 more in communities that lost power. These groups faced additional health risks during the storm and were less capable of gaining access to appropriate care …. Furthermore, the unpredictable storm conditions increased the risk that any New Yorker could require life-saving medical care" (The City of New York, 2013, p. 145).**

Like residential facilities, community-based ambulatory facilities vary widely in terms of ownership, licensure and governance. They are built to varying physical standards. Facilities with more than four patients incapable of self-preservation (such as an ambulatory surgery center) in states that require the use of FGI Guidelines must meet requirements for enhanced life safety systems and emergency power. Physician office practices, cancer treatment centers, and the vast majority of ambulatory facilities with fewer than four patients incapable of self-preservation are considered "business occupancies." Many are located in rental spaces, either in commercial ground floors or as tenants in multi-tenant office/commercial buildings. Hence, when the commercial building loses power, all tenants are affected. Failures of ambulatory facilities may result from the following:

- Reliance upon the minimum flood elevations designated by local zoning and FEMA maps (when weather events exceed these thresholds, the effects on envelope and infrastructure are catastrophic)
- Reliance upon municipal flood protection infrastructure that fails, such as the levees in New Orleans
- Vulnerability of building enclosure, infrastructure systems and/or interiors to severe damage from wind, projectiles and/or water
- Reliance on municipal electrical grids with inadequate emergency power provisions in the case of grid failure
- Disruption of transportation

infrastructure and gasoline shortages, limiting the ability of staff and patients to access the facilities

In extreme weather events, particular specialty care providers, including dialysis units, mental health and drug/alcohol treatment centers, face unique challenges if forced to close. These patients require consistent, frequent long-term outpatient care. When patients are forced to shift providers, gaps in treatment plans occur. The SIRR report notes that patients:

**"with pressing health care needs—dialysis patients or those on methadone, for instance—had to seek alternative care immediately, often from hospital emergency departments or mobile medical vans staffed by doctors and nurses from community clinics and other health care workers. The longer providers remained closed, the greater the numbers of individuals who had to look elsewhere for care" (The City of New York, 2013, p. 149).**

After being closed by a disaster, community-based providers generally have a seven day window to resume care before emergency departments and hospitals are affected by their absence. Jersey Shore University Medical Center in Neptune, N.J. remained functional during and after Superstorm Sandy, but was near some of the hardest-hit communities. Steven Littleson, president, observed: "The biggest challenge is making up for the other services that are not available in the community." Littleson admitted the hospital had not prepared to become the region's major primary-care and social-services provider. "If there is a lesson here, it is to gear up for a broader array of primary-care services, post-event" (Evans and Carlson 2012). This notion of advance preparation for a different, potentially expanded health care patient surge profile post-event is a key element of hospital resilience planning. Understanding the network vulnerabilities before extreme weather events can lead to enhanced resilience recommendations for key ambulatory services.

The SIRR report notes that, in New York, more than 10% of ambulatory capacity resides within the 100-year flood zone in newly-released 2014 FEMA Flood Insurance Rate Maps. In coastal areas, there remain possibilities for significant disruption of the ambulatory care network in extreme weather events. As a result, New York City recommendations include equipping a portion of ambulatory health facilities in 100- and 500-year floodplains with emergency power provisions and external generator hookups (The City of New York, 2013).

In addition to disrupting mental health service delivery, extreme weather events can also increase the need for mental health services, as impacted communities cope with the stressors inherent in loss of individual life, livelihoods or possessions as well as loss of community cohesion (Shukla, 2013).

## Retail and Home Care

Health care and health care support services are delivered through an extensive network of retail providers, ranging from urgent care centers to dialysis centers to retail pharmacies. Major pharmacy retailers are able to provide mobile services once roads reopen. In addition, many hospice patients and homebound elderly patients with chronic diseases are cared for at home through a network of home care providers. Extreme weather can be challenging for continuity of care as this excerpt from the SIRR report summarizes:

**"Home-based care was impacted primarily by disruptions in the transportation system. The public transportation shutdown, travel restrictions on single-occupancy cars, and gasoline shortages all made it difficult for nurses and aides to reach the homes of patients scattered across the five boroughs. If and when providers finally did reach their destinations, elevators that were out of service—due to power outages or flood damage— often made it challenging for staff to reach patients on upper floors in high-rise buildings. The power, water, and heat outages within patients' homes were also problematic, increasing the likelihood that existing medical conditions would worsen or new ones would develop" (The City of New York, 2013, p. 149)**

Informal, unstructured aggregations of vulnerable populations are also increasingly common. These Naturally Occurring Retirement Communities (NORC's) often form in coastal communities or in small cities across the U.S. For example apartment buildings that have a cohort of residents that have aged in place can become, in essence, a retirement community (Masotti, Fick and MacLeod, 2006). These multi-family residential buildings have no primary resilience characteristics, such as elevators on emergency power, and are vulnerable to primary grid and water supply interruptions. The population is less able to use stairs to carry water and food home over extended blackouts, or to effectively clean when services are restored.

## The State of Florida's Path to Increased Health Care Resilience

In 1992, Hurricane Andrew made landfall 20 miles south of the apex of the Miami business district. In addition to the staggering human cost, the valuation of destroyed property was, until that time, the largest in United States history. Homestead Hospital, severely damaged by the storm, was partially reopened within seven days of the event. In 2007, it was completely replaced by a state-of-the-art facility designed to withstand stronger storms, but not before the loss of more than 50 percent of its staff, who left the storm-ravaged region following the event. Even after 21 years, the town of Homestead, Florida has not fully recovered from the storm. Despite being the sole community hospital in the region, the hospital continues to face operational losses due to a changed community.

Hurricane Andrew's impacts on health care facility infrastructure led Florida to completely reconsider preparedness and resilience, including development of a robust integrated statewide emergency management program. A series of policy documents, most notably the 1993 Lewis Report, recommended that the state enact a series of building codes that would ensure that hospitals, nursing homes, and intermediate care facilities for the developmentally disabled be constructed to withstand storm damage and be self-supporting during and immediately following coastal hurricane events. The Agency for Health Care Administration (AHCA) developed a series of regulations requiring wind and impact-resistant building envelopes, equipment-anchoring systems, and emergency generators above surge levels for all new facilities constructed over the last 20 years. In addition to on-site emergency generators, facilities are required to have external connections for portable generators that can provide operational power to the entire facility. The state prohibits new hospital construction in the 100-year hurricane surge inundation zone; it requires all health care projects to adhere to the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) modeling for Category 3 (Saffir-Simpson scale) storms and to set elevations for floors and patient/resident support infrastructure equipment based upon the results. These requirements notably improve performance. See *Case Study of Tampa General*, on page 58 of this guide.

With regard to retrofitting, the situation has remained complex due to concerns about the cost of proactive requirements for hardening, particularly in the vast inventory of existing hospitals and nursing homes. For facilities damaged by storms, all replacement systems were required to meet the newly enacted codes. For ongoing general retrofits, there was no similar requirement until 2004, when the Florida Building Code was revised to require all ongoing renovations, such as window replacements and generator replacements, to comply with current standards for facility hardening. This carefully-worded mandate has accelerated improvements in existing buildings. A comprehensive set of guidelines for coastal storm nursing home retrofits is included in their *1999 Recommended Physical Plant Improvements to Existing Nursing Homes for Disaster Preparedness* (S. Gregory, personal communication, January 20, 2014).

## CASE STUDY: Miami Children's Hospital, Miami, Florida

The 268-bed Miami Children's Hospital (MCH) serves seven counties in southern Florida, including populous Miami-Dade County, and is the region's only specialty hospital for children. Beginning in 2001, MCH underwent a state-of-the-art retrofit to enable it to withstand a Category 4 hurricane. It is now wrapped in a hurricane resistant shell.

Following implementation of more stringent building codes in the 1990s, an assessment of the mid-1980s facility's exterior construction revealed that it was unsafe when wind speeds reached those typically associated with a Category 2 hurricane, a common occurrence in southern Florida. Since many of the special pediatric services provided at MCH are not available in other area hospitals, a hurricane event would have been detrimental to children in need of specialized medical care if evacuations had to take place or if the facility was closed during repair after a storm.

Hospital administrators had to solve a two-fold problem: how to fund the renovation project, and how to execute the retrofit and renovations without disrupting medical services. The hospital received funding through FEMA's Hazard Mitigation Grant Program (HMGP), administered by the Florida Department of Community Affairs (DCA). A $5 million HMGP grant was awarded by the State of Florida to help pay for the $11.3 million project. The retrofit strengthened the building by encapsulating the three-story structure in pre-molded panels of glass fiber reinforced concrete (GFRC). The panel system, anchored into the building's existing support structure, forms a protective cocoon around the hospital and, along with impact-resistant windows and a strengthened roof, enables the building to withstand winds of up to 200 miles per hour. The architect's approach of working from the outside to the inside of the building made it possible for surgeries, diagnoses, and nursing care for the hospital's young patients to continue uninterrupted throughout all phases of the renovation.

Figure 1: Miami Children's Hospital retrofitted its façade to withstand hurricane force winds.

The project was completed in the spring of 2004, just prior to Florida's hurricane season. Young patients and their families did not need to evacuate from the hospital when Hurricanes Frances and Jeanne struck. In addition, the hospital welcomed over 60 children who lived at home but were evacuated from the Florida Keys—children who depended on ventilators or other electrically-powered medical equipment.

During Hurricane Frances, MCH was the temporary refuge for nearly 1,000 staff members and their families. According to Kevin Hammeran, Senior Vice President and Chief Operating Officer during this period:

"The strengthened building has enhanced the hospital administration's ability to recruit staff to serve during hurricanes. Many employees feel safer at the hospital during a storm than in their own homes. We also have eliminated barriers by providing on-campus shelter for family members of storm-duty staff. Knowing their spouses and children are within the safe confines of the hospital gives peace of mind to those working through the storm."

In 2005, the hospital hosted medical evacuees and families who were displaced by Hurricanes Katrina and Wilma.

(Source: U.S. Department of Homeland Security, 2014)

# EXTREME WEATHER RISKS

Given the current state of health care infrastructure resilience, how are future extreme weather events likely to affect health care delivery in the U.S.? This section examines different types of extreme weather events, reviews projections about the frequency and intensity of these events, and discusses the current state of the U.S. health care infrastructure's resilience to these events.

This document focuses on the effect of climate change and increased climate variability on health care systems and infrastructure. As noted previously, climate change affects the health of populations in a variety of ways, and health care systems need to be aware of these impacts in allocating resources and planning for services. A full description of these impacts, however, is beyond the scope of this document. The reader is referred to the Third National Climate assessment [Melillo et al., 2014] and relevant federal websites *http://www.cdc.gov/climateandhealth/publications.htm*, *http://www.niehs.nih.gov/research/programs/geh/climatechange/health_impacts/index.cfm*, and *http://www.globalchange.gov/what-we-do/link-climate-health] for further information*.

## Temperature Extremes: Heat and Cold Waves

Heat and cold waves are typically defined as events exceeding specified temperature thresholds over a minimum number of days. Thresholds are often geographically specific – the significance of night temperatures greater than 80 degrees F is more significant in Chicago than it is in Houston. The data indicate that over the last several decades heat waves are generally increasing, while cold waves are decreasing (Peterson et al., 2013). At the same time, recent "polar vortex" cold events in the central and southern U.S. are proving challenging to infrastructure and health care services.

A heat wave is an extended period of extreme heat, and is often accompanied by high or low humidity extremes. The National Oceanic and Atmospheric Administration (NOAA) summarizes the unique aspects of heat waves:

**"Extreme heat may be one of the most underrated and least understood of the deadly weather phenomena. In contrast to the visible, destructive, and violent nature associated with 'deadly weather,' like floods, hurricanes, and tornadoes, a heat wave is a 'silent disaster.' Unlike violent weather events that cause extensive physical destruction and whose victims are easily discernible, the hazards of extreme heat are dramatically less apparent, especially at the onset" (NOAA, 1995, p. viii)**

There has been a remarkable run of record-shattering heat waves in recent years. The Russian heat wave of 2010 that set forests ablaze, the historic heat wave in Texas in 2011, and the "Summer in March" in the U.S. Midwest in 2012 are all memorable heat waves. The 2003 heat wave in France claimed 14,802 lives. Across the contiguous United States, new record high temperatures in the past decade have outnumbered new record lows by a ratio of 2:1. There are a number of models that suggest there will be an increase of heat waves and seasonal shift for the U.S. in the coming decades.

Most heat injuries that occur during a heat wave are caused by overexposure to heat or activity that is too strenuous given the weather and the person's age and physical condition. Older adults, young children and those who are sick or overweight are more likely to succumb to extreme heat. Also, asphalt and concrete store heat longer than natural surfaces and gradually release heat at night, which can produce higher nighttime temperatures. This is known as the urban heat island effect. Residents of economically disadvantaged communities are less likely to have air conditioning in their housing or the ability to pay for it. Consequently, people living in large urban areas may be at greater risk from the effects of a prolonged heat wave than those living in rural areas. In sealed buildings (buildings without operable windows), loss of mechanical cooling (air conditioning) during heat waves can produce a rapid rise in interior temperatures, rendering spaces uninhabitable.

According to the *CDC*, 660 people die nationwide from heat waves each year, making it the leading cause of weather-related mortality in the country. Studies suggest that, if current emissions hold steady, excess heat-related deaths in the U.S. could climb from the current average of about 700 each year to between 3,000 and 5,000 per year by 2050 (U.S. CDC 2013).

During heat waves, health care service volumes surge as residents in the area present to emergency departments, urgent care centers, and physician practices. At the same time, the urban energy infrastructure is over-stressed; the electrical grid is challenged to provide sufficient energy to meet residential and commercial cooling demands. As a result, rolling electrical blackouts often accompany extended heat waves, which can compromise health care delivery. Urban hospitals, as large electricity consumers, are often asked to shift to emergency power generation in order to free grid resources during peak demand periods.

Many hospitals do not have their cooling systems on their emergency power generation systems; when blackouts occur, hospitals are required to continue to operate their basic ventilation systems but may lose portions of their space cooling systems. For the most part, hospitals are sealed buildings; i.e., they do not incorporate operable windows due to infection control and pressurization requirements. In recent years (and, in particular, following the extended 2006 blackout in the northeastern U.S.), many hospitals have improved their resilience to heat waves by voluntarily increasing their emergency power capability above minimum regulatory requirements to include mechanical cooling. In Florida, hospitals are required to have an external generator connection that allows additional generator capacity to supplement the facility-level infrastructure. New hospitals must have their cooling on emergency power due to concerns about high humidity and mold/mildew impacts on indoor environments during extended power outages.

Nursing homes and assisted living facilities are often not equipped to provide emergency cooling when grid power is lost. While many of these buildings include operable windows, concerns about patient safety have limited the extent of window operability, and high humidity climates present a range of challenges. Certainly, however, operable windows (and engineered natural ventilation systems) are a key element of passive survivability during extended heat waves in non-acute residential health care settings in many parts of the United States. Ambulatory facilities vary widely in their emergency power provisions and capabilities.

The National Weather Service defines a cold wave (or, in some regions, a cold snap) as a phenomenon distinguished by a rapid fall in temperature within a 24 hour period. The criterion depends on the rate at which the temperature falls and the minimum to which it falls, as well as the geographic region of the country where it occurs. Extreme winter cold is often devastating to agriculture and livestock. Cold waves affect much larger geographic areas than blizzards, ice storms, and other winter hazards. While the frequency of cold waves has been decreasing over the past few decades, they still occur and can have significant impact (Peterson et al., 2013).

A cold wave can cause poorly insulated water supply pipes and mains to freeze. It may impact building water supply piping, if not buried deeply enough underground. In addition, regions of the U.S. that experience limited cold weather have come to rely on electric heating for residential buildings; hence, when temperatures plunge, electrical demand peaks or exceeds grid capacity, resulting in rolling blackouts. In addition, cold waves accompanied by precipitation often produce ice storms, resulting in massive transportation disruptions, electrical grid interruptions, and increased emergency service activities as auto accidents and slip-and-fall injuries peak. Like heat waves, cold waves have greater effects on the poor and elderly, as these populations are less likely to have the financial

## CASE STUDY: University of South Alabama Medical Center, Mobile, Alabama

Amid a heat wave in August 2010, University of South Alabama Medical Center lost both its primary and secondary cooling systems, and the air temperature in the medical center rose to over 95 degrees with very high humidity. The medical center, the sole level-one trauma center in the southwest part of the state, had 41 patients in the ICU who were negatively affected by the rising heat in the facility. Moving ICU patients who are already clinging to life can have disastrous consequences, and loss of this facility's services would have a drastic negative impact on the health and welfare of the public in the areas it served.

The medical center reached out to the Alabama Department of Public Health's Center for Emergency Preparedness (ADPH-CEP). ADPH had purchased portable cooling systems for their medical surge units with federal Hospital Preparedness Program (HPP) funds. The department was able to deploy these units with an escort from Alabama State Troopers. The units were on-site and operational within five hours of the medical center's request. (United States Department of Health and Human Services [HHS], 2009). Evacuation of ICU patients was not required.

resources to adequately heat their homes, manage snow removal, and are more vulnerable to injury. The National Weather Service refers to winter storms as the "Deceptive Killers" because most deaths are indirectly related to the storm (NOAA, 2008). Instead, people die in traffic accidents on icy roads and of hypothermia from prolonged exposure to cold.

## Tropical Cyclones and Hurricanes, Coastal Storms, and Surge

A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. Tropical cyclones rotate counterclockwise in the Northern Hemisphere. They are classified as follows:

- Tropical Depression: a tropical cyclone with maximum sustained winds of 38 mph (33 knots) or less
- Tropical Storm: a tropical cyclone with maximum sustained winds of 39 to 73 mph (34 to 63 knots)
- Hurricane: a tropical cyclone with maximum sustained winds of 74 mph (64 knots) or higher (in the western North Pacific, hurricanes are called typhoons; similar storms in the Indian Ocean and South Pacific are called cyclones)
- Major Hurricane: a tropical cyclone with maximum sustained winds of 111 mph (96 knots) or higher, corresponding to a Category 3, 4 or 5 on the Saffir-Simpson Hurricane Wind Scale (NOAA, 2013)

All Atlantic and Gulf of Mexico coastal areas are subject to hurricanes. Parts of the southwest United States and the Pacific Coast also experience heavy rains and floods each year from hurricanes that originate in the Gulf of Mexico. The Atlantic hurricane season runs from June 1st to November 30th; the Eastern Pacific hurricane season runs from May 15th to November 30th.

The vast majority of coastal cities and regions rely upon FEMA Flood Insurance Rate Maps (FIRMs) when developing their coastal flood hazard assessments, zoning regulations and building code requirements. FIRMs are developed for communities that choose to participate in the National Flood Insurance Program; as a result, the requirements for property insurance coverage are tied to the elevations outlined by the FIRM. Communities also use FIRMs to manage development in and near floodplains.

Many FIRMs date from the late 1970s and 1980s. These maps are periodically updated to reflect increased understandings gained from actual storm experiences, recorded surges, and development impacts along the coastline. New Preliminary Work Maps (PWMs) have been released in 2013 for the New York/New Jersey coast to assist communities rebuilding from Sandy, which represent substantial shifts from previous 100-year and 500-year floodplains. The FEMA Flood Map Service Center (*https://msc.fema.gov/portal*) has the most recent information on FEMA mapping.

Many hospitals constructed in 100-year and 500-year floodplains are now being required to meet current construction code standards for flood-resistant construction. This is a complex requirement, as many hospitals were constructed under much earlier floodplain maps and may or may not have been required to meet this level of construction when they were built. New York City has enacted regulations requiring new hospitals to place infrastructure and essential services above the 500-year flood elevation to account for projected sea level rise, ensuring that these buildings can continue to serve New Yorkers for many decades into the future. In addition, there is growing awareness that hospital campuses must be capable of "island" operation—that is, able to maintain operational capability even when losing municipal electricity, thermal energy, water and sewage utility systems for extended periods of time. Previous policy assumed all necessary services would be restored within 96 hours.

Existing hospital buildings on coastal floodplain sites should assess current and projected storm surge data as they undertake infrastructure upgrades to ensure that storm surge and coastal flooding do not affect critical building systems, including generators and information technology (IT)/communication systems. Most hospitals are not mandated to upgrade or protect their electrical equipment, emergency power systems, and domestic water pumps to the 500-year flood elevation; for many, this requires elevating the equipment, hardening equipment in place (for example, through the use of submarine doors), or dry flood-proofing basements and lower floors—a prohibitively expensive undertaking. In order to avoid evacuation if utility power is lost, hospitals must ensure that emergency power systems—generators and fuel pumps—are accessible to building staff at all times, so that emergency power can be maintained continuously, even during flood conditions. To avoid placing an undue financial burden on providers, hospitals are not required to retroactively relocate or protect critical clinical service programs (such as emergency departments, lab or imaging equipment, or kitchens and laundries) for which other workarounds can be implemented. Nevertheless, protection for these critical functional program areas should be encouraged as a best practice, since they could be essential for some facilities to remain in operation, depending on their layout and unique risks. Many providers have already met these requirements, either because local regulations demand it or because they are proactively hardening their infrastructure based on accumulated experience. For example, many hospital generators in coastal areas are elevated. However, fuel storage tanks, fuel vents, and fuel pumps may be vulnerable if they remain below flood elevations. In addition, power, emergency power, and water are all necessary to support a shelter-in-place situation, and investments in infrastructure resilience are needed to minimize future evacuation risk. Accordingly, many providers have already assessed their potential vulnerabilities and are addressing them.

Residential care facilities in coastal areas are more vulnerable than those located inland. Few coastal states require the same level of construction as the Florida example above. Following Sandy, New York City is matching Florida's mandate that new nursing homes and intermediate care facilities be constructed with additional resiliency measures for their emergency power and water supply systems, to allow staff and patients to shelter in place safely during a disaster. Power in these residential facilities is needed not only for standard operational requirements such as lighting, elevators, water pumps, use of medical equipment, and communications, but also for essential emergency operations such as pumping floodwater out of basements if flood protection fails.

Because on-site generators may fail when used at full loads for an extended period of time, coastal hospitals and nursing home facilities are increasingly required to have an electrical pre-connection for external mobile generators. The ability to switch quickly from the electrical system to a mobile generator can significantly reduce the likelihood of emergency evacuations during or following a disaster. External generator connections allow the facility to size on-site generators for code-required life safety, critical patient care equipment (those systems that must be able to be operational within 10 seconds of power loss), and critical medical support services; additional mobile generators can be used to handle air conditioning and other systems that can tolerate longer disruption. Prior to a major weather event, external generators can be safely mobilized nearby, and safely deployed once the event has passed. However, consideration of mobile generators is dependent upon reliable access—such solutions may not be appropriate for barrier islands or locations that could be rendered unreachable by road.

Adult residential care facilities, such as homes for developmentally disabled, rehabilitation facilities, and assisted living, are not generally required to have emergency power systems. Their residents are more ambulatory and less fragile than nursing home patients, but they nevertheless require care and living assistance that is dependent on working electricity. For this reason, coastal municipalities are beginning to require new facilities either to install an emergency generator that is adequately protected or to arrange for pre-connection to external stand-by generators.

## Lessons Learned from Hurricane Katrina

On Monday, August 29, 2005, Hurricane Katrina, the 11th tropical storm of the 2005 season, made landfall as a Category 3 storm east of New Orleans. Katrina initially caused minimal damage to the operating hospital system, including Tulane's Medical Center, Charity Hospital, and Tenet's Memorial Hospital. The National Hurricane Center's Tropical Cyclone Report concluded that most of the city of New Orleans experienced sustained surface winds of Category 1 or 2 strength, so buildings sustained only minimal wind damage. Indeed, most thought that New Orleans had come through relatively unscathed.

Later that day, levees that were supposed to protect the city failed. Over the next 24-48 hours, several feet of water flooded 80 percent of the city. Communications systems at all levels were inadequate, so city, state and federal officials made decisions based on information supplied by television reporters in parts of the city that were not yet flooded. Government officials believed and stated that the levees had held, when in reality, large segments of the city were under water.

By Monday evening, flood water started to enter Tulane's University Hospital, The Medical Center of Louisiana New Orleans (MCLNO) Charity Hospital campus, the Veterans Administration Medical Center (VAMC) and medical school buildings. During that night, basements were filled with water, and several feet of water flooded the first floor of all the buildings in the downtown medical center. Although only essential clinical personnel and their families were supposed to enter these facilities prior to the storm, many others sought shelter there.

Initially, emergency generators provided power; however, those generator systems did not include cooling or dehumidification loads, so temperatures in the hospitals rapidly soared into the upper 90s and were made intolerable by 100% humidity. Lower floors of the buildings were inundated with backed-up sewage. For several days, faculty, residents, nurses and hospital personnel performed heroically, caring for patients in appalling conditions. At MCLNO's Charity Hospital, people threw furniture through the sealed windows to access fresh air.

At Tulane Medical Center, hospital engineering staff fashioned a makeshift helipad on a parking garage roof to evacuate 200 patients and 1500 personnel 48 to 72 hours after the storm, as generators ran out of fuel or failed and it became apparent that no fuel would arrive. Patients were transported in passenger pickup trucks, as ambulances were too tall to access the parking deck.

Hurricane Katrina left New Orleans in ruins. Following the storm, MCLNO (Charity Hospital) and the VAMC were too severely damaged to make refurbishing a viable option. Those facilities are instead being reconstructed, sharing some facilities and services. The closure of MCLNO and the VAMC meant the loss of approximately 70% of Tulane's teaching beds. The school returned to New Orleans after relocating to Houston for the 2006 – 2007 academic year. Before Katrina, Tulane's School of Medicine and School of Public Health and Tropical Medicine trained more MD, MPH graduates than any other school in the country (Taylor, 2007).

Determining a method for both hazard mitigation and resilience is nuanced and can require important community choices. In 2008, the National Trust for Historic Preservation placed Charity Hospital and its adjacent mid-city neighborhood on its annual list of "America's 11 Most Endangered Places." Preservation-minded citizens hoped to prevent destruction of 18 square blocks of historic homes and buildings slated for removal in favor of the new Veterans Health Administration and Louisiana State University hospitals that would replace Charity and the VAMC. Despite these efforts, construction began on the new complex in January 2013. Local press reported that "an irreplaceable part of the city's history was lost, demonstrating that a replacement hospital designed for structural resilience can do as much damage as a hazard with respect to a local neighborhood." The set of community health issues that accompany the evacuation and closing of a hospital facility should be considered as part of a multi- hazard risk assessment process (Rudowitz, Roland, & Shartzer,2006; Hrickiewicz & Kehoe, 2006; Gray & Hebert, 2006).

## CASE STUDY: University of Texas Medical Branch (UTMB), Galveston Island, Texas

The University of Texas Medical Branch is a health care campus located on Galveston Island, spanning 85 acres and comprising multiple hospitals, including a Texas Department of Corrections medical facility, the Level 1 center for a nine-county region, a medical school, and an assortment of specialized clinics, centers, and institutes. The campus employs 13,000, provides the only health care to the island's 57,000 residents, and manages 8 million yearly visits.

It houses a high-security national bio-conatinmnet laboratory for Bio-Safety Level 4 research, one of only a few such facilities in the United States. The campus relies on a shared district infrastructure.

On September 13, 2008, Hurricane Ike hit the Galveston waterfront with 110 mph winds and a 15-foot storm surge, causing $29.6 billion in damages. It was the third most costly storm in U.S. history. UTMB evacuated the inpatient hospitals before the storm at a cost of $20 million. By the time the storm passed, nearly every one of the campus's one hundred structures had sustained damage at a combined cost of almost $1 billion. Hospital functions and services were shut down for months; the emergency department closed for nearly a year. In the context of the national economic recession, the situation on the Texas coast faced major hurdles in capital funding. After much discussion by the University of Texas Board of Regents about the long-term viability of the Medical Branch on the Island, the decision was made to reconstruct the campus.

Figure 2: The new clinical services building at UTMB consolidates departments formerly housed in hospital buildings at or below grade

The recovery focused on four goals:

- Repairing damaged facilities to pre-disaster conditions
- Improve facilities to better serve UTMB and its customers
- Enhance the resilience of those facilities to reduce the damage from future events
- Maximize FEMA and insurance reimbursement for disaster-related costs

Key elements of the infrastructure replacement included elevation of vulnerable mechanical and electrical infrastructure above the ground level in the health care core, dry flood-proofing of radiation oncology treatment rooms, and the creation of a new 6-story clinical services building to house all the primary functions that were previously on the first floor or lower level of the eight hospitals in the health care core complex: pharmacology, food services, sterile processing, blood bank, laundry, and storage. A new ground level concourse, built from water- resistant materials, connects the existing buildings; the ground level runs on standalone mechanical and electrical services. A 100,000 square foot primary care pavilion was reconstructed with a flood wall to 5 feet above ground level, connecting to a slurry wall 20 feet below grade. All surfaces on floors within 20 feet of grade on all buildings were replaced with water resistant materials.

In addition, UTMB constructed a new district heating plant, complete with an underground distribution system, to allow rapid recovery of systems for the hospitals. The existing elevated steam and chilled water lines, which were heavily damaged in the storm, were removed. A new 210-bed hospital is under construction. At the same time, UTMB notes that it remains dependent upon critical utilities, including water, sewer, natural gas, power, telephone and data systems, external to the campus. Hence, they continue to diversify services and expand facilities on the mainland while mitigating risk on the Galveston Island campus. In a presentation to the American Meteorological Society, Steven LeBlanc, PE, MBA, Assistant Vice President at UTMB, summarized the lessons learned:

"The storm is just an instance in time; recovery is where all the hard work and decisions are made. Recovery is also where opportunities reside: sustainable design is a must. Hurricanes come in approximately 20-year cycles; there is a generation to forget what you learned. It is critical to build to protect the future" (LeBlanc, 2013).

## Inland Flooding from Extreme Rain

Heavy precipitation contributes to increased flooding. This pattern has already been observed around the world. The frequency of great floods (100-year floods in large basins) increased substantially during the 20th century. Flooding in large river basins, such as the Mississippi, is based on extreme precipitation that is sustained for weeks or months. In spring, heavy rains over fallen snow can contribute to flooding in northern regions. In the U.S., 90-day periods of heavy rainfall were 20% more common from 1981 to 2006 than in any earlier 25-year period on record. Record-breaking Mississippi flooding occurred in 2008 and 2011 in association with very heavy rains, followed by extensive flooding further north in the Missouri River basin due to heavy rain and snowmelt.

Natural variability cannot explain the observed changes in precipitation intensity or geographic distribution of precipitation. Rather, the observed changes follow from basic physical principles and are consistent with a combination of natural factors and human influence. A 4% increase in atmospheric moisture has been observed, consistent with a warming climate (Trenberth et al., 2007). The increased moisture in the atmosphere is driving the shift to heavier but less frequent rains. While an atmosphere that holds more moisture has greater potential to produce heavier precipitation, precipitation events also become less frequent and shorter, as it takes longer to recharge the atmosphere with moisture (Trenberth, 2011). There is increasing scientific consensus that the observed increase in heavy participation

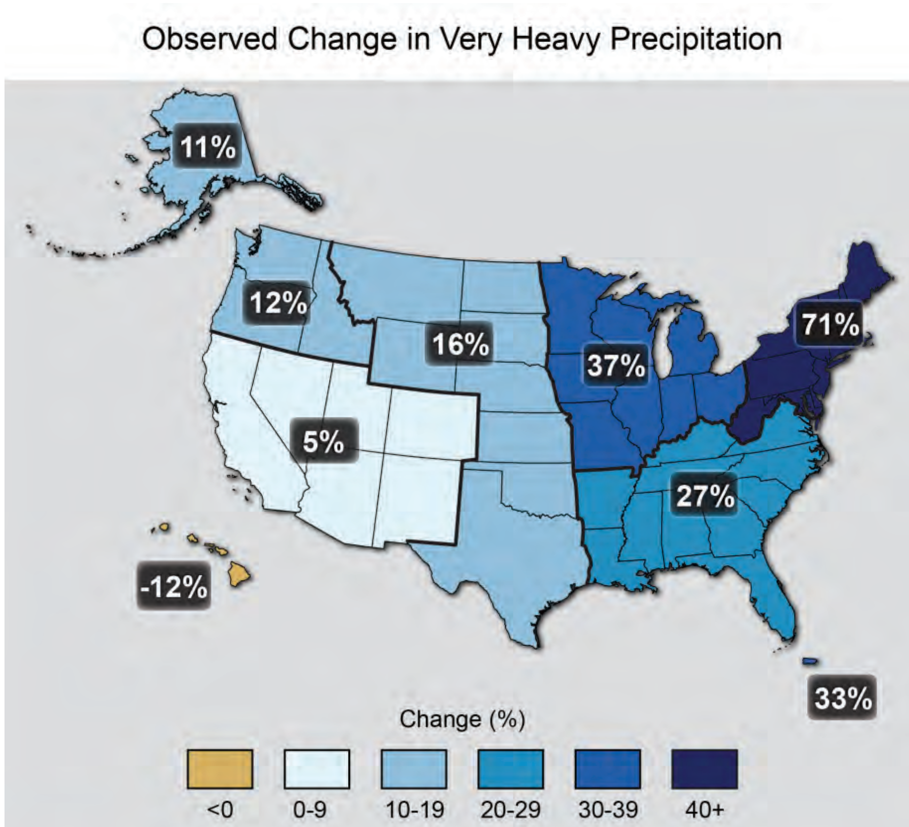


Figure 3: The map shows the percentage increases in very heavy precipitation (defined as the heaviest 1 percent of all daily events) from 1958 to 2012 for each region. There are clear trends toward more heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest. (Melilo et al., 2014)

is the result of human activity (Karl et al., 2008; Stott et al., 2010; Min, Zhang, Zwiers, & Hegert, 2011).

A map that shows increased amounts of very heavy precipitation across the U.S. suggests that the Northeast has seen the largest increase, followed by the Great Lakes/Upper Midwest and Alaska. The National Weather Service (NWS) has provided maps of experimental long-range river flood risks and national significant river flood outlooks to aid health care organizations in understanding both current and projected risks.

Large river basin flood control has been primarily managed by the U.S. Army Corps of Engineers, as many river basins are dammed for agriculture and water withdrawal. Despite this management, large flood events are increasing. The Mississippi River floods in April/May 2008 and in 2011 were among the largest and most damaging along the waterway in the past century, rivaling and exceeding major floods in 1927 and 1993.

In April 2011, two major storm systems deluged the Mississippi River watershed with record rainfall. Areas flooded along the length of the river itself in Illinois, Iowa, Missouri, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana. According to a report compiled by the U.S. Army Corps of Engineers, the event caused $2.8 billion in damage, and the system of levees, reservoirs, and floodways was tested as it never had been previously (Sainz, 2013). Almost all of the levee or floodwall systems were damaged. The floodways at Birds Point-New Madrid in Illinois and the Morganza Floodway and Bonnet Carre Spillway in Louisiana were opened to relieve the stress on the system, marking the first time that three floodways had been operated during a single flood. Cairo, Illinois was saved only by opening a 2 mile length of a Missouri levee, sacrificing 130,000 acres of farmland and 100 homes. Seventeen hospitals and 11 nursing homes were considered at a high risk of flooding and 4 health care facilities were evacuated.

Cities and states have relied upon basin management agencies to set flood levels and infrastructure threshold conditions. Likewise, hospitals have been built in consideration of such recommendations. Recent events have exceeded predicted thresholds, prompting calls for change in river management practices. Along the Mississippi River and other river basins across North America, cities and counties are buying property to begin the process of restoring flood plains and wetlands. While this change in approach is underway, the impacts from extreme weather events may produce unpredictable outcomes.

Given the increase in threshold values for flood crest elevations associated with climate change and the shifting approach to large river basin management, it is important for state and local policymakers to set clear and consistent criteria for flood-proofing in hospitals and residential care facilities located on or adjacent to river basin floodplains.

## CASE STUDY: Mercy Medical Center, Cedar Rapids, Iowa

Tim Charles, Mercy Hospital's President and CEO, remembers the 2008 event this way (Ford, 2013):

"We had prepared for all kinds of disasters, but I'm not being at all facetious when I say that flooding and patient evacuation were not in the game book. We called the staff together and put out a call for employees to help sandbag. I remember saying that we didn't think we were going to be affected by water, but we were sandbagging as a precautionary measure."

When the city's sewer system was overwhelmed, water began backing up into the lower levels of Mercy. Employees rushed from bathroom to bathroom, removing toilets and sinks and plugging the holes with towels, sandbags and inflatable rubber bladders. Within hours, the decision was made to evacuate the remaining 183 patients before potential loss of emergency generators housed in the basement would render evacuation of the 9-story building more difficult. It took nearly seven hours to move the patients and medical equipment through the halls, down the elevator, and safely out of harm's way. Once the building was safely emptied of patients, hundreds of volunteers spent the night sandbagging to prevent the water from overtaking the facility.

The central power plant for Mercy had been expanded and relocated from its prior basement location to a freestanding central utility plant on higher ground on the north side of the hospital. Because the plant was undamaged, the hospital was able to reopen in 16 days, once the flood damage was repaired at a cost of $68 million (Saporito, 2013).

St. Luke's Hospital, located nearby on higher ground, took 52 of Mercy's patients and about twelve Mercy nurses to open a vacant nursing unit. Additional help poured in from everywhere, including what was dubbed the "Big Relief from the Big Easy." New Orleans medical staff knew all too well what Cedar Rapids was experiencing—Katrina survivors came with donated items and Cajun home cooking.

As Tim Charles told Iowa Public Television (IPTV 2008):

"Over the next roughly 107 days from the night of the flood we worked diligently with all of the contractors from the local community to reclaim the facility and to remodel it. We had a theme that we were operating with during this entire time which was we would rise above the flood better than ever".

A compelling short film about the 100 days following the flood can be viewed at *http://www.youtube.com/watch?v=buxaMgaT6ls*

Since the flood, Cedar Rapids has purchased 1,300 homes and 100 businesses in the flood plain that was inundated by what the city calls its "800-year-flood." Mayor Ron Corbett told the Washington Post "We're really moving people out of harm's way" to establish a 220-acre "floodable greenway" (Vastag and Sellars, 2011).

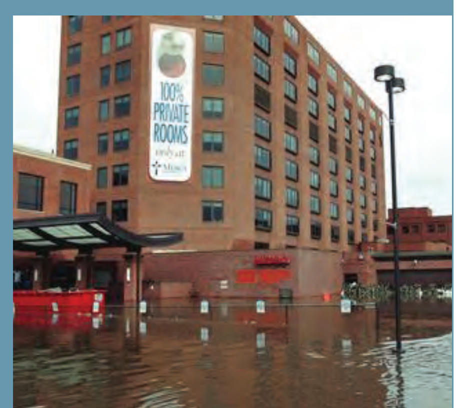


Figure 4: Mercy Medical Center, Cedar Rapids, Iowa (2008). Reprinted with permission from The Cedar Rapids Gazette.

## Tornadoes and Extreme Wind Events

Tornadoes are part of severe convective storms, which occur all over the Earth. In fact, tornadoes have been documented in every state of the U.S. and on every continent except Antarctica. Some parts of the world, however, are much more prone to tornadoes than others: the middle latitudes, between about 30° and 50° North or South, provide the most favorable environment for their formation. This is the region where cold, polar air meets warmer, subtropical air, often generating convective precipitation along the collision boundaries. The areas most frequently hit by tornadoes are also considered the most fertile agricultural zones of the world. The United States has the world's highest absolute tornado count, with an average of over 1,000 tornadoes recorded each year. Canada is a distant second, with around 100 per year (NOAA, 2014). For data on historical tornadoes by state or intensity, information about categorization, see the NOAA U.S. Tornado Climatology website.

NOAA reports that there is no clear trend in the frequency or strength of tornadoes since the 1950s for the U.S. as a whole (2013). Incomplete and inconsistent record keeping makes it difficult to assess how local thunderstorms and tornadoes in the United States have been affected by climate change. What is known is that climate change creates a warmer, moister environment that may fuel additional thunderstorms. Computer models of a warming climate indicate that conditions may become more conducive to severe thunderstorms in some regions. Thunderstorms provide a favorable environment for tornado formation, but tornadoes also require wind shear, a highly uncertain element in climate models.

Average wind speed over the world's oceans has increased between 5 and 10% over the past 20 years, and the speed of extreme winds (the strongest 1% of winds) has increased by at least 15% over the majority of oceans. On the other hand, surface wind speed over land appears to be declining slightly in many mid-latitude locations, including the United States. High-altitude circulation changes associated with climate change may affect wind speeds, but land use factors such as urban development and vegetation growth are also major contributors to slowing land surface winds.

Tornadoes and extreme wind events wreak havoc on buildings, particularly those constructed prior to the 1970s, when building codes began to focus on wind resistance of structural elements such as windows and roofs. Wind tunnel modeling has become much more advanced, allowing predictive modeling of the impact of high wind on building designs and air flow. In order to survive the most severe tornadoes (Enhanced Fujita (EF)-5), facilities must be built to withstand wind velocities of 200 miles per hour, with particular attention to fastening equipment and façade elements to minimize the risk of airborne debris becoming projectiles in the wind.

Many U.S. Critical Access Hospitals in tornado-prone regions date from the 1950s or 60s, prior to contemporary codes and standards. Retrofits of façades and mechanical systems are expensive and complex, particularly for hospitals that must remain operational.

It is not surprising that tornadoes have devastated many hospitals in the last decade. St John's Regional Medical Center in Joplin, Missouri (183 beds, see its case study below); Kiowa Hospital in Greensburg, Kansas (13 beds, see its case study in Part 3); and Moore Medical Center in Moore, Oklahoma (30 beds) are just three of the many hospitals that have been damaged by tornadoes. More wind resistant requirements for new residential care settings, including nursing homes and intermediate care facilities, must also be in place for a generation before resilient care settings are the norm.

## CASE STUDY: St. John's Regional Medical Center, Joplin, MO (Mercy Hospital Joplin) and Freeman Health System, Joplin, MO

In the late afternoon of Sunday, May 22, 2011, a catastrophic EF-5 tornado struck Joplin, Jasper County, and Newton County in southwest Missouri. With winds in excess of 200 miles per hour, the 3/4-mile wide tornado cut a 6-mile path of destruction through central Joplin. The tornado caused 161 fatalities and approximately 1,371 injuries, making it the single deadliest U.S. tornado since 1947 and the eighth most deadly in history. Thousands of structures were destroyed or damaged, including single-family homes, apartment buildings, retail stores, and St. John's Regional Medical Center. Freeman Health System, a smaller nearby hospital that escaped a direct hit, responded to this medical surge incident.

Figure 5: A photo taken from the roof of Mercy Hospital conveys the scope of the devastation. The hospital was a complete loss.

The initial priority at Mercy Hospital was a complete, immediate hospital evacuation. At the time of impact, clinical and nonclinical staff knew to immediately begin evacuation procedures. Windows were blown out; roof-mounted equipment, and the roofing itself, was dislodged. More than 183 patients, staff and visitors were evacuated in 90 minutes, safely dodging debris along the way. Five critical care patients and one visitor died. Within a week, a 60-bed temporary field hospital was established in the parking lot of the destroyed facility.

Freeman Health System, the second hospital in the immediate vicinity, was immediately on complete generator power. There was a massive communications failure; all staff was needed, but because it was Sunday, no OR staff or surgeons were on-site. Within 2-4 hours after the tornado, an estimated 400 patients were in triage areas, and 120 patients were in the ED. An estimated 70-100 ambulances had arrived to the area. Within 12 hours post-tornado, water pressure had dropped, and Freeman prepared for an extended water outage (Missouri Hospital Association [MHA], 2012).

Work on a replacement Mercy Hospital began in 2012; the facility is scheduled to open in early 2015. It will feature two underground levels and eight levels above ground. Storm-resistant features include laminated glass throughout the facility, hurricane-rated windows in critical areas, a concrete and brick exterior, two independent electrical feeds, two water supplies, two generators housed in a storm-resistant building (either generator can power the hospital independently), and interior (storm-resistant) stairwells that are equipped with emergency lighting (Mercy Hospital Joplin, 2013).

## Drought

Trends in drought also have strong regional variations. In much of the Southeast and large parts of the West, the frequency of drought has increased with rising temperatures over the past 50 years. In other regions, such as the Midwest and Great Plains, droughts are occurring less often.

Droughts are likely to become more frequent and severe in some regions. The Southwest, in particular, is expected to experience increasing drought as changes in atmospheric circulation patterns cause the dry zone just outside the tropics to expand farther northward into the United States. Models project that extreme dust events, combined with global warming, could advance the spring thaw in the mountains of the Upper Colorado River Basin by as many as 6 weeks by 2050. The earlier disappearance of snow could amplify water disputes, extend the fire season, and place stress on aquatic ecosystems.

Hospitals are generally among the top 10 potable water consumers in their communities. Residential and ambulatory facilities consume far less water than hospitals, but require potable water supplies to operate. The first step for all health care facilities in handling extreme drought is potable water conservation: water-efficient fixtures and devices. Moving large process water loads, such as cooling tower makeup water or landscape irrigation, to municipal reclaimed water sources provides another key strategy to operating with radically reduced potable water in arid regions. In some areas where rainfall is concentrated and seasonal, captured rainwater and condensate from air handlers

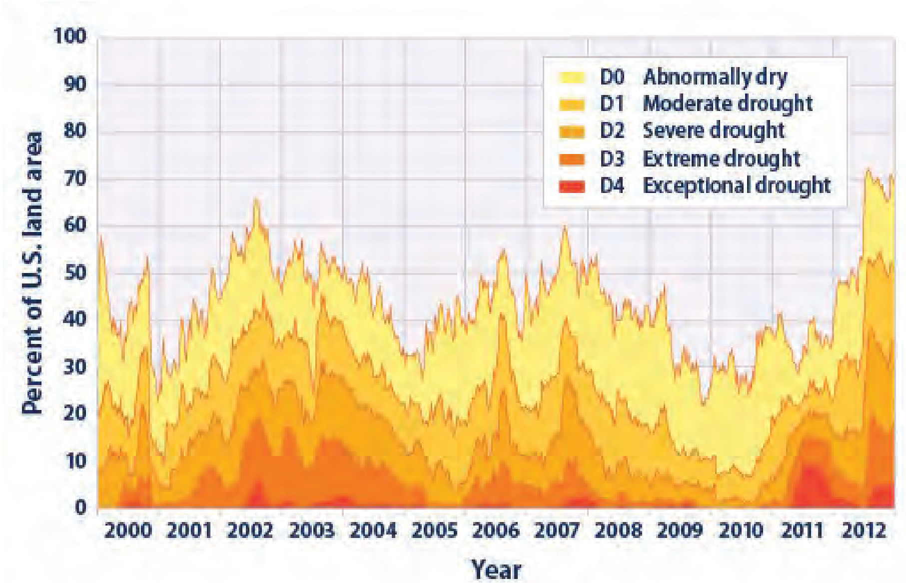


Figure 6: This chart shows the percentage of U.S. lands classified under drought conditions from 2000 through 2012, according to the U.S. Drought Monitor classification system, described in the table at *http://www.epa.gov/climatechange/science/indicators/weather-climate/drought.html*. The data cover all 50 states plus Puerto Rico (United States Environmental Protection Agency [EPA], 2012).

can effectively reduce potable water demand. Local municipalities may restrict the collection and use of rainwater. In 2012, Kiowa Hospital (see the case study on page 56) became the first hospital to use captured rainwater to flush toilets, a system that requires separate water supply plumbing for toilets. Water conservation can reduce water fixture use by 40% or more (which is approximately 20% of the total water use of a facility), and shifting process loads to municipal reclaimed systems can double that savings. Water efficient landscaping can save an additional 5%, particularly in drought-prone regions, and using drought-resistant plants is a growing trend. There are no specific requirements for on-site water storage in health care facilities, though Emergency Operations Plans are asked to address the issue of water supply disruptions.

While droughts have not, to date, caused severe disruptions to health care services, a range of other weather-related water supply disruptions have led to significant service disruptions. These are documented in Part 3.

## Wildfires

Higher spring and summer temperatures, along with an earlier spring melt, are the primary factors driving the increasing frequency of large wildfires and longer fire season in the western U.S. over recent decades, as demonstrated by the record-breaking fires in 2013 in the Southwest and Rocky Mountain Region. The drought, heat wave and associated record wildfires that hit Texas and the Southern plains in the summer of 2011 cost $12 billion, according to meteorologist Steve Bowen of re-insurer Aon Benfield (Rice and Raasch, 2012). The 2014 California drought is estimated to be responsible for $1.7 billion in agricultural losses and more than 14,000 associated jobs (Bernstein, 2014). Increasing temperature peaks correlate with increasing wildfire vulnerabilities.

Hospitals may force evacuation when wildfires encroach. Hospital ventilation systems require an outdoor fresh air supply to maintain indoor air quality and pressurization; if the outdoor air quality is severely compromised by smoke, it may be impossible to safely house patients and staff in the building. Forest fires have caused a number of planned, limited duration evacuations in the U.S., most recently at Camp Pendleton Naval Hospital in California and St. Luke's Wood River Valley Medical Center in Idaho. However, hospitals remain important in fire areas in order to treat firefighters and residents; hospitals in fire-prone areas should consider isolating emergency department ventilation systems and enabling recirculated air during emergency conditions. In addition, portable scrubbers can be placed in nursing units to improve air quality once outdoor ventilation systems must be shut down.

## CASE STUDY: Memorial Hospital, Colorado Springs, Colorado

In June, 2013, the Black Forest fire claimed two lives, destroyed at least 509 homes, and damaged 17 others. An estimated 300 employees from Memorial Hospital and Children's Hospital Colorado at Memorial were evacuated or pre-evacuated from their homes. When Memorial Hospital got reports of the encroaching fire, they immediately began preparing based on their 2012 experience with the Waldo Canyon fire. Each of these fires was larger than any preceding fire.

Memorial's Safety and Facilities departments began "environmental rounds," monitoring air quality in the buildings. The team placed mobile air scrubbers at Memorial Hospital North, which was nearly full with patients, and at Memorial Hospital Central. Memorial worked with building managers at off-site locations to maintain air quality in those buildings. Outside, the sky turned pewter in color, as it had on June 26, 2012 when the Waldo Canyon Fire roared into the Mountain Shadows subdivision, killing two people and destroying 347 homes.

Figure 7: A view of the approaching forest fire from the Memorial Hospital Helipad.

### CASE STUDY: Providence Holy Cross Medical Center, Burbank, CA

In 2008, two wildfires affected southern California: the Sesnon fire (a natural fire in October that lasted 5 days) and the Sayre fire (an arson in November that lasted 6 days). The Sesnon Fire resulted in $12.6 million in damages. The main threat to Providence from this fire was smoke, not fire. The Sayre fire was more intense. It crossed a highway, preventing 40% of the medical staff from reaching the facility. The fire caused $13 million in damages.

Providence Holy Cross Medical Center, the only local area trauma center in Burbank, received more than 200 patients from neighboring hospitals and canceled all elective surgeries. Providence was able to stay open and operational during both fires, thanks in large part to the use of HEPA filters. These filters were purchased for pandemic flu preparedness to purify the air and to support the central ventilation system for maintaining zero pressures (which is critical for quarantine rooms). In this case, the utilization of equipment intended for one purpose actually helped the hospital remain open and functional during a fire/weather event (Thomas, 2011).

## Landslides, Liquefaction, and Avalanches

With increasing extreme rainfall and snowfall events, the risk of landslides, liquefaction and avalanches may also increase. In a landslide, masses of rock, earth or debris move down a slope. Debris and mud flows are rivers of rock, earth, and other debris saturated with water. They develop when water rapidly accumulates in the ground, during heavy rainfall or rapid snowmelt, changing the earth into a flowing river of mud or "slurry." They can flow rapidly, striking with little or no warning at avalanche speeds. They also can travel several miles from their source, growing in size as they pick up trees, boulders, cars and other materials. Landslides may damage properties directly in the path of travel of the slide, or disrupt roads and critical infrastructure.

Nationally, landslides account for over $2 billion of loss annually and result in an estimated 25 to 50 deaths a year. However, they remain relatively understudied. While in the past, landslides have generally been associated with seismic events, tsunamis or volcanic eruption, increased precipitation and land mismanagement, particularly in mountain, canyon and coastal regions, has increased focus on landslide vulnerabilities. In areas burned by forest and brush fires, a lower threshold of precipitation may initiate landslides. Mapping of landslide vulnerabilities is conducted sporadically, often at a regional or even site-specific level. Some regions of high seismicity have developed maps of the areas susceptible to landslides based on average slopes, geologic soil types, and the past history of sliding. Sites within these susceptible zones require site-specific investigation. A small ancillary office structure on the University of Minnesota Medical Center was partially evacuated in June, 2014 when a 100 yard section of embankment directly adjacent to the hospital campus gave way following 3-6" of rainfall in a single day, the worst single rainfall event since 1871 and the culmination of the wettest June on record.

Soils that are loose and saturated with water are prone to liquefaction. While liquefaction is particularly associated with seismic events, it can also occur along shorelines and following periods of intense rainfall. Soil liquefaction can significantly damage the built environment. Buildings whose foundations bear directly on sand that liquefies will experience a sudden loss of support, resulting in drastic and irregular settlement of the building causing structural damage, or may leave the structure unserviceable afterwards, even without structural damage.

An avalanche is a rapid flow of snow down a sloping surface. While some avalanches are caused by human activities, in some cases they may result either from weakening in the snowpack or increased load due to precipitation. Avalanches that occur in this way are known as spontaneous avalanches. Generally, once initiated, avalanches grow rapidly as they entrain more snow. In mountainous terrain, avalanches are among the most serious objective natural hazards to life and property, with their destructive capability resulting from their potential to carry enormous masses of snow at high speeds. There is no universally accepted classification of avalanches—avalanches can be described by their size, their destructive potential, their initiation mechanism, their composition and their dynamics. In areas prone to avalanches, a range of mechanical mitigation measures can be deployed, ranging from use of explosives to snow fences to avalanche dams.

## INSTITUTION-LEVEL INFRASTRUCTURE: ASSESSING HAZARDS AND VULNERABILITIES

Climate change considerations should be integrated into institutional-level hazard and vulnerability assessments that are conducted as part of preparedness planning for extreme weather. Consideration of how climate change may enhance the weather hazards chronicled above, overlaid on the health care delivery setting (hospital, nursing home, intermediate care), is an important first step in assessing infrastructure's vulnerabilities to extreme weather hazards.

Institutional health care infrastructure can be divided into three types: structural, non-structural, and operational (FEMA, 2011). This Guide and Toolkit addresses structural and non-structural infrastructure, but since operational needs often drive non-structural decisions, those considerations are also addressed to some degree in this resource. For example, hospitals and long-term care facilities need to provide secure housing for staff and their families in an extreme weather emergency; this need may drive co-development of hotel facilities or contracts with existing neighboring hotels that can be activated in emergency planning.

### Structural Vulnerability

Structural vulnerability considers potential damage to structural components of a building or institution structure. Foundations, bearing walls, columns and beams, staircases, floors and roof decks, or other types of structural components that help support a building are structural components. Applied to site planning, structural components may include roads, vaults, or bridges. The structural aspects of design and construction in most hazard-prone areas are regulated by building codes and other regulations. Such codes are usually prescriptive in nature: they establish minimum requirements that are occasionally updated with newly-acquired knowledge. The building regulations alone, however, cannot guarantee uninterrupted operation of a hospital or residential health care facility, because many other factors affect hospital functions.

### Non-structural Vulnerability

The effects of damage to non-structural building components and equipment, as well as the effects of breakdowns in public utility services, communication/IT infrastructure, transportation, re-supply, or other organizational aspects of hospital operations, can be as disruptive and dangerous to patients as any structural damage. Non-structural components include architectural components, such as exterior walls, window and roofing, as well as interior components of buildings, such as suspended ceilings. Collapse of these components has caused a number of evacuations and closures of hospitals following a hazard event.

Ventilation systems are extremely vulnerable to disruption as a result of indirect building damage. Winds often overturn improperly attached roof-mounted ventilation and air conditioning equipment, while the ductwork is susceptible to collapse once the building enclosure is penetrated. Airborne debris from windstorms or forest fires can quickly clog the air filtration systems, rendering them impaired or inoperable.

Hospitals and other residential care facilities depend on several essential pipe systems. Medical gases are among the most important substances that must be channeled through pipes, along with water, steam, and fire sprinkler systems. Physicians and nurses depend on oxygen and other gases for patient care. Unless properly secured and braced, these installations can be easily dislodged or broken, causing dangerous leakage and potential additional damage.

In floods, stormwater management is critical – as rainfall events intensify in regions of the U.S., roof drainage systems, stormwater retention basins and drywell systems may overflow and cause localized flooding and water damage. Sewers are apt to overflow, back up, or break down. Waste disposal is essential for any residential health care setting, because when the toilets back up, or sterilizers, dishwashers, and other automated cleaning equipment cannot be discharged, patient care is immediately affected. Retention ponds or holding tanks, coupled with backflow and diversion valves, can be employed to solve this problem. However, in many health care facilities, this issue has not been adequately addressed. Landscape and advanced stormwater management techniques can improve groundwater infiltration and reduce surface runoff and flooding.

Elevator service is vulnerable not only to power outage, but also to direct damage to elevator installations. Wind and windborne debris can damage elevator penthouses, opening a path for water penetration that can disable elevator motors and controls, as has happened during recent hurricanes. Flooding of elevator pits was a common problem during Hurricane Katrina and Superstorm Sandy, and it is often responsible for the loss of elevator service.

The emergency power supply system is probably the most critical element of a health care system. Together with fuel supply and storage facilities, this system enables all the other hospital installations and equipment that have not sustained direct physical damage to function normally in any disaster. As the nature of diagnosis and treatment becomes more dependent on computers, monitors, and other electrical equipment, the need for emergency power will continue to grow. The experience of Hurricane Katrina demonstrated the need for emergency power coverage even for services that typically have not been regarded as critical in both hospitals and residential care facilities, such as climate control and air conditioning systems. Extreme heat caused a number of hospitals to evacuate their patients and staff when the conditions became unbearable.

## Organizational Vulnerabilities

Most health care organizations have disaster mitigation or emergency operation plans, but not all of them provide organizational alternatives when the normal daily movement of staff, patients, equipment, and supplies are compromised. The critical nature and interdependence of these processes represent a separate category of vulnerabilities that need careful attention. The disruption of administrative services by natural events can impair hospital functions as much as physical damage.

Any prolonged isolation or blockage of streets serving a residential health care facility can impair supply replenishment, including fuel for emergency power generation. Following Hurricane Katrina, many hospitals were isolated by floodwaters for five or more days and, in many cases, could not replenish critical supplies, which in some instances contributed to the decision to finally evacuate the facility.

Ultimately, workers, from clinical care staff to food service personnel to environmental services workers, keep health care facilities functioning. Personnel stay past their shifts or arrive early in order to help transfer fragile patients from facilities in flood zones. During the height of the Superstorm Sandy, NYU Langone Medical Center's personnel evacuated the hospital, carrying sick patients down the stairs into awaiting ambulances. Many nursing home employees worked 36-hour shifts due to staffing shortages and loss of services. Both in acute care and residential settings, health care workers are first responders, engaging in lifesaving measures that may expose them to dangerous conditions or injury. Hence, the organizational vulnerabilities must include assessment of the potential workplace hazards that may arise in emergencies, and planning should address measures to mitigate those hazards. For example, if hazardous materials are stored in areas prone to flooding, and personnel must access those areas during a flood for critical operational tasks, how are they protected?

Likewise, the need to safely care for the families of workers during emergencies cannot be underestimated. Hospitals and long-term care facilities must have effective plans to house up to 1,000 additional people nearby, out of harm's way, in buildings that have power, water, and services. Health care facilities in disaster areas are creating innovative partnerships with hospitality and housing organizations to quickly be able to mobilize additional housing units. Community Hospital at Toms River, New Jersey purchased 100 pet crates to enable staff to safely move their house pets to the hospital when their families were evacuated after Superstorm Sandy.

Finally, climate considerations call into question how long emergencies must be managed. Four days, five days— there are stories of facilities that safely harbored in place for more than 100 hours, only to finally need to evacuate due to organizational failures. Community Hospital at Toms River (profiled on page 60) pre-ordered supplies before the storm hit, and converted conference facilities to store them. The question of duration is a key one for facility owners and policymakers moving forward in improving resilience.

It is imperative to recognize the role of front line health care workers, from clinical care to environmental services workers, and the broader community in planning for enhanced organizational resilience. Front-line workers should participate in the development of health care risk assessment and emergency plans, in risk assessment and emergency plan reevaluations and update, including lessons learned after specific emergency events. The broader community may offer both organizational assets, and require supplies or services, during and after an event. For example, a volunteer community organization called "snow angels" mobilized to transport hospital workers to and from Jefferson Medical Center during West Virginia's 2014 ice storms, when hazardous driving conditions reduced mobility (Vincent, 2014). At the same time, disruption of potable water services, food supplies, or other community necessities may bring the community to the door of a hospital seeking assistance. Hence, it is critical to understand the broader operational expectations during and after events.

### Transportation and Site Access

Transportation infrastructure is inherently long-lived. Bridges, tunnels, ports, and runways may remain in service for decades, while rights-of-way and specific facilities continue to be used for transportation purposes for much longer. In addition to normal deterioration, transportation infrastructure is subject to a range of environmental risks over long time spans, including wildfire, flood, landslide, geologic subsidence, rock falls, snow, ice, extreme temperatures, earthquakes, storms, hurricanes, and tornadoes.

Existing infrastructure has been built to many different design standards, and its current and future environmental risk is similarly varied. As environmental risks change, the probability of unexpected failures may increase. Further, as existing infrastructure approaches the end of its service life, decisions about replacement or abandonment should, but may not currently, account for changing future risks. In reviewing transportation infrastructure for critical health care delivery, it is important to understand the underlying vulnerabilities of tunnels, bridges, access roadways, and, where applicable, public transit services. The U.S. Department of Transportation summarizes its approach to climate resilience as follows:

**"Transportation systems are potentially vulnerable to the loss of key elements. Therefore selectively adding redundant infrastructure may be a more efficient strategy than hardening many individual facilities on the existing system. System resilience is best viewed across transportation modes and multiple system owners. While some key elements are obvious, other dependencies may be less well recognized" (U.S. Department of Transportation, 2011).**

Road and rail systems are vulnerable to extreme heat, buckling rail track, and asphalt breakdown. More air conditioning loads in transit can overload power grids, causing brownouts and power failures. Excessive heat can cause signal or electrical equipment breakdowns. Increasing temperatures may create greater demands from hydroelectric systems that depend on water flow, which may reduce the water available for commercial shipping.

Severe precipitation that causes flooding of roadways, tunnels, and evacuation routes can reduce the life of highway infrastructure. It can also increase road washout, landslides, and mudslides that damage roadways and overloaded drainage systems, causing traffic backups and street flooding. Rising sea levels can affect transit agencies on the coast, disrupting rail and roadways. Some of these effects, such as sea level rise and increased precipitation intensity, present greater challenges to the transportation system and infrastructure when combined with subsidence of the land and vulnerable local geology, as well as storm surge and wave impacts associated with coastal storms. For example, storm surge can damage and destroy coastal roadways, bridges and airports, and sea level rise could exacerbate such effects.

## SPECIAL SECTION: SUPERSTORM SANDY AND NEW YORK CITY

**"In keeping with the overarching goals of the Special Initiative for Rebuilding and Resiliency—to minimize the impacts of climate change and enable quick recovery after extreme weather events—the City of New York will make the health care system more resilient. To ensure that hospitals, nursing homes, and adult care facilities can operate continuously during extreme weather, the City will require that new facilities be built to higher resiliency standards and existing providers are hardened to protect critical systems" (The City of New York, 2013).**

A vast, complex health care system has evolved to meet the needs of New York's diverse 8.2 million people, and Superstorm Sandy caused disruptions across that system. The City of New York Special Initiative on Rebuilding and Resiliency (SIRR) report summarized the situation:

**"The storm completely shut down six hospitals and 26 residential-care facilities. More than 6,400 patients were evacuated through efforts coordinated by the Health care Evacuation Center (HEC). Providers who remained open strained to fill the health care void—hospitals repurposed**

lobbies as inpatient rooms, adult care facilities siphoned gas from vehicles to run emergency power generators, and nursing home staff lived on-site for four or more days until their replacements arrived" (The City of New York, 2013).

Five acute care and one psychiatric hospital were evacuated—a total of 2000 patients. Three hospitals closed in advance of the storm: New York Downtown (Manhattan) closed after notice of a potential pre-emptive utility district steam shutdown, while the Department of Veterans Affairs's New York Harbor Hospital (Manhattan) and South Beach Psychiatric Center (Staten Island) closed due to concerns about possible flooding. Three other hospitals—New York University's Langone Medical Center (Manhattan), Bellevue Hospital (Manhattan), and Coney Island Hospital (Brooklyn)—evacuated during or after Sandy due to the failure of multiple electrical and mechanical systems, including emergency power systems. In the immediate aftermath of Sandy, hospital bed capacity was down 8% citywide.

While ten hospitals remained open, some sustained minimal flooding damage or operated on emergency generators due to the widespread utility power outages throughout the city that continued for seven days—dealing with volume surges from storm victims and closures. Others narrowly escaped flood damage. For example, Metropolitan Hospital in upper Manhattan just missed having its critical electrical systems flooded, and floodwaters came within inches of the entrance to Staten Island University Hospital's north campus.

Sixty-one nursing homes and adult care facilities were in areas impacted by power outages and/or flooding. Half of these providers continued to operate—some because they sustained minimal or no damage, others because they had effective emergency plans. But within a week of the storm, 26 facilities had to be shut down, and another five partially evacuated, which reduced citywide residential capacity by 4,600 beds and led to the evacuation of 4,500 residents. Although two nursing homes and one adult care facility evacuated patients in advance of the storm, 28 others evacuated under emergency conditions. These stressful emergency scenarios added significantly to patient risk, but fortunately there was no loss of life during any Sandy-related evacuations in the city.

These closures affected hospitals as well, preventing them from discharging patients to nursing homes as they normally would have done. Instead, hospital beds that could have been available for new patients remained occupied by existing nursing home patients. Hospital and nursing home closures disrupted health care service delivery for months following the October event—some hospitals remained closed for more than 100 days.

Their summary findings (Figure 8) of reasons for disruptions and evacuation are instructive for all health care providers.

Without exception, the loss of (or lack of) emergency power following the loss of municipal grid power was the primary reason that hospitals, adult care facilities, and nursing homes evacuated. Flooded critical infrastructure, such as ground floors, electrical switchgear, and heating/cooling systems, was the secondary reason. In ambulatory settings, the disruption to staff and patient travel became the primary reason for disruption, followed by loss of communication/IT systems. While hospitals also experienced these outages, there were acceptable workarounds (battery radios, for example) in place.

Based on the damage sustained after this "storm of the century" struck, the City attempted to assess the future risk:

"Preliminary Work Maps (PWMs) from the Federal Emergency Management Agency (FEMA) place at least 300 more buildings, housing, and health care providers in the 100-year floodplain than were in the floodplain in the 1983 Flood Insurance Rate Maps (FIRMs). Based on high-end projections for sea level rise from the New York City Panel on Climate Change (NPCC), another 200 facilities will be in the 100-year floodplain by the 2020s, and a total of 1,000 health care facilities will be in the 100 year floodplain by the 2050s" (The City of New York, 2013).

The report concluded that the location of health care infrastructure, in its present condition, poses unacceptable risks to the health and safety of New Yorkers. As a result of this work, the SIRR recommended 14 initiatives, including the following:

- **Initiative 1 (enacted):** new hospital buildings will be required to meet construction code standards for flood-resistant construction to the 500-year flood elevation, which is a higher than the 100-year flood elevation to which protection is required today.

- **Initiative 2 (slated):** existing hospital buildings in today's 500-year floodplain will meet, by 2030, a subset of the amended New York City Construction Code standards through building retrofits.
- **Initiative 3 (enacted):** support Health and Hospital Corporation's efforts to protect existing emergency departments located below the 500-year floodplain elevation to ensure availability.
- **Initiative 4 (enacted):** new nursing home facilities in the 500-year floodplain will be constructed with additional resiliency measures for their emergency power systems, including placing additional systems on generators as well as installing external portable generator hookups.
- **Initiative 5 (slated):** require retrofitting of existing nursing homes in the 100-year floodplain by 2030 to meet standards for protection of electrical equipment and emergency power systems, including external hookups.

This assessment and the follow-up actions demonstrate how health care providers and policymakers can evolve resilience measures to meet future weather risk challenges.

| Provider | Impact | Building | Equipment (elevators. Imaging) | Utilities (power, water) | Heating/ cooling | Commun-ications/ IT | Staff | Supplies |
|---|---|---|---|---|---|---|---|---|
| Hospital | Evacuations/ closures/ reduced services | Flooded | Flooded | Back-up failed | Flooded | Phone/ internet outages | Staff couldn't travel | Limited deliveries |
| Nursing homes/ adult care facilities | Evacuations | Flooded | No back-up power | Back-up failed (NH) / no back-up (ACF) | No back-up | Phone/ internet outages | Staff couldn't travel | Limited deliveries |
| Community-based providers | Closures / reduced services | Flooded | No back-up power | No back-up | No back-up | Phone/ internet outages | Staff couldn't travel | Limited deliveries |
| Home-based providers | Reduced services | Disruptions in patients' homes/residences, e.g. loss of power, elevators not working | | | | Phone/ internet outages | Staff couldn't travel | Delayed deliveries |

Primary reason for disruption | Secondary Reason | Tertiary reason

Figure 8: This table indicates the top three causes of disruption to health care delivery in the aftermath of Superstorm Sandy, including hospitals, nursing homes, community, and home-based providers (The City of New York, 2013).

# PART 3: SOLUTIONS FOR THE FUTURE INFRASTRUCTURE SOLUTIONS FOR IMPROVED HEALTH CARE CLIMATE RESILIENCE

"The past practice of rebuilding for the most recent disaster will increasingly leave communities vulnerable to future hazards, and to the consequences from climate change and rising sea level. As resources become scarce, communities will be less able to repeat unsustainable or non-resilient approaches to community development. Yet, many communities are not now aware of their options for improved resilience" (Ewing & Synolakis, 2010).

## OVERVIEW

The unprecedented number of weather-related disasters with total damages in excess of $1 billion between 2011- 2013 has undoubtedly fueled interest in resilience of facilities and communities, including health care facilities. The combined financial and health impacts of these extreme weather events on hospital evacuation and nursing home damage is resulting in renewed emphasis on developing and promulgating infrastructure solutions for health care climate resilience. These events have also provided opportunities to learn from past disasters so that health care facilities, and the communities they serve, can be more resilient in the future.

Large hazardous events will occur and will inevitably cause some damage, but these events need not result in catastrophic losses or total debilitation. Storms, hurricanes, and tornadoes are not avoidable, but their consequences—the loss of human life, property, and essential services—can be avoided or reduced when a facility and the organization that manages it are resilient.

Key lessons emerge when reviewing post-disaster health care failures and evacuations:

- For critical health care facilities such as hospitals, it may no longer be adequate to depend upon current external community or regionally based mitigation strategies. Hospitals should plan to remain operational even when these larger regional systems fail. Unlike the earlier generation of hospitals that failed after Hurricane Katrina, new hospitals in New Orleans are constructed "upside down": essential medical services and infrastructure are at higher elevations to anticipate a failure of the levee system. Architect Thomas Fisher, in *Designing to Avoid Disaster* (2013), reminds us that "going forward, good design and planning will be based on the understanding that nothing will work as planned, or even at all."
- For critical health care facilities, it is no longer acceptable to design new buildings using current disaster thresholds. Planning must recognize that hospitals have a minimum life of 50 years. Health care organizations should use predictive climate models to set design values, such as maximum outdoor air temperatures for load sizing, maximum rainfall events for stormwater systems, projected sea level rise for minimum elevations, and maximum wind speeds for enclosures of critical spaces.
- Because recent research and experience suggests that shelter-in-place is the safest long-term option for residential settings, specific infrastructure improvements are required to ensure availability of primary power, emergency power, and water during and following disasters (Dosa et al., 2011; Hyer, 2013).
- Increasing energy demands at academic health center campuses, which provide patient care, education, and research facilities, contribute to the growth of on-site power and thermal energy generation as backup to grid-supplied energy sources for enhanced reliability and reduced greenhouse gas emissions. Emerging technologies, from combined heat and power to fuel cells, provide reliable forms of on-site electrical generation in both normal and extended emergency operation. While these systems do not replace the need for diesel generators, the ability to "island" this distributed generation during extended outages provides additional energy resilience.
- Duplicative emergency power systems that deliver little to no value during normal, day-to-day operation are less likely to attract adequate investment and maintenance from the private sector. Therefore, such on-site systems will be built and maintained as cheaply as possible, and are likely to have a high rate of failure during extended emergencies. Particularly as resilience strategies move out from hospitals into sub-acute and residential settings, creative and innovative system solutions that deliver value at all times should be prioritized. For example, Florida allows residential facilities to include an external generator connection rather than requiring on-site generator equipment; private vendors can move mobile generator capacity from disaster to disaster.

Indeed, the collective experience from recent extreme weather events underscores the need for an expanded approach to health care resilience. Health care infrastructure must embrace sustainable site planning and infrastructure solutions that both mitigate potential extreme weather impacts and support the continued, uninterrupted functioning of hospitals and residential health care facilities long after the immediate threat has passed, until normal or "new normal" infrastructure services resume. Personnel responsible for making a health care facility safer for patients, more resistant to damage, or capable of continued operations in a post-disaster situation must consider the following questions (FEMA, 2011):

- What types and magnitudes of hazard events are anticipated at the site?
- What are the vulnerabilities of the site or existing building to natural hazards?
- What are the anticipated frequencies of hazard events?
- What level of loss/damage/disruption/injury, if any, is acceptable?
- What might be the financial impact of extended downtime on the institution?
- What is the impact to the community if the hospital cannot maintain operations in the aftermath of a disaster?

This section examines new and emergent practices that integrate sustainable design strategies and resilience thinking in 21st century health care building infrastructure. It begins with defining five elements of enhanced infrastructure climate resilience, continues with an examination of each infrastructure system on a typical health care campus, and concludes with a discussion of embedding resilience in infrastructure decision making. The role of the hospital as an important regional resource is becoming far more prominent, and the reconsideration of health care facilities as potential "safe harbors" offers a model for related community planning initiatives. Weaving neighborhood and community benefits into health care campus design produces an effectively functioning facility as well as a lasting anchor for community health and resilience.

## RESILIENT DESIGN PRINCIPLES

**"A resilience-based approach focuses on learning how to respond, adapt to and evolve with change and surprise, while avoiding changes that would move local and global social–ecological systems closer to tipping points that would threaten the life-supporting and life-enhancing capacity of these systems"(duPlessis, 2012).**

In an era of increasing severe weather, resilient design principles are being developed to guide future construction. Literature on resilience thinking emphasizes that a resilient building or development is one that improves opportunities post-disaster through adaptation. The most resilient are able to mitigate and minimize damage, provide support and emergency services, and take advantage of the post-disaster situation to improve or facilitate positive change economically, socially and ecologically (duPlessis 2012; Larsen et al., 2011).

The Australian National Strategy for Disaster Resilience (National Emergency Management Committee [NEMC], 2009) includes the following four core features in its description of a resilient community:

- functioning well while under stress
- successful adaptation
- self-reliance
- social capacity

What are the principles around which resilient systems are designed? The non-profit Resilient Design Institute offers ten principles to inform resilient design thinking in the future (see following page). These principles can be applied at an individual building, campus, community, or global scale.

## Resilient Design Principles

1. **Resilience transcends scales.** Strategies to address resilience apply to individual buildings, communities, and larger regional and ecosystem scales; they also apply on different time scales, from immediate to long-term.
2. **Resilient systems provide for basic human needs.** These include potable water, sanitation, energy, livable conditions (temperature and humidity), lighting, safe air, occupant health, and food; these should be equitably distributed.
3. **Diverse and redundant systems are inherently more resilient.** More diverse communities, ecosystems, economies, and social systems are better able to respond to interruptions or change, making them inherently more resilient. While sometimes in conflict with efficiency and green building priorities, redundant systems for such needs as electricity, water, and transportation improve resilience.
4. **Simple, passive, and flexible systems are more resilient.** Passive or manual-override systems are more resilient than complex solutions that can break down and require ongoing maintenance. Flexible solutions are able to adapt to changing conditions both in the short- and long-term.
5. **Durability strengthens resilience.** Strategies that increase durability enhance resilience. Durability involves not only building practices, but also building design (beautiful buildings will be maintained and last longer), infrastructure, and ecosystems.
6. **Locally available, renewable, or reclaimed resources are more resilient.** Reliance on abundant local resources, such as solar energy, annually replenished groundwater, and local food provides greater resilience than dependence on nonrenewable resources or resources from far away.
7. **Resilience anticipates interruptions and a dynamic future.** Adaptation to a changing climate with higher temperatures, more intense storms, sea level rise, flooding, drought, and wildfire is a growing necessity, while non-climate-related natural disasters, such as earthquakes and solar flares, and anthropogenic actions like terrorism and cyberterrorism, also call for resilient design. Responding to change is an opportunity for a wide range of system improvements.
8. **Find and promote resilience in nature.** Natural systems have evolved to achieve resilience; we can enhance resilience by applying lessons from nature. Strategies that protect the natural environment enhance resilience for all living systems.
9. **Social equity and community contribute to resilience.** Strong, culturally diverse communities in which people know, respect, and care for each other will fare better during times of stress or disturbance. Social aspects of resilience can be as important as physical responses.
10. **Resilience is not absolute.** Recognize that incremental steps can be taken and that total resilience in the face of all situations is not possible. Implement what is feasible in the short term and work to achieve greater resilience in stages.

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This Guide and Toolkit is focused at the building and campus level. At the same time, it recognizes that hospital campuses and health care delivery is situated within communities, and residential and ambulatory care settings beyond the hospital offer important community services. Moreover, a single health system may include multiple hospital campuses in distinct and diverse communities; as health systems undertake resilience planning efforts, a keen understanding of the relationship of the health care settings to individual communities is essential.

## FRAMEWORK FOR CLIMATE RESILIENT HEALTH CARE SETTINGS

Today there are many examples of resilience principles being incorporated in new and existing health care buildings in the U.S. and beyond. This Guide and Toolkit captures and illustrates these principles and practices for health care settings in a five-element framework (see Figure 9), adapted and modified from a broader UN framework for community resilience (UNISDR, 2012). The goal of this framework is to facilitate the improvement of resilience in health care institutions for today and tomorrow. Each of these elements is described in detail below, with case study examples provided to illustrate applications. The Toolkit supports further exploration of each element.

It is understood that these five elements are nested within a broader framework that begins with institutional and administrative support for broader disaster or emergency preparedness efforts, and includes education and training as well as disaster response, recovery, and rebuilding, all of which

| | | |
|---|---|---|
| Element 1 | Multi-hazard Assessment- Understanding Climate Risk | Maintain up-to-date data on climate hazards and infrastructure vulnerabilities, prepare risk assessments and use these to inform infrastructure planning and decisions. Keep a well-maintained data base of disaster losses. |
| Element 2 | Land Use Planning, Building Design and Regulation | Understand the building regulatory, design and land use planning context within which the facility is situated. What codes were in place when the building was constructed? Is the enclosure vulnerable? What are the larger local and community land use issues, stormwater or other weather hazard management issues? |
| Element 3 | Infrastructure Protection and Resilience | Not all hazards are destined to cause disasters. Pre-emptive measures can help avoid disruption, incapacitation or loss of use of critical infrastructure services. Invest, design and construct new sustainable infrastructure in appropriate locations and to a higher standard of hazard and climate resilience to withstand future events. |
| Element 4 | Protect Vital Facilities and Functions: Clinical Care and Personnel | Hospitals serve essential functions during and after a disaster, as they continue to shelter patients in place as well as accommodate and treat survivors. ED's and imaging areas must remain operational. Nursing homes and residential facilities house medically fragile and vulnerable populations. Vital service functions: kitchens, laundry, etc, may also be vulnerable. Research facilities often house animals, years of valuable research samples and data. Understand priority and vulnerable functional needs and areas; prioritize resilience of those facilities. Understand personnel commuting patterns; put in place systems for accommodating personnel and families during and after events. |
| Element 5 | Environmental Protection and Strengthening of Ecosystems | Protect ecosystems and natural buffers to mitigate floods, storm surges and other hazards to which your building, campus or city may be vulnerable. Adapt to climate change by building on good risk reduction practices. |

Figure 9: The five elements of climate resilient health care infrastructure form the basis for exploring a facility or campuses responses to the challenges of climate change and extreme weather.

are outside the scope of this Guide and Toolkit. By focusing specifically on improving health care infrastructure resilience, this Guide and Toolkit aims to reduce future vulnerabilities and loss, and improve the functioning of a broad range of health care facilities and organizations in the face of climate change and more extreme weather events.

## Element 1: Multi-Hazard Assessment: Understanding Climate Risks and Community Vulnerabilities

If health care organizations lack a basic understanding of the present and future climate risks they may face, planning for disaster risk reduction may be ineffective. Relying only on municipal codes and regulations places critical facilities at risk. Risk analysis and assessments are essential to informed decision-making, prioritization of projects, and longer-range planning. For example, UT Galveston (see case study on page 21) made an informed decision to diversify and expand its facilities on the mainland following the extreme flooding of Galveston Island.

Health care organizations should conduct a Climate Risk Assessment (see Figure 10 and Toolkit) so that they may better understand and catalog present and future extreme weather risks. Hospital and health systems that operate multiple campuses (in many instances across varying climate zones) should complete climate risk assessments for all their sites. Hospital systems should carefully consider how each campus interacts with its community, as well as how resources and capacity might shift if extreme weather affects some or all of a system's regional assets.

These contextual considerations may be particularly relevant in comparing the needs of urban and rural facilities—for example, during or following a disaster a rural community may rely on its hospital for essential community services, such as food, water or basic shelter, while an urban setting may provide residents with a wider array of options.

Other vital assessment steps include reviewing community vulnerability assessment reports and findings. Similarly, it is important to meet with local and regional governing authorities or planning departments to understand preferred local and regional risk assessment methodologies and tools. For example, the state of Florida requires SLOSH modeling for establishing storm surge and inundation, while New York City uses Flood Insurance Risk Maps (FIRM's) and applies additional factors for sea level rise. Additional technical expertise may be available through local universities, municipal planning departments, or consultants.

NOAA's National Weather Service has resources that explain coastal and riverine flooding, tornadoes, hurricanes, drought, and wildfire risks. Climate change scenarios and climate models are also available to assist property owners in understanding future risks (in this case, to 2050 or 2080). The University of Michigan and U.S. Green Building Council have published a major resource for understanding regional climate change and its impact on the built environment (Larsen et. al., 2011) for all regions of the country.

Planning should anticipate that hospital buildings will operate for their full life cycles, 50 to 75 years. For sub-acute and other residential health care uses such as long-term care, a 30-year planning horizon may be sufficient. Such planning requires significant review of climate change scenarios, including both effects on weather extremes as well as projected sea level rise.

The basic components of climate risk assessment include:

- **Historic loss data:** Consult or maintain an updated database of extreme weather losses from past events on your campus, city or region.
- **Hazard assessment:** Establish and map the intensity and probability of extreme weather events (see Toolkit and Figure 10 below).
- **Capacity assessment:** Identify the capacities and resources available within your organization, neighborhood or community to provide redundancy in order to enhance resilience.
- **Community Vulnerability assessment:** Identify the degree of vulnerability and exposures to hazards your community may face, and the likely impact of that vulnerability on both medical services (patient surge) and non-traditional needs (beyond clinical care) the community may expect a medical facility to provide.
- **Campus Vulnerability assessment:** Determine the degree of vulnerability and exposure to the hazard your campus or building(s) may face (bring forward conclusions from Element 2).

The need to embrace a multi-hazard approach is essential, especially for facilities located in areas that may be exposed to a variety of hazards. While this Guide and Toolkit focuses on climate-related hazards, hospitals must consider a broad range of additional risks, from bio-terrorism to pandemics. Multi-hazard assessments can reveal potentially conflicting effects of mitigation measures. Thus, the results of a climate risk assessment should be included in an organization's larger Hazard Vulnerability Analysis. The importance of this has become increasingly evident following the catastrophic failures that have occurred.

"The aim should be to anticipate and coordinate how the building and its systems interact, how mitigation of the risk from one hazard can influence the building's vulnerability to others, and how undesirable conditions and conflicts may be avoided or resolved. Through the application of a multi-hazard and multi-disciplinary approach, cost savings, efficiency, and better performance can be achieved in programming and planning new buildings and retrofitting existing ones" (FEMA, 2011).

Developers of risk assessments should engage and gather input from, at a minimum, Safety/Emergency Management, Transport, Critical clinical department personnel (including Labs and Pharmacy, Respiratory Therapy), Support Services (Laundry, Environmental Services, Food Service), Infection Control, Engineering/Physical Plant, Human Resources, and Administration. Each of these groups, in turn, should ensure the representation of front-line workers who have deep understandings of both operational constraints and opportunities. Critical facilities should include community stakeholders, and develop the assessment in partnership with the broader community, state or regional hospital/health care associations, local and regional governments, and public health agencies.

**Risk Assessment: Impact of Climate Change on the Healthcare System**

| | | | | |
|---|---|---|---|---|
| | | minor risk | | |
| | | moderate risk | | |
| | | major risk | | |
| **Hazard** | Today | 2030 | 2050 | Comments |
| **Gradual** | | | | |
| Sea Level Rise | | | | |
| Increased Precipitation (Rain and/or Snow) | | | | |
| Increased Drought | | | | |
| Higher Average Temperature | | | | |
| **Extreme Events** | | | | |
| Coastal Flooding and Storm Surge | | | | |
| Heavy downpours | | | | |
| Riverine flooding | | | | |
| Heat Waves | | | | |
| Cold Waves | | | | |
| High Winds | | | | |
| Forest Fires | | | | |

Figure 10: A sample checklist to assist health care organizations in aggregating climate risk across a range of extreme weather hazards.

## CASE STUDY: Spaulding Rehabilitation Hospital, Boston, MA

In 2005, Partners HealthCare purchased a contaminated brownfield parcel of land in the Charlestown Navy Yard to replace their Spaulding rehabilitation facility. The site is on the promontory where the Little Mystic Channel meets Boston Harbor and is at virtual sea level. When Hurricane Katrina devastated the health care infrastructure in the Gulf region, Partners recognized their potential vulnerability and created a set of voluntary best-practice requirements for the new Spaulding Rehabilitation Hospital, which opened in 2013. This facility is the first building on the Boston waterfront to design for projected sea level rise.

Key decisions included:

- Placing the First Floor elevation 30" above the projected 500-year flood elevation, while maintaining universal access for rehabilitation patients
- Placing all critical patient care functions above the first floor
- Ensuring a high performance envelope, including triple-glazed windows and exterior shading, to improve thermal performance and prevent low interior temperatures/freezing if heating is lost in winter months or overheating if cooling or ventilation is inoperable in summer months
- Incorporating key-operable windows in patient rooms, so that if the building cooling or ventilation system is inoperable, indoor overheating can be avoided in summer months and patients can shelter-in- place (after Katrina, indoor temperatures in sealed hospitals exceeded 100 degrees, which prompted staff to break windows with furniture in order to provide ventilation)
- Placing all critical mechanical/electrical infrastructure on the roof and above flood elevations, to minimize possibility of interruption
- Implementing gas-fired on-site cogeneration (CHP) to provide efficiency and redundancy for power generation in the event of grid loss or diesel generator issues (CHP infrastructure is on the roof, as are emergency diesel generators)
- Implementing extensive green roofs to mitigate stormwater discharge during heavy rainfalls

None of these measures, which collectively added between .3 and .5 percent to the initial cost of construction, was mandated by federal, state, or local codes. In fact, Partners had to overcome substantial utility resistance to locating cogeneration and major electrical switchgear above the ground floor. In addition to providing enhanced resilience to extreme weather, the building envelope and energy conservation measures reduce energy demand in normal operation, in turn reducing carbon emissions. The building uses an estimated 30% less energy than a conventional building. The ongoing operational savings from these envelope and system measures more than offset the additional capital investment.

Figure 11: Spaulding Rehabilitation Hospital, completed in 2013 on the Boston waterfront, includes such resilience features as an elevated first floor and roof-mounted electromechanical infrastructure.

## Element 2: Land Use Planning, Building Design, and Regulation

Land use decision-making affects the resilience of a campus or building. Several generations of land use planning decisions have severely disrupted a range of ecosystem services and natural resilience to extreme weather events. For example, infilling of wetlands in coastal regions and the loss of protective dunes have increased coastal storm surge vulnerabilities. Likewise, development along the Mississippi River, with its complex system of levees and dikes, has disrupted the natural flows and functions of floodplains. It is therefore imperative to understand the broader land use context within which a building or campus is located or being planned, and to consider the ways that land use decision making can mitigate or exacerbate severe weather impacts.

In some regions of the U.S., local regulation prohibits locating critical medical facilities inside the 100-year or 500-year flood zones. Other regions allow development inside floodplains, with a range of requirements for location. For example, Spaulding Rehabilitation Hospital was just completed on the Boston waterfront; the state of Florida, on the other hand, prohibits new hospital construction in the 100-year surge and inundation area. Residential health care uses (particularly nursing homes and assisted living facilities) have grown rapidly in vulnerable coastal regions, and local land use regulations are increasingly mandating improved resilience measures (e.g., emergency power, higher design flood elevations) for such facilities. Shorefront Rehabilitation Center, in Brooklyn, New York, demonstrates how conducting a risk assessment and employing more resilient construction can allow a facility to remain operational throughout extreme weather events (see case study on page 45).

Finally, there is the matter of how, and under what set of regulations, buildings have been constructed. Recent extreme weather events suggest that relying on historical baselines will not ensure future building performance, especially for critical buildings such as hospitals. Considering extreme weather hazards in conjunction with building type and potential building vulnerabilities will help health care organizations improve their climate resilience.

### Land Use, Siting, and Landscape

Sustainable design has radically transformed approaches to land use at the individual site and building level, producing approaches that will likely improve resilience to extreme weather events. Many of these strategies are equally appropriate for retrofitting and new development. The case study of Texas Medical Center (Element 5, below) demonstrates how even the largest urban medical campus in the U.S. can radically transform its campus land use approach (and partner with its broader community) to better manage extreme rainfall.

> The U.S. Green Building Council's LEED® Rating System (*www.usgbc.org*) and the Sustainable Sites Initiative (*www.sustainablesites.org*), an interdisciplinary effort by the American Society of Landscape Architects; the Lady Bird Johnson Wildflower Center at The University of Texas at Austin; and the United States Botanic Garden, Washington, DC, provide voluntary national guidelines and performance benchmarks for sustainable land design and Construction practices.

| | | |
|---|---|---|
| **Transportation Infrastructure** | Pavement design and engineering are affected by temperature, precipitation, freezing and thawing, and solar radiation. | Climate change, including changes in temperature and precipitation trends, may reduce the life expectancy of pavement that is designed based on past climate data. |
| **Stormwater Management** | Stormwater management systems, including retention and detention ponds, are sized using past precipitation data and current definitions of 50- or 100-year storm events. | Heavy precipitation events and storms may overwhelm stormwater management systems more frequently in the future. Major storm events may cause serious flooding if stormwater systems are not designed to handle greater quantity and intensity of precipitation. |
| **Landscape Design** | Landscapes are designed with current precipitation patterns, temperature patterns, and plant hardiness zones in mind. | Climate change, including changes in precipitation and temperature patterns, will affect landscape design, including native plants. Climate change will also shift plant hardiness zones northward, affecting plant selection. |

Figure 12: Examples of how climate data can be used to inform land use and transportation decision making (Larsen et al., 2011).

Hospital and long term care campuses are often standalone facilities, surrounded by surface parking and located away from other retail and commercial services. Collocation of health care facilities with additional retail or service settings, such as food service, retail pharmacies, and laundromats, can improve long-term resilience by providing auxiliary services to personnel and the public during extended weather disruptions. Hospitals within walking distances of residential neighborhoods may also encourage essential personnel to live nearby (see Element 4).

Orientation of the building can affect the thermal and wind performance of the envelope. Orienting buildings to minimize thermal loads, particularly heat loads, will reduce the probability of overheating if a building's air conditioning systems fail. In climates dominated by heat, exterior solar shading devices can reduce extremes of solar gain. In such climates, consideration of covered parking also becomes more critical.

Research suggests that changes in plant hardiness zones may occur as a result of increasing temperatures, more intense and frequent heat and precipitation events, and longer periods between storm events. Models suggest a systematic habitat shift toward the poles (Parmesan & Yohe, 2003). In areas subject to coastal flooding, landscapes must be able to tolerate saltwater inundation. Following Superstorm Sandy, New York City enacted new plant species requirements (Building Resiliency Task Force [BRTF], 2013). Changes to precipitation patterns, length of seasons, and average ambient temperatures will be determining factors in climate-adapted landscape design. At the same time, less frequent, even if more intense, rain events will place additional strain on landscape irrigation sources. In such conditions, it will become increasingly important to consider using native, drought tolerant plant species and harvesting and storing rainwater on site, whether through specific landscape features or rainwater cistern systems.

## CASE STUDY: Boulder Community Foothills Hospital, Boulder, CO

**Located on the east side of Boulder, Colorado, the Boulder Community Foothills Hospital (BCFH) is framed by the Flatirons, the first of the Rocky Mountains rising steeply above the Front Range plains to the east. The facility, completed in 2003 but not fully occupied until 2004, was the first LEED-certified hospital building in the U.S. It includes a range of innovative site and land use strategies.**

**Early in the planning process for the facility, a search for suitable sites revealed that few vacant parcels of sufficient size (16-17 acres) were available within the city limits. However, a 39-acre parcel in the county was just over the city boundary and could be annexed into the city. The site was entirely within the floodplain of Boulder Creek and a tributary, Bear Canyon Creek, which merge on the property. Two reservoirs are located upstream: Barker Dam on Boulder Creek and Grosse Reservoir on Bear Canyon Creek.**

The City of Boulder required that the design of the hospital meet the standards of the city's building code and floodplain management ordinance, which resulted in several measures to provide a higher level of protection against flood hazards than is required for buildings that do not provide critical services. The 17 acres of the site that were needed for the campus, entirely outside of the designated floodway, were proposed to be filled to one foot above the 100-year flood elevation. The remaining 22 acres were placed in conservation easement. Engineering analyses were performed to demonstrate that no increase in flood elevations would result.

Because of anticipated high groundwater and the fact that the below-grade areas are constructed into fill that is subject to saturation during flooding, all below-grade areas are designed and certified as floodproofed spaces. Floodproofing extends two feet above the 100-year flood elevation, and one foot above the 500-year flood elevation.

The City of Boulder has experienced severe flooding of Boulder Creek on numerous occasions, and has been actively undertaking efforts to clear portions of the floodplain for use as a greenway and public open space. Prompted by concern about how effectively it could respond to serious flooding, in early 2006 the city developed a scenario that involved catastrophic flooding, bridge failures, and numerous flooded buildings and neighborhoods. The drill was organized with partners throughout the area, including the Boulder Community Foothills Hospital and other health care facilities (FEMA, 2011). Clearly, the hospital's close collaboration with the

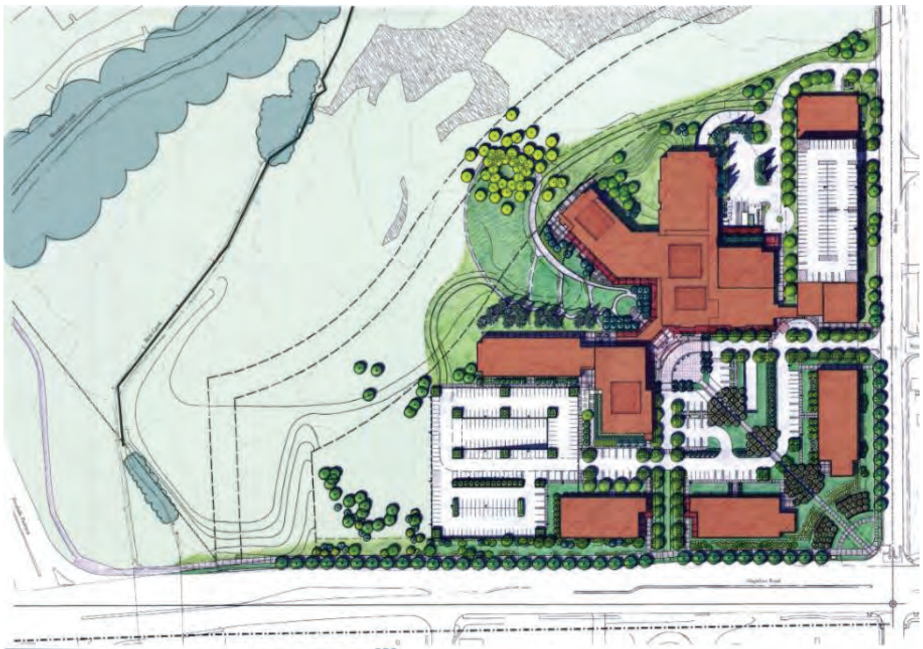

Figure 13: The site plan for Boulder Community Hospital, a 39-acre parcel located entirely within the Boulder Creek floodplain, elevates the developed area and includes 22 acres of conservation easement.

City of Boulder and broader community resulted in the integration of these advanced measures during the early stages of design, when resilience could be integrated at little to no additional cost to the project.

## Transportation and Site Access

The decision to evacuate UT Medical Branch on Galveston Island (see the case study on page 21) was based primarily on the vulnerability of the bridge to the mainland. That bridge, if damaged, would not have been available for later evacuation of patients, not to mention the ongoing flow of supplies, staff, and the functioning of the campus for an extended period of time. New hospital construction along the Gulf Coast anticipates the need to receive personnel, supplies and the injured during extended periods of floodwater inundation. These new hospitals include boat docks and launches at upper levels. Collectively, these represent an emergent set of considerations both during and after extreme weather events.

Hospital campuses have been significantly hampered by travel disruptions and restrictions following extreme weather events. Access to gasoline, restricted access on bridges, and disruptions to major public transit systems have caused lingering access issues for hospitals.

In flood-prone areas, some state or local regulatory authorities require that access roads be designed so that the driving surface is at the design flood elevation (DFE) or no more than 1 to 2 feet below the DFE. At a minimum, a hospital's access road should be at least as high as the adjacent public road so that the same level of access is provided during flooding (FEMA, 2011).

The following strategies highlight emergent practices in mitigating and adapting transportation vulnerabilities:

- Enhance data on local contextual factors: understand local transportation conditions and context, infrastructure age, and impacts from past weather events.
- Assess access roads and building evacuation routes for extreme weather vulnerabilities, and consider whether downed trees floods, or blocked culverts will affect road use and site access.
- Develop extreme weather impact scenarios based on recent events, forecasts, and local conditions to identify vulnerabilities and cascading effects.
- Develop or maintain access redundancies (ensure site or campus access from at least two roads).
- Understand evacuation routes and procedures when locating helipads, ambulance drop-off zones, and other vital points of access.
- Develop carpool and vanpool systems for "normal" operation that can be activated following extreme weather emergencies.

## Building Regulations

For existing health care campuses, it is important to understand the codes that were in place when buildings were constructed, while for new campuses, it is imperative to compare future climate risk projections to current local codes. Most states have adopted model national building codes to govern the construction of buildings, sometimes modifying them to reflect local considerations. In general, building codes address minimum standards of construction, based on accumulated experience. For example, prior to 1970, buildings in the United States were not constructed with enhanced wind resistance for tornadoes or hurricanes. Modeling building performance in high winds was either prohibitively expensive or impossible. Impact-resistant glazing did not exist.

Since the 1970s, coastal cities have benefitted from better tracking of ocean wind speeds and their likely effects on development. Resulting building regulations mandate façade performance to particular wind velocities. High wind strategies are employed in areas where wind velocities can exceed 90 miles per hour: hurricane and tornado-prone regions often require hardening façade performance to higher wind speeds. Floodplain mapping, updated in the 1970s and 1980s, resulted in local building code regulations mandating the hardening of facilities in floodplains. Some states have modified their local codes to respond to particulars of extreme weather, enacting substantial provisions for both wind-resistance and flood-proofing of critical buildings.

Newer local regulations have moved toward performance-based codes rather than prescriptive requirements—for example, designating that a building enclosure must be resistant to 200 mile per hour winds without prescribing the precise strategies to achieve this requirement. This regulatory approach places more responsibility on building owners and their design professionals

## CASE STUDY: Shorefront Rehabilitation Center, Brooklyn, NY

**Built in 1994, the Shorefront Center for Rehabilitation and Nursing Care was designed to comply with building code requirements for flood-resistant construction due to its proximity to the ocean. Built to exceed the 500-year flood elevation by three feet, the entire facility is elevated nearly 30 feet above ground, with parking spaces located below. All of the building's systems and equipment are also elevated and thus protected from floodwaters. The emergency power supply is furnished with enough capacity to run medical equipment, elevators, and heating, ventilation, and air conditioning (HVAC) systems to ensure the facility can continue to operate during power outages. Furthermore, the elevated first floor houses only the lobby and other support services. Community and administrative space is located on the second floor, and residents' and patients' rooms start on the third.**

**During Sandy, the building functioned as planned. At the peak of the storm, floodwaters filled the parking area and reached the lobby door but did not enter the building. Emergency power generators remained safe and supplied backup power for four days while area-wide power was out. The nursing home's emergency plans for food and medical supplies allowed staff and patients to shelter in place despite limited transportation for incoming supplies Shorefront was not only able to provide continuous care to its residents during and after Sandy, it also assisted people from the local community who sought food and shelter (SIRR, p 149).**

Figure 14: Shorefront Rehabilitation Center, Brooklyn, NY, functioned as planned during and after Superstorm Sandy. The structure was designed to accommodate storm surge at its base levels; all critical infrastructure is above flood elevations.

to determine how such performance requirements can be achieved.

### Building Envelope and Vertical Transportation Systems

FEMA publishes its findings on building vulnerabilities and failures from every major extreme weather disaster as a series of Mitigation Assessment Team (MAT) reports. Based on these and other investigations, it has developed guidance on best practices for building envelopes to withstand hurricanes, tornadoes, flooding, and earthquakes, including checklists that improve assessment processes. Because building enclosure failures have been a common occurrence in high wind and flooding events, understanding the vulnerabilities of existing enclosures and developing a plan to harden those enclosures is an important aspect of climate resilience.

Key practices for addressing wind vulnerabilities include:

- Properly anchoring roofing and rooftop equipment in high wind areas (in many instances, roofs and equipment are blown off, leading to water penetration and evacuation of buildings)
- Removing all items that may become projectiles, e.g., loose furniture and equipment, ballasted (gravel) roofs within 1500 feet of critical buildings
- Designing enclosures to resist high wind, including wind and impact resistant glazing and façade construction

Additional guidance on improving wind and flood performance of building façades and envelopes is found in FEMA's publication #577, Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings. This document includes useful checklists for building structural and non-structural vulnerabilities.

Green Building and Climate Resilience: Understanding impacts and preparing for Changing Conditions, published by the University of Michigan and U.S. Green Building Council, includes a range of strategies for retrofitting envelopes for improved performance.

Vertical transportation systems are also vulnerable to flooding and wind damage. High winds can damage rooftop penthouses containing elevator machine rooms; elevator pits are prone to flooding, which disables elevators. While elevators are included as part of the emergency power systems, physical damage may render them useless in emergencies. During and after both Katrina and Sandy, patient evacuation was conducted via stairwells. NYU Langone Medical Center, New York, was designing a new public elevator system for a major bed tower prior to Sandy; these elevators do not extend to below grade floors, reducing the possibility for flooding (Schwabacher, 2014). Mercy Hospital, Joplin has designed multiple elevator banks to minimize the risk of wind damage disabling all elevators.

## CASE STUDY: Louisiana Heart Hospital, Lacombe, LA

Prudent decision-making during the design and construction of Louisiana Heart Hospital contributed to its ability to withstand Hurricane Katrina. Opened in February 2003, the hospital is a 58-bed specialty care facility. The non- flood zone property was selected for its convenient location above the storm surge projection. Wynn Searle, the Vice President of Operations/Hospital Development at Medcath, Incorporated, stated that "its location dictated a wind- resistant design per code requirements, including common engineering safety features."

A wetland survey revealed the need for extensive site preparation, including placing more than $1 million worth of sand to compress the swamp-like soil. Safety measures included the installation of impact-resistant windows that meet the missile impact test created for hurricane-prone areas by Miami-Dade County, Florida. These reinforced windows are designed to sustain the force of winds of 130 to 140 mph. According to Mr. Searle, "measures were taken to attach the roof membrane to meet a certain 'wind uplift requirement' (determined by their insurance company and testing lab) to preclude uplift from significant wind storms."

One advantage of these construction techniques is lower flood insurance premiums. According to hospital officials, these premiums would have been considerably higher if they had not used such hurricane-resistant methods and materials. There were additional costs associated with the damage prevention measures, but the minimal damage sustained by the hospital and the ability to continue to operate demonstrated their cost effectiveness for the organization.

An independent water-treatment plant for domestic water supply and fire protection, and a 1,700-foot well that was drilled during construction allowed the facility to function without municipal water after the disaster. During Katrina, the hospital's two large generators engaged when electrical power failed. Additional diesel fuel was ordered as the storm approached, enabling the hospital to run the air-conditioning units and continue dialysis treatments, cardiac catheterization lab procedures, and surgeries. The protocol for back-up diesel fuel has since been addressed and cylinders have been purchased to hold an additional 1,800 gallons of fuel on site.

During Katrina, all entrances to the hospital except the emergency entrance were blockaded and sandbagged. No flooding occurred; mechanical roof screen panels bolted to a support system on the roof caused the only damage to the hospital. The hurricane winds played havoc with the panels, slashing parts of the hospital roof and causing some leaks. Flying debris damaged several cars in the parking lot. The hospital remained operational (United States Department of Homeland Security, 2012).

Figure 15: Louisiana Heart Hospital, designed to withstand high winds, successfully operated through Hurricane Katrina

## CASE STUDY: Mercy Hospital, Joplin, MO

Within three months following the destruction of St. Johns Regional Hospital in Joplin, MO, a temporary modular building replacement was erected on the former hospital parking lot. At the same time, an accelerated design and planning process for the replacement facility began. The building, scheduled for completion in early 2015, has incorporated a number of specific "hardening" features to respond to tornado risk.

First, critical care areas—intensive care and neonatal intensive care—are outfitted with 250 mph impact resistant windows; the ED, bridge, and clinic "safe rooms" are outfitted with 140 mph windows. The central utility plant (CUP) is located in a separate, standalone "hardened" building (as opposed to a pre-engineered lightweight metal structure, a current common practice); services are connected through an underground tunnel. Critical infrastructure is placed below grade in the CUP. Specific façade elements include concrete roof decks (versus metal deck), precast siding (in lieu of lightweight Exterior Insulation and Finishing Systems (EIFS)), and safety windows. A reinforced core and stairwells provide additional safe haven areas within the building. An independent water service is included.


Figure 16: The new Mercy Hospital, Joplin, Kansas is being constructed to resist high winds.

### Passive Survivability

A critical element of sheltering in place during extended power outages is the potential for loss of mechanical ventilation, air conditioning and humidification or dehumidification functions. Clearly, a focus of residential health care resilience planning should be extending critical conditioning system performance, even if conditioning power is provided through external generator hookup capabilities. At the same time, secondary or redundant passive solutions should be considered for various reasons: unless very large, generators are rarely able to provide air conditioning or general lighting. Increasing attention is on enhancing building envelope design to reduce solar gain or heat loss to extend habitable temperatures for longer periods of time. Passive survivability measures should be carefully considered in conjunction with multiple hazard assessment: some measures may be inappropriate for chemical or bio-terrorism events.

Strategies to extend passive survivability include implementation of building façade design measures ranging from enhanced insulation, roof overhangs, or fixed solar shading devices, to the use of operable windows, which permit enhanced thermal comfort. While operable windows are not generally used in hospitals, they may be appropriate for other residential health care settings, such as nursing homes, rehabilitation facilities, and the like. They may also be included to mitigate overheating in hospital buildings in the event a building remains occupied following total system failure, as a safety measure for patients awaiting evacuation following a catastrophic event. The experience of staff breaking windows in hospitals

## CASE STUDY: Washington State Veterans Home, Retsil, WA

When the Washington State Department of Veterans Affairs began planning for a new skilled nursing facility, residents and staff were actively engaged to define the qualities of the best skilled nursing care environment for veterans. When the project team asked residents to describe their ideal environment, they identified many sustainable design solutions—operable windows, daylight, and access to the outdoors. Recognizing the Sinclair Inlet, with its mild microclimate and sea breezes, as a unique, manageable natural resource, the design features a naturally ventilated cooling solution—there is no mechanical cooling installed in the facility (Guenther & Vittori, 2008; Younger, 2007).

Figure 17: Washington State Veterans' Home orients resident wings to maximize passive cooling and prevailing winds, and includes engineered natural ventilation to replace air conditioning.

following Katrina as indoor temperatures exceeded 100 degrees suggests that window operability in emergencies may be prudent. Spaulding Rehabilitation Hospital, Boston, MA, includes key-operable windows in resident rooms as an enhanced resilience measure, while the Washington State Veterans Home in Retsil, Washington, includes them as a basic design feature.

## Element 3: Infrastructure Protection and Resilience

**Katrina showed that hospitals depend heavily on citywide infrastructure— electrical power, communications, water, security, and transportation—that can be disrupted by an area-wide disaster ... it was the combined loss of essential infrastructure and utilities that put hospitals and their patients into such perilous circumstances. Disaster planning after Katrina for hospitals must incorporate the possible loss of essential infrastructure (Gray & Hebert, 2006).**

Infrastructure protection and resilience is a key element of health care facility operation through extreme weather events. In Hurricane Sandy, the failure of both grid power and emergency generators forced hospital evacuations. While generators were located above flood elevations, critical infrastructure components—fuel pumps, fuel tanks, electrical switchgear—were not. This section examines energy, water, and waste infrastructure, as well as fire protection and communication infrastructure; all of these components are necessary to safely shelter in place during and after an extreme weather event.

### Energy and Utility Infrastructure: power and thermal energy

Particular care must be exercised with energy and utility infrastructure in high wind and flood hazard zones. Utilities include all systems, equipment, and fixtures, including mechanical, electrical, plumbing, heating, ventilating, and air conditioning. Utility systems and equipment are best protected when elevated above the DFE (plus freeboard, if required to account for sea level rise projections). Equipment that is required for emergency functioning during or immediately after an event, such as emergency generators and fuel tanks, should be installed well above the DFE. In some cases, equipment can be located inside protective floodproofed enclosures, although it must be recognized that if flooding exceeds the design level of the enclosure, the equipment may be adversely affected—Bellevue Hospital was evacuated after a fuel pump, protected behind a submarine door for more than 48 hours, failed.

Plumbing conduits, water supply lines, gas lines, and electric cables that must extend below the DFE should be located, anchored, and protected to resist the effects of flooding. At UT Medical Branch, Galveston Island, elevated steam and power lines were severely damaged by wind; in the reconstruction, they were securely buried in a flood- proofed tunnel system. By contrast, the Texas Medical Center, Houston, where wind is less of a threat than severe flooding, has raised its utility infrastructure in secure above grade intra-building walkway structures.

Additional guidance on improving the flood resistance of utility installations in existing buildings is found in FEMA publication #348, Protecting Building Utilities From Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems.

### Energy Efficiency

Energy efficiency measures may be regarded as a first step in resilience planning. The less energy required to operate a health care facility, the longer that facility can remain operational on a given capacity of reserve fossil fuel. Energy efficiency retrofit measures in existing hospitals can routinely save 20-25% of energy demand; in new buildings, high performance systems can reduce the average energy consumption by 40-50% or more below national average (Guenther & Vittori, 2013). Hospitals and other buildings can benchmark their energy performance using EPA's ENERGY STAR Portfolio Manager, a free online tool used by to measure and track energy consumption as well as greenhouse gas emissions. Other free tools and resources, including a health care savings financial analysis calculator, are available (EPA, 2014).

For new buildings, the Targeting 100! research completed by a consortium led by the University of Washington provides guidance for reducing hospital energy intensity by 60% below current average consumption. The ASHRAE Advanced Energy Design Guides include a compendium of strategies for large hospitals, small hospitals and medical office buildings to reduce energy demand by 30 to 50%.

### District Thermal Energy Systems

District energy systems distribute steam, hot water and/or chilled water from a central plant to individual buildings through a network of pipes. The International District Energy Association estimates that there are more than 5,800 district energy systems in the U.S., primarily serving urban downtowns, university or hospital complexes, or military bases (International District Energy Association [IDEA], 2014). By combining many thermal loads, district energy provides economies of scale to effectively implement high efficiency fossil fuel and renewable energy technologies. Large, co-located, multi-owner health care campuses are rapidly coalescing into "medical campuses," often with an independent legal and governance entity as property and operations manager. In this arrangement, individual academic, research, and health care entities are assigning parking, traffic, and site management functions to a larger campus entity. Often, the medical campus includes a district energy system supplying thermal energy and power to the campus, offering load sharing advantages and, potentially, improved reliability. Texas Medical Center is one such an entity.

### Power Reliability and Emergency Power

The vast majority of hospitals rely on municipal utility grids for electrical service, with on-site boiler and chiller plants providing thermal energy needs at either an individual building level or, increasingly, through an on-site free- standing Central Utility Plant (CUP). Hospitals are required to include emergency power generation that activates within 10 seconds of loss of grid power, with sufficient fuel for 96 hours of operation. Emergency power systems are generally comprised of on-site electrical generators, powered by reserves of diesel fuel, and are sized to cover critical medical equipment and building system loads, including, at a minimum, building ventilation (not conditioning), vertical transportation, and key support service requirements. Diesel generator systems are required to be tested monthly, and once every three years under full load conditions for 4 hours.

Historically, the use of on-site backup generators is related to grid reliability; the more reliable the grid, the less generators are used. However, in large urban areas hospital owners increasingly utilize diesel backup generators as a form of peak load reduction during peak electrical demand in hot summer months. Because backup generators are generally seldom used, they can encounter problems in an actual emergency. During the extended Northeast blackout in 2003, nearly half of New York City's 58 hospitals' emergency generator systems encountered reliability problems during the extended use period (Hampson, Bourgeois, Dillingham, & Panzarella, 2013).

As backup generator systems expand in capacity to add air conditioning or cover ever-expanding hospital campuses, the emissions associated with their routine testing and use during peak loads may approach EPA allowable limits under the Clean Air Act. Diesel generators are noisy; the testing and use in or near residential neighborhoods is at best a nuisance, at worst a health hazard. Hence, hospitals have begun to search for more reliable normal and extended emergency power generation solutions.

### Combined Heat and Power (CHP)

As the scale of medical campuses increases, hospital requirements for more reliable on-site electrical generating systems have increased; many are investing in grid-connected combined heat and power systems (CHP) to generate power on-site and reduce reliance on municipal grid infrastructure. The Veterans Administration, for example, installs campus CHP on all new VA medical center campuses. While these systems require a longer time to safely shut down, disconnect from municipal grid infrastructure, and safely resume in island mode—10 minutes or more—their more reliable uninterrupted operation through extended periods of grid disruption is proving to be beneficial for long-range resilience. In some areas of the country, utility regulations restrict their application in emergency situations. Technical challenges inherent in 10-second power resumption means that these systems still require diesel generator supplemental power, even if only for the switchover period.

CHP systems are a highly efficient form of distributed generation, typically designed to power a single large

## CASE STUDY: Greenwich Hospital, Greenwich, CT

The Greenwich Hospital is a 175-bed, 500,000 square foot ENERGY STAR certified (2011, 2010) medical center located in Greenwich, CT. Its CHP system, installed in 2008, consists of two 1,250 kW natural gas-fired reciprocating engines. The hospital also has a 2,000 kW backup generator. The system typically runs 24 hours a day, 7 days a week, except for routine maintenance. The hospital uses the thermal output of the system for hot water and space heating. The hospital also participates in a demand response program with EnerNOC, which calls on the hospital to go off the grid for stabilization purposes if the grid is in danger of an outage. The hospital is compensated at a rate of $30/kW when called upon to disconnect from the grid. This provides another financial revenue stream from the CHP system, beyond the energy operating savings.

The area surrounding Greenwich Hospital lost power due to Superstorm Sandy for approximately 7 days. When the hospital lost grid power, it went down for about 7 seconds before the backup generators kicked in and power was restored. The transition from using grid power to operating solely on the CHP system went as planned, with the CHP system shutting down and restarting in island mode, while power was supplied to the hospital by backup generators. The whole transition process took approximately 5 minutes. Due to its CHP system, Greenwich Hospital was able to continue normal operations throughout the storm. The hospital admitted 20 additional patients during the outage period, raising the patient count from 136 to 156. In addition, 150 extra staff stayed overnight to ensure the hospital remained fully functioning (ORNL, 2013).

Figure 18: The Greenwich Hospital's on-site combined heat and power system operated without incident throughout the 7-day loss of utility services following Superstorm Sandy.

building, campus, or group of facilities. In the context of critical infrastructure applications, these CHP systems are comprised of on-site electrical generators (primarily fueled with natural gas) that achieve high efficiency by capturing heat, a byproduct of electricity production that would otherwise be wasted. The captured heat can be used to provide steam or hot water to the facility for space heating, cooling, or other processes. Capturing and using the waste heat allows CHP systems to reach fuel efficiencies of up to 80%, compared with about 45% for conventional separate heat and power. This is both environmentally and economically advantageous. CHP systems can use the existing, centralized electricity grid as a backup source to meet peak electricity needs and provide power when the CHP system is down for maintenance or in an emergency outage.

If the electricity grid is impaired, the CHP system continues to operate in “island mode,” ensuring an uninterrupted supply of electricity to the host facility, dependent upon an uninterrupted power supply. During and after Superstorm Sandy, combined heat and power (CHP) enabled a number of critical infrastructure and other facilities to continue their operations when the electric grid went down (see Greenwich Hospital Case Study below). Oak Ridge National Laboratory reports:

**“In general, a CHP system that runs consistently throughout the year is more reliable in an emergency than a backup generator system that only runs during emergencies. Because it is relied upon daily for needed energy services, a CHP system is also more likely to be properly maintained, operated by trained staff, and to have a steady supply of fuel” (Hampson, Bourgeois, Dillingham & Panzarella, 2013).**

For many hospital owners, this shift to CHP is significantly contributing to greenhouse gas reduction and is a cornerstone of voluntary climate commitments. Partners HealthCare, for example, is implementing CHP its 11-hospital system by 2020 as part of its strategy to meet the initial 50% GHG reduction target mandated by the Massachusetts Global Warming Solutions Act (Guenther & Vittori, 2013). The damage caused by hurricanes along the Texas and Louisiana Gulf Coast in the past several years have propelled the adoption of critical infrastructure policies in these two states. Additionally, due in part to the Northeast blackout in 2003, storm events, security threats, and other concerns, New York State has also been a strong proponent of CHP at critical infrastructure facilities.

Additional guidance on CHP can be found in the U.S. Department of Energy and EPA Guide to Using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings and Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities, by ICF International, prepared for Oak Ridge National Laboratory (Hampson, Bourgeois, Dillingham & Panzarella, 2013). Health Care Without Harm has teamed with the Boston Green Ribbon Commission to publish Powering the Future of Health Care: Financial and operational Resilience—Combined Heat and Power Guide for Massachusetts Hospital Decision Makers (Benden, Veilleux et.al., 2013).

## Renewable Energy

On-site renewable energy systems provide enhanced resilience. Many U.S. hospitals are installing wind or solar energy systems for both thermal energy (domestic hot water heating) and electric power generation. To date, the performance of renewable energy systems in extreme weather events has been good, with limited damage to such systems from high winds or flooding. Some hospitals have benefitted from Power Purchase Agreement (PPA) installations on parking lots and roofs. Third party power providers who continue to own the equipment fund these arrangements; hospitals provide the site and purchase the power.

The Department of Energy National Renewable Energy Lab (NREL) provides technical guidance and resources for renewable energy applications in health care settings. The Renewable Resource Data Center (RReDC) provides access to an extensive collection of renewable energy resource data, maps, and tools. NREL’s energy disaster recovery program offers a broad range of services, including whole-community energy planning, on-site technical assistance, energy-efficient design and rebuilding strategies. It assisted Greensburg, KN, and Kiowa County Memorial Hospital in the rebuilding of a clean energy community.

Gundersen Health System (Wisconsin, Minnesota, Iowa) was the first U.S. health system to target (2008) and reach energy independence (2014).

The system, consisting of more than 60 locations, offset its energy consumption through a diverse, locally sourced, portfolio of projects. They include: four wind turbines, two dairy digester projects, a landfill gas to energy project, a bio-mass boiler, geothermal wells, and solar projects (Gundersen Health System, 2014; Guenther & Vittori, 2013).

### Water Use and Supply

Consistent access to a reliable potable water supply is another key element of resilience. The Joint Commission requires hospitals to address the provision of water as part of their Emergency Operations Plan (EOP), but does not require a specific reserve capacity. The Center for Medicare and Medicaid Services (CMS) Conditions for Participation/Conditions for Coverage (42 CFR 482.41) also requires that health care facilities make provisions in their preparedness plans for situations in which water supply interruptions may occur. There is, however, no standard for the quantity of reserve or back-up water that is required; it varies by state and region. The *Emergency Water Supply Planning Guide for Hospitals and Health Care Facilities* (see sidebar on right) can assist hospitals in planning for a disruption of water; it suggests that health care facilities maintain enough water for 8 hours of emergency distribution. The state of California requires hospitals to keep a minimum of 96 hours of potable water available should the municipal water supply fail in a seismic event. Hospitals that plan for alternative supplies use a storage tank, a large supply of bottled water, or a combination of these approaches. Other hospitals and long-term care facilities have independent, secondary wells capable of supplying building needs if the municipal supply is compromised.

Water supply interruptions can result from water main breaks (extreme cold or age) or flooding or high wind damage to municipal water infrastructure. In other instances, water pump failures (due to flooding or lack of power) can compromise water availability in upper floors of buildings. A water main break in Boston in May 2010 interrupted water supply to Boston's hospitals, some of which succeeded in rerouting pipes for alternate sourcing while others survived on bottled water. Scott Lillibridge, professor of epidemiology at Texas A&M University, north of Galveston, notes how close the hospitals of Houston came to collapse in the aftermath of Hurricane Ike, when the storm disabled the city's water pumping systems: "The lack of water pressure to hospitals in Houston in the immediate post-disaster period almost resulted in one of the largest patient evacuations in history. Without water for toilets, laundry and food service, the hospitals were down to their last 24 hours of patient services." There was not sufficient bed capacity in the entire state to receive evacuees from Texas Medical Center (World Health Organization, 2009).

Some examples of hospital water supply interruptions at health care facilities (CDC 2011):

- A hospital in Florida lost water service for 5 hours due to a nearby water main break.
- A hospital in Nevada lost water service for 12 hours because of a break in its main supply line.
- A hospital in West Virginia lost service for 12 hours and 30 hours during two separate incidents because of nearby water main breaks.
- A hospital in Mississippi lost service for 18 hours as a result of Hurricane Katrina.
- A hospital in Texas lost water service for 48 hours due to an ice storm that caused a citywide power outage that included the water treatment plant.
- A nursing home in Florida lost its water service for more than 48 hours as a result of Hurricane Ivan.

**The Centers for Disease Control and Prevention and American Water Works Association have an Emergency Water Supply Planning Guide for Hospitals and Healthcare Facilities to assist health care facilities in meeting requirements of EOP's required by CMS and Joint Commission, estimating water demands, and preparing options for meeting demands during extended supply interruptions. The CDC, NOAA and EPA have a resource for public health professionals preparing for drought: When Every Drop Counts: Protecting Public Health During Drought Conditions.**

One of the key challenges with fixed quantity emergency water supplies is accurately estimating demand—clearly, the lower the potable water demand, the longer a given supply of water will last. Many hospitals and nursing homes have not historically tracked water usage; there are few reliable benchmarks for water consumption. ENERGY STAR and EPA WaterSense programs show that only 2% of program participants are hospitals and 2% are medical office buildings. However, hospitals demonstrate the widest range of water use intensity, from negligible use to more than 150 gallons per square foot per year (EPA, 2012). The American Society of Plumbing Engineers' (ASPE's) out-of-print publication, *High-Rise Plumbing Design* by Alfred Steele, P.E., CIPE, estimates the minimum hourly flow rate of domestic water for a hospital to be 3 gallons per bed, per hour, with an average daily consumption estimated between 235 and 300 gallons per bed, excluding HVAC systems (Salfarlie, 2012). At the same time, because health care organizations generally view probability of water supply interruption as a low risk, supplies may be undersized for actual demand. Water supply resilience is improved through a range of measures: water conservation, on-site water capture, and reclaimed water reuse systems.

### Water Conservation

The prospect of long-range drought and potable water stress due to changes in rainfall patterns in many regions are leading municipalities to enact stricter water use policies. Water conservation has been a focus of health care sustainable design; Providence St. Peter Medical Center in Olympia, WA reports a reduction of 60% in potable water use over a 10-year period based on a steady program of fixture and equipment retrofits (Guenther & Vittori, 2013).

Water conservation measures, such as low flow fixtures, reduce potable water demand in sanitary fixtures by as much as 40%. Cooling towers for air conditioning systems can consume as much as 50% of the total potable water demand; increasingly, hospitals and nursing homes are shifting to non-potable water sources for such process uses, including captured condensate from air handling units, municipal reclaimed water, and rainwater harvesting.

### Independent Water Services

In order to meet the requirement for adequate water during municipal disruptions, hospitals and nursing homes may install independent well water services. Many hospitals in Florida have independent wells, given the high water demand associated with cooling towers and air conditioning systems during emergency conditions. The Wisconsin Hospital Emergency Preparedness Program provided a multi-phase funding opportunity to allow hospitals to develop on-site wells for use during water emergencies. A total of 13 hospitals completed the installation (UMN, 2014). Kiowa County Memorial Hospital and Mercy Hospital, Joplin have a second independent well water service; the municipal infrastructure was destroyed in a tornado. In fact, the Missouri Hospital Association, noting that its health care infrastructure was largely unprepared for the myriad of weather disasters that have struck in recent years—blizzards, floods, tornadoes— states: “Hospitals should not depend on utilities and should consider redundant systems and partnership for water and power sources” (MHA, 2012).

At the same time, independent water services may have reliability and quality challenges. Although drought most commonly is defined climatologically, water supply emergencies or drought can also be exacerbated by human activities. For example, even when precipitation is occurring at average rates within a specific area, urban expansion and development without regard to existing water supply and water system capacity can trigger a human-induced drought. For surface water to be harvested for potable consumption, it must be treated to satisfy federal drinking water standards. In many areas of the U.S. concerned with long-range drought, parallel non-potable water distribution systems are being installed to enable the collection and redistribution of reclaimed or recycled “graywater.” Alternative methods for using rainwater also are being developed. For example, buildings are increasingly being engineered with the capability to collect and use rainwater for nonpotable applications (such as for flushing toilets and landscape irrigation).

Extreme weather events may compromise local water supply quality; if contamination is a risk, fixed potable water storage may be the best option. One of the key resilience benefits of independent water service (rather than storage of a fixed water supply) is the potential ability for hospitals to provide clean water to the larger community in the days following a disaster. Access to potable water is a key element of community resilience. After Katrina, citizens were unable to access reliable sources. Hospitals, more than any other critical building type, should place a high priority on developing independent, high-quality reliable secondary water supplies.

### Reclaimed Water Reuse and Rainwater Capture

Municipalities in drought-prone regions are installing large-scale municipal reclaimed water systems to meet the process (non-potable) water needs of their communities. In hospitals, process demands may aggregate to as much as 70% of total water use; finding reliable alternative sources of water is a key element of enhanced resilience in a future with stressed potable water supplies. Captured condensate (the water generated from dehumidification processes in air handling units) is becoming an on-site process water resource in more humid regions of the country. University Health System, San Antonio, uses the municipal reclaimed water system for cooling tower make-up water. Rush University Medical Center, Chicago, uses a combination of captured rainwater and condensate, providing an added measure of reliability should the municipal system be disrupted.

The capturing of on-site rainwater as a resource is regulated on both a state and local level. Hospitals and medical facilities are beginning to employ rainwater catchment systems to provide water for irrigation, cooling towers, and other process loads. Southeast Louisiana Veterans Health Care Center in New Orleans has a 1 million gallon rainwater cistern to capture rainwater for cooling and process uses. At Kiowa County Memorial Hospital in Greensburg, KS, captured rainwater is used to flush toilets. These solutions significantly boost the performance of the hospital when municipal potable water sources are compromised.

## CASE STUDY: Kiowa County Memorial Hospital, Greensburg, KS

On May 4, 2007, an EF-5 tornado estimated to be 1.7 miles wide with 205 mph winds struck the city of Greensburg and Kiowa County, Kansas. Damage to Greensburg was significant, with over 90% of the structures in the community severely damaged or destroyed. FEMA activated the Long-Term Community Recovery (LTCR) program, which integrated assistance from the State of Kansas and federal agencies focused on the community's long-term recovery goals. The program provided coordination of resources and planning services in support of the area's recovery effort; one of the key elements was a community planning process that focused on and produced a long-term community recovery plan (FEMA, 2009) to guide more resilient and climate-adapted redevelopment.

With technical assistance from the Department of Energy and the National Renewable Energy Lab, the town converted from fossil fuel electrical generation to 100% wind-generated power. The Greensburg Wind Farm consists of 10 1.25 megawatt (MW) wind turbines that supply 12.5 MW of renewable power to the town. That's enough energy to power every house, business, and municipal building in Greensburg and sell power to other Kansas municipalities. John Deere Renewable Energy built the wind farm and maintains the project (the Deere dealership was destroyed in the tornado; this was Deere's entry into the renewable energy market). All Greensburg buildings are constructed to meet LEED Platinum certification criteria; while the town initially made an exception for the hospital, hospital leadership accepted the challenge to deliver a LEED Platinum replacement building.

According to Mary Sweet, Administrator:

"The tornado not only destroyed our community and hospital—it caused a major shift in how we make decisions. In rebuilding, we learned not to look at the initial cost only, but to look at environmental impact, long term cost savings, and sustainable and renewable resources."

In addition to becoming the first U.S. hospital to operate with 100% renewable (carbon neutral) energy in 2011, it incorporates rainwater harvesting and advanced water conservation strategies.

The replacement Kiowa County Hospital is the first Critical Access hospital to achieve U.S. Green Building Council LEED-Platinum designation, and the second hospital in the U.S. to earn this award. According to energy analysis modeling results, the new hospital is 32% more energy efficient than an ASHRAE-compliant building of the same size and shape. Many of the efficiency measures included in the hospital were incorporated into the Advanced Energy *Design Guide for Small Hospitals and Health Care Facilities*, an energy efficiency guide developed by DOE/NREL in collaboration with national professional societies, and a pivotal market tool for designing small low- energy health care buildings. It includes a 50 kW on-site wind turbine to provide approximately 40% of its total electrical load (or 100% of its base load) and uses the Greensburg wind farm to supply the balance. It has limited on-site combustion of fossil fuel (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2010; FEMA, 2009; Guenther & Vittori, 2013).

Figure 19: The wind turbine at Kiowa County Memorial Hospital serves as a reminder of the commitment to clean energy sources and enhanced resilience.

### Sewage/Wastewater

In flood situations, all plumbing fixtures connected to the potable water system may become weak points in the system if they allow floodwaters to contaminate the system. Fixtures below the DFE should be isolated from those above DFE. Wastewater system components become sources of contamination during floods. Rising floodwaters may force untreated sewage to back up through toilets or floor drains. Specially designed devices that prevent backflow can be installed, or restrooms below the DFE can be provided with overhead piping that may require specially designed pumps to operate properly. One of the key code measures enacted by New York City following Superstorm Sandy is a requirement for backflow prevention on sewer lines in all existing and new buildings.

On-site wastewater treatment facilities provide an added measure of resilience. To date, the only U.S. health care facility to employ this technology remains the Oregon Health and Sciences University Center for Health and Healing in Portland, OR, which uses an on-site anaerobic system to treat sewage and recirculates conveyance water for toilet flushing in a closed loop.

## Element 4: Protect Vital Clinical Care Facilities and Functions

**"We expect prompt medical attention for an injury or medical problem. This is even more important during Mass Emergencies that require care for large numbers of casualties. If hospital operations are disrupted or disabled the adverse effect of such disasters are quickly compounded with catastrophic results" (FEMA, 2011).**

## CASE STUDY: Oregon Health and Sciences University Center for Health and Healing, Portland, OR

The city of Portland, like many older U.S. cities, has an overburdened sewer infrastructure, so this LEED Platinum- certified project, which opened in 2006, included on-site sewage treatment, with treated effluent used for toilet flushing and irrigation. The building includes a complex stack of ambulatory medical uses, including wellness, fitness, and physical therapy facilities, plus a conference center on the lower floors; outpatient clinics, imaging, and ambulatory surgery on the middle floors; and offices and laboratories on top.

100% of the rainwater is harvested and used for irrigation, sewage treatment makeup water, and other process uses. The center has four separate water systems, including a blackwater system that feeds a non-potable water supply, a conventional potable water system, and rainwater collection system that feeds the fire water cistern as well as the mechanical system. One of the center's major documented impacts for subsequent LEED Existing Building Operation and Maintenance (EBOM) certification includes saving more than 5 million gallons of drinkable water annually through these aggressive water strategies. (Portland Office of Sustainable Development, 2014; Guenther & Vittori, 2013)

Figure 20: The Oregon Health and Sciences University Center for Health and Healing uses four separate water systems to reduce reliance on both the municipal potable water system and sewage treatment system. It captures, treats, and recycles the building sewage conveyance water using an on-site bio-reactor system.

During emergencies, health care facilities are responsible for more than sheltering residents in place—they are often called upon to deliver medical services to large numbers of injured people. It is imperative that hospitals maintain not only operational infrastructure services, but also vital medical care delivery services. Certainly, recent extreme weather events have demonstrated that ground floor emergency departments in flood-prone areas cannot provide reliable care; likewise, expensive and necessary diagnostic imaging equipment (often located on ground floors due to weight and need for proximity to the ED) may also be destroyed or rendered unusable.

Even if vital mechanical and electrical infrastructure is out of harm's way, medical care delivery—from submerged departments to corridors connecting egress and transfer pathways—can be severely hampered. Surges of patients often follow weather disasters. Tornado survivors in Joplin flooded the one small emergency department that remained open. In wildfires, hospital emergency departments near the fire must remain operational to treat firefighters and affected community residents.

Hospitals must also prepare and stockpile supplies—more supplies than their "just in time" system inventories anticipate—to remain operational through extended transportation and supply chain disruption. Just as critical, hospitals require health care workers from medical professionals to environmental services workers to deliver both direct patient care and necessary support services, such as meal preparation and laundry. In extreme weather events, hospitals must house large numbers of workers, their families and even their pets, in order to continue to deliver high-quality, uninterrupted care while cut off from transportation systems and re-supply infrastructure.

To address these multiple needs, hospitals in flood-prone regions are being planned and designed "upside-down" with critical infrastructure on rooftops and electromechanical distribution systems fed from the roof downward. This section examines the organization of programs and buildings for uninterrupted health care service delivery and surge management through extreme weather events.

### Locations of Critical Programs: EDs, Imaging

There has been a significant shift in the planning for hospitals in flood-prone regions based upon the lessons learned in repeated Florida and Gulf Coast hurricanes. These lessons are moving up the east coast: Spaulding Rehabilitation Hospital, Boston, for example, has no vital medical or resident services on the ground level; all required medical care delivery is well above the 500-year flood level.

Emergency departments (EDs) present particular challenges. Generally, these are located at grade to facilitate ambulance and public access. However, in flood-prone areas, this often places EDs below design flood elevation (DFE) and at risk. Many hospitals have effectively lost use of their EDs and related imaging areas both during and for extended periods following extreme weather events. In coastal areas prone to repeated surge and inundation, hospitals are moving their EDs to higher floors and constructing vehicular and ambulance ramps for normal operation. This has an additional resilience benefit: during high water periods, the ramps facilitate boat mooring to deliver

## CASE STUDY: Tampa General Hospital, Tampa, FL

Tampa General Hospital's emergency department (ED) facilitates disaster response in adverse weather events, such as hurricanes and flooding. The ED is located on the second floor; it includes a vehicle ramp for ambulances and a dedicated elevator for visitors and walk-in patients from the ground level. To accommodate patient surge, additional locked medical gas cabinets are located throughout the ED in waiting areas, conference rooms, and administrative areas. In the case of a major event, the adjacent parking garage is designed to quickly become a triage area (Bosch, 2013).

Figure 21: Tampa General Hospital's emergency department is on the second floor, well above the flood surge and inundation level. The vehicular ramp is shown here.

patients, staff, and emergency supplies. Both Tampa General Hospital, Tampa, FL and Southeast Louisiana Veterans Health Care Center, New Orleans, LA are examples of this programmatic shift.

### Evacuation Routes: Heliports and Building Connectivity

During Katrina, continued high water prohibited at-grade evacuation of medical facilities; many New Orleans hospitals had grade-level helipads. There was limited ability to accommodate boats. Staff at Tulane Medical Center removed light fixtures from the parking garage roof to improvise a heliport when they could not access the ground level facility due to flooding, then had to improvise a safe transport route for patients. In Manhattan, hospitals are prohibited from installing rooftop heliports. The only viable evacuation route during Sandy was at grade once water subsided. Clearly, it is important that hospitals have redundancy in their evacuation routes to avoid entrapment.

The Federal Aviation Administration, Department of Transportation, and many insurance underwriters and industry safety organizations recommend that all hospitals construct a permanent, certified heliport landing area on their property for safety. The decision to place heliports on roof areas versus the ground should include consideration of flooding vulnerabilities. Heliports require fuel storage, which poses added risk on rooftop areas.

In the aftermath of tornadoes and high wind events, debris (including parts of the hospital building) strewn around the exterior of hospital properties can make roadways and pedestrian routes between buildings dangerous or impassable, which can severely hinder both ongoing shelter-in-place activities or evacuation processes. Understanding the risks, and developing strategies to minimize them, is a key element of resilience planning.

Safe paths of travel between buildings are a key element of successful management during and after extreme weather events. Many hospital campuses, such as the Texas Medical Center use underground tunnels as their primary form of pedestrian and utility connectivity. Since the 2001 flood event, Texas Medical Center has constructed a replacement building connection system for pedestrians, service and utilities at the second floor. Tampa General, as noted above, located its ED convenient to the parking garage area designated for patient surge to facilitate improved management in mass casualty emergencies.

Figure 22: Debris outside the Joplin Hospital Emergency Department, following the EF-5 tornado, complicated evacuation procedures.

### Personnel Accommodation, Supplies, and Patient Surge

Hospitals, long-term care, rehabilitation facilities—in short, all residential health care facilities—require round-the- clock staffing to remain in operation. Front-line health care workers include both clinical care staff—doctors and nurses—as well as aides and diagnostic technicians, food service and environmental services personnel, administrators and engineers required to ensure that safe, quality patient care continues uninterrupted. In addition to full or part-time employees, there are often large numbers of contract consultants. Extreme weather events, like many types of emergencies, cause transportation disruptions and can result in significant restrictions on travel, ranging from high-occupancy restrictions on bridges to fuel rationing. In many instances, restrictions extend to “essential personnel” only, and emergency preparedness plans have often neglected to include non-clinical personnel in this category – which further exacerbates staffing shortages. Emerging electronic ID systems, downloadable to smartphones, are promising to improve this situation substantially, and will allow critical facilities, such as hospitals and nursing homes, to determine a broader group of personnel to classify as “essential workers” in emergency circumstances.

For shelter-in-place, critical personnel may be required to remain on-site during and after events. This can create an extremely stressful situation if immediate family members are left to fend for themselves at home. When communication systems are disrupted, as they often are, the stress level among personnel can reach a critical level. In addition, personnel are often required to take on essential roles that are beyond their general job description, and can be placed in harm’s way. Hence, it is critical to engage front-line workers in planning in order to understand the organizational vulnerabilities (as described in Part 2) that extreme weather events may reveal, and to prepare and equip personnel for such circumstances.

Hospitals are increasingly preparing to house substantial numbers of personnel, with families and their pets, during and following extreme weather events. This can mean securing nearby hotels, consolidating patients in order to use unoccupied patient care units for staff, or repurposing on-call, office, and conference areas for staff accommodation. If there is significant patient surge, options for personnel space may become severely limited.

In an era of "just-in-time" deliveries and limited on-site inventory, severe weather events can disrupt patient care if sufficient supplies are not secured prior to the event. For advance notice events, facilities that intend to shelter in place must secure sufficient food and supply inventories to operate for extended (and difficult to predict) durations. Organizing and storing these supplies in accessible location(s) out of harm's way can present space challenges, and stockpiles of supplies can expand beyond core medical items to include items that personnel and their families may need during the recovery period, such as batteries and firewood. Hospital systems that provide consolidated warehousing of medical supplies may have some advantages, but should carefully consider the potential for constrained access to affected hospital sites when planning for centralized warehousing. Hospitals often convert administrative areas, conference rooms, and other areas for emergency supply storage in order to address the vulnerability of flood-prone storage areas or the need for longer-term inventory.

## CASE STUDY: Community Medical Center, Barnabas Health, Toms River, NJ

Community Medical Center, Toms River is located 50 miles north of where Superstorm Sandy made landfall, 8 miles from the Atlantic Ocean. While the 592-bed facility was safe from direct storm impacts, the administration realized that more than 65% of their physicians and employees lived in areas that were likely to be severely impacted—low-lying coastal communities and barrier islands that could have significant infrastructure and transportation disruptions—and 30% were in mandatory or recommended evacuation zones.

Because of the advance warning, the hospital prepared. Supply deliveries, including non-perishable food items, ice and water, were increased. Cots were deployed; an "employee concierge" was assigned. Rooms at a nearby hotel were secured. The cafeteria was converted to male/female sleeping areas. Prior to the storm, approximately 300 essential staff, their families, and pets were relocated to the facility. Laundry facilities (3 sets of washers and dryers) and an internet café were installed in the hospital within a week of the storm for staff use for the extended post- storm recovery period.

During the storm, the hospital lost normal power for close to 48 hours, and generators deployed. The hospital treated a large influx of patients with minor injuries, the "worried well" in need of temporary shelter, and patients with special needs (asthmatics, dialysis, particular medications). Close to 5,000 meals were prepared and served each day in the 8 days following the storm; in addition, catered dinners were provided for staff and families. They distributed ice, flashlights, batteries, and firewood to employees that remained in their nearby homes without power. In total, 130 employees lost homes or had homes that were not habitable following the storm, while many others lost cars, clothing or personal belongings. Some lessons learned: staff shower hot water systems should be on emergency power, as should outlets in office and cafeteria areas that may be used as housing in surge situations (Bryant, 2013)

Figure 23: This washed out bridge along the New Jersey shore following Superstorm Sandy demonstrates how vulnerable residential shoreline communities can become disconnected from transportation infrastructure; if large numbers of medical personnel live in such communities, hospitals and long term care facilities must plan to relocate those staff prior to major storm events.

## CASE STUDY: Southeast Louisiana Veterans Health Care Center (SLVHCS), New Orleans, LA

This 1,700,000 square foot replacement campus for the VA Hospital and Charity Hospital, both closed following Katrina, incorporates a comprehensive set of resilience strategies unique to the challenges of post-Katrina New Orleans. A 7-day "defend in place" capability applies the lessons learned from Hurricane Katrina to create a resilient hospital infrastructure. The facility can remain fully operational without outside support during a disaster, with enough provisions and accommodations for up to 1,000 staff and patients.

Its floor elevation and critical functions are designed to survive a future levee failure. All mission-critical mechanical and electrical infrastructure is located on upper levels, while required program components, such as the emergency department and patient beds, are placed at least 20 feet above the established BFE. Ambulances use a dedicated ramp to reach the facility (it can double as a boat launch). The kitchen is on floor 4, while the cafeteria, deemed to be less critical, is on the ground floor—food travels in a dedicated elevator during normal operation. Travel from building to building can be accomplished entirely indoors at elevations well above the BFE.

The facilities energy plant stores 320,000 gallons of fuel, enough for a full week, and can collect and store over a million gallons of rainwater on-site to reduce use of city water for cooling systems and other uses during normal operation and provide needed water if the city supply is disrupted or unavailable. There is also a 6,000-square foot warehouse on-site to store emergency supplies. The building enclosure and windows are designed to survive at least Category 3 hurricane winds. The building contains an on-site sewage treatment system capable of processing and holding waste for five to seven days. The parking structure roof serves as a heliport, capable of supporting Black Hawk helicopters in an evacuation (Healthcare Construction + Operations News, 2012).

Figure 24: The new Southeast Louisiana Veterans Health Care Center (SLVHCS) features a range of enhanced resilience and infrastructure planning measures. The building is designed to operate for a minimum of seven days, even if all of New Orleans's utility and infrastructure services are lost.

## Element 5: Environmental Protection and Strengthening of Ecosystems

Healthy ecosystems support life and health. The United Nations Millennium Ecosystem Assessment (Corvalan, Hales, & McMichael, 2005) established that "ecosystems are critical to human well-being—to our health, our prosperity, our security, and to our social and cultural identity." ***Ecosystem services*** are goods and services of direct or indirect benefit to humans that are produced by ecosystem processes involving the interaction of living elements, such as vegetation and soil organisms, and non-living elements, such as bedrock, water, and air.

This section is a review of how certain conventional, accepted land practices affect the interrelated operations of functioning ecosystems, followed by a description of the benefits of adopting sustainable practices. The following elements of ecosystem services should be supported:

- **Treating water as a resource:** Eliminate unnecessary irrigation and harvest rainwater.
- **Valuing soils:** Improve infiltration, reduce runoff, and filter stormwater.
- **Preserving and enhancing vegetative cover and open space:** Maintain wildlife corridors, habitat, wetlands, and reduce the development footprint.

The New York City Green Infrastructure Plan (2010) presents approaches to improving water quality on-site through green infrastructure strategies. The U.S. EPA has a Green Infrastructure website with tools and resources for building owners.

### Treating Water as a resource: eliminate unnecessary irrigation and harvest rainwater

Water cycles through Earth's atmosphere, oceans, land, and biosphere; shaping weather and climate, supporting plant growth, and enabling life. On a well-vegetated site with healthy, open soils, rainwater is absorbed and transpired by vegetation, or soaks into the soil and is filtered as it re-enters underground aquifers. In developed areas, rainwater runs off into storm sewers, and is lost to the natural cycles. Landscapes have evolved to be irrigation intensive, requiring massive amounts of water to be sustained (as much as 5% of a hospital's water budget is used by landscape). Insofar as climate change is expected to impact rainfall, leading to less frequent, more intensive rainfall events, it becomes more important to view water as a resource: harvesting rainwater and holding back stormwater discharge. Separate metering and controls of irrigation system water allow health care facilities to suspend irrigation water use (both potable and non-potable) during drought emergencies.

### Valuing Soils: improve infiltration, reduce runoff, and filter stormwater

One of the key elements of sustainable land use planning is a reversal in approach to stormwater management. Historically, stormwater has been treated as a nuisance, with both municipal and on-site infrastructure focused on getting rid of it as quickly as possible. In many cities and towns, older stormwater systems are combined with sewer systems, leading to significant overflows of both in extreme rainfall events or flooding. There has been limited attention paid to the issue of impervious surfaces (parking, walks and roadways) and the impact to duration of extreme rainfall events. If water cannot soak into the ground, it moves deeper inland or into basements and occupied areas.

Rather than getting rid of stormwater as quickly as possible, a sustainable approach to stormwater management involves finding ways to harvest it on site and use it for irrigation, ornamental water features, and groundwater recharge. Green roof (vegetated roofs) and blue roof (stormwater retention) technologies in urban areas reduce the volume of stormwater flow during extreme rainfall events. Permeable or pervious paving, reduced paved areas, constructed wetlands and management of natural bio-swales and stormwater catchment systems that recharge groundwater are also important mitigation techniques that can be implemented at an individual site level. Technology exists to integrate systems that mimic nature's capacity to store, filter, and clean water. This is particularly important for health care facilities that rely on well water as either a primary or backup potable water source.

The Energy Independence and Security Act of 2007 (EISA) instructs federal agencies to "use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the p*redevelopment hydrology* of the property with regard to the temperature, rate … " for any project with a footprint that exceeds 5,000 square feet. For additional guidance and resources on Integrated Stormwater Management practices, see the EPA Stormwater Management Best Practices website at *http://www.epa.gov/oaintrnt/stormwater/best_practices.htm*.

Key best practices of sustainable stormwater management include:

- Protecting and restoring existing hydrologic functions through planting native or appropriate non-native vegetation, re-grading soils where necessary, and restoring the functions of floodplains, and riparian and wetland buffers
- Managing stormwater on site by reducing impervious surfaces, harvesting rainwater, and directing remaining stormwater runoff to soil and vegetation-based water treatment methods, such as rain gardens, bio-swales, wetlands, and green roofs (groundwater recharge is becoming increasingly important in aquifer-dependent regions of the country)
- Using stormwater for beneficial purposes (e.g., collecting it for irrigation and other non-potable uses)

Figure 25: These bioswales at Kiowa County Memorial Hospital filter stormwater and support the Ogalalla Aquifer recharge. Rooftop rainwater is collected for irrigation and toilet flushing.

### Preserving vegetative cover and open space: maintain wildlife corridors, habitat, and reduce development footprint

The continued urbanization and disruption of natural systems, particularly in urban areas and coastal and riverine floodplains, intensifies the damage from extreme weather events. Urban heat island impacts intensify health impacts from heat waves; impervious surfaces amplify surge and inundation impacts. As communities have in-filled wetlands and developed former floodplains, the damage from extreme weather events has increased. It is important to preserve vegetative cover and open space.

The City of Chicago, which has experienced extreme heat waves since 1995, has an aggressive program to reduce urban heat island impacts. The City mapped Chicago's hottest spots and is targeting its cooling and energy efficiency efforts, such as the cool roofs and green roof grant programs, to those areas. In addition, the City overlaid a map of 311 and 911 calls regarding heat-related emergencies to assess the correlation between urban heat islands and heat stress-related issues. During the past 15 years, Chicago planted more than 500,000 trees and achieved a City-wide tree count of 4.1 million trees. The City plans to plant approximately 1 million new trees by 2020. They are replacing 1,900 miles of paved alleyways with permeable paving to infiltrate stormwater and allow the alleyways to be part of a night cooling system (City of Chicago, 2014).

More than a decade ago, it was recognized that, at least in highly developed regions, the vast majority of easily developable sites were developed. *Architectural Record* magazine offered the precautionary observation that future development would occur on sites that had, generations earlier, been pronounced "undevelopable" and would bear additional costs and risks. In Katrina, the historic French Quarter of New Orleans—the originally developed "high ground"—did not flood. Instead, more recently developed, low-lying communities bore the majority of the damage.

In the coming decades, it will become increasingly essential to evaluate sites and their ecosystem services contributions, and tailor development decisions to prudent investment choices. From understanding and supporting underlying site hydrology to important wildlife corridors, protecting and restoring underlying ecosystem services as a tool to enhance resilience is emerging as an important consideration.

## CASE STUDY: Texas Medical Center, Houston, Texas

In 2001, Tropical Storm Allison inflicted historic 1000-year flooding on downtown Houston, Texas—more than 80 miles inland from the coast. Categorized as the costliest tropical storm in U.S. history, Allison parked itself over southeast Texas from June 5-9, 2001, dumping more than 3 feet of rain (almost 30 in. of which fell over a 48-hr period) on the Houston metro area. The storm statistics are startling: Allison left 22 dead and caused almost $5 billion in damage to Harris County alone.

Texas Medical Center, a 700+ acre complex of 13 hospitals, two specialty institutions, two medical schools, four nursing schools, and schools in various health-related professions, was virtually shut down as a result of flooded infrastructure: emergency generators, electrical switchgear, and boiler and chiller plants all sustained damage. About 30,000 research animals, housed in the basement of Baylor College of Medicine, drowned. Researchers saw years worth of work wiped out, including lab animals, computer data, lost records, and tissue samples.

The following systems were not operational after the storm: electrical power, emergency electrical power, HVAC, laboratory and fume hood exhaust systems, domestic cold and hot water, compressed air and vacuum systems, fire detection and suppression systems, and basement sanitary and storm sewer systems. Basements, which were interconnected among the 100 buildings, contained the incoming service from Houston Light and Power (5kV) as well as several unit substations along with motor control centers, distribution panels, and transformers.

After the flood, all the institutions relocated critical infrastructure and program areas above projected flood elevations, a process that took years to complete. At the same time, to lessen the impact of future storms like Allison, the Texas Medical Center organization, which acts as a "city government" for the 42 hospitals, universities, and other institutions that make up Texas Medical Center, embarked on the development of a long-term hazard mitigation plan. The plan, which continues to be implemented, incorporates 42 proactive sustainable design measures to reduce the impact from future extreme weather events. Texas Medical Center consulted with hydrology experts and officials from the city of Houston, FEMA, the Harris County Flood Control District, the Harris County Subsidence District, Reliant Energy, Southwestern Bell, and others, demonstrating that resilience measures require the engagement of a broad range of stakeholders.

Key elements of the plan include:

- A new 48-megawatt central campus CHP utility plant run by its own power company, with distribution via an elevated utility walkway, that both eliminates dependence on the Houston utility grid for necessary power and reduces carbon emissions by bringing electrical generation on-site
- An advanced stormwater management system that prioritizes open space for stormwater recharge through advanced systems (this includes completion of the Brays Bayou federal project, which flood control district officials say will lower the water level in Brays Bayou during a storm comparable to Allison by five feet; partially funded by the federal government, the project includes widening the bayou, raising 31 bridges and adding a large water detention pond north of the Texas Medical Center)
- Requirements that all new developments on campus follow stormwater management guidelines and implement streetscape improvements—designs based on such requirements improve access to nature for the campus by integrating landscape and water into the formerly highly urbanized and paved campus

Texas Medical Center has implemented some additional measures, including installation of a solar-powered system that monitors subsidence in the area. Since 1976, the medical center has subsided more than three and one-half feet due to the pumping of groundwater to be used as drinking water, an important fact to consider in constructing new buildings at elevations high enough to be safe from future flooding. Potable water conservation has become another key element of consideration.

## Texas Medical Center, Houston, Texas *continued*

Figure 26: This aerial view of Texas Medical Center illustrates the creation of landscape buffers to enhance stormwater management.


Figure 27: A site plan of the proposed enhancements to landscape and stormwater features, including the definition of a landscape core at the heart of the medical campus.

Figure 28: Texas Medical Center improvements include elevated walkways that provide utility distribution as well as advanced stormwater management strategies.

## MEASURING RESILIENCE: NEED AND METRICS

**"Enhancing the nation's resilience will not be easy, nor will it be cheap. But the urgency is there and we need to begin the process now in order to build a national ethos that will make the nation safer, stronger, more secure, and more sustainable for our children and grandchildren." -- Susan Cutter, Chair, Committee on Increasing National Resilience to Hazards and Disasters; Committee on Science, Engineering, and Public Policy, The National Academies (2012)**

Measurement of resilience is important but elusive. Establishing metrics is imperative if progress is to be measured. Any effort to compare benefits of increasing resilience with the costs of improvements requires a basis of measurement. At the moment, there is no unified, consistent metric for measuring resilience of health care infrastructure.

Resilience is not something health care organizations are experienced with measuring. However, many organizations have attempted to measure resilience or vulnerability for the U.S. using both community-based, bottom-up approaches and top-down, centralized measurement. For example, the Coastal Resilience Index provides an example of a community-based approach to a self-assessment process to derive an index of resilience to storm events. The results are a Low, Medium, and High rating on specific elements, such as critical infrastructure, which are then correlated to produce an overall state-of-the-community resilience score, along with an estimate of the time it would take for reoccupation of the community following a disaster.

By contrast, the Argonne National Laboratory Resilience Index measures the resilience of critical infrastructure through a highly structured interview process conducted by the Department of Homeland Security's Protective Security Advisors. Using an infrastructure survey tool, these interviews cover more than 1,500 variables. A five-stage aggregation process is then used to combine the items into a single Resilience Index (called the Protective Measure Index, or PMI) that ranges from 0 (lowest resilience) to 100 (highest resilience) for a given critical infrastructure or key resource sector and for a given threat. To date, the DHS has performed this assessment for more than 200 hospitals.

In 2011, The National Research Council (2012) convened a committee to review the state of resilience metrics both in the U.S. and globally. Their report recommended the following (modified here to apply to an institutional level):

- Any approach to measuring resilience must address multiple hazards and must be adaptable to the needs of specific institutions or communities and the hazards they face.
- Resilience measurement must be place-based and capable of dealing with a wide range of sizes.
- An index must include many dimensions, from the physical resilience of the built and natural environment and critical infrastructure to aspects of human/social resilience, such as the existence of strong social and health care networks, a strong economic base, or good governance.

The Council's final recommendation was that the Department of Homeland Security, in conjunction with other federal agencies and public/private partners, develop a National Resilience Scorecard that could be used by communities to indicate the ability of critical infrastructure, including health care infrastructure, to withstand or recover rapidly from impacts; indicators of the ability of buildings and other critical structures to withstand the physical and ecological impacts of disasters; and factors that capture the special needs of individuals and groups, including vulnerable health status populations. In order to inform future development of such an index, health care organizations should begin the process of assessing and measuring resilience.

## EMBEDDING RESILIENCE IN INFRASTRUCTURE DECISIONS

**"Current efforts are hampered by a lack of solid information about the benefits, costs, and effectiveness of various adaptation options, by uncertainty about future climate impacts at a scale necessary for decision-making, and by a lack of coordination" (Wilbanks, Yohe, Mengelt, & Casola, 2010).**

This Guide represents a first step in understanding the components of infrastructure resilience; the Toolkit begins the process of embedding this thinking into infrastructure decision making. It outlines a five phase process that institutions can take to understand and improve their resilience to the climate and health challenges of today and the future:

- Phase One: Diagnosis and assessment of climate and health risk
- Phase Two: Assessing vulnerabilities and risks to the institution
- Phase Three: Developing a resilience and adaptation plan
- Phase Four: Implementing the plan
- Phase Five: Evaluating and revising the plan

## INVESTING IN RESILIENCE

There are many reasons for a health care organization to prioritize resilience as part of its community leadership and sustainability agendas. The United Nations Office of Disaster Risk Reduction (UNIDSR, 2012) notes: "Paying attention to protection and resilience will improve environmental, social and economic conditions, including combating the future variables of climate change, and leave the community more prosperous and secure than before."

The World Health organization (WHO) calculates that the price for retrofitting the non-structural items costs as little as 1% of the value of a hospital, while possibly protecting up to 90% of the hospital's assets (2009). FEMA (2007) notes that the most common points of hospital failure from storms are the elevator machinery, windows, and generators. Bolstering protection of these building assets often costs less than the cost to rebuild. In addition, many building elements and infrastructure equipment are replaced in the course of a hospital building's useful life. The rising cost of energy is making energy retrofits more cost-effective; improving resilience aspects of mechanical and electrical infrastructure while retrofitting for improved energy performance provides multiple benefits from a single investment. By contrast, hospital damages from extreme weather events range from $600,000 to $2 billion per facility. Meteorologist Wendy Marie Thomas (2011) noted that "mitigation for hospital buildings is likened to the health adage that says 'an ounce of prevention is better than a pound of cure.'"

Mercy Hospital, Joplin, believes that it incurred cost premiums in the range of 3% for its tornado resilience measures; Spaulding Rehabilitation Hospital in Boston estimates the premium for coastal flooding resilience is in the range of 0.3%. For new buildings, these examples suggest that increased resilience is achievable for modest financial investments. The investments in energy efficiency offer financial payback of immediate to as much as 8 years—for health care organizations that own large building portfolios, even 8 year payback (or 12.5% rate of return) can be viewed as cost-effective.

From the immediate disruptions to the lasting impacts of storm devastation on communities profiled in this Guide, a picture emerges of the importance of health care institutions, such as hospitals and nursing homes, in coming through these events with a minimum of disruption, and supporting the larger community in the enormous task of recovery and adapting to what may well be a "new normal."

The World Health Organization (WHO) launched its Save Lives: Make hospitals safe in emergencies campaign in 2009 to raise attention to the number of health and societal dominoes that fall when disasters strike hospitals. It proclaimed that the "most costly hospital is the one that fails." This is because prevention, in the form of mitigation, costs much less than the direct cost of repair and indirect cost of rebuilding the community around it. Certainly, there are social and human gains achievable: lives and property saved in disaster or emergency situations, with a dramatic reduction in fatalities and prompt treatment of serious injuries. Less damage leads to protected community assets and cultural heritage, with less diversion of hospital and community resources to disaster response and recovery.

"The most costly hospital is the one that fails." World Health Organization, 2009

Finally, while a comprehensive business case for hospital resilience has not been developed, UNIDSR suggests that an important benefit of resilience planning is assurance for public and private investors in anticipation of fewer disaster losses, leading to increased private investment in homes, buildings and other properties that comply with safety standards and build community wealth. Uninterrupted medical services means preserving employment for the hospital and allied businesses that depend upon a functioning health care setting for their livelihood; extended disruption often leads to loss of a pivotal economic anchor in communities. In the aftermath of Katrina, the New York Times reported "Of all the factors blocking the economic revival of New Orleans, the shattered health care system may be the most important —and perhaps the most intractable" (Eaton, 2007).

## CONCLUSION

**"… the science, engineering, and emergency management solutions needed to protect these critical infrastructures and to promote continuity of operations already exist. [The goal] is to tap the available potential in this nation to protect the only infrastructure that provides for our health, and is a major piece of the engine that keeps the nation moving." Wendy Marie Thomas, American Meteorological Society Policy Program (2008)**

This Guide and Toolkit highlights how extreme weather events can cause building failures that ultimately disrupt the continuum of health care delivery during the events and in their aftermath. Focused attention on protecting the physical infrastructure of hospital and residential care settings can offer some increased ability to keep buildings and people safe through future climate change scenarios. It requires a combination of meteorological data and climate scenario forecasting to understand risk, engineering knowledge to prepare existing and new health care buildings to manage and adapt to those risks, and investments in strengthening ecosystem services to mitigate the effects of such events. The Guide and Toolkit consolidates the lessons learned and emergent practices for resilient health care infrastructure that can be gathered from the extreme weather events of the past two decades in order to inform the design and planning of critical health care infrastructure in the decades ahead.

Unlike a single FEMA Mitigation Assessment Team report or a regional post-disaster guidance document, this

Guide and Toolkit focuses on health care infrastructure and its response to any and all weather hazards in order to find both practices and strategies that serve the unique programmatic and patient safety realities of health care settings as well as hazard-specific infrastructure responses. In so doing, it allows health care owners to identify potential strategies that can improve resilience to not only extreme weather events already experienced in a region, but possible future weather events as well. It can assist health care organizations in selecting strategies that improve responses to multiple potential hazards—from heat waves to cold waves, tornadoes to flooding. It consolidates meteorological tools, case studies, and resources prepared by federal agencies, states, cities, as well as the private sector.

It builds upon the challenge outlined above: to protect the infrastructure that protects the nation's health. There can be no higher purpose, and no greater success, than to inform health care infrastructure design toward a more resilient and sustainable future. This is the promise of the President's Climate Action Plan. The imperative is clear.

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## PART 3: SOLUTIONS FOR THE FUTURE


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## ABOUT THE AUTHORS

**Robin Guenther, FAIA, LEED Fellow,** is a practicing architect and author, Principal at Perkins+Will and Senior Advisor to Health Care Without Harm. Robin works at the intersection of health care architecture and sustainable policy and participates in a wide range of initiatives while continuing to practice. In 2013, following Superstorm Sandy, Robin co-chaired the Critical Buildings Committee of the New York City Building Resiliency Task Force. She serves on the U.S. Green Building Council (USGBC) Green Buildings and Human Health Task Force, co-coordinated the Green Guide for Health Care, served on LEED for Healthcare committee, and released the second edition of *Sustainable Healthcare Architecture* with Gail Vittori in May 2013. She served on the 2006 and 2010 FGI Guidelines Revision Committee. She holds a Master of Architecture degree from the University of Michigan, a Graduate Diploma from the Architectural Association, London, and is a Fellow of both the American Institute of Architects and the US Green Building Council.

**John M. Balbus, M.D., M.P.H.,** is the Senior Advisor for Public Health to the Director of the National Institute of Environmental Health Sciences and Director of the NIEHS-WHO Collaborating Centre for Environmental Health Sciences. He serves as HHS principal to the U.S. Global Change Research Program (USGCRP) and also co-chairs working groups on Climate Change and Human Health for the USGCRP and for the National Institutes of Health. Balbus was a lead author for the health chapter of the 3rd US National Climate Assessment. He served as review editor of the Urban Areas chapter for the recent 5th Assessment Report of the Intergovernmental Panel on Climate Change and is a co-convening lead author of the ongoing USGCRP Climate Health Assessment. Balbus received his A.B. degree in Biochemistry from Harvard University, his M.D. from the University of Pennsylvania, and his M.P.H. from the Johns Hopkins School of Public Health.

## ACKNOWLEDGEMENT OF STAKEHOLDER COMMENTS

The authors thank the following individuals for their valuable comments during the stakeholder review process:

- John Cutler
- Kim Dyches
- Sarah Goes
- Cindra James
- Sherline Lee
- Hubert Murray
- Clark Reed
- Matthew Schilling
- Christina Vernon
- Jalonne L. White-Newsome

DEPARTMENT OF HEALTH & HUMAN SERVICES USA