DISASTER RESILIENCE FRAMEWORK

75% Draft for San Diego, CA Workshop

11 February 2015

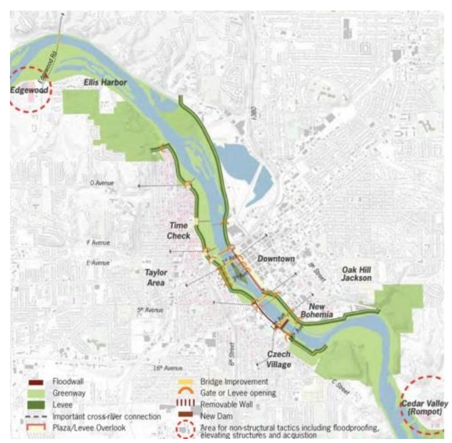
Executive Summary

Developing a Disaster Resilient Plan. In the United States, there are always a handful of individual communities working to recover from a hazard event. Whether due to severe weather, fire, floods or earthquakes, each community will eventually need to recover from a hazard event. All communities recover, but the length of recovery and the ultimate outcome depends on planning, preparedness, mitigation, response, and facilitation of the recovery. A disaster resilient community recovers quickly and to a better state than before the event occurred. An unprepared community often faces decades of recovery and may never achieve full restoration.

Envisioning a Better Outcome. Communities are overwhelmed with issues, policies, and regulations that need to be addressed. Each demands time and investment to resolve. Dealing with low probability-high consequence hazard events is often a low priority without a government mandate or recent event that focuses community interests. These stories illustrate the reality: resilience planning makes a major difference in how well community recovery is executed and illustrates why it should become part of normal planning and operations.

Cedar Rapids, Iowa. Cedar Rapids, Iowa, has multiple sources of natural hazards: floods, severe weather, tornadoes, severe windstorms, and heat waves. The city is also just downstream from a commercial nuclear power facility. The community has a well exercised evacuation plan for dealing with a nuclear disaster. Those plans played a large role during the flooding of 2008 when the river crested at well above its predicted 500-year flood event (http://www.cedar-rapids.org/city-news/flood-recovery-progress/floodrecoveryplans/Pages/FloodRecoveryTimeline.aspx). No lives were lost in that event because the evacuation plans were in place (NRC 2012). In addition, because the City Council and City Manager instituted a community engagement process to develop a shared vision and planning system months before the 2008 flood, they successfully responded to the flooding. Currently, they are rapidly implementing their Recovery and Reinvestment Plan, which is improving the community's resilience for flooding events (CARRI 2013).

Downtown Cedar Rapids, Iowa, during the 2008 Floods that Crested at 31 Feet
http://www.nydailynews.com/news/world/flooding-puts-cedar-rapids-iowa-water-article-1.292913



Cedar Rapids, Iowa Resilience Plan
http://corridorrecovery.org/rcrp/04_flood_management_map.asp)

Figure 1. Cedar Rapids, Iowa

Figure 2. Santiago Chile Skyline. A Resilient City in a Resilient Nation. (en.wikipedia.org)

Chile. Chile is a country that knows earthquakes well. After a massive event in 1960, the country developed and continued to update stringent building codes and emergency response procedures. In 2010, the country experienced a similar major seismic event that caused damage from Santiago in the North to Conception 500 miles to the south and generated a large tsunami. New emergency response procedures that grew out of hat experience, along with greatly improved building standards that had been in place for 50 years, resulted in much less damage, especially to high-rise residential buildings. Power restoration began to critical infrastructure within days; within a few months over 50,000 provisional homes had been constructed; and within three years infrastructure repairs were complete. Within four years, nearly all subsidized home rebuilding projects were complete. Even though this extreme event caused widespread damage to older buildings and infrastructure systems, the extent of modern construction and the response and recovery plans that were in place allowed the communities, with the assistance of the national government, to manage the event and rapidly build back in a way that is better prepared for the next seismic event (Britannica.com 2015).

Figure 3. NGO Make-it-right reconstruction plans for New Orleans 9th Ward (www.makeitright.org)

New Orleans, Louisiana. Hurricane Katrina (2005) followed a scenario that had been frequently predicted and was the focus of multiple State and Federal response exercises. One scenario even envisioned a levee breach. However, numerous communities and industrial facilities that support national fuel supplies were severely damaged. Communities either did not understand the threat posed by storm surge or ignored the predictions and did not prepare at the local level for response and recovery (APA 2014). The lack of suitable design codes, response plans, processes to coordinate various local, state, and Federal agencies, and local leadership stalled the recovery. In New Orleans, the local government now has the New Orleans Redevelopment Authority (NORA, http://www.noraworks.org/) that supports land stewardship, commercial revitalization, and affordable housing. Organizations like Habitat for Humanity, Make-it-Right Foundation, and Rebuilding Together New Orleans (RTNO 2015, http://www.rtno.org/) have, in cooperation with local government and community leaders, made significant, though somewhat controversial, strides in aiding homeowners to return to their communities and rebuild their lives. However, the population is at approximately 75% of its pre-Katrina levels after 10 years (APA 2014) and it may be decades before New Orleans fully recovers from the event.

The Resilient Community. The concept of setting recovery goals for community resilience is easy to understand but requires detailed development and involvement by all stakeholders. Community resilience addresses the complex interactions of people, the services they need, and the local economy that sustains life and drives growth. Community resilience requires a governance structure that sets direction and provides services, and a built environment that supports the community's social institutions. The built environment is the foundation of recovery; governance sets the direction; financing governs the pace; and the community provides the support and will to make improvements.

Disaster resilience planning must eventually include in depth understanding of a community's interwoven social, political, and economic systems; how they are supported by the built environment; a clear understanding of their vulnerability and damage for expected hazard events; and how any damage will impact community recovery. The most useful plans are developed by a broad cross section of planners and stakeholders and include a sufficient level of detail that informs specific short and long term actions aimed at improving resilience over time.

This Disaster Resilience Framework provides a methodology and supporting detail to help communities understand and characterize their social community and built environment, and how to link the community's social institutions with the built environment. With that understanding, the resilience plan can identify the buildings and infrastructure systems and the levels of functionality needed during and after a hazard event, including recovery plans to restore community functionality. The gaps between desired and anticipated performance of the physical infrastructure are prioritized, and strategies are developed to implement the resilience plan. The framework provides guidance on developing a community-level resilience plan, with specific guidance for identifying the social aspects of resilience, their dependence on buildings and infrastructure systems, and is compatible with FEMA Mitigation plans.

Striving for community disaster resilience need not be expensive, but the process is unique for each community and will take time both to implement and to accrue benefits. The process to achieve disaster resilience requires concentration; persistence; a willingness to understand the present effectiveness of the social institutions, governance, economics, the buildings, and infrastructure systems; and the consequences for the community that an actual hazard event will trigger. The intersection of a community's daily needs and the anticipated damage from hazard events forms the basis for resilience planning.

Short term plans can be developed for emergency and interim solutions that can be implemented if the event occurs tomorrow. Long term plans provide the roadmap for eventually achieving disaster resilience. It begins by envisioning a better outcome, understanding your community, developing a resilience plan, and initiating implementation.

Many communities have Mitigation Plans, which are required by FEMA since the passage of the Disaster Mitigation Act in 2000 (DMA 2000). These plans are complementary to Community Resilience Planning outlined in the framework. A combination of FEMA-directed mitigation planning and the resilience planning described in this framework provides a first step toward becoming a disaster resilient community.

Understanding Your Community and its Built Environment. Communities are gatherings of people who need places to live, work, find security, and a sense of belonging so they can grow and achieve. All communities have a common set of social institutions in place to meet the needs of individuals and households. While common in description, they are organized and delivered uniquely in each community.

Individual needs and social institutions are described in Chapter 2 and include Family and Kinship, Economic, Government, Health Care, Education, Community service organizations, Religious Organizations and others that support belief systems, and the media. When considering a community's social institutions and their dependence on the built environment, it is important to recognize and address social vulnerability and inequity since all people do not have equal access to the social institutions nor do they have the same needs. This becomes especially critical after a hazard event occurs.

Linking a community's social institutions to the built-environment is illustrated in Chapter 2. People need housing, kids need schools, neighborhoods need retail districts, businesses need suitable facilities and everyone needs healthcare, a transportation network, electricity, fuel, water, sewer systems and communication tools. Any disruption in availability of these services needs immediate attention, even without a hazard event.

In a perfect world, hazard events would not cause serious disruptions or damage to the built environment or its support of individuals and social institutions. Unfortunately, that is not the case. Most of the built environment in the nation does not have the ability to remain in service after significant hazard events occur, even though most people are not prepared to be on their own after disruptive events. This reality is demonstrated every time a significant hazard event occurs. Most communities try to rebuild as quickly as possible to restore damaged buildings and infrastructure, sometimes waiving code enforcement, with no time to develop improved reconstruction plans. The significant amount of funding available for rebuilding becomes a lost opportunity without a plan to improve community resilience.

In reality, only a fraction of the built environment is essential in the first few days after a significant hazard event, primarily to support emergency response. More of the built environment needs to be functional in the subsequent weeks and months of recovery. The key question is, "When do the buildings and infrastructure systems that support each social institution needs to be fully restored to service?" The desired time for recovery of community functions is the performance goal. The difference between the current anticipated performance and the desired performance is the key question to be answered during resilience planning.

Developing a Community Resilience Plan. The NIST framework provides a methodology for developing a Community Resilience Plan that accounts for social aspects of resilience when setting performance goals and recovery plans for the built environment. For example, the buildings and infrastructure systems that support emergency response typically include hospitals, police and fire stations, and emergency response centers. Housing and neighborhoods need to be restored within weeks with special attention to vulnerable populations. Once people are safe, recovery attention turns to restoring government, business, industry, education, general healthcare, and other services. Desired performance goals in terms of recovery times for community functions are set, informed by social issues. The current anticipated performance of the existing infrastructure may indicate longer recovery times than identified in the plan and that cause significant impediments to community recovery.

Understanding the gaps between desired and actual performance are determined for specific clusters of buildings and infrastructure systems and can then inform short and long terms solutions. In the short term, these gaps can be addressed with interim plans for emergency response and temporary actions. In the long term, new construction can be designed to the designated performance goals and the existing infrastructure can be retrofit as appropriate. Recognizing the balance between pre-event and post-event actions and resource allocation is a key outcome of the process. Not all buildings and systems need to be mitigated or retrofit to current standards to achieve resilience.

Figure 4 shows a flow chart of the Community Resilience Planning process. First steps include establishing the core resilience planning team, determining social assets and identifying key social needs for community recovery, and determining physical infrastructure assets and natural resources that support the key social needs. With this community

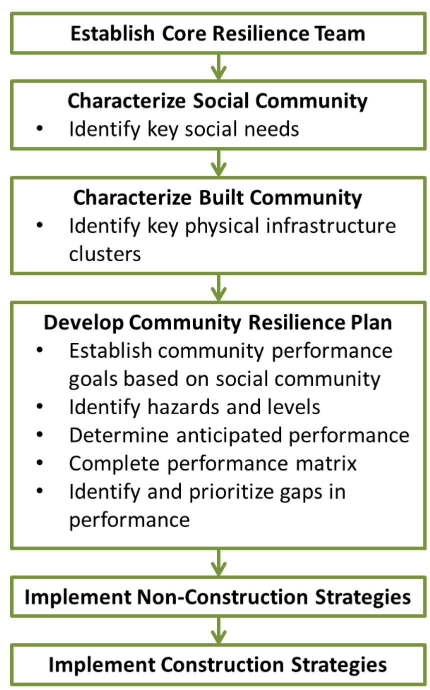


Figure 4: Flow Chart for Developing Resilience Plan

information, the community resilience plan is developed with the following steps: 1) establish community-level performance goals, 2) determine anticipated performance of infrastructure clusters; 3) complete the performance matrix, and 4) identify and prioritize gaps between the desired and anticipated performance for the clusters and each hazard. Once the gaps are prioritized, the community can develop strategies to mitigate damage and improve recovery of functions across the community.

The built environment is a complex and highly interdependent system of systems. Buildings generally house the functions that support the social institutions. Their functionality after a hazard event not only depends on the condition of the building but also on the infrastructure systems that service it. Roads are needed to access the building, and electricity, water, sewer systems, and communication networks are needed to let it operate and function as intended.

Infrastructure systems are also highly interdependent with each other. For example, the electrical power system needs roads for their crews to access damaged areas and restore power, water for cooling, and communication networks for repair coordination, etc. The framework presents considerations and examples of interdependencies that may need to be addressed when setting performance goals for recovery of community functions. Substantial background information is also provided about buildings and infrastructure systems, as well as guidance for setting performance goals, and strategies for improvement of infrastructure systems for new and existing construction.

Figure 4 is further developed through a description of core activities for developing a community resilience plan in Table 1. The social dimensions of the community are reviewed to identify important functions for the community, and when they need to be available during or after a hazard event. This includes considerations for the needs of individuals and social, government, business, industry, and financial institutions. Buildings and infrastructure systems that support the identified social functions are grouped, or clustered, as a subsystem. Additionally, anticipated hazards and the effects of changing conditions are identified. The desired and expected performance (i.e., recovery of function) of the clustered subsystems after a hazard event is evaluated. Significant gaps between these two performance levels are prioritized for strategies for improvement. Last, strategies are developed to address prioritized needs in the built environment.

Table 1. Core Activities for Community Resilience

Characterize Community's Social Dimensions	• Identify and assess actual and desired functions of social institutions, including business, industry, and financial systems, based on individual/social needs met by these institutions and social vulnerabilities. • Identify key stakeholders and representatives for decision making.
Characterize Community's Built Environment and Hazards	• Identify and assess building and infrastructure systems, including condition, location, and vulnerabilities, and the ways in which the built environment support social functions. • Identify hazard types and range of levels or intensities and changing conditions that the community anticipates. • Identify key stakeholders and representatives for decision making.
Develop Plan for Community Resilience	• Establish desired performance goals for the built environment during and after a hazard event that meet needed social functions after a hazard event with input from all key stakeholders • Identify and prioritize gaps in the desired performance of the built environment that need to be addressed to improve community resilience
Implement Strategies for Existing Built Environment	• Identify methods that may include mitigation, retrofit, or relocation options • Prioritize strategies based on gaps in the desired performance goals
Implement Strategies for New Built Environment	• Adopt provisions to improve the integrated performance of the built environment, such as land use, zoning, codes and standards, and local ordinances for buildings and infrastructure systems

This process is conducted at the community level for each hazard, with supporting detailed plans for buildings and infrastructure systems. Each hazard is evaluated at three hazard levels to help comunities understand performance across a reasonable range of expected hazard levels or intensities. For instance, a hazard event is likely to occur near the design level as well as below and above the design level over a 50 to 100 year period. Communities need to understand how their social systems and built environment will perform and recover over the range of hazard levels. A detailed overview of buildings and infrastructure systems is provided that addresses system performance for hazard events, how performance may affect community resilience, a review of primary codes, standards, and regulations, and possible strategies for setting performance goals and determining prioritization of resilience efforts. There is also a summary of available guidance, metrics, and tools for assessing community resilience.

Community Resilience and Mitigation Planning. Nearly 24,000 communities, representing 80% of the people in the United States, have developed mitigation plans in accordance with Federal Emergency Management Agency (FEMA) guidance. As mitigation is a component of resilience, these communities are taking substantive steps toward planning for resilience. A planning process that includes a detailed consideration of the built environment as outlined in the Disaster Resilience Framework and incorporates ongoing mitigation planning provides a comprehensive understanding of community resilience.

With the existing community mitigation planning structures, expanding the scope to resilience is the next logical step. Those already involved in mitigation activities have similar types of roles and responsibilities needed for resilience. The mitigation planning process emphasizes public participation in vetting mitigation strategies with targets, actions and priorities. Community resilience plans can be built around existing mitigation plans using the framework techniques related to the built environment.

Chapter 2 of the framework provides a methodology for understanding communities and their needs from the built environment. Chapter 3 describes a process for doing a risk assessment of the built environment which then informs both short and long term implementation planning. In FEMA's Local Mitigation Planning Handbook, the Hazard Mitigation Plan has 9 Tasks, from defining the planning area and team through Creating a Safe and Resilient Community, that are compatible with the resilience activities described in the framework.

Additionally, FEMA was tasked through Presidential Policy Directive 8 (PPD-8) on National Preparedness to produce a series of frameworks to address the spectrum of prevention, protection, mitigation, response, and recovery. Each Mission Area has a framework document associated with it that describes the roles and responsibilities of the whole community. The NIST Disaster Resilience Framework complements the PPD-8 framework documents by providing a methodology and specific guidance for developing a prioritization plan, at the local level, for recovering the function of buildings and infrastructure following a disruptive event to meet the societal goals of the community. The Disaster Resilience Framework allows a community to consider the interdependencies among buildings, infrastructure and the social and economic systems present in the community and consider the downstream cascading effects that can occur due to disruptions in these systems.

1. Framework Introduction

1.1. Overview

Communities are places where people live, work, play, and build their futures. Each community has its own identity based on its location, history, leadership, available resources, and the people who live and work there. Successful communities provide their members with the means to meet essential needs as well as pursue their interests and aspirations.

All communities are subject to disruptive events. Across the nation, communities experience disruptions from weather events, infrastructure failures, cyber-attacks, technological accidents, sea level rise, or other disruptive events. Buildings and infrastructure systems are vital to community prosperity and health. If these systems fail or are damaged, essential services are interrupted. Depending on the magnitude and duration of the disruptive event, communities may experience anything from temporary interruptions in services to a permanent loss of businesses and relocation of residents.

Community resilience is the ability of a community to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions. Communities are looking for ways to become more resilient to disasters. This framework focuses on community resilience planning for the built environment, where the performance goals for the physical infrastructure systems are informed by the needs of the residents and social institutions. The built environment includes buildings and infrastructure systems, including power, communication, water and wastewater, and transportation systems.

Communities are increasingly aware of the need to become proactive and take steps to improve their resiliency, by preparing for anticipated hazards, adapting to changing conditions, and withstanding and recovering rapidly from disruptions. Changing conditions include the effects of aging infrastructure systems and climate change, such as sea level rise in coastal areas. In a resilient community, a hazard event at the design level should cause only local disruptions that the community can tolerate without long-term detrimental effects. If an unanticipated or extreme event occurs, the resilience planning and preparation should reduce the extent of disruption and recovery time. Additionally, communities that have a well-developed resilience plan are prepared to recover in a way that improves sustainability and resilience.

The Disaster Resilience Framework provides communities with a methodology to plan for resilience by prioritizing improvements to buildings and infrastructure systems based on their importance in supporting social institutions and economic functions in the community. Communities should implement resilience plans as a part of their long-term community planning process. Integrated long-term planning and implementation of measures to improve resilience can benefit community goals, such as providing an attractive, vibrant place to live for residents and a reliable environment for businesses to locate. A resilient community also provides day-to-day benefits to communities by reducing daily disruptions if improved design and construction practices are adopted. Even if it is many years before a significant hazard occurs, the community's resilience plan will continue to improve the performance of buildings and infrastructure systems to other hazards, including interdependencies and cascading effects of system failures.

This community resilience methodology has a set of core activities for developing a community resilience plan, presented in Chapters 2 to 9:

- Characterize Social Dimensions of the Community
- Characterize Built Environment and Hazards
- Plan for Community Resilience
- Develop Strategies for Existing Built Environment

- Develop Strategies for New Built Environment

Community resilience planning for the built environment requires input from all stakeholders, including local government, owners and operators of buildings and infrastructure systems, and residents with equal representation from the community's social institutions and economic functions. When all interests and needs are addressed in a comprehensive evaluation at the community level, communities develop a transparent, supportable path forward that is embraced and supported by everyone. Additionally, precious resources can be allocated based on a community-wide evaluation that prioritizes needed improvements.

1.2. Defining Communities

Communities are highly variable and diverse, with geographic areas and populations ranging from small, rural communities to large, urban, dense communities. Communities also differ by their histories, cultures, social make-up, businesses, industries, and access to and availability of resources.

The Community Capitals Framework, depicted in Figure 1-1, describes community assets and resources in terms of various forms of capital: natural, built (physical), financial (economic), human, social, political, and cultural. Each of the community capitals are interrelated and interact with each other, and can be considered the collective set of assets available within a given community.

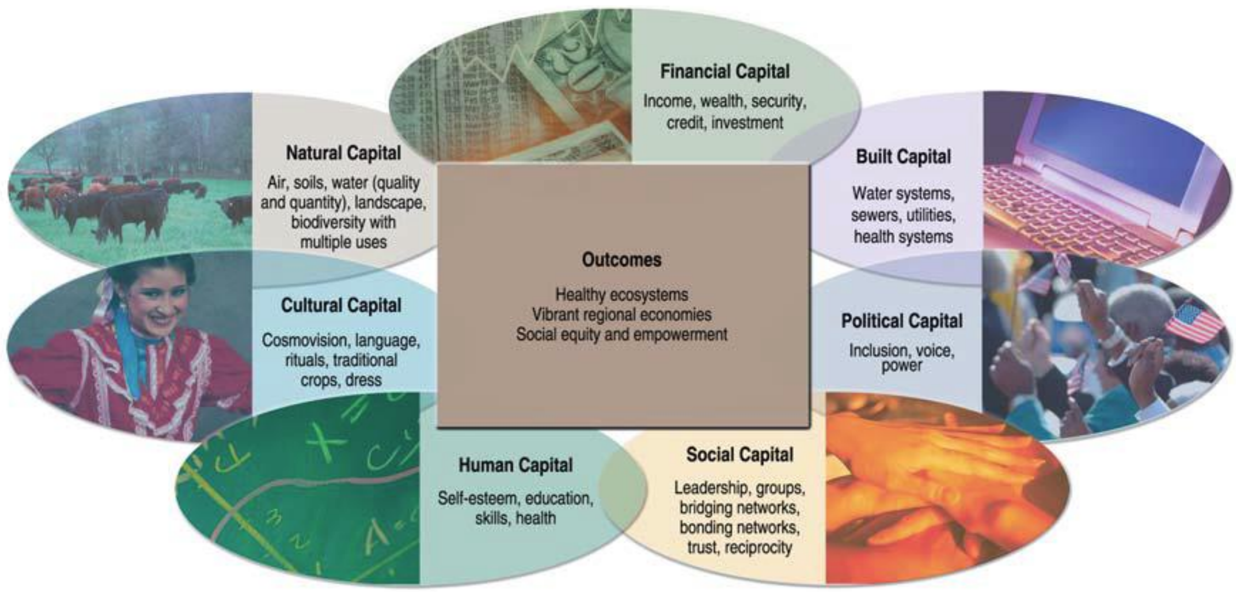


Figure 1-1: The Community Capitals Framework (Flora et al, 2008).

Community capitals are described as:[1]

- ***Natural –*** resources such as air, land, water, minerals, oil, and the overall stability of ecosystems
- ***Built –*** buildings and infrastructure systems within a community
- ***Financial –*** financial savings, income, investments, and available credit at the community-level
- ***Human –*** the knowledge, skills, health and physical ability of community members
- ***Social –*** social networks, associations, and the trust generated by them among groups and individuals within the community
- ***Political –*** having access to resources and the ability/power to influence their distribution; also, the ability to engage external entities in efforts to achieve goals

[1] Ritchie, Liesel A. and D.A. Gill, "Considering Community Capitals in Disaster Recovery and Resilience." http://www.riskinstitute.org/peri/component/option,com_deeppockets/task,catContShow/cat,86/id,1086/Itemid,84/.

- ***Cultural* –** language, symbols, mannerisms, attitudes, competencies, and orientations of local community members/groups.

Knowledge about each type of capital in a community provides stakeholders with valuable information, as it contributes to understanding about the community's well-being, sustainable development, and resilience. Awareness of community capitals helps identify short-term and long-term benefits, whether or not a hazard event occurs, and provides input to mitigation, preparedness, response, and recovery plans and investments.

While all the types of capitals are important to each community, this report focuses primarily on built capital (buildings and infrastructure systems), with consideration of how built capital supports other capitals within a community. The needs of citizens and social institutions, government, industry, and business should help define functional requirements for a community's buildings and infrastructure systems, as illustrated in Figure 1-2. For instance, after a significant hazard event, will residents be able to remain in their homes? Can governments communicate with residents to inform them and support recovery efforts? Will businesses and industries be able to resume operations within a reasonable period? These types of social needs determine the performance expected from a community's buildings and infrastructure systems. However, functional requirements at the community level are often not explicitly established.

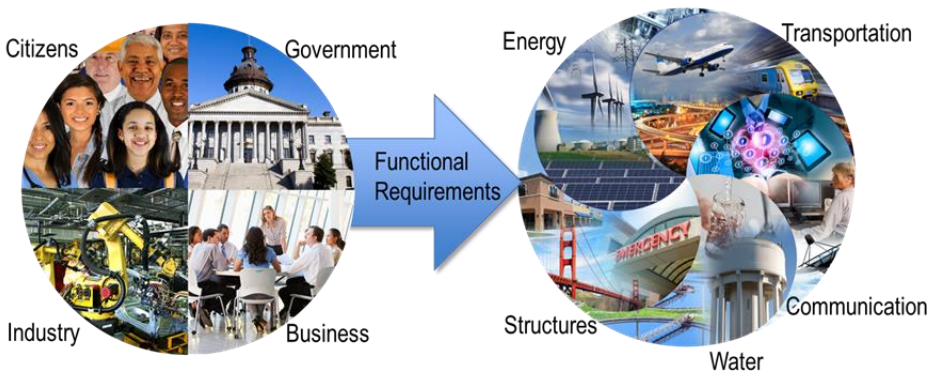


Figure 1-2: Social activities, such as individual citizens and social institutions, business and government define the functional requirements of the community buildings and infrastructure systems.

A resilience plan offers a community answers and available alternative options. There may be multiple solutions or multiple stages to meet a requirement, including alternative or temporary solutions to meet the immediate need, as well as restoring a building or infrastructure system.

Functional buildings and infrastructure systems are necessary for communities to prosper. When buildings and infrastructure systems are damaged by hazard events, social services are interrupted, economic losses soar, and precious resources must be re-allocated to repair and rebuild. When the damage is extensive, the recovery process can be a significant drain on local residents and their resources and can be drawn out over years.

1.3. Community Resilience

The term "resilience" is used in many ways. The definition for the framework is contained in Presidential Policy Directive 21 (PPD-21).[2] The definition states, "The term 'resilience' means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions." Under this broad definition, resilience includes activities already conducted by some communities, such as disaster preparedness, hazard mitigation, code adoption and enforcement, and emergency response.

[2] Presidential Policy Directive 21, http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.

In the context of this framework, the phrase "prepare for and adapt to changing conditions" refers to preparing for conditions that are likely to occur within the lifetime of a facility or infrastructure system, such as a hazard event, and hazard intensities or physical conditions that may change over time. Depending on location, this may include effects of climate change, such as sea level rise in coastal areas or a change in understanding of a hazard such as tornadoes. Changing conditions also include changes in our use of infrastructure systems. For example, increasing the use of communication and information devices leads to evolving levels of dependencies on information and power systems. Changing conditions may also include aging effects on infrastructure systems. If buildings and infrastructure systems are designed, maintained and operated properly, disruption to community functions should reduce over time, as more of the built environment will be performing at levels compatible with community resilience goals.

The second part of the definition, "withstand and recover quickly from disruptions," must be examined for the anticipated range of possible hazard events. In a resilient community, a hazard event at the design level may cause local disruptions tolerated by the community without long-term detrimental effects (e.g., permanent relocation of residents or business). If an unanticipated or extreme event occurs, the resilience planning and preparation will likely reduce the extent of disruption and recovery time. Additionally, communities that have a well-developed resilience plan are prepared for the recovery process.

1.4. Community Resilience of the Built Environment

1.4.1. Resilience Concept

Figure 1-3 illustrates the concept of resilience for an element of the built environment in terms of 'functionality' versus 'recovery time.' Functionality is a measure of how well a building or infrastructure system is able to operate and perform at its intended purpose. Recovery time provides a measure of how long a building or system function is unavailable or is operating at a reduced capacity. Recovery time also provides an indirect measure of the pre-event condition of the system, the performance of the system during the event, and the level of damage sustained.

Planning for resilience can minimize or even eliminate loss of functionality for a range of hazard event intensities, depending on the available solutions, resources, and priorities. For hazard events, loss of functionality occurs suddenly – on the order of minutes to days – due to physical damage to one or more systems, whereas recovery of functionality may take anywhere from hours to years. Typically, a lesser degree of lost functionality corresponds to a reduced time to full recovery. However, this simple example does not account for dependencies on other systems.

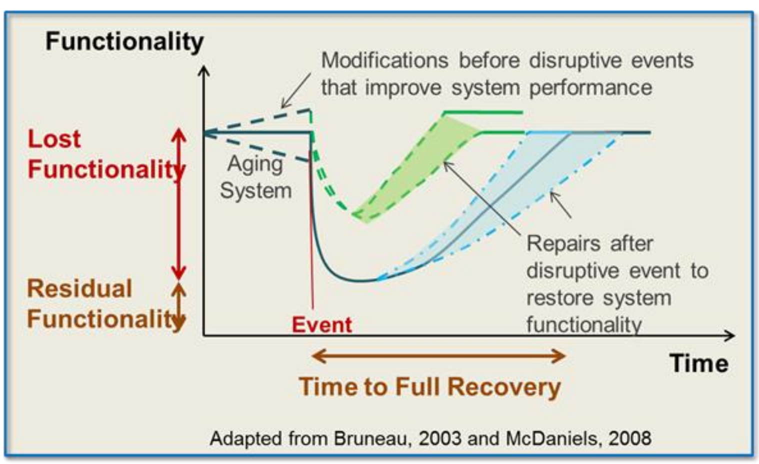


Figure 1-3: Resilience can be expressed simply, in terms of system functionality and the time to recover functionality following a disruptive hazard event.

1.5. Why Is Community Resilience Needed?

Hazard events can disrupt community functions so extensively that they result in permanent changes. Hurricane Katrina, in 2005, and Superstorm Sandy, in 2012, both caused extensive damage across many communities that are still recovering. However, even for lesser storm events, communities across our country experience significant damage each year. There were between 45 and 81 Presidential disaster declarations each year, from January 2000 to January 2011, for floods, hurricanes, tornadoes, earthquakes, fire events, and severe storms (FEMA 2011). Many of the disaster declarations were for hazard events with loads less than current design levels. Communities need to be proactive in staying resilient and minimizing and mitigating disruptions.

Communities currently reduce threats and vulnerabilities through activities that include adoption and enforcement of codes, standards, and regulations, as well as preparedness, mitigation, codes and standards-based design, and emergency management. These activities are necessary and prudent, but they are not enough to make a community resilient. Community resilience also requires that the built environment maintains acceptable levels of functionality during and after events. More specifically, communities should develop plans that recover the built environment to full functionality within a specified period. The recovery times are based on the role and importance of each facility or system within the community and the extent of disruption that can be tolerated while remaining functional.

However, across the nation, communities continue to experience significant damage and losses, despite robust adoption and enforcement of best practices, regulations, and codes and standards. This is partly because each one is developed independently for buildings and each infrastructure system and they do not address interdependencies between systems, nor community-level performance goals. As a result, integrated performance and dependencies between buildings and infrastructure systems cannot currently be addressed solely through the universal adoption of codes and regulations.

Additionally, communities are primarily composed of existing construction. Buildings and infrastructure systems are built to different standards based on the understanding of the hazards at the time. Many of the nation’s infrastructure systems are reaching the end of their useful service life or operating in a degraded state. The American Society of Civil Engineers (ASCE) is committed to protecting the health, safety, and welfare of the public. As such, ASCE is equally committed to improving the nation’s infrastructure systems. To document the national needs, a Report Card is issued to evaluate the condition and performance in 16 categories for infrastructure systems, assigning letter grades that are based on physical condition and needed investments for improvement. In 2013 (ASCE 2013), the overall Grade was a D+ with estimated investment of $3.6 trillion needed by 2020. Further, not all of these systems are operated and maintained as intended, some operate beyond design lifetimes, and the replacement rate for the built infrastructure is slow. While this deteriorated state is a cause for significant concern, it is also an opportunity to develop and implement a new paradigm – community resilience – when planning for and envisioning the future of each community.

1.5.1. Developing a Plan for Community Resilience

Resilience Activities. For a community to have a resilient built environment, additional activities are needed beyond code adoption and enforcement. Figure 1-4 depicts how community resilience can be addressed at the community level. Disruptive events, including all anticipated hazards and effects of changing conditions are countered by a community resilience plan that includes performance goals for the built environment, and supporting strategies that include mitigation, response, and recovery activities. Other aspects of a resilient community – security, protection, emergency response, business continuity, and other issues related to human health, safety, and general welfare – may also inform the performance goals for the built environment. Plans to improve community resilience may also include land use policy, temporary measures, and other non-structural approaches.

Mitigation through Land Use Planning. Land use planning is an important part of community planning and mitigation measures. Building and infrastructure design and construction are just one part of a comprehensive community development process that involves both new and renewed development. For communities that are built out, or are concerned about areas already constructed, there are two resilience options: (a) implement land use planning and redevelopment strategies to reduce the potential damage and disruption before a hazard event if there is political will and resources to do so and (b) develop plans for alternate land use/redevelopment strategies as part of the recovery process (return of functions and repairs/rebuilding). These options are part of hazards-based community development processes, particularly in geologic and flood-prone hazard areas.

Figure 1-4. Community resilience can be achieved over time by developing performance goals and implementing methods to mitigate, resist, or recover from damage imposed by hazards, degradation, and climate change effects.

Hazards. Many older systems are difficult to improve through mitigation or design improvements. Therefore, it is helpful for communities to understand how their built environment (buildings and supporting infrastructure systems) will respond to a range of hazard levels or intensities. A hazard that occurs several times during the life of the system, such as every 10 to 20 years, is not expected to cause significant damage, and is referred to as a *Routine Hazard* event in this framework. *Expected Hazard* events, or design-level hazard events, may occur over the service life of a system. At a minimum, buildings are anticipated to remain stable during a hazard event, so that occupants can evacuate safely. However, the building may need to be repaired or replaced, depending on the hazard event and the extent and type of damage. Occasionally, *Extreme Hazard* events occur with a greater level or intensity than the Design Hazard. A system's capacity may be exceeded and cause widespread, cascading damage to other systems. These varying levels of hazard should all be considered with appropriate levels of emergency response and recovery plans.

Performance Goals. Inclusion of desired performance goals versus anticipated performance of the built environment to hazard events, *and* expected recovery sequences, time, and costs provides a complete basis for communities to allocate resources and prioritize improvements. Ideally, community resilience planning should integrate with long-term plans for economic development to achieve improved social and economic well-being in the long term. San Francisco and the state of Oregon are developing and implementing this approach for resilience planning (SPUR 2009, Yu, Wilson, and Wang 2014).

Implementation. Community resilience is achieved over time through implementation of prioritized improvements occurring as funds and opportunities are available. Resilience planning at the individual system level, without a comprehensive understanding of the social and economic drivers present and the role of building or infrastructure systems in the community, may be incomplete and less effective.

With a resilience plan, answers and alternative options for the restoration of the built environment will be available and understood by the community. There may be multiple solutions or multiple stages to meet a requirement, including temporary or short-term solutions to meet immediate needs as well as long-term, permanent solutions that restore buildings or infrastructure systems.

Core Activities. Table 1-1 lists core activities for developing a community resilience plan. The social dimensions of the community identify what functions are important to a community, and when they need to be available during or after an event.

Table 1-1: Core Activities for Community Resilience

Establish Core Resilience Team	• Identify Chief Resilience Officer or other resilience leader • Establish Resilience Office within community government • Engage key stakeholders
Characterize Social Dimensions of the Community	• Identify and assess actual and desired functions of social institutions, including business, industry, and financial systems, based on individual/social needs met by these institutions and social vulnerabilities. • Identify key stakeholders and representatives for decision making.
Characterize Built Environment and Hazards of the Community	• Identify and assess building and infrastructure systems, including condition, location, and vulnerabilities, and the ways in which the built environment support social functions. • Identify hazard types and range of levels or intensities and changing conditions that the community anticipates. • Identify key stakeholders and representatives for decision making.
Develop Plan for Community Resilience	• Establish desired and expected performance goals for the built environment during and after a hazard event that meet needed social functions after a hazard event with input from all key stakeholders • Identify and prioritize gaps in the desired performance of the built environment that need to be addressed to improve community resilience
Implement Strategies for Existing Built Environment	• Identify methods that may include mitigation, retrofit, or relocation options • Prioritize strategies based on gaps in the desired performance goals
Implement Strategies for New Built Environment	• Adopt provisions to improve the integrated performance of the built environment, such as land use, zoning, codes and standards, and local ordinances for buildings and infrastructure systems

Chapter 2 discusses considerations for the needs of individuals and how a community meets these needs through social institutions, including government, business, industry, health care, and education institutions. Buildings and infrastructure systems that support the identified social functions are grouped, or clustered, as a subsystem. Additionally, anticipated hazards and the effects of changing conditions are identified. The desired and expected performance (i.e., recovery of function) of the clustered subsystems after a hazard event is evaluated. Significant gaps between these two performance levels are prioritized into strategies for improvement. Last, strategies are developed to address prioritized needs in the built environment. Chapter 3 offers guidance related to this process at the community level, and the basis for three hazard levels and intensities for each hazard. Chapters 5 to 9 provide a more detailed overview of buildings and infrastructure systems' performance in hazard events of all sizes, how they may affect community resilience, primary codes, standards, and regulations, and strategies for setting performance goals and determining prioritization and improvement of mitigation efforts.

Resilience Guidance, Metrics and Tools. Chapter 10 summarizes available guidance, metrics, and tools for assessing community resilience. The chapter presents three types of community resilience metrics: recovery times for restoring function in building and infrastructure systems; economic metrics that represent business, tax base, income, local services and amenities; and sustained growth, and social metrics that represent survival, safety and security, sense of belonging, and growth and achievement. The chapter further reviews examples of existing community resilience assessment tools and identifies the primary metrics used in each method.

1.6. Other Federal Activities Supporting Resilience

1.6.1. The National Preparedness Frameworks

For the last several years, the Federal Government worked to improve the resilience of the nation to disruptive events such as natural and human-caused hazards. This effort resulted in a number of guidance documents and tools for use to assess threats, hazards, and vulnerabilities in buildings and infrastructure systems and to develop approaches to reduce or eliminate those vulnerabilities. In particular, the Federal Emergency Management Agency (FEMA) was tasked through Presidential Policy Directive 8 on National Preparedness to produce a series of frameworks to address the spectrum of prevention, protection, mitigation, response, and recovery. This section provides a brief overview of the Presidential Policy Directive 8 frameworks and the relationship of the NIST Disaster Resilience framework to those documents.

On March 30, 2011, the President issued Presidential Policy Directive 8 (PPD-8), on National Preparedness.[3] PPD-8 directed the Secretary of Homeland Security to develop a National Preparedness Goal, establish a National Preparedness System, build and sustain preparedness, and submit a National Preparedness report annually.

The National Preparedness Goal, developed in response to PPD-8 is:

> *"A secure and resilient nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk."*[4]

The National Preparedness Goal further established 31 core capabilities necessary to achieve the goal.[5] These core capabilities are organized into five mission areas: Prevention, Protection, Mitigation, Response, and Recovery. Each mission area has a framework document that describes the roles and responsibilities of the whole community.

- Individuals, families, and households
- Communities
- Non-governmental organizations (NGOs)
- Private sector entities
- Local governments
- State, tribal, territorial, and insular area governments
- Federal Government

With the exception of the National Prevention Framework, which specifically addresses, "the capabilities necessary to avoid, prevent, or stop a threatened or actual act of terrorism,"[6] the remaining framework documents address protection, mitigation, and response to all hazards – natural and human-caused. The National Response Framework, while structured somewhat differently to address the roles that state, tribal and, especially, the federal government play in supporting recovery following a major event. The

[3] Presidential Policy Directive, PPD-8 – National Preparedness, http://www.dhs.gov/presidential-policy-directive-8-national-preparedness.
[4] National Preparedness Goal, https://www.fema.gov/national-preparedness-goal.
[5] National Preparedness Goal, Core Capabilities, https://www.fema.gov/core-capabilities.
[6] National Prevention Framework, http://www.fema.gov/media-library-data/20130726-1913-25045-6071/final_national_prevention_framework_20130501.pdf, page 1.

documents also emphasize the role of community and local government in recovery and especially in pre-event planning for the recovery.

The PPD-8 framework documents distinguish between community and local government. The PPD-8 documents consider communities as "unified groups that share goals, values, or purposes, and may operate independently of geographic boundaries or jurisdictions."[7] When NIST refers to "community" in the Disaster Resilience Framework, it refers to an entity defined by a clear geographical boundary and a governance structure capable of making or influencing decisions that affect resilience. The NIST Disaster Resilience Framework recognizes the importance of these organizations to community resilience, but relies on the local government to coordinate closely with these organizations when establishing plans and priorities for the built environment, so that these organizations are able to carry out their roles in support of response and recovery when disruptive events occur.

The NIST Disaster Resilience Framework complements the PPD-8 framework documents by providing a methodology and specific guidance for developing a prioritization plan, at the local level, to reestablish the function of buildings and infrastructure following a disruptive event, so as to meet the societal goals of the community. The Disaster Resilience Framework allows communities to consider interdependencies among buildings, infrastructure and the social and economic systems present in the community. The Disaster Resilience Framework also considers potential downstream cascading effects that occur from disruptions in these systems. The Disaster Resilience Framework provides a critical to identify and address opportunities to enhance resilience.

1.6.2. Disaster Mitigation Assessment

Nearly 24,000 communities, representing 80% of the people in the United States, have developed mitigation plans in accordance with FEMA Disaster Mitigation Assessment guidance[8], based on the Disaster Mitigation Act of 2000[9]. As mitigation is a component of resilience, these communities are taking substantive steps toward planning for resilience. A planning process that includes a detailed consideration of the built environment as outlined in the Disaster Resilience Framework and incorporates ongoing mitigation planning provides a comprehensive understanding of community resilience.

With the existing community mitigation planning structures, expanding the scope to resilience is the next logical step. Those already involved in mitigation activities have similar types of roles and responsibilities needed for resilience. The mitigation planning process emphasizes public participation in vetting mitigation strategies with targets, actions and priorities. Community resilience plans can be built around existing mitigation plans using the framework techniques related to the built environment.

1.7. Disaster Resilience Framework and Supporting Activities

1.7.1. Disaster Resilience Framework

The framework addresses resilience at the community scale, and provides an adaptable process for communities of varying size and complexity. Communities have a governance structure that can lead development, manage resources, and enforce codes, standards, regulations and other policies. In implementing mitigation and recovery planning, community resilience planning aims to engage the whole community to transform their interdependencies into opportunities for progressive investments in their future that have tangible, everyday benefits with big payoffs.

Resilience of the built environment can be assessed at local, regional, or national scales, depending on the infrastructure systems under consideration and the entity conducting the assessment. For instance, many electric power systems provide service to a region with a number of communities. A resilience assessment

[7] National Protection Framework, http://www.fema.gov/media-library-data/1406717583765-996837bf788e20e977eb5079f4174240/FINAL_National_Protection_Framework_20140729.pdf, page 6.
[8] https://www.fema.gov/multi-hazard-mitigation-plan-status
[9] https://www.fema.gov/media-library/assets/documents/4596

by the power company of its system would likely be at a regional scale. However, a community receiving service from the power company would assess the resilience of its infrastructure systems within the community boundaries, based on individually established needs and performance goals. Part of the community resilience plan should include coordination with and input from the power company to inform the community performance goals. While a community will not own all the infrastructure systems operating within its boundaries, their plans should include input from building and infrastructure system owners.

The framework provides guidance on how to identify a community's social functions and establish supporting performance goals for recovery of function for the built environment. Achieving a resilient built environment requires the participation of many parties, from decision makers to system operators and users of the systems. Thus, this framework is intended for several audiences: community-level decision makers, owners and operators of buildings and infrastructure systems, and planners and designers of the built environment.

The executive summary provides an overview of why community resilience should be incorporated into community development plans, community resilience activities, and how other ongoing plans, such as mitigation plans, can be incorporated into community resilience plans. Chapters 2 to 4 provide community level guidance for resilience planning and describe the process for setting performance goals, identifying hazards and vulnerabilities, and planning for recovery after a hazard event. These chapters should inform those tasked with developing community level plans and coordinating with owners and operators of infrastructure systems and organizations. Chapters 5 to 9 offer specific resilience guidance for buildings and infrastructure systems and Chapter 10 provides guidance on available resilience tools and metrics.

Chapter 2 supplies guidance on the types of social functions and vulnerabilities that a community may need to address following a disaster event, including education, health care, economic and government functions, and on how social needs can help define the performance goals for the built environment.

Chapter 3 presents guidance on developing integrated performance goals for recovery of the community, independent of hazards. In other words, the community needs to envision how it wants to function during, and recover after, an event. It is strongly recommended that communities define performance goals for several levels of a hazard: routine hazards, expected hazards, and extreme hazards. When the performance goals are evaluated for each hazard level, different vulnerabilities may be identified.

Chapter 4 addresses known interdependencies between infrastructure systems, and identifies the types of cascading events that may occur given the failure of an individual infrastructure system. Knowledge of possible dependencies will improve recovery planning.

Chapters 5 to 9 describe the process in more detail for buildings, building clusters and infrastructure systems (i.e., transportation, power, communication, and water and wastewater systems), with a focus on owners and operators. The guidance includes considerations for determining desired and expected performance goals for recovery of function, based on the guidance provided in Chapter 3. These chapters also describe the types of systems that should be considered and the regulatory environment under which they are designed. Primary codes, standards, tools, and best practices are also identified.

Chapter 10 provides an annotated listing of available metrics and tools to support resilience planning and implementation.

Due to the significant breadth of stakeholders and knowledge required to develop this report, NIST consulted experts in each of the infrastructure domains, held a series of workshops to engage a number of stakeholders across the country, and solicited public comments during the framework development.

1.7.2. Disaster Resilience Standards Panel

A Disaster Resilience Standards Panel (DRSP), representing the broad spectrum of the stakeholder community, will support the further framework development and refinement. The DRSP will operate as an independent organization for the broad range of stakeholders to address community resilience issues. Stakeholder interests include community planning, disaster recovery, emergency management, business continuity, insurance/re-insurance, state and local government, design, construction, and maintenance of buildings and infrastructure systems (water and wastewater, energy, communications, transportation), and standards and code development. The DRSP will also develop Model Resilience Guidelines for communities to enhance their disaster resilience.

1.7.3. Model Resilience Guidelines

The Model Resilience Guidelines will promote best practices and help communities develop their own disaster resilience plan. Expected topics include:

- Disaster-Resilient Performance Goals for Buildings and Infrastructure Systems
- Evaluating Community Disaster Resilience
- Procedures for Achieving Resilience Performance Goals
- Prioritizing Risk Reduction Activities at the Community Level

1.8. References

FEMA (2011) Presidential Disaster Declarations, January 10, 2000 to January 1, 2011, https://www.hsdl.org/?view&did=12383

Flora, C.B, M. Emery, S. Fey, C. Bregendahl (2008) Community Capitals: A Tool for Evaluating Strategic Interventions and Projects. Pp. 1186-1187 in Goreham ed., *Encyclopedia of Rural America: The Land and People*. Millerton, N.Y.: Grey House Publishing

McAllister, T.P. (2013) Developing Guidelines and Standards for Disaster Resilience of the Built Environment: A Research Needs Assessment, NIST TN 1795, National Institute of Standards and Technology, Gaithersburg, MD, 20899.

NAC (2012) Disaster Resilience, A National Imperative, The National Academies Press, Washington D.C., www.nap.edu

PPD-21 (2013) Presidential Policy Directive/PPD-21, The White House, March 30, 2011. http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

2. The Social Context for Community Resilience

2.1. Introduction

Achieving community resilience is a social process; hazard events can damage the built environment, making it difficult for the community to function. This framework provides communities with a methodology to plan for resilience by prioritizing buildings and infrastructure systems based on their importance in supporting the social and economic functions in the community. In other words, ***the social and economic functions of a community drive the requirements of the built environment.***

For the purpose of this framework, a community is defined as "people who live, work, learn, and/or play together under the jurisdiction of a governance structure, such as a town, city or county." However, it is acknowledged that "community" can also refer to groupings of people based on a number of other factors, including geography, demographics, values, common interests or goals, and economics. For example, the five frameworks within the National Preparedness Goal[1] define community as "groups that share goals, values, and institutions. They are not always bound by geographic boundaries or political subdivisions. Instead, they may be faith-based organizations, neighborhood partnerships, advocacy groups, academia, social and community groups, and associations." However, there is value in defining community by the presence of a local governance structure. It is within this structure that community leaders (both public and private) can come together to make decisions and take steps that improve the resilience of their community.

This chapter can guide community thinking on the social and economic drivers for community resilience of the built environment. This chapter describes the social dimensions of communities, highlighting the needs of community members and the ways in which communities can organize to meet these needs (i.e., via social institutions, or the pattern of beliefs and behaviors that meet basic individual and household needs), while acknowledging that any type of organizational system can foster inequalities among people within a community. This chapter discusses a process of prioritizing social institutions, and in turn, the built environment, when planning for resilience, by identifying the ways social institutions rely on each other and the built environment to function. In an attempt to help communities plan for resilience, this chapter also provides examples of communities that experienced extreme disasters and implemented their own prioritization processes for restoration, reconstruction, and recovery. The chapter concludes with a discussion of the importance of community engagement during the resilience planning process.

2.2. Social Dimensions of a Community

The term, community, as defined in this framework, is situated between neighborhoods (which are made up of individuals and families) and states, regions and/or provinces, and the nation. Figure 2-1 shows this organization. Although communities often interact with state, regional, and national entities, this chapter focuses on individuals and families who live within neighborhoods and interact with their local systems, services, and the entities that exist in their communities to meet their needs.

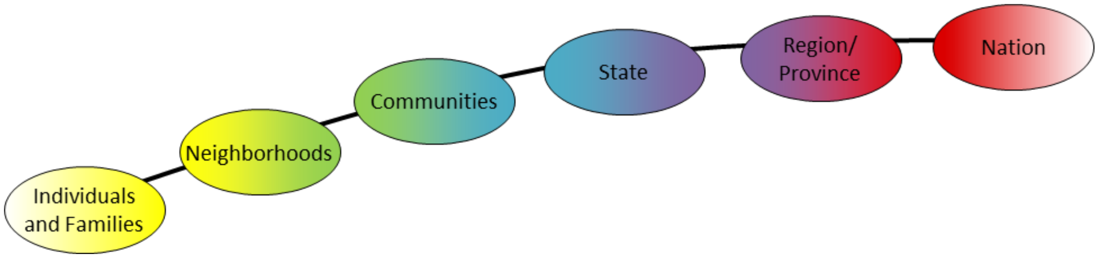


Figure 2-1: Levels of a Community (Adapted from John Plodinec, CARRI, redrawn here)

[1] https://www.fema.gov/national-preparedness-goal

2.2.1. Understanding Needs of Community Members

Individuals and households in any community have a set of needs they strive to meet on a daily basis. Figure 2-2 presents these individual/household needs in a hierarchical manner, showing the most fundamental needs at the bottom (survival).[2] Although there are more detailed conceptual models that discuss human needs (e.g., see Max-Neef 1991) this approach – adapted from Maslow's Hierarchy of Needs (1943) – captures the most essential dimensions with which this chapter is concerned.

The first and most fundamental need is that of survival. Survival includes necessary physical requirements, such as air, water, food, shelter, and clothing. If these needs are not met, the human body cannot sustain life – people cannot live longer than 5 days without water and 6 weeks without food (assuming inadequate water supply).[3] Survival also includes protection of life from the aforementioned disasters.

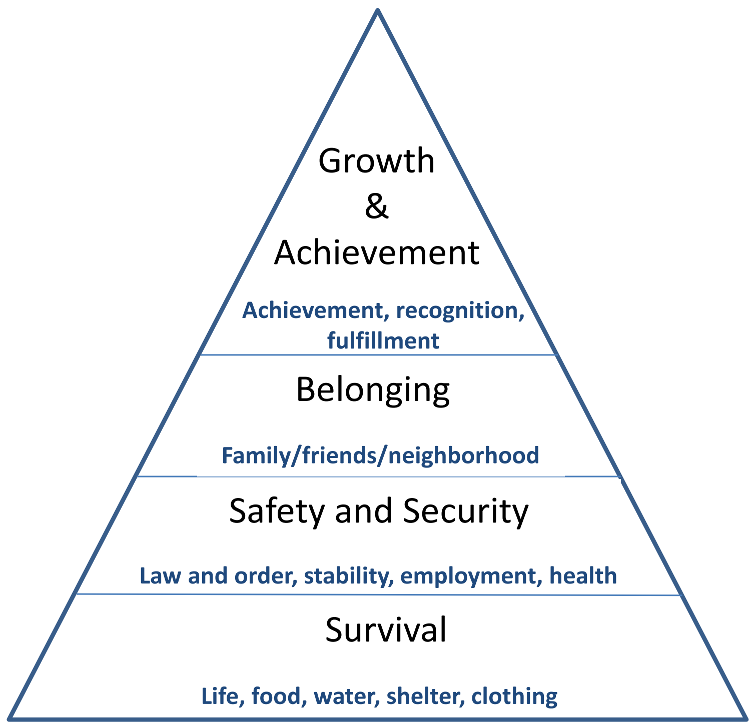


Figure 2-2: The hierarchy of human needs (Adapted from Maslow's Hierarchy of Needs – a psychological perspective)

The second need, safety and security, includes all aspects of personal, financial (economic) security, and health and well-being. People require safety and security in their personal lives from situations of violence, physical/verbal abuse, war, etc. They also must know their families and friendship networks are secure. Individuals need financial safety (e.g., job security, a consistent income, savings accounts, insurance policies, and other types of financial safety nets). Studies of disasters during the recovery phase[4,5] show that people are likely to relocate to another community in search of new employment[6] and/or economic gain (e.g., higher wages)[7], or because they lost access to their non-liquid assets (e.g., farm land or fishing boats).[8,9]

[2] Adapted from Maslow's Hierarchy of Needs – from a psychological perspective

[3] Scientific American. http://www.scientificamerican.com/article/how-long-can-a-person-sur/

[4] Dickinson, Simon Bernard. 2013. *Post-Disaster Mobilities: Exploring household relocation after the Canterbury Earthquakes*. M.S. Thesis, Department of Geography, University of Canterbury, Christchurch, NZ.

[5] Binder, Sherri Brokopp. 2014. *Resilience and Postdisaster Relocation: A study of New York's home buyout plan in the wake of Hurricane Sandy*. PhD Thesis, Department of Psychology, University of Hawaii, US.

[6] **Sanders, S., Bowie, S., & Bowie, Y.** (2003). Lessons learned on forced relocation of older adults: The impact of Hurricane Andrew on health, mental health, and social support of public housing residents. *Journal of Gerontological Social Work, 40* [4], 23-35; **Fraser, J. C., Doyle, M. W., & Young, H.** (2006). Creating Effective Flood Mitigation Policies. *Eos, 87*(27), 265–270; **Hunter, L. M.** (2005). Migration and Environmental Hazards. *Population and environment*, *26*(4), 273–302. doi:10.1007/s11111-005-3343-x.

[7] Belcher, J., & Bates, F. (1983). Aftermath of natural disasters: Coping through residential mobility. *Disasters, 7* [2], 118-128.

[8] Black, R., Kniveton, D., Skeldon, R., Coppard, D., Murata, A., & Schmidt-Verkerk, K. (2008). *Demographics and Climate Change: Future Trends and their Policy Implications for Migration.* Retrieved from http://r4d.dfid.gov.uk/PDF/Outputs/MigrationGlobPov/WP- T27.pdf.

[9] Gray, C., Frankenberg, E., Gillespie, T., Sumantri, C., & Thomas, D. (2009). *Population Displacement and Mobility in Sumatra after the Tsunami.* Retrieved from http://iussp2009.princeton. edu/papers/90318.

These studies emphasize the importance of providing employment and financial security to those within a community. Finally, people require safety from negative health conditions, so they can enjoy life and consistent well-being in their communities.

The third need is belonging, which can represent belonging and acceptance among various groups of people (e.g., family, friends, school groups, sports teams, work colleagues, religious congregation) or belonging to a place or location. In relation to groups of people, experts often discuss the concept of social capital within a community. Social capital describes the networks and relationships that connect members of a community[10], including the extensiveness and interconnectedness of social networks within the community, levels of civic engagement, and interpersonal, inter-organizational, and institutional trust.[11,12] Research into disaster recovery shows that the likelihood of people leaving a community increases when social networks are lost[9], showing the importance of a sense of belonging within a community.

In relation to place, disaster research demonstrates that individuals benefit from a strong sense of belonging to a place, which inhibits their desire to relocate after a disaster.[13,14] A strong place attachment or sense of belonging to a place can be influenced by, for example, home ownership or having strong, extensive social networks within the community.

[Note to reviewers: In a future draft, this section will be expanded, especially the importance of social capital within a community and what that might mean for different places around the U.S.]

The fourth need, at the top of Figure 2-2, is labeled "growth and achievement." Humans need to feel a sense of achievement and that they are respected in society. In the figure, this need is accompanied by a need for continual growth and exploration within society, including an individual's ability to realize his/her full potential – to accomplish all that he/she can – within his/her lifetime. Although these needs may seem less tangible than others, growth and achievement are as important as other needs, often being accomplished through educational achievement and/or participation in arts and recreation.

Maslow's hierarchy, supported by research studies from disaster recovery, identifies the functions of a resilient community.[15] For example, based on the hierarchy of needs, a resilient community: 1) safeguards human life; 2) delivers basic needs; 3) provides safety and security from a personal, financial, and health/well-being perspective; 4) facilitates human relationships and identification (with groups and to a place); and 5) supports growth and achievement. Communities perform all of these functions through social institutions.

2.2.2. Social Institutions Common to all Communities

A social institution is a complex, organized pattern of beliefs and behaviors that meets basic individual and household needs. Traditional studies identify five major institutions as common to all societies: 1) family, 2) education, 3) government, 4) religion, and 5) economy – each of which is overlapping and interdependent. Recent conceptualizations include broader notions of each institution, identifying additional types of social institutions. This chapter describes eight social institutions:

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[10] Reference the work of Robert Putnam and Daniel Aldrich's book on the topic Building Resilience.

[11] National Research Council of the National Academies. 2006. Facing Hazards and Disasters; Understanding human dimensions, National Academies Press, Washington, DC.

[12] Aldrich, D.P. and M.A. Meyer. 2014. "Social Capital and Community Resilience" American Behavioral Scientist, Published online 1 October 2014.

[13] Groen, J. A. and A.E. Polivka. 2009. *Going Home after Hurricane Katrina: Determinants of Return Migration and Changes in Affected Areas*. Working Paper 428. BLS Working papers, U.S. Department of Labor, U.S. Bureau of Labor Statistics.

[14] Cutter, S.L., K.D. Ash, C.T. Emrich. 2014. "The geographies of community disaster resilience" *Global Environmental Change*, Volume 29, Pages 65-77.

[15] City Resilience Framework. April 2014. http://www.sciencedirect.com/science/article/pii/S0959378014001459.

1. Family and Kinship
2. Economic
3. Government
4. Health Care
5. Education
6. Community Service Organizations
7. Religious Organizations and Others that Support Belief Systems
8. Media

Generally, these institutions satisfy the basic needs of society by defining dominant social values, socializing individuals, establishing patterns of social behavior, and providing roles for individuals. In doing so, institutions contribute to the welfare of society by preserving social order and supporting other institutions.[16] Sections 2.2.2.1 through 2.2.2.8 summarize the socially-based purposes and functions each institution serves in communities, as well as the human needs they meet in the context of Maslow's hierarchy.

2.2.2.1. Family and Kinship

Family is the first institution to which we are exposed within a community. Within a family, an individual can learn about the world and the importance of love, care, and a sense of belonging. The family unit is typically defined as a relationship between two or more people who are related by birth, marriage, or adoption. However, it is difficult to define fully what is meant by the term "family," since our understanding varies across cultures and over time. We might consider only those within our family of origin as part of our family unit, even limiting the family unit to those living in the same residence.[17] More often, however, our definition of family broadens to include extended family members (e.g., grandparents, aunts, uncles and cousins), or even long-time friends, friends of family, or other individuals who are not related by blood or marriage. Tight, close-knit bonds are developed within family/kinship units that, among other factors, can determine a community's level of resilience in response to a hazard/disaster event.[18]

Proximity of family members to one another is also an important consideration. Family members may live within the same residence or different residences within the same community, providing larger numbers of close-knit groups within a community to respond and recover from an event. In other cases, family members may live in different geographical parts of the world. While such distance may decrease the opportunity for social capital, it provides additional sheltering options to family members who wish to evacuate a community that has been disrupted by a hazard event, either temporarily or permanently.

Family or kinship units exist to support all human needs in Maslow's hierarchy, from the very basic needs to the need for growth and achievement. It is the responsibility of the family or kinship unit to provide

[16] Notably, this description is primarily a functionalist characterization of social institutions, which may be met with some criticism. For example, the functionalist perspective tends to dismiss the role of human agency with respect to institutions and focuses on maintenance of the status quo – which are necessary in creating and supporting resilience. Readers are encouraged to consider social institutions to better understand which ways social needs are linked to and rely upon the built environment, rather than employing a strict functionalist approach.

[17] "The Concept of The Family: Demographic and Genealogical Perspectives" by Charles B. Nam: http://www.ncsociology.org/sociationtoday/v22/family.htm

[18] Aldrich, D.P. and M.A. Meyer. 2014. "Social Capital and Community Resilience" American Behavioral Scientist, Published online 1 October 2014. Ritchie, L.A. and Gill, D.A. Forthcoming. "The Role of Social Capital in Community Disaster Resilience." Invited book chapter for *The Resiliency Challenge: Transforming Theory to Reality*. Virginia Tech Center for Community Security and Resilience.

support and resources to meet survival, safety and security, belonging and acceptance, and growth and achievement needs.

2.2.2.2. Economic

Economic institutions facilitate the allocation of scarce resources across society. Producers and suppliers combine factors of production (e.g., land, labor, and capital) to create goods and services that meet the needs and desires of consumers. The availability of production factors, along with the demand of consumers, determines the final mix of goods and services produced, supplied, and consumed.

The economy is a mechanism by which most human needs are satisfied. While not all needs are provided for, the economy produces goods and services that fulfill some element of survival, safety and security, belonging, and growth and achievement from Maslow's hierarchy. Some needs are met through the direct consumption of goods and services (e.g., food and shelter). Other needs are satisfied as a result of a functioning economy. For example, employment affords individuals the means to provide, but also can afford opportunities for (career) growth and achievement. Further, many commercial and for-profit venues (such as colleges, shopping malls, barbershops, and restaurants) facilitate the social gatherings of individuals with shared interests and life experiences, providing people with a sense of belonging. It is obvious then, that the pursuit of economic interests also creates values that have no market; yet, these potentially large, non-market values are also vulnerable to disasters.

Good Production and Service Supply. Industries within the economy are classified by their production or supply role. Three economic sectors exist: primary, secondary, and tertiary.

- *Primary Economic Sector:* this sector includes producers of raw materials, such as the agriculture, forestry, fishing, and mining industries. In 2011, these industries represented 3.1% of U.S. gross domestic product.[19]
- *Secondary Economic Sector*: This sector includes producers of goods, such as the manufacturing and construction industries. In 2011, these industries represented 15.9% of U.S. gross domestic product.
- *Tertiary Economic Sector*: This sector includes suppliers of services, such as utilities, wholesale and retail trade, transportation and warehousing, information, financial activities, professional and business services, education services, health care and social assistance, leisure and hospitality, other services, and federal, state, and local government. In 2011, these industries represented 81.0% of U.S. gross domestic product.

Labor Supply. Of the 316 million people in the U.S. in 2013, approximately 144 million were employed, with around 11 million, aged 16 and over, unemployed (Table 2-1). Unemployed individuals are those that do not have a job, have recently looked for work, and are able to work. Industries that have low unemployment and high weekly hours might find it difficult to handle a disruption. For example, mining, quarrying, and oil and gas extraction has few unemployed individuals, who are likely spread out over a large area. Additionally, they work long hours compared to other industries. This situation might make it difficult for this industry to adapt to a disruption as few workers can fill in and the workers in place could not increase their hours by as much as other industries.

[19] Gross domestic product (GDP) is the market value of goods and services produced by labor and capital in a country. In 2011, U.S. GDP measured $15.1 trillion.

Table 2-1: U.S. Employment Characteristics, 2013 (Bureau of Labor Statistics, 2015)

	Employed (Thousands)	Unemployed (Thousands)	Avg Wkly Hours		Avg Hourly Earnings	
Agriculture and related	2 130	141	-		-	
Mining, quarrying, and oil and gas extraction	1 065	64	43.90		29.73	
Construction	9 271	935	39.00		26.12	
Manufacturing	14 869	1 019	40.80		24.35	
Wholesale and retail trade	19 653	1 463	35.05	*	22.13	*
Transportation and utilities	7 415	406	40.45	**	28.77	**
Information	2 960	175	36.70		32.90	
Financial activities	9 849	424	37.10		30.15	
Professional and business services	16 793	1 284	36.10		28.52	
Education and health services	32 535	1 098	32.70		24.44	
Leisure and hospitality	13 554	1 379	26.00		13.50	
Other services	7 127	445	31.70		21.40	
Public administration/Government	6 708	851	-		-	
Self-employed, family, and other	-	1 774	-		-	
Total	**143 929**	**11 458**	**-**		**-**	

* Average of wholesale trade and retail trade
** Average of transportation/warehousing and utilities

Source: Bureau of Labor Statistics. Current Population Survey. <www.bls.gov>

Consumer Demand. In 2013, personal consumption expenditures amounted to $11.5 trillion or 68% of GDP, while investment amounted to $2.6 trillion (16% of GDP). Government consumption amounted to $3.1 trillion (19% of GDP), and net exports were $-508.2 billion. As seen in Table 2-2, approximately a third of personal consumption expenditures went toward goods, while the rest went towards services.

Table 2-2: Consumption Expenditures as a Percent of Total, by Type of Product (2013)

Goods	34%	Services	66%
• Durable goods	11%	• Household consumption	64%
▪ Motor vehicles and parts	4%	▪ Housing and utilities	18%
▪ Furnishings and household equipment	2%	▪ Health care	17%
▪ Recreational goods and vehicles	3%	▪ Transportation services	3%
▪ Other durable goods	2%	▪ Recreation services	4%
• Nondurable goods	23%	▪ Food services and accommodations	6%
▪ Food and beverages (off-premises)	8%	▪ Financial services and insurance	7%
▪ Clothing and footwear	3%	▪ Other services	9%
▪ Gasoline and other energy goods	4%	• Consumption expenditures of nonprofit institutions serving households	3%
▪ Other nondurable goods	8%		

2.2.2.3. Government

Governments exist at the national, state, and local levels to write, execute, and interpret and enforce laws and regulations. The government acts as a mechanism by which human needs are satisfied, many of which are not provided for in the private market due to inefficiencies. The government's roles and functions are typically divided across the executive, legislative, and judicial branches. Laws, regulations, and services provided by the government protect life and property, preserve peace and well-being, strengthen group identity and norms, and define social and economic goals for the future. In response to a disaster, the government may provide for many of Maslow's needs, starting with the necessities of food, water, and shelter and extending through safety and security. However, the governmental entity providing service may shift during a disaster from federal to local, or even necessitate change from private to public, for example; and such shifts could alter local reliance on the built environment.

Local governments, which are the focus of this framework, are made up of general and specific purpose entities. General purpose entities include county, municipal, and township governments. Specific purpose entities are more singular in function, such as school districts. In 2012, there were 90,059 local governments, with 43% serving a general purpose.[20]

Community Development. Community development is a major issue for local communities. Community development largely consists of attracting and retaining businesses and jobs, enhancing local amenities, addressing poverty and inequality, and maintaining the quality of the local environment. Communities that cannot attract and retain businesses and jobs tend to fare more poorly after disasters than communities that can. Generally, a community that cannot attract and retain businesses and jobs is in decline.

For most cities, local revenue sources consist of some combination of property and sales tax. Sales tax revenue is increased by attracting commercial businesses and jobs. Property tax revenue is generally increased by rising property values. Improving disaster resilience can help increase property values, since a reduction in losses that a property owner will suffer increases the value of that property to the owner.

Poverty & Income Distribution. Poverty and income distribution are also a major concern of local communities. Many projects communities pursue are aimed at decreasing poverty in their neighborhoods; and many external funding sources available to communities are aimed at alleviating poverty. These issues intersect with disaster resilience in that the disadvantaged are often most vulnerable to disasters. Improving disaster resilience often starts with protecting the disadvantaged.

Local communities often hope to improve the quality of life for residents by developing and improving local amenities. Often communities hope that improving local amenities will indirectly attract and retain businesses and jobs. Providing local services is a core function of local governments. In particular, local governments typically supply schools, roads and public safety. Public safety and roads directly impact the resilience of a community in the face of hazards. Schools serve as an amenity that can attract jobs and businesses.

Sustainability. Local governments are interested in ensuring their communities are sustainable, via two distinct ideas. First, local governments hope to protect and improve their environments. Being “green” and maintaining a small footprint are important to local communities. In turn, these can impact disaster resilience. Second, local governments strive for a vibrant and thriving economy. Communities with weak economies tend to fare poorly, relative to those with stronger economies, after disasters.

2.2.2.4. Health Care

Health is a “state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.”[21] Health care is the social institution within a community that specializes in promoting, monitoring, maintaining, and restoring health.[22] According to the World Health Organization, regardless of how they are organized, all health systems have to carry out six basic functions: 1) provide health services; 2) develop health workers; 3) develop a functioning health information system; 4) provide equitable access to essential medical products, vaccines, and technologies; 5) mobilize and allocate finances; and 6) ensure leadership and governance.[22]

[20] http://www2.census.gov/govs/cog/g12_org.pdf
[21] Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.
[22] WHO framework: http://www.who.int/healthsystems/strategy/everybodys_business.pdf.

The health care institution primarily meets the survival, and safety and security needs of Maslow's hierarchy. However, a community may consider that, through obtaining a higher level of well-being for its members, a strong community-based health care system can assist with the need for belonging as well as growth and achievement.

Health care systems consist of a complex and diverse set of players. Many individuals and organizations are involved in the health care system, including educational and research institutions, medical suppliers, insurers, health care providers, payers (e.g., commercial insurers and employers), claims processers, and regulators/policy makers.[23] Within the health care system, many of these groups can fall under other institutions that are discussed in this section, including education, the economy, and government.

The different types of services delivered by health care providers within a community, however, are unique to the healthcare institution:[23,24]

- ***Preventative care*** – aims to prevent future injury or illness, including blood pressure, diabetes and cholesterol tests, cancer screenings, counseling on topics such as quitting smoking or losing weight, routine vaccinations, counseling, screening and vaccinations to ensure healthy pregnancies, and flu shots[25]
- ***Primary care*** – provides integrated health care services aimed at providing the patient with a broad spectrum of preventative and curative care over a period of time[26]
- ***Specialized care*** – provides specialized care by physicians trained in a particular field (e.g., neurology, cardiology, dermatology, etc.), usually upon referral from primary care[27]
- ***Chronic or long-term care*** – addresses pre-existing or long-term illness
- ***Sub-acute care*** – needed by a patients who do not require hospital care (acute care), yet need more intensive skilled nursing care[28]
- ***Acute care*** – addresses short-term or severe illness with a shorter timeframe (i.e., emergency care)
- ***Rehabilitative care*** – aids a person in restoring lost skills or function from an injury or illness (physical or mental)
- ***End-of-life care*** – care for those facing a life-limiting illness or injury
- ***Mental or behavioral health care*** – treating health conditions that "are characterized by alterations in thinking, mood, or behavior (or some combination thereof) associated with distress and/or impaired functioning."[29] Depression is the most common mental illness. Experts believe depression will be the second leading cause of disability throughout the world by 2020.[30]

An element of each of these services can include prescription of medication to patients, highlighting the increasing importance of pharmacy services and staff.

One important difference among all health care services is the urgency of care. Some services, for example, acute and chronic or long-term care (i.e., assisted living facilities, nursing homes, adult homes),

[23] Shi, Leiyu and Douglas A. Singh 2008. Delivering Health Care in America: A systems approach. Jones & Bartlett Learning, …
[24] Module 5: Healthcare Systems, US Healthcare Delivery Systems (Appropriate reference needed for this presentation), link: http://www.aptrweb.org/?page=module5.
[25] http://www.hhs.gov/healthcare/rights/preventive-care/
[26] http://www.medicinenet.com/script/main/art.asp?articlekey=5042
[27] http://www.hopkinsmedicine.org/patient_care/pay_bill/insurance_footnotes.html
[28] http://www.dhcs.ca.gov/provgovpart/Pages/SubacuteCare.aspx
[29] U.S. Department of Health and Human Services. *Mental Health: A Report of the Surgeon General.* Rockville, MD: U.S. Department of Health and Human Services; Substance Abuse and Mental Health Services Administration, Center for Mental Health Services, National Institutes of Health, National Institute of Mental Health, 1999.
[30] http://www.cdc.gov/mentalhealth/basics.htm

provide patients with critical, life-saving care. Each community must assess health care services provided to its members and assign priority to those services rated as most critical.

2.2.2.5. Education

Education is the primary social institution dedicated to the transfer of knowledge, skills, and values from one individual or group to another. Typically, when one thinks of education, formal education comes to mind. Formal education can begin in nursery school, and continues through primary and secondary school – often referred to as elementary, middle, and high schools. Formal education also includes higher education in colleges and universities.

Formal education typically exposes young people to societal norms, customs, and ideologies; provides a means for cultural innovation and social integration; and facilitates their understanding of social roles. By its very nature, formal education serves the secondary, but equally important, functions of providing childcare for one-parent or two-career families and establishing social networks.

Knowledge, skills, and values transfer in other ways within the education institution, including adult education (or continuing education), special education, and informal education. Adult education provides educational programs or courses for adults who are out of the formal education system. Adult education ranges from basic literacy to personal fulfillment (e.g., culinary or language classes) to attainment of an advanced degree.[31] Special education provides "specifically-designed instruction to meet the unique needs of a child [or adult] with a disability."[32] Finally, informal education can include any other means of knowledge, skills, or value transfer, including visiting museums, reading books, attending book clubs, or participating in recreational classes or demonstrations.

The educational institution primarily meets the growth and achievement needs of Maslow's hierarchy. However, attending any of the forms of education, described in the preceding paragraphs, satisfies an individual's need for belonging. Additionally, formal educational institutions provide meals to children in nursery, primary, and secondary schools, meeting the survival need.

2.2.2.6. Community Service Organizations

Community service organizations (CSOs) are non-profit and non-governmental entities of varying sizes and missions that provide services to individuals around the U.S. It is important to note here that, while organizations such as the Red Cross and the Salvation Army – which are active in disaster-related response and recovery efforts – may be considered CSOs, this section also considers organizations that do not necessarily have a disaster-related focus as part of their missions. Generally speaking, these organizations tend to operate at a local level, often relying on volunteers to support minimal full-time staff. CSOs typically focus in the arenas of human services, natural environment conservation or restoration, and urban safety and revitalization.[33] At the most fundamental level, CSOs may assist individuals in meeting basic needs, such as shelter, food, and clothing, as well as provide emotional and mental health support. They may also enhance the overall quality of life in a community by engaging in work related to neighborhood revitalization, affordable housing, food security, accessible transportation, senior citizens associations, community sustainability, humanitarian/disaster response, medical relief funds, after school programs, youth homes and centers, skill building and education, and civic engagement.

With respect to Maslow's hierarchy, CSOs address human needs related to survival, safety and security, belonging, and growth and achievement. The nature of the needs met by any given CSO depends on its mission and the people it serves. In many cases, CSOs fulfill daily needs of survival, safety and security,

[31] http://adulted.about.com/od/whatisadultlearning/p/whatisadulteducation.htm
[32] http://idea.ed.gov/explore/view/p/,root,regs,300,A,300%252E39,
[33] http://eder671nonprofit.pbworks.com/w/page/18541471/CBOs%20-%20Introduction

belonging, and growth and achievement for the elderly, people living in poverty, racial and ethnic minority groups, people with disabilities, and those suffering from chronic debilitating illness. These needs may not otherwise be met by traditional family and kinship groups. Other types of CSOs, such as civic, social, and recreational clubs (e.g., Rotary Clubs, Boys and Girls Clubs, after school programs) are more likely to meet, on a regular basis, the needs associated with belonging and growth and achievement, rather than meeting basic needs. CSOs that comprise this social institution depend upon other social institutions, as well as on the built environment.

2.2.2.7. Religious Organizations and Others that Support Belief Systems

This section addresses social institutions, including religious organizations, as well as other groups that support various belief systems, such as philosophies, ideologies, and science. From a traditional sociological perspective, religion is one of society's fundamental institutions.

As an institution, religion involves shared patterns of beliefs and behaviors that bring people together, helping them to understand the meaning and purpose of life. Religion is additionally characterized as groups that provide a sense of solidarity and common purpose.[34] Generally, the institution of religion facilitates social cohesion, emotional support, and social control, in addition to serving as an instrument for socialization and providing answers for unexplained natural phenomena. Organizations, other than religious, that support belief systems serve a similar function.

As an institution, organizations that support belief systems primarily meet the belonging and growth and achievement needs identified by Maslow. In some cases, they also address basic survival needs by providing food and shelter.

2.2.2.8. Media

Mass media refers to the channels of communication that, in some way, disseminate information to large numbers of people. A channel or form of communication is often referred to as "one-to-many" in that one person (for example, the author of a book) communicates his/her information to an audience of many. The communication is one-way, as there is rarely an ability to provide feedback to the author.[35] Mass media requires a vehicle – often print media (e.g., newspaper, books, magazines), radio, television, cable, and telecommunications (e.g., internet sites).

Within the last 25 years, the opportunity for many-to-many communication was created with development of computer networks. Internet chatrooms, peer-to-peer networks, and social network media provide means for mass audiences to simultaneously interact and communicate with each other.

The mass media institution has four main functions and four additional sub-functions. The main four functions are: dissemination of information, education of the masses (directly or indirectly, via documentaries, interviews, etc.), entertainment, and persuasion. Additional sub-functions include surveillance (watching society to warn about threatening actions); interpretation (supplying data and facts, explaining and interpreting events and situations); linkages, joining together other types of social institutions (Section 2.5.1); and socialization or the transmission of culture.[36]

The media connects individuals with information from around the world, the nation, the state, and the local community. Most communities have local media outlets that disseminate information about local conditions on a daily basis, via local newspapers, websites, magazines, radio stations, and/or television. Additionally, some local communities house main offices or headquarters of world-, national-, or state-level news outlets. For example, CNN's world headquarters is located in Atlanta, GA.

[34] https://globalsociology.pbworks.com/w/page/14711247/Religion
[35] http://www.sociology.org.uk/media_defined.pdf
[36] http://theonlinemedia.blogspot.com/2012/06/functions-of-mass-media.html

When a hazard event occurs, information about the event can come from any level of mass media. Depending upon the hazard event's lead or warning time, all levels of news outlets often rush to the location provide coverage. For hazard events with little or no lead-time, local media broadcasters and writers are often first on scene; however, within hours or days, media outlets from around the world converge to cover the story. It is not until days – or even weeks – after an event, when all larger-scale media outlets have left the area, that the dissemination of response and recovery information falls solely to local media sources.

The media institution, at all levels, meets many of Maslow's hierarchy of needs. First, media meets safety and security needs, by providing information, interpretation and surveillance to the masses. Additionally, via its socialization function, it promotes belonging among its audience. Finally, the media institution meets the need for growth and achievement by educating and entertaining society.

2.2.3. Social Vulnerabilities and Disasters

In thinking about the roles of institutions in a community, it is important to recognize and address social vulnerability and inequity. Not all people use these systems and/or have access to community systems in the same ways. Therefore, the needs of everyone likely to be affected in a disaster (or on a day-to-day basis), such as the elderly, people living in poverty, racial and ethnic minority groups, disabled, and those suffering from chronic illness, may not be addressed. In addition, renters, students, single-parent families, small business owners, culturally diverse groups, and historic neighborhoods may not be adequately represented. [37] Therefore, interactions of individuals/households with community systems can introduce inequalities among certain subpopulations of a community.

These inequalities tend to worsen in the context of a disaster. Specifically, a large and growing body of empirical research on hazards and disasters shows that risk is not distributed or shared equally across all groups.[37] Pre-disaster vulnerability, inherent in social institutions, may negatively impact response, recovery, and resilience following a disaster event. For example, some individuals and groups face greater risks than others based upon where they are located in the community, the buildings in which they are located (e.g., inferior housing), or having to rely only on public transportation. These groups are also more likely to be marginalized from the political process, with little voice in disaster planning, response, and recovery activities.

[Note to reviewers: Additional text will be added here (i.e., Paton, Phillips Chapter 2, specifically noting that vulnerable populations bring resources to the table – e.g., Community and advocacy groups represent important sources of information and links to particular populations); Will also mention that community engagement and its importance is discussed at length later in this chapter.]

Vulnerability and inequity are mentioned here to ensure all community members and their resources (or lack of resources) are considered when planning for resilience. Community leaders should identify those populations who are most affected – not only in and after a disaster, but also on a day-to-day basis, to make resilience-based decisions that improve life-safety and the well-being of all community members. Communities can assess their social vulnerability using a variety of tools, including the Social Vulnerability Index,[38] and obtain further information on vulnerable populations here.[37]

2.3. Prioritization of Social Institutions and their Functions

The previous section (2.2) of this chapter discussed the social dimensions of a community, including individuals, families, neighborhoods, and the social institutions that exist to support the needs of community members. Additionally, Section 2.2.3 draws attention to the fact that not all community

[37] Phillips, Brenda. 2009. *Disaster Recovery.* Boca Raton, FL: Taylor and Francis CRC Press.
[38] Reference to the Social Vulnerability Index (University of South Carolina): http://webra.cas.sc.edu/hvri/products/sovi.aspx

members have equal access to social institutions. Overall, this chapter described eight social institutions in detail, including their functions, services, and the ways they meet particular needs from Maslow's hierarchy.

It is important to understand the types of social institutions present in a community, especially in resilience planning, because hazard events can interrupt the functions of these institutions. Hazards can damage the built environment, making it more difficult for the community, and in turn, its social institutions, to function. However, social institutions may not all carry the same weight within a community – in that they meet different needs of communities in different ways, and some needs (as shown by Maslow's hierarchy) are more urgent than others, especially immediately after an extreme event. Therefore, the community must decide which social institutions (or aspects of those institutions) are required to function without interruption after a disaster (e.g., critical health care), while others can withstand partial functioning for some previously designated period of time (e.g., education). These types of decisions are made by the community when planning for resilience.

To help communities prioritize their social institutions, functions, and, in turn, their buildings and infrastructure systems, communities must answer the following questions: 1) ***How do social institutions rely on the built environment to function?*** and 2) ***How do social institutions rely on one another to function?***

First, note that not all social institutions rely on the built environment in the same way. Some institutions rely more heavily on the built environment (for example health care via hospitals or other specialized buildings), while other institutions are less reliant. A religious congregation, for example, does not require a building in which to gather or worship.

Second, social institutions rely on one another to function as well. This reliance is called "interdependencies" among social institutions. Even within particular institutions, such as the economic or government institutions, industries/entities rely on each another to perform their functions. Communities should understand this interconnectedness when planning for resilience.

The following two sections discuss the ways in which social institutions rely on the built environment (Section 2.3.1) and each other (Section 2.3.2). In each case, for each social institution, we provide examples of linkages.

2.3.1. Dependence of Social Institutions on the Built Environment

The built environment supports many of the functions of social institutions within a community. It is important that a community's own social institutions identify the ways in which the built environment supports each institution's functions. Each of the following sections offers several examples of linkages between social institutions and the built environment, specifically buildings, transportation, water/wastewater, power/energy, and communication systems under normal circumstances. Additional examples are provided to explore additional linkages between social institutions and the built environment in the event of a disaster.

2.3.1.1. Family and Kinship

In meeting the needs of Maslow's hierarchy, members of the family unit rely on one another and other social institutions, as well as on the built environment. The family institution relies directly on the built environment for housing and protection to meet its survival needs. Members of the family unit also rely on the built environment to communicate with one another, to meet its safety and security, belonging, and growth and achievement needs.

Table 2-1 provides examples of the ways the family and kinship institution relies on the built environment on a regular, day-to-day basis. In a disaster, additional links between family and the built environment can be made, including the link between transportation and family for evacuation, or the link between communication and family to establish situational awareness about family members' safety after a hazard event occurs. Additionally, transportation and communication can be used to reunite family members following an event.

2.3.1.2. Economic

The built environment is integral to the U.S. economy. For example, buildings house manufacturing facilities, raw material processing plants, office space, commercial retail sales points, the workforce, and consumers. Water and power systems are used to create goods and services. Transportation is used to distribute raw materials and intermediate goods to producers and final goods to consumers. Communication networks transmit supply and demand signals. Components of the built environment also represent some of the final goods produced from economic activity. The built environment supports functions of the economy *and* is owned and/or created by it.

Structures and critical infrastructure often play several roles in supporting economic activity. For example, roads support the transport of (1) raw materials to production facilities, (2) final goods to retail stores, and ultimately, to consumers, and (3) workers to their places of employment. Disruptions to individual components of the built environment have the potential to ripple through the economy.

Table 2-2 through Table 2-6 illustrate some of the ways the built environment supports economic activity. It is important to acknowledge the role many of these assets play during the response and recovery phases of a disaster. The availability of goods that support survival (e.g., food and water) is critical during the response phase, suggesting the importance of functioning stores, and the means to access them. Whereas, places of employment are vital during the recovery phase by keeping the labor force in place while maintaining the tax base.

2.3.1.3. Government

Structures and critical infrastructure often play several roles in supporting major government functions. The government functions are grouped by executive, legislative, and judiciary. Table 2-7 through Table 2-9 show their linkages with the built environment.

It is also important to acknowledge the role many of these assets play during the response and recovery phases of a disaster. Some assets may play an elevated role (e.g., emergency operation centers and police, fire, and EMS stations) while others may support an entirely different function than during ordinary times (e.g., schools to support government provided services, such as shelters).

2.3.1.4. Health care

The built environment supports many of the functions provided by the health care institution within a community. Table 2-10 provides examples of the ways in which the health care institution relies on the built environment on a regular, day-to-day basis. In a disaster, some functions may shift, increasing the importance of understanding the links between health and the built environment. One example is that particular health care buildings, like hospitals, could also be used as a shelter during a hazard event.

2.3.1.5. Education

The built environment also supports the functions of the education institution. In today's society, some of the ways in which we transfer knowledge, skills and values are done via the Internet or virtually, often without the need to congregate within the same building or structure. However, even in remote situations, where the need for a particular building is absent, we rely on communications systems to function.

Table 2-11 provides examples of the ways in which the education institution relies on the built environment on a day-to-day basis. In a disaster, some functions may shift, increasing the importance of understanding the links between education and the built environment. One example is that school buildings could serve as shelters during and after an event. In the aftermath of disasters, school buildings, in particular, could also emerge as central meeting locations for response and recovery activities.

2.3.1.6. Community Service Organizations

Increasingly, faith-based and other community organizations provide more services to a greater number of community residents on a daily basis.[39,40] CSOs, particularly those that provide essential services, such as shelter, food, and basic medical services, rely upon the built infrastructure to meet the basic survival needs of those they serve.

Table 2-12 provides some examples of the ways in which CSOs rely on the built environment on a regular, day-to-day basis. In the event of a disaster, the role of CSOs, particularly those that provide essential services, becomes even more critical, and the importance of understanding the links between CSOs and the built environment increases. As noted by Ritchie et al. (2008) in a comprehensive study of disaster preparedness among community-based organizations:

> *After major disasters, frail elderly people living alone still will need meals and other services; low-income disaster victims will need assistance from community clinics; services for people with AIDS and for those with chronic mental illness will need to remain operational; and immigrants still will need aid and support from the same organizations that provide assistance during non-disaster times.*

In the event of a disaster, buildings are vital to the protection and safety of staff and clients. It is also critical that CSOs communicate with their staff, volunteers, emergency providers, as well as those they serve, to meet safety and security needs. Similarly, CSOs rely upon transportation to ensure that staff and volunteers can reach their facilities to maintain operations, and that clients can reach the facilities to obtain services during the days and weeks following a disaster event. In many cases, demands for the types of assistance provided by CSOs increase substantially following a disaster, as more people seek assistance. In post-disaster contexts, CSOs of almost any type may adapt and expand their roles and services to support community disaster response and recovery efforts.

In the long term, CSOs also provide settings in which Maslow's belonging and growth and achievement needs are met after a disaster. Apart from organizations that provide essential services, CSOs such as civic, social, and recreational clubs (e.g., Rotary Clubs, Boys and Girls Clubs, after school programs) become increasingly important in community recovery processes by providing opportunities and physical settings to draw upon, maintain, and to build social capital. For example, buildings that house CSOs may provide a place for recovery planning. This is an important consideration with respect to understanding the needs of CSOs as related to the built environment in terms of broader community resilience.

2.3.1.7. Religious Organizations and Others that Support Belief Systems

As mentioned earlier, religious organizations and others that support belief systems rely on the built environment to function, albeit not as heavily as other social institutions. Examples of linkages between the religious organizations and others that support belief systems and the built environment are shown in Table 2-13.

As with community service organizations, described in the previous section, the roles of religious and other organizations may change in the context of a disaster. For example, buildings regularly used for

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[39] Ritchie, L.A., Tierney, K., Austin, D., Beres, M., Bevc, C., Gilbert, B., and Sutton, J. 2008. "Disaster Preparedness Among Community-Based Organizations in the City and County of San Francisco." Boulder, CO: The University of Colorado, Institute of Behavioral Science, Natural Hazards Center.

[40] Ritchie, L.A., Tierney, K, and Gilbert. B. 2011. "Disaster Preparedness among Community-Based Organizations in the City and County of San Francisco: Serving The Most Vulnerable." Pp. 3-39 in D.S. Miller and J.D. Rivera (eds.) *Community Disaster Recovery and Resiliency: Exploring Global Opportunities and Challenges*. Boca Raton, FL: Taylor and Francis.

worship and meetings might serve as evacuation shelters for congregants and members, as well as for residents from the broader community. In these cases, the buildings may also serve as places that protect vulnerable populations by continuing to or adapting to provide and house essential services such as food, water, and medical supplies; they may also protect and preserve religious and cultural artifacts and documents. In the aftermath of disasters, church buildings, in particular, tend to emerge as central meeting locations in the days and weeks during response and recovery activities.

2.3.1.8. Media

As with any institution, media relies on the built environment to serve its functions in one way or another. Table 2-14 provides some examples of the ways the media institution relies on the built environment on a regular, day-to-day basis. In the event of a disaster, some functions may shift, increasing the importance of understanding the links between the media and the built environment. For example, a functioning communication system will allow for communication with the public prior to, during, and after a disaster (to disseminate response and recovery information).

[Note to reviewers: A future draft will include the importance of situational awareness before, during and after a disaster.]

Table 2-1: Family and Kinship: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within the Family/kinship Institution	Provide a place to live, build a family, provide sustenance	Access to and from housing	Provide for safe source of water for drinking/eating, cooking, cleaning, cooling, laundry, fire protection; provide for the removal and treatment of waste	Allow for use of housing (lighting, heating, cooling), use of appliances, charging of electronics	Support communication within and outside of housing
How purpose is actualized through the built environment (examples)	Housing (single-family, multi-family, etc.)	Roads/bridges, airports, mass transit, sea ports	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones (landline and mobile), computers, TV and radio media

Table 2-2: Production of Raw Materials: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within the Production of Raw Materials	Prepare materials for transport, store materials, house equipment and machinery	Distribute goods for processing	Production input, cool or heat to facilitate production process, fire protection, eliminate production waste	Ability to operate machinery, use building (e.g., lighting)	Obtain market signals, support production and safety activities
How purpose is actualized through the built environment (examples)	Processing facility, warehouse	Roads and bridges, airports, railways and rail stations, seaports, pipelines	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet

Table 2-3: Production of Goods: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within the Production of Goods	Design and develop goods (buildings and manufactured products), process raw materials, production location, store goods, package and prepare for distribution	Obtain labor and capital, distribute intermediate goods, distribute final goods for sale	Production input, cool or heat to facilitate production process, fire protection, eliminate production waste	Ability to operate machinery, use building (e.g., lighting)	Obtain market signals, support production and safety activities, advertising
How purpose is actualized through the built environment (examples)	Commercial office, Processing plant, manufacturing facility, warehouse, goods (buildings and manufactured products) for sale	Roads and bridges, airports, railways and rail stations, seaports	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media

542 ***Table 2-4: Supply of Services: Examples of Purposes with Links to the Built Environment***

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within the Supply of Services	Point of sale, non-sale, service use area	Bring sellers (providers) and consumers together	Service input, equipment operation, eliminate waste, fire protection	Service input, power for machinery, lighting for the building	Obtain market signals, support production and safety activities, advertising, transmit and receive financial transactions
How purpose is actualized through the built environment (examples)	Stores, malls, restaurants, banks, commercial offices, hotels, schools and colleges, hospitals and medical facilities, arenas/stadia, salons and barbershops, internet cafes, online storefronts, gas stations, airports	Roads and bridges, airports, railways and rail stations, seaports	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media

543 ***Table 2-5: Labor Supply: Examples of Purposes with Links to the Built Environment***

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within Labor Supply	Location of employment, residence	Getting to and returning from work	Allow for safe use of structure/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Power for point of sale devices, lighting, heating and cooling	Offer and deliver services
How purpose is actualized through the built environment (examples)	Production facility, commercial office, warehouse, store, houses and apartments	Roads and bridges, airports, railways and rail stations, seaports	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media

544 ***Table 2-6: Consumption: Examples of Purposes with Links to the Built Environment***

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within Consumption	Point of sale, non-sale, service use area	Bring sellers (providers) and consumers together	Allow for safe use of structure/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Power for point of sale devices, power for point of non-sale, service use area, lighting, heating and cooling	Obtain information on goods and services available, process payments

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
How purpose is actualized through the built environment (examples)	Stores, malls, restaurants, commercial offices, schools and colleges, hospitals and medical facilities, arenas/stadia, salons and barbershops, internet cafes, online storefronts, gas stations, airports, houses and apartments	Roads and bridges, airports, railways and rail stations, seaports	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media

545 ***Table 2-7: Executive Function: Examples of Purposes with Links to the Built Environment***

	Buildings	Transportation	Water/wastewater	Power/energy	Communication
Purpose (or function) within Executive	Provide work and meeting space for leaders and staff, serve as a document repository, protect communication systems, house public safety and emergency response capabilities (people, equipment, vehicles), provide public spaces	Provide access to services, facilitates delivery of services (including emergency response)	Allow for safe use of structure/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Lighting, heating and cooling	Transmission of information, including emergency messaging, public access to government
How purpose is actualized through the built environment (examples)	Offices, police stations, fire and EMS stations, emergency operations centers (EOCs), military installations, jails and prisons	Roads, airports, railways, seaports, bridges, tunnels	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media, 911 call centers, reverse 911, social media, community alert and warning systems

546 ***Table 2-8: Legislative Function: Examples of Purposes with Links to the Built Environment***

	Buildings	Transportation	Water/wastewater	Power/energy	Communication
Purpose (or function) within Legislative	Provide work and meeting space for leaders and staff, serve as a document repository, protect communication systems, public spaces	Provide physical access to lawmakers and law-making bodies	Allow for safe use of structure/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Lighting, heating and cooling	Transmission of information, public access to government
How purpose is actualized through the built environment (examples)	Offices, government chambers	Roads, airports, railways, seaports, bridges, tunnels	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media, 911 call centers, reverse 911, social media

547 **_Table 2-9: Judicial Function: Examples of Purposes with Links to the Built Environment_**

	Buildings	Transportation	Water/wastewater	Power/energy	Communication
Purpose (or function) within Judicial	Provide work and meeting space for leaders and staff, serve as a document repository, protect communication systems, provide public spaces	Provide physical access to legal venues	Allow for safe use of structure (drinking, cooling, cleaning, eliminating personal waste), fire protection	Lighting, heating and cooling	Transmission of information, public access to government
How purpose is actualized through the built environment (examples)	Offices, courts and courthouses, libraries and archives	Roads, airports, railways, seaports, bridges, tunnels	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Telephones, computers, internet, TV and radio media, 911 call centers, reverse 911, social media

548 **_Table 2-10: Health Care: Examples of Purposes with Links to the Built Environment_**

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within Health Care	Provide a place for emergency, short- and long-term health needs (physical and mental); Storage for medical records, equipment, pharmaceuticals	Provide access to and from the facility for patients, staff	Allow for safe use of health care facility (drinking, cooling, cleaning, laundry, eliminating personal waste), and ability to use specific medical equipment that require water (e.g., dialysis), fire protection	Allow for use of facility, including technology, equipment, lights/electricity for all rooms/offices, computers and appliances	Communicate within facility, access information/ resources (e.g., medical records), communicate outside of facility
How purpose is actualized through the built environment (examples)	Hospitals, Clinics, Mental health agencies, clinics, hospitals, Urgent care centers, Poison centers, Dialysis centers, Rehabilitation centers, Hospices, Assisted living facilities, Nursing homes; Pharmacies	Roads/bridges, Vehicles - buses – public, subways, personal vehicles	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Internet, emergency communication system, phones (voice and text), email

549 **_Table 2-11: Education: Examples of Purposes with Links to the Built Environment_**

	Buildings	Transportation	Water/wastewater	Power/energy	Communication
Purpose (or function) within the Educational Institution	Provide a place to learn, to interact/connect, storage for equipment and books	Provide access to and from the facility to students/parents, teachers	Allow for safe use of educational facility/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Allow for use of educational facility, including power to classrooms, computers, appliances, offices	Communicate within facility, access information/resources (e.g., online), communicate outside of facility
How purpose is actualized through the built environment (examples)	Schools, universities (campus and dormitories), educational offices, museums, libraries	Roads/bridges, Vehicles - buses – public, subways, personal vehicles	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Internet, emergency communication system, phones (voice and text), email

Table 2-12: Community Service Organizations: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within CSOs	Provide a place where basic needs can be met (in some cases, shelter and sustenance), facility where people can interact with others	Provide access to and from the CSO facility to clients/staff/ volunteers	Allow for safe use of CSO facility/comfort (drinking, cooling, cleaning, eliminating personal waste), fire protection	Allow for use of CSO facility, including lights/electricity, power for appliances	Communicate with clients/staff/ volunteers; between CSOs; outside the CSO facility
How purpose is actualized through the built environment (examples)	Housing and provision of sustenance	Roads/bridges, Vehicles – public transportation (buses, subways) personal vehicles	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Internet, emergency communication system, phones (voice and text), email

Table 2-13: Religious Organizations and Others that Support Belief Systems: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within Religious Organizations and Others	Provide place of worship, social interaction, education, daycare, and other basic services; Provide places to house and protect religious and cultural artifacts/ documents *(the buildings themselves may be considered sacred or have symbolic meaning)*	Provide access to and from the facility to organization leaders/staff/ congregation/ community members	Allow for safe use of religious/belief facility (drinking, cooling, cleaning, eliminating personal waste), fire protection	Allow for use of facility (congregation, community members), including lights/electricity to all rooms, power for appliances	Communicate with leaders/staff/ congregation/ community members; outside of the facility
How purpose is actualized through the built environment (examples)	Churches, synagogues, other places of worship, meeting places	Roads/bridges, Vehicles – public transportation (buses, subways) personal vehicles	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Internet, emergency communication system, phones (voice and text), email

Table 2-14: Media: Examples of Purposes with Links to the Built Environment

	Buildings	Transportation	Water/ wastewater	Power/energy	Communication
Purpose (or function) within Media	Provide a place to disseminate news and information, protect all media technology and equipment	Provide physical access to and from facilities, also to news sites	Allow for safe use of facility (drinking, cooling, cleaning, eliminating personal waste), fire protection	Allow for use of facilities, allow for use of broadcasting/ media equipment	Communicate within facility, access information/ resources (e.g., online), broadcast information outside of facility (media function)
How purpose is actualized through the built environment (examples)	News and broadcasting stations, Television stations, Radio station, Newspapers/ magazine publishing, Publishers' headquarters, Offices, Equipment/ computer storage	Roads/bridges, Vehicles – public transportation (buses, subways) personal vehicles News/ broadcasting vehicles	Pipelines, pumps/stations, valves, fire hydrants, water and wastewater treatment facilities, storage tanks	Generation facilities, grids, substations, lines, pipelines	Internet, emergency communication system, phones (voice and text), email *Note to reviewer: Links will be made to Chapter 8*

In addition to relying on the built environment, social institutions also rely on one another to function. In turn, damage to the built environment may affect one social institution directly, which can have ripple effects on other institutions. The following section discusses the interdependencies of social institutions, to help communities think about prioritizing the built environment for resilience planning.

2.3.2. Dependence of Social Institutions on Other Social Institutions

A disruption in the built environment that affects one social institution will likely also affect others, since social institutions are linked with each other in many ways. It is important for a community to identify the ways social institution are linked with each other, referred to here as ***interdependencies***. Since each community is different, it is impossible to provide an exhaustive list of all of the ways social institutions can become dependent on one another. Instead, examples of interdependencies among social institutions are provided here[41]:

- *Government and economic institutions*: The longer it takes businesses to recover, the higher the potential for loss of local taxes (e.g., sales taxes); the longer it takes for law firms to recover, the higher the potential for courthouse delays[42].
- *Economic and family/kinship institutions*: The longer it takes for businesses to recover, the higher the potential for unemployment; Suppliers of goods and service (e.g., restaurants, staff) need a customer base and, at the same time, people need places to shop for goods and services[43].
- *Economic (labor), family/kinship, and education/government*: Without childcare, people may be unable to return to work and earn income, which may result in temporary or permanent relocation of the person/family.
- *Government and family/kinship*: People may encounter delays and/or difficulties in rebuilding (or may not wish to rebuild) due to new land use or zoning policies and building department policies (e.g., inspections or permitting).
- *Healthcare, education, economic, government, or media and family/kinship*: Each social institution needs staff and/or employees (e.g., doctors, nurses, medical technicians, billing, as examples for health care) to function
- *Government, economic, and family/kinship:* People may be unable to return to work without food and water at home, insurance appointments, and/or disaster assistance.
- *Government, media, and family/kinship*: The media serves as an intermediary between the government and the members of a community[44] and often works to link certain social institutions together.

Additionally, interdependencies also exist among services located within each institution. For example, industries located within a community (i.e., the economic institution) can depend upon each other to function.

Industries can be important drivers of the economy due to their size (e.g., contribution to GDP), proportion of the workforce they employ, and/or their importance with other industries (e.g., as producers and consumers of intermediate goods from other industries). A disruption to the built environment has the potential to affect several, seemingly unrelated industries across the economy through these inter-industry relationships. National and regional input-output models capture the inter-industry linkages.

[41] Holistic Disaster Recovery Document, Natural Hazards Center (PERI).
[42] Case study/example of this was Cedar Rapids, Iowa:
(http://blogs.mlmins.com/ruatrisk/?p=25)
(http://www.abajournal.com/news/article/cedar_rapids_law_firm_opens_offices_in_nearby_middle_school)
[43] Brenda Phillips Infrastructure chapter.
[44] http://theonlinemedia.blogspot.com/2012/06/functions-of-mass-media.html

Table 2-15 presents each industry's (1) size in millions of dollars of GDP, (2) percent contribution to total GDP, (3) 'impact per dollar demand,' and (4) 'impact of dollar supply.' The percent contribution of GDP shows the total flows from an industry as a percent of all flows in the economy. The impact per dollar demand is the value of GDP from other industries needed to produce one dollar of GDP from the listed industry – it shows what happens when flows to an industry are disrupted. The impact per dollar supply is the change in GDP that results from a dollar change in GDP from the listed industry – it shows what happens when the flows from an industry are disrupted. For example, the Wholesale and Retail Trade industry added $1.96 trillion dollars to the U.S. economy in 2011, which constituted 13% of U.S. GDP. To produce $1.0 million of GDP in Wholesale and Retail Trade, required $1.4 million of GDP produced by the other industries in the economy. To produce $1.0 million of GDP from other industries in the economy requires $1.94 million of GDP produced by Wholesale and Retail Trade.

Table 2-15: Industry size and inter-industry relevance (2011)*

Industry	GDP ($ million)	% GDP	Impact $/ Demand	Impact $/ Supply
Agriculture and Mining	466,194	3.1	1.74	1.92
Food, Beverages and Tobacco	221,187	1.5	3.36	2.48
Other Manufacturing	1,627,644	10.8	2.08	1.66
Electricity, Gas and Water Supply	246,896	1.6	1.21	2.62
Construction	549,011	3.6	1.69	2.70
Wholesale and Retail Trade	1,960,689	13.0	1.40	1.94
Hotels and Restaurants	473,854	3.1	1.71	2.68
Inland Transport	191,587	1.3	1.82	2.51
Water Transport	14,819	0.1	2.14	2.99
Air Transport	65,468	0.4	2.07	2.97
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	142,442	0.9	1.44	2.33
Post and Telecommunications	370,637	2.5	1.62	2.33
Finance and Real Estate	5,034,867	33.4	1.50	1.36
Public Admin and Defense; Compulsory Social Security	1,853,704	12.3	1.54	2.68
Community, Social and Personal Services	1,869,079	12.4	1.57	2.35

*Data sources: World Input-Output Database. http://www.wiod.org/new_site/database/wiots.htm; Marcel P. Timmer (2012), "The World Input-Output Database (WIOD): Contents, Sources and Methods", WIOD Working Paper Number 10, downloadable at <http://www.wiod.org/publications/papers/wiod10.pdf>

A smaller impact per dollar demand value implies a larger potential for an industry to be affected by disruptions in other industries. For example, the Electricity, Gas, and Water Supply industry is the most sensitive to production value changes from the rest of the economy. A smaller impact per dollar supply value implies a larger potential for other industries to be affected by a disruption from an industry (e.g., the economy is most sensitive to production value changes from the Finance and Real Estate industry).

The example in Table 2-15 details data on industry size and inter-industry relevance at a national level. This example can help communities think about the ways their industries, at the local level, interconnect and provide some guidance on how to quantify interdependencies, if the industry size and relevance data exists at the local level.

2.4. Community Examples of Recovery and Resilience

The process of resilience planning and prioritization is community-specific. Communities vary in size, social make-up (including social vulnerabilities), culture and traditions, and disaster history, which can influence a community's industrial composition (i.e., major industries), governance and regulations, social capital, economics/budgeting, and access to and types of built environment (assets). Therefore, there is no one-size-fits-all approach for communities in the U.S. to think about planning and prioritizing institutions, services, and/or systems for resilience.

Examples in this section show the ways in which communities, who experienced extreme disasters, have thought about and prioritized for the restoration of the built environment. Although resilience priorities can and should be set by communities of all types, regardless of their experiences with disasters, examples are provided here of community priorities set directly after experiencing large-scale, extreme disasters.

Joplin, Missouri developed priorities/goals during their recovery from the EF5 tornado that devastated their city on May 22, 2011; a city of 50,000 residents that increases to over 200,000 people during the workweek. The 2011 Joplin, MO tornado, which left a path of destruction eight miles long and ¾ miles wide, claimed 161 lives and injured over 1,000 people, in addition to damaging city infrastructure, parks, and 7,500 structures.[45] In response to the disaster, Joplin, MO created the Citizen Advisory Recovery Team (CART) to provide community members with a platform to bring post-disaster recovery ideas to the table, form a consensus, and allow these ideas to be taken to the City Council for consideration. On November 7, 2011, after multiple public meetings, CART presented its recommendations to the City Council for consideration and adoption. The City adopted CART's report and created the Implementation Task Force (ITF) to be the lead public/private entity in the redevelopment. The ITF included leadership from the CART and representatives of the City of Joplin, Duquesne, Joplin Schools, and the Joplin Area Chamber of Commerce. The role of the ITF was to assign responsibilities and priorities to the plan. As a result, several projects were developed that fell under four main headings: housing and neighborhoods, schools and community facilities, infrastructure and environment, and economic development. As a way to summarize these projects, the ITF plan provided a list of recovery goals:[46]

- Replace lost residential housing, office, commercial, medical, etc.
- Create ties from the redeveloped area to downtown Joplin
- Expand opportunities for employment
- Create destination activity center(s)
- Establish a memorial to those lost in the storm
- Address other projects and goals as developed by the CART
- Use redevelopment efforts as a catalyst to build upon existing goals for development and redevelopment in Joplin, including a parkway or series of neighborhood parks supporting the recovering neighborhoods; develop a performance and visual arts center; create a community and/or event center; and extend the walk/bike paths.

In another example, ***Greensburg, Kansas*** prioritized sustainable development after a tornado hit their town on May 4, 2007, killing 13 people and injuring more than 60 others. The tornado destroyed 95% of the town's structures and seriously damaging the other 5%. Immediately after the disaster, 50% of the population relocated to other areas, and eventually, FEMA installed mobile homes that housed around 300 families.[47] Greensburg, KS is now the "world's leading community in LEED-certified buildings per capita."[47] With support from the community, the Greensburg City Council adopted the resolution that, "all large public buildings in Greensburg with a footprint exceeding 4,000 square feet must meet the LEED-platinum standards of the U.S. Green Building Council and utilize renewable energy sources." Reconstruction is almost complete, with the entire community powered by renewable energy and the

[45] http://www.joplincc.com/Joplin%20Pays%20It%20Forward%20-%20Community%20Leaders%20Share%20Our%20Recovery%20Lessons.pdf
[46] http://joplinmo.org/DocumentCenter/View/2687
[47] http://www.usatoday.com/story/news/greenhouse/2013/04/13/greensburg-kansas/2078901/

construction of six LEED-platinum certified buildings, including the city hall, the memorial hospital, and the K-12 school.

Additionally, one question that communities may ask even before setting priorities is whether their current geographical/physical location allows them to reach their recovery and resilience goals. Community members, from ***Christchurch, New Zealand***, for example, after their series of major earthquakes in 2010 and 2011 or ***Rockaway Peninsula in New York*** after Hurricane Sandy hit in 2012, are faced with short-term and long-term relocation decisions based on new land-use and zoning initiatives. In these cases, the first priority is relocation.

[Note to reviewers: In a future draft, this section will end with a paragraph relating to resilience, stating that in the same ways that communities are planning for and executing recovery actions, communities can plan for and execute resilience actions – differently – in ways that work for them.]

2.5. Community Engagement in Resilience

[Note to reviewers: In a future draft, this section will begin with a discussion on the social science evidence of the role and importance of social capital. Also, may link this section with the section on Social Vulnerabilities (2.2.3) – discussion on how community engagement can help to identify and offset community vulnerabilities.]

For communities to become engaged in the pursuit of resilience, there needs to be a collective belief in the potential threat from the hazard(s) and the value of investing in resilience. These beliefs and values also reflect the level of risk a community is willing to tolerate, which is usually based on experience and available science. Without direct disaster experience, communities rely on science to present hazard probabilities and design options for reducing or avoiding exposure to these endemic community hazards. Without direct experience, the effectiveness of science to engage communities depends on the trust established between scientists and decision makers in having a common understanding of purpose, roles, responsibilities, and limitations as they relate to potential disasters and the means to plan, detect, notify and respond to threats.

Communities may seek out opportunities to pursue resilience based on observed disasters at similar scales or levels of development as their own, which trigger changes in beliefs or values as to the merits of resilience. Another manner of engaging community decision makers may come from translating the value of investing in resilience into their performance goals of long-term growth and into the values of sustainability. Many communities have adopted sustainability as a goal for the sake of reducing the dependence on natural and other limited resources through efforts such as recycling, smart technologies, shared community resources and collective expectations of livability goals, such as the simplicity movement. These steps demonstrate a stronger and more dynamic interface between a built community and the natural environment – one that recognizes the interdependency between human systems and natural systems. The health of one affects the overall health and functionality of the other.

Resilience comes into play when communities understand how their forbears' decisions resulted in their level of risk (increased or diminished) from potential disasters as well as available opportunities to reduce future losses, either by directly mitigating risk and/or planning to recover in a more risk-averse fashion following a damaging event. Ideally, resilience, as a concept, should help communities demonstrate credible investments toward improved livability during and after expected hazards. It should also expedite recovery following extreme disaster events due to forward thinking, planning and prioritizing in advance, to take advantage of recovery and reconstruction opportunities. This pursuit of resilience should provide a competitive edge for potential business and residential prospects evaluating a location for investments.

Resilience, like sustainability, encourages a better understanding of interdependence between a community and its geographical setting. This understanding can be viewed as a starting point for community identity and belonging that relates to a sense of place and quality of life that starts with community members feeling safer, more secure, and less likely to have their lives disrupted by hazards. They share in the beliefs and values of resilience and that the investments in resilience are worthwhile for their sense of growth and achievement.

3. Community Disaster Resilience for the Built Environment

3.1. Community Level Disaster Resilience

Communities come in varying sizes and with varying cultures; and they all face a wide range of opportunities, challenges, and hazards. A community can be defined in many ways, from a single neighborhood to a nation. For purposes of this framework, a community is defined as "people who live, work, learn, and/or play together under the jurisdiction of a governance structure, such as a town, city or county."

Community disaster resilience is best addressed by plans based on the available social services, supported at the neighborhood level, organized around a well-orchestrated community effort, and functional physical infrastructure. As described in Chapter 2, community disaster resilience planning should begin by defining the needs of the community's citizens, which are supported by a community's social institutions, prior to hazard events and during recovery. Those needs provide the basis for establishing performance goals for the built environment. The built environment is an essential part of community disaster resilience. A strong foundation provides the building clusters (buildings of similar function) and infrastructure systems needed by the people, businesses and government to restore the neighborhoods, care for vulnerable populations, and restore the community's economy. Chapter 2 defines how the social institutions are linked to and rely on building clusters and infrastructure systems during the recovery. To understand what is needed from the building clusters and infrastructure systems during recovery, desired performance levels (functionality) and associated restoration times need to be defined for each with the expectation that temporary measures will be provided in the interim. Those definitions, which become the metrics for resilience, are compared to the existing conditions to define gaps that represent opportunities for improvement.

Every community is different and will approach development of a community resilience plan from a different perspective, tolerance for risk, expectation of services to be provided, and planning process. The vitality and usability of the plan depends of its unique adaptation to its community. The plan development and iimplementation will require a broad base of support.

3.1.1. Community Disaster Resilience for the Built Environment

The term "resilience" means the ability to prepare for and adapt to changing conditions, and withstand and recover rapidly from disruptions. As related to the built environment, resilience means the ability of identified buildings and infrastructure systems to return to full occupancy and function, as soon as they are needed, to support a well-planned and expedited recovery. After identifying the social services to be provided and the necessary building clusters and infrastructure systems, the next step is to identify how soon each is required after a hazard event occurs. Timing will depend on both the type and intensity of the event, the age and composition of the community, and available assistance from neighboring communities, regions, and state.

Achieving and maintaining community resilience is an ongoing effort that involves planning and will benefit from mitigation before the hazard event, followed by emergency response, restoration and long-term reconstruction after the event. This framework defines a process for developing a community plan that will inform actions before, during, and after an expected hazard event occurs.

As outlined in Chapter 1, a variety of efforts were initiated in the past 15 years related to community resilience. Beginning in 2007, the San Francisco Planning and Research Association (SPUR) pioneered this style of resilience planning. Their work's, focus was at the community level, specifically considering what San Francisco needed from policies and programs to become a Disaster Resilient City (www.spur.org). SPUR's work produced multiple policy papers and recommendations covering broad issues of disaster resilience. Their policy recommendations focused on what is needed before the disaster, for disaster response, and after the disaster (see Table 3-1).

The Oregon Seismic Safety Policy Advisory Commission led a planning effort in 2012 to 2013 that followed the SPUR concepts and defined actions from Oregon communities needed to survive and rebound from a magnitude 9.0 Cascadia earthquake and tsunami (http://www.oregon.gov/OMD/OEM/osspac/docs). The plan determined the impacts of the earthquake statewide, defined acceptable time frames to restore functions needed to accelerate statewide recovery, and recommended changes in practices and policies, that if implemented over the next 50 years, the plans will allow Oregon to reach desired resilience targets.

Communities benefit from determining the levels of disaster resilience required for their physical infrastructure. This is best done for several levels of each prevalent hazard. Accordingly, each individual building or system will derive its resilience goals and performance levels from those defined by the community for its cluster and function.

Table 3-1: The SPUR Plan for San Francisco (SPUR 2009).

SPUR's Resilient City Initiative	
Before the Disaster	Our Before the Disaster work has focused on key questions related to disaster planning. What do we need to be doing now to make sure that our built environment can recover quickly from a major earthquake? Which existing buildings need to be retrofitted, and to what standard of performance? How do we encourage better performance from new buildings? How do we strengthen our infrastructure so that our buildings are serviceable after an earthquake? SPUR addresses these and other questions in four Before the Disaster papers published in the February 2009 edition of the *Urbanist*.
Disaster Response	Disaster Response focuses on activities during the days and weeks following a catastrophic event, including damage assessment, ensuring the safety of responders, communications and control, evacuation, public health and safety and restoration of vital systems. SPUR has recently completed a paper on the culture of preparedness, which focuses on disaster planning and preparedness in San Francisco's neighborhoods.
After the Disaster	Our After the Disaster task force is asking several key questions: After a catastrophe, are we prepared to rebuild our city to a state even better than it was before? What plans and systems of governance does San Francisco need if it is to be effectively positioned to rebuild? What lessons can be learned from recovery experiences in lower Manhattan, New Orleans, Haiti, Chile, China, and beyond? This task force will be working to complete major papers on long-term recovery, covering the topics of transportation, governance, planning, and housing.

3.1.2. Contributing Factors to Resilience

Just as the prevalent hazards are different across the country, so are the communities with respect to their age, composition, capabilities, and values. The initial process of developing a community disaster resilience plan requires an estimation of how quickly a community needs to recover from each prevalent hazard to maintain its population, workforce, and economic viability given its current built environment and planned development. Hurricane Katrina demonstrated that New Orleans was not resilient for flood events because of the impact of flood damage on housing of the workforce. Other communities may be resilient for all but extreme events, because of their location, inherently resilient government, ability to meet social needs, and redundancy in their built environment. The impact of the 1994 Northridge earthquake on the cities in the San Fernando Valley was a good example of inherent resilience. Decades of good building codes prevented all but a few casualties, yielded a rapidly repairable physical infrastructure, and the availability of housing just outside the damage zone, which allowed the workforce to return quickly.

From among the many metrics that give communities their distinguishing characteristics, the following discussion illustrates how they may inform development of a resilience plan. Our discussion is organized around Social Systems, Political Systems, Economic Systems and the Built and Natural Environment. Each characteristic needs to be considered by community resilience planners as they seek to identify their strengths and adapt ideas from other communities.

Social Systems

- ***Attitudes.*** Communities that have experienced a disaster learn from the experience. If the resulting recovery effort is orderly and successful, they may develop a sense of contentment with their status quo, even if the experience was based on a moderate event. If the resulting recovery was challenging, drawn out and less than successful in the short term, they may move more aggressively toward a resilient state in the reconstruction process. A window of opportunity opens for 1 to 2 years, during which people are interested in resilience activities and making big changes to their planning processes and codes. Communities that have not experienced a damaging hazard event are unlikely to be proactive and develop disaster resilience plans.

- ***Age of the Community.*** Age brings mature and sophisticated social institutions, efficient and informed governance, historically significant landmarks, deep-rooted cultural values, and more. It also brings an aging physical infrastructure that contributes to resilience gaps. With more and larger gaps comes the challenging task of determining priorities for closing the gaps in an orderly manner.
- ***Social Vulnerability and Inequity.*** Not all people use and/or have access to a community's buildings and infrastructure systems in the same ways. These systems typically reflect the people who created them, and may not address the needs of everyone likely to be affected in a hazard event (or on a day-to-day basis) such as the elderly, people living in poverty, racial and ethnic minority groups, people with disabilities, and those suffering from chronic and/or mental illness. Others that may not be adequately represented are renters, students, single-parent families, small business owners, culturally diverse groups, and historic neighborhoods. Moreover, hazard events tend to create settings in which populations on the margins of vulnerability become vulnerable, increasing the number of people in this category.

Built and Natural Environment

- ***Natural Capital.*** Each community has a unique location, topology and green infrastructure that contribute to its culture, vitality, and vulnerability to hazards. For example, a dense tree canopy increases the vulnerability to severe weather; hills and mountains contribute to landslide vulnerability; flat ground or locations near rivers, lakes, or other bodies of water may be susceptible to flooding and liquefaction vulnerability. Community resilience planning must take these features into account in assessments and mitigation plans.
- ***Codes, Standards, Administration, and Enforcement.*** Local building codes and enforcement are key tools for building physical infrastructure that performs as anticipated and for retrofitting at opportune times. To achieve resilience, local codes may need to be more stringent than national model standards. A community's history with adoption, administration, and enforcement of codes will significantly influence the degree of inherent resilience present in the physical infrastructure. There must be a commitment to funding these activities for the resilience plan to be effective.
- ***Architecture and Construction*** – Not all buildings and systems are built alike. Vulnerability to damage depends on the construction materials and their combustibility, structural and non-structural systems, quality of construction, size and shape of the building or systems, codes and practices in place during construction, and the building's current condition. The hundreds of permutations of architecture and construction styles vary by community and impact the communities' resilience. For example, in San Francisco, the multi-family apartment buildings of the 1920s and 1930s are a unique construction style particularly vulnerable to moderate and larger earthquakes. The over 6,000 buildings represent a significant amount of housing that will be uninhabitable after a moderate or large seismic event and will create a demand for interim housing that cannot be provided within the city limits. As a result, one of San Francisco's first resilience programs is a mandatory program to retrofit these buildings to a shelter-in-place level.

Economic Systems

- ***Economic Drivers***. The financial health of a community depends largely on the availability of jobs and a strong set of economic drivers. The vulnerability of the economy to a hazard event depends on the transportability of its industries. Knowledge-based industries can relocate if the workforce or needed physical infrastructure is not quickly restored; research and development industries are more rooted, because of the related laboratory and test facilities; manufacturing is deeply rooted and hard to move; most tourism is permanent and only needs to be restored. The restoration times and priorities built into a community's disaster resilience plan need to recognize the mobility of the key industries that support their economy.

- ***Financial Conditions***. Communities are typically faced with broad-ranging financial demands for expanded governance and new programs aimed at addressing deficient conditions. Each program requires staff support and funds to achieve the desired outcome. Disaster resilience, which is one of many community needs, requires financial support for emergency responders, planners, and building officials, and funds to develop and implement disaster resilience plans. The speed of recovery depends on those plans and the ability to implement them under recovery conditions.
- ***Resources***. Ongoing efforts to encourage development and achieve sustainability through energy efficiency and alternate energy generation have created a variety of new funding mechanisms. Community-backed bonds, locally-crafted loan programs, taxes, and FEMA mitigation grants are being used to finance mitigation projects. Tax incentives can also be enacted as a means to underwrite activities that are needed for community resilience. A lack of immediate funding should not overly influence the content of the disaster resilience plan. The plan should point to the need for new funding solutions.

Political Systems

- ***Priorities for Emerging Public Policies***. Communities face multiple opportunities that bring new public policies and priorities. A transparent and holistic community disaster resilience plan, with informed recovery plans and prioritized mitigation options, offers the opportunity for a community to balance the cost and benefit of becoming more resilient with other competing opportunities and demands.
- ***Governance Structure***. While resilience planning begins at the neighborhood level, the process and structure needed to build up to a community-level resilience plan will depend on the community governance structure. For a community that is an incorporated city, the plan will be self-contained and represent the needs of multiple neighborhoods served by the city departments and agencies. If the community is an unincorporated portion of a county, the plan will benefit from the capabilities of multiple neighborhoods and the interaction, interdependence, and mutual assistance inherent in the other communities that form the unincorporated areas of the county. In both cases, communities will need to look outside their jurisdictions to understand and plan for their dependence on others in their region.
- ***Hazard Mitigation Planning***. The Disaster Mitigation Act of 2000 specifically addresses mitigation planning and requires state and local governments to prepare multi-hazard mitigation plans as a precondition for receiving FEMA mitigation project grants. Many communities have produced such plans and update them every 5 years. This Community Disaster Resilience Framework can significantly inform the Community Capabilities, Risk Assessment, and Mitigation Strategy included in the FEMA Mitigation Plan. An existing Mitigation Plan can provide much of the planning information needed for identifying assets, resources, and stakeholders. Hazard Mitigation Plans are not regulatory, and if these plans are to have a measured impact to promote resilience activities, they should be formally adopted into compliance with the community's land use, zoning, and building code regulations (APA 2010).

3.1.3. Acceptable Risks

Acceptable risk can be defined "as the level of human and/or material injury or loss…. that is considered to be tolerable by a society or authorities in view of the social, political, and economic cost-benefit analysis" (Businessdictionary.com, 2015). Risk is often defined and interpreted differently by engineers, laypeople, community leaders, and other stakeholders, based on their level of understanding and expectations. Risks to the built environment are affected by land use planning, possible hazard events, adoption and enforcement of codes and standards, and maintenance and operation of physical infrastructure. Risk levels currently embodied in the built environment can be inferred from the national model building codes, standards, and guidelines. The consensus process of codes and standards provides the best mechanism for defining minimum levels of acceptable risk for the built environment. The risks in the codes and standards account for hazard levels, performance of various types of construction, and the consequences of damage or failure. Standards and guideline writers bring their personal experiences to the development process. They normalize the experience for application to other vulnerable regions via various metrics and formulations, and develop guidance for designing to an equivalent acceptable level. Codes, standards, and guidelines also provide minimum design criteria for many natural hazards and building and infrastructure performance.

Each community's current land use policies and construction standards are an inherent measure of the risk they have accepted with regard to the built environment. This decision is often influenced by other factors such as costs, politics, and desire for growth. For this reason, construction practices and the degree of compliance with current national standards varies dramatically across the nation. It is common for local jurisdictions to amend the national standard and eliminate provisions they deem unnecessary. The lack of personal experience with a damaging hazard event and the lack of understanding about the level of damage expected when a significant hazard event occurs often lead to misconceptions of a community's vulnerability. Communities should recognize their vulnerabilities based on national experience, not just local events, by adopting and enforcing the current national land use policies (e.g., flood zones) and model codes. The cost of compliance for new construction is minor compared to future savings.

The resilience planning process needs to consider the performance expectations eimbedded in adopted design codes as an indicator for the community's existing physical infrastructure, as outlined in Chapters 5 through 9. Since the performance expectation is focused at the community level, the plan does not insist that all buildings meet the same performance level. Instead, selected building clusters and infrastructure systems with specific functions for community recover should meet the needed performance. A community's decisions for damage levels and required functionality in the built environment defines their level of acceptable risk.

3.1.4. Implementing Community Resilience Planning

A community resilience plan should be developed through a collaborative arrangement between the Chief Executive's office (e.g., Mayor), community departments and key stakeholders, including representatives of the community's social institutions (e.g., community organizations, nongovernmental organizations, business/industry groups, health care, education, etc.), representatives of the physical infrastructure systems, and interested community members. Because of the holistic nature of the plan and the need to be fully supported during implementation, a public-private partnership is the best mechanism to develop the resilience plan. Guidance related to building a planning team is well documented in the FEMA Local Mitigation Planning Handbook. FEMA suggest beginning with existing community organizations or committees and involving all agencies and organizations involved in hazard response and mitigation planning.

The Community Resilience Planning Team will vary in size and breadth depending on the community. The following organizations that include elected officials, Departments, Businesses and Service Professionals and volunteer organizations, are examples those that should be considered for inclusion in the team depending on the size and makeup of the community.

Elected Officials

- ***The Office of the Chief Executive (e.g., Mayor)*** provides leadership, encourages collaboration between departments, and serves as the link to the stakeholders in organizing, compiling, and vetting the plan throughout the community. The office also serves as the point of contact for interactions with neighboring communities within the region and the State. A Chief Resilience Officer or other leader within the office should lead the effort.

- ***City Council or Board of Supervisors*** represents the diversity of community opinion, adopts the needed plans, and enacts legislation for needed mandatory mitigation efforts.

Departments

- The ***Department of Building and Safety*** identifies appropriate codes and standards for adoption; provides plan check and inspection services as needed, to assure proper construction; provides post event inspection services aimed at restoring functionality, as soon as possible. The department should also develop and maintain a GIS-based mapping database of all community physical infrastructure, and social institutions and their relationship to the physical infrastructure.
- The ***Department of Public Works*** is responsible for publicly owned buildings, roads, and infrastructure, and identifies emergency response and recovery routes.
- ***Fire Departments/Districts*** are responsible for codes and enforcement of construction standards related to fire safety and brings expertise related to urban fires, wild fires, and fire following hazard events.
- ***Parks and Recreation*** identifies open spaces available for emergency or interim use for housing and other neighborhood functions**.**
- The ***Public Utilities Commission*** is responsible for overseeing publicly owned utility systems and assists in developing recovery goals.
- The ***Planning Department*** identifies pre-event land use and mitigation opportunities and post-event recovery opportunities that will improve the city's layout and reduce vulnerabilities through repair and reconstruction projects and future development.
- The ***Emergency Management Department*** identifies what is needed from the physical infrastructure to streamline response and recovery of the social structure of the community, including defining a set of standardized hashtags to facilitate community-wide information transfer

Business and Service Professionals

- ***Chambers of Commerce, Community Business Districts, Building Owners, and Managers*** provide the business perspective on resilience planning and recovery in terms of their needs for workforce, buildings, utilities, and other infrastructure systems, as well as how their needs should influence the performance levels selected.
- ***Service and Utility Providers*** hold the keys to rapid recovery of functionality and should work together to understand the community needs and priorities for recovery, as well as the interdependencies they share.
- ***Architects and Engineers*** help determine the design and performance capabilities for the physical infrastructure and assist in the development of suitable standards and guidelines. They can help establish desired performance goals and the actual performance anticipated for the existing built environment.

Volunteer Organizations

- ***Nongovernment Organizations*** (NGO) consist of any non-profit, voluntary citizens' groups that are organized on a local, national or international level and is task-oriented. NGOs perform a variety of service and humanitarian functions, bring citizen concerns to Governments, advocate and monitor policies and encourage political participation through provision of information. Within the Community Service social institution (See Chapter 2), NGOs provide support to other social institutions, especially those that provide services to vulnerable and at-risk populations
- ***National Voluntary Organizations Active in Disaster*** (VOADS) is a nonprofit, nonpartisan, membership-based organization that helps to build resiliency in communities nationwide. It serves as the forum where organizations share knowledge and resources throughout the disaster cycle — preparation, response, recovery and mitigation — to help disaster survivors and their communities.

- ***Community Service Organizations (CSOs)*** are volunteer, membership based groups that provide service to the community's social institutions and will have a role in the post-disaster environment.

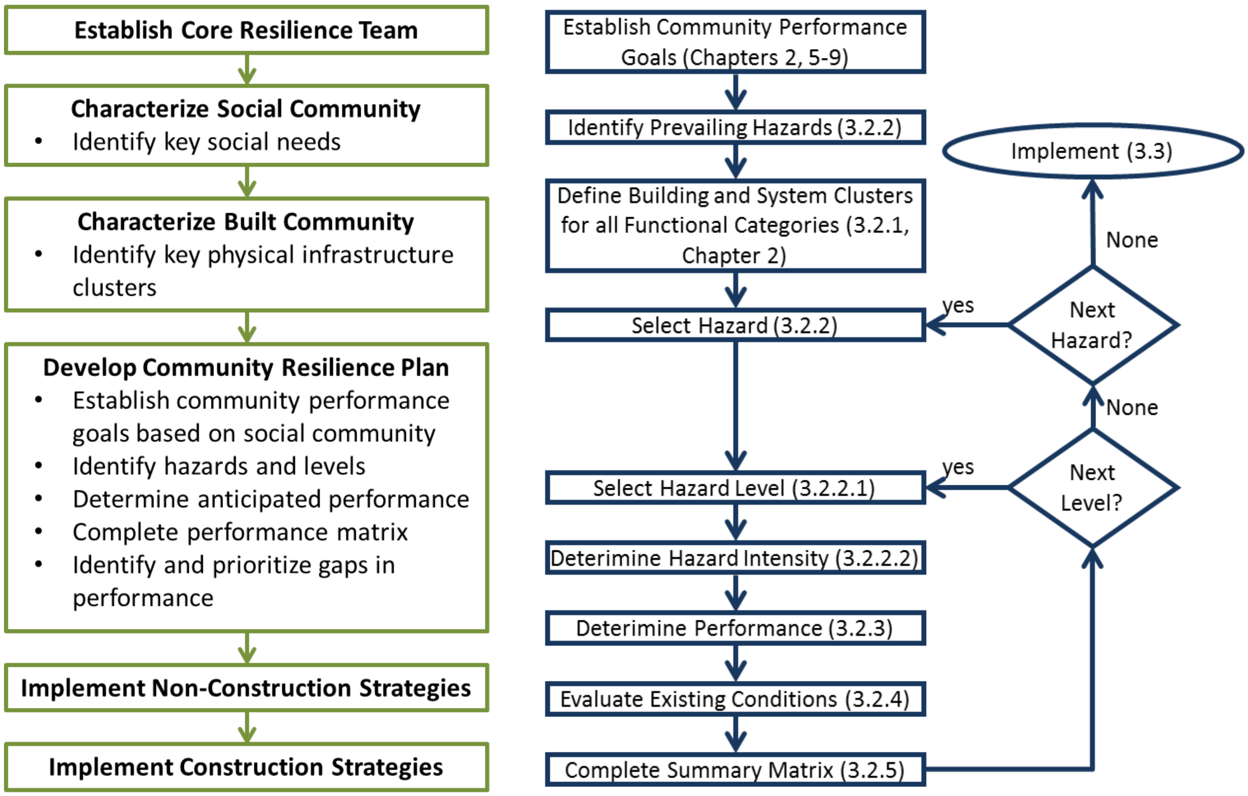
Implementing a resilience plan for the built environment is a long-term effort that requires constant attention, monitoring, and evolution. Because of the cost and the need to transform the governance systems, real estate, and construction cultures, it can easily take up to 50 years or more to fully implement. Once the resilience performance goals for buildings and systems are adopted, all new construction can be built in compliance at very little additional cost. Studies, such as FEMA 313 (1998), show that the increased costs range from 0 to 5 %. Unfortunately, this alone will only have a long-term impact, since the vast majority of buildings and systems will not conform until replaced or retrofitted. Retrofitting existing facilities to achieve new performance goals are generally considered to be cost prohibitive. However, the resilience plan allows resilience gaps related to clusters of buildings or infrastructure systems to be judged in terms of relative importance to the community, mitigated as appropriate, and can provide short-term interim, post recovery strategies.

3.2. Pathway to Community Resilience

Figure 3-1 shows a flow chart of the Community Resilience Planning process. First steps include establishing the core resilience planning team, determining social assets and identifying key social needs for community recovery, and determining physical infrastructure assets and natural resources that support these key social needs. With this community information, the community resilience plan is developed with the following steps: 1) establish community-level performance goals, 2) determine anticipated performance of infrastructure clusters; 3) complete the performance matrix, and 4) identify and prioritize gaps between the desired and anticipated performance for the clusters and each hazard. Once the gaps are prioritized, the community can develop strategies to mitigate damage and improve recovery of functions across the community. This path is compatible with the FEMA Mitigation Plan (FEMA 2013), which many communities are using. However, the plan to community resilience goes a step farther to envision and plan for recovery of functionality across the community.

When a hazard occurs, each building and infrastructure system should protect the occupants from serious injury or death. This goal can be achieved by adopting and enforcing current building codes. In addition to safety, communities need to determine how soon their buildings and infrastructure systems will need to be functional to support community recovery. The desired recovery times will depend on the needs of the social institutions, the size of the area affected during the hazard event, and the anticipated level of disruption in terms of affected area (e.g., local vs. widespread) and loss of functionality. The outcome of planning is summarized in a *Summary Resilience Matrix*, as defined in Section 3.2.5.

Given this set of performance goals organized around hazards, physical infrastructure system clusters, and anticipated levels of disruption, communities can develop and implement a resilience plan and strategies to improve the anticipated performance. Anticipated performance measures include safety, functionality, and recovery times. Comparing the performance of the existing built environment to the performance goals identifies opportunities for mitigation or other plans, such as relocation either before or after a hazard event.



a. Core Activities for Developing a Resilient Community

b. Flow Chart for Developing a Community Resilience Plan

Figure 3-1: Flow Chart for Developing Resilience Plan

3.2.1. Identify Clusters of Buildings and Infrastructure Systems

Clusters of buildings and supporting infrastructure systems that support social needs and emergency response efforts after a hazard event need to be identified. The cluster ensures that all supporting systems are functional so that the buildings and infrastructure systems can operate as intended. Chapters 5 through 9 provide specific guidance on how to define the clusters of facilities and support systems needed for each phase of recovery, short term, intermediate, and long term. Table 3-2 lists the buildings that are likely needed during each recovery phase within a cluster. Refer to Chapter 4 for guidance on considering the interdependencies between physical infrastructure systems.

Table 3-2: Buildings and Facilities in Clusters by Recovery Phase

Recovery Phase	Buildings in Clusters
1. Short Term	**Critical Facilities**
	1. Hospitals and Essential healthcare facilities 2. Police and Fire Stations 3. Emergency Operations Centers 4. Disaster Debris and Recycling Centers
	Emergency Housing
	1. Public Shelters 2. Residential Shelter-in-Place 3. Food Distribution Centers 4. Nursing Homes, Transitional Housing 5. Animal Shelters 6. Faith and Community-Based Organizations 7. Emergency Shelter for Emergency Response and Recovery Workers 8. Gas Stations (location known by community) 9. Banking Facilities (location known by community)
2. Intermediate	**Housing/Neighborhoods/Business**
	1. Essential City Services Facilities 2. Schools 3. Medical Provider Offices 4. Neighborhood Retail Stores 5. Local Businesses 6. Daycare Centers 7. Houses of Worship, Meditation, and Exercise 8. Buildings or Space for Social Services (e.g., Child Services) and Prosecution Activities 9. Temporary Spaces for Worship 10. Temporary Space for Morgue 11. Temporary Spaces for Bath Houses 12. Temporary Spaces for Markets 13. Temporary Spaces for Banks 14. Temporary Spaces for Pharmacies 15. Local Grocery Stores (location known by community)
3. Long Term	**Community Recovery**
	1. Residential Housing 2. Commercial and Industrial Businesses 3. Non-Emergency City Services 4. Resilient Landscape Repair, Redesign, Reconstruction, and Repairs to Domestic Environment

3.2.2. Hazard Events

This framework is based on resilience planning for three levels of a hazard events that are referred to as routine, expected, and extreme. The definition of each level depends on the characterization of the hazard and a community's tolerance for damage or loss of function.

Communities should select the prevailing hazards that may damage physical infrastructure, which may include:

- ***Wind –*** storms, hurricane, tornadoes
- ***Earthquake –*** ground shaking, faulting, landslides, liquefaction
- ***Inundation –*** riverine flooding, coastal flooding, tsunami
- ***Fire –*** urban/building, wildfire, and fire following a hazard event
- ***Snow or Rain –*** freeze or thaw
- ***Human-caused –*** blast, vehicular impact, toxic environmental contamination as a result of industrial or other accidents as well as due to clean-up/disposal methods after a hazard event

3.2.2.1. Hazard Levels for Resilience Planning

For each hazard selected, communities should determine the three levels of hazard intensity or magnitude for use in the framework. Each should be defined in the same terms that are used for design.

- ***Routine –*** Hazard level is below the expected (design) level and occurs more frequently. Buildings and infrastructure systems should remain fully functional and not experience any significant damage that would disrupt the flow of normal living.
- ***Expected –*** Design hazard level, where the design level is based on codes, may be greater than the minimum required by codes, or may be set for the building or infrastructure system based on other criteria. Buildings and systems should remain functional at a level sufficient to support the response and recovery of the community. This level is based on the design level normally used for buildings.
- ***Extreme –*** Hazard level is above the expected (design) level and may be referred to as the maximum considered occurrence based on the historic record and changes anticipated due to climate change. However, this hazard level should not need to be the largest possible hazard level that can be envisioned, but rather one that the community wants to be able to recover from, though it will take longer than for an expected hazard event. Critical facilities and infrastructure systems should remain functional at this level. Other building and infrastructure systems should perform at a level that protects the occupants and allows them to egress without assistance. In addition, emergency response plans should be based on scenarios that represent this hazard level.

As an example, Table 3-3 contains the definitions that SPUR used for the three levels of seismic hazard they recommended for San Francisco resilience planning.

Table 3-3: Sample Hazard definition for earthquakes developed by SPUR for San Francisco

Routine	***Earthquakes that are likely to occur routinely.*** Routine earthquakes are defined as having a 70% probability of occurring in 50 years. In general, earthquakes of this size will have magnitudes equal to 5.0 – 5.5, should not cause any noticeable damage, and should only serve as a reminder of the inevitable. San Francisco's Department of Building Inspection (DBI) uses this earthquake level in their Administrative Bulletin AB 083 for purposes of defining the "service level" performance of tall buildings.
Expected	***An earthquake that can reasonably be expected to occur once during the useful life of a structure or system.*** It is defined as having a 10% probability of occurrence in 50 years. San Francisco's Community Action Plan for Seismic Safety (CAPSS) assumed that a magnitude 7.2 earthquake located on the peninsula segment of the San Andreas Fault would produce this level of shaking in most of the city.
Extreme (Maximum Considered Earthquake)	***The extreme earthquake that can reasonably be expected to occur on a nearby fault.*** It is defined as having a 2% probability of occurrence in 50 years. The CAPSS defined magnitude 7.9 earthquake located on the peninsula segment of the San Andreas Fault would produce this level of shaking in most of the city.

The American Society of Civil Engineers (ASCE) Standard 7-10 *Minimum Design Loads for Buildings and Other Structures* defines minimum hazard levels for design nationwide. Table 3-4 presents suggested design hazard levels for buildings and facilities based on ASCE 7-10. Communities may define the size of a hazard they wish to consider for each level, based on the table or based on other available information. It is important that hazard levels are selected and characterized in a manner that can be used by design professionals in design and retrofit of facilities.

Table 3-4: Design Loads for Buildings and Facilities (ASCE 7-10)

Hazard	Routine	Expected	Extreme
Ground Snow	50 year	300 to 500 year[1]	TBD
Rain	[2]	[2]	[2]
Wind – Extratropical	50 year	700 year	3,000 year[3]
Wind – Hurricane	50 to 100 year	700 year	3,000 year[3]
Wind – Tornado	[3]	[3]	[3]
Earthquake[4]	50 year	500 year	2,500 year
Tsunami	50 year	500 year	2,500 year
Flood	100 year	100 to 500 year	TBD
Fire – Wildfire	[4]	[4]	[4]
Fire –Urban/Manmade	[4]	[4]	[4]
Blast / Terrorism	[5]	[5]	[5]

[1] For the northeast, 1.6 (the LRFD factor on snow load) times the 50-year ground snow load is equivalent to the 300 to 500 year snow load.

[2] Rain is designed by rainfall intensity of inches per hour or mm/h, as specified by the local code.

[3] Tornado and tsunami loads are not addressed in ASCE 7-10. Tornadoes are presently classified by the EF scale. Tsunami loads are based on a proposal for ASCE 7-16.

[4] Hazards to be determined in conjunction with design professionals based on deterministic scenarios.

[5] Hazards to be determined based on deterministic scenarios. Reference UFC 03-020-01 for examples of deterministic scenarios.

3.2.2.2. Hazard Intensity

The impact of hazards depends on more than just size and frequency. The impact also depends on the size of the area affected, the extent of civilization in the affected area, the impact of the damage, and the community's ability to respond. The size of the affected area depends on the particular hazard, as does the geographic distribution of the intensity. A wildfire in the wilderness areas of the California Sierra Nevada Mountains, where there is little population, can burn many square miles of forest with little disruption. On the other hand, the 1992 Oakland Hills firestorm covered only 1520 acres, but killed 11, destroyed nearly 4,000 homes and apartments, and caused $1.5 billion in damage. The affected area was relatively small compared to other wildfires; but the disruption to the affected population and built environment was severe.

For purposes of this framework, the terms *affected area* and *anticipated disruption level* are defined in terms of the Community and the impacts of a hazard event at the present time.

Table 3-5: Affected Area and Anticipated Disruption Level

	Category	Definition
Affected area	Localized	Damage and lost functionality is contained within an isolated area of the community. While the Emergency Operations Center (EOC) may open, it is able to organize needed actions within a few days and allow the community to return to normal operations and manages recovery. Economic impacts are localized
	Community	Significant damage and loss of functionality is contained within the community, such that assistance is available from neighboring areas that were not affected. The EOC opens, directs the response and turns recovery over to usual processes once the City governance structure takes over. Economic impacts extend to the region or state.
	Regional	Significant damage occurs beyond community boundaries. Area needing emergency response and recovery assistance covers multiple communities in a region, each activating their respective EOCs and seeking assistance in response and recovery from outside the region. Economic impacts may extend national and globally.
Anticipated Disruption Level	Minor	All required response and recovery assistance is handled within the normal operating procedures of the affected community agencies, departments, and local businesses with little to no disruption to the normal flow of living. Critical facilities and emergency housing are functional and community infrastructure systems are functional with local minor damage.
	Moderate	Community EOC activates and all response and recovery assistance is orchestrated locally, primarily using local resources. Critical facilities and emergency housing are functional and community infrastructure systems are partially functional.
	Severe	Response and recovery efforts are beyond the authority and capability of local communities that are affected and outside coordination is needed to meet the needs of the multiple jurisdictions affected. Professional services and physical resources are needed from outside of the region. Critical facilities and emergency housing have moderate damage but can be occupied with repairs, community infrastructure systems are not functional for most needs.

3.2.3. Community Performance Goals

Performance goals for buildings, building clusters and infrastructure systems are a combination of performance levels during the hazard event and recovery times. Standard definitions for performance levels that cover safety and functionality assure uniform development of community plans and the codes, guidelines, manuals of practice, and analytical tools that support them. Recovery times are needed to identify the extent of temporary facilities and systems that will be needed, as well as for prioritizing repair and reconstruction that recognizes local, regional, and possibly national and international implications of damage due to a hazard event. For instance, if a production plant in a community is the national supplier for a particular good, the impact of damage to the plant extends well beyond the community.

3.2.3.1. Performance Levels for Buildings

To assure that a community framework is compatible with codes and standards, and other guidance documents for physical infrastructure, common definitions of performance are needed for facilities and infrastructure systems. Setting performance goals for both safety and functionality informs plans for new construction and any needed retrofitting of existing buildings and infrastructure systems. For new construction, such performance goals help improve a community's resilience over time. For existing construction, performance goals help identify clusters of buildings and infrastructure systems that may benefit retrofitting or other measures to provide the needed performance. Table 3-6 provides standard definitions for building performance levels that are used for seismic performance of buildings, but are adopted here for general application to performance for all hazards.

Table 3-6: Performance Definitions for Buildings

Category	Performance Standard
A. Safe and operational	These are facilities that suffer only minor damage and have the ability to function without interruption. Essential facilities such as hospitals and emergency operations centers need to have this level of function.
B. Safe and usable during repair	These are facilities that experience moderate damage to their finishes, contents and support systems. They will receive green tags when inspected and will be safe to occupy after the hazard event. This level of performance is suitable for shelter-in-place residential buildings, neighborhood businesses and services, and other businesses or services deemed important to community recovery.
C. Safe and not usable	These facilities meet the minimum safety goals, but a significant number will remain closed until they are repaired. These facilities will receive yellow tags. This performance may be suitable for some of the facilities that support the community's economy. Demand for business and market factors will determine when they should be repaired or replaced.
D. Unsafe – partial or complete collapse	These facilities are dangerous because the extent of damage may lead to casualties.

3.2.3.2. Performance Recovery Levels for Building Clusters and Infrastructure Systems

Performance levels for building clusters and infrastructure systems are defined in terms of the time needed to restore the cluster or system to full functionality. Recovery times will vary with the hazard under consideration. Early in the planning process, generalized time frames such as days, weeks, and months are sufficient. Disaster response and recovery traditionally is organized around sequential recovery stages or phases. Recovery phases are defined in a variety of ways by deferent programs, but generally have common goals. The Department of Homeland Security (DHS) National Disaster Response Plan defines them as short, intermediate and long term as shown in Figure 3-2 with a series of activities defined in each. While each begins early in the recovery time frame, the bulk of effort follows sequential stages.

Figure 3-2: National Disaster Recovery Framework (NDEF) Recovery Continuum (NDRF 2014)

The three recovery phases use the terms in the NDRF and are defined in Table 3-7. While discrete time frames are designated, it is recognized and expected that there will be considerable overlap in their imitation and completion, and each recovery phase could conceivably start shortly after the hazard event. The time frames shown are suggestions related to expected hazard events and may not be applicable for all plans.

Table 3-7: Recover Phases

Phase	Name	Time Frame	Condition of the built environment
I	Short Term	0 to 3 days	Initial emergency response and staging for recovery
II	Intermediate	1 to 12 weeks	Housing restored and ongoing social needs met
III	Long Term	4 to 36+ months	Reconstruction in support of economic recovery

For Buildings in Clusters. While individual buildings are assigned performance levels that reflect their role in the community, as noted above, the performance of a cluster with multiple buildings depends on how many of the buildings are restored and functioning. For purposes of planning, it is helpful to set goals for three levels of cluster recovery for the percentage of buildings recovered.

Table 3-8: Building Performance Recovery Levels

Category	Performance Level
30% Restored	Minimum number needed to initiate the activities assigned to the cluster
60% Resorted	Minimum number needed to initiate usual operations
90% Restored	Minimum number needed to declare cluster is operating at normal capacity

For Infrastructure Systems. The recovery of infrastructure systems needs to be measured in terms of its ability to restore service as a percentage of full capacity. While the components of the system are measured and rated in terms of the performance levels defined above, the overall performance of the system needs a system-wide categorization based on restoration of service.

Table 3-9: Infrastructure Performance Recovery Levels

Category	Performance Level
I	Resume 90% service within days and 100% within weeks
II	Resume 90% service within weeks and 100% within months
III	Resume 90% service within months and 100% within years

3.2.4. Anticipated Performance of the Physical Infrastructure Clusters

The majority of buildings and infrastructure systems in service today have been designed to serve their intended functions on a daily basis under the normal environmental conditions. Buildings and other structures are also designed to provide occupant safety during an expected (design) level hazard event, but they may not continue to be functional. The design of buildings and physical infrastructure systems are provided by experienced architects and engineers following their community codes and standards of practice. The codes and standards of practice are continually evolving due to changing technology, changing needs, and to address observed performance issues during hazard events. Current design practices related to predicting performance for the expected or extreme hazard event are uneven, and may be based on expert judgment or past experience of other communities. The technologies needed to estimate the anticipated performance of existing buildings and infrastructure systems are constantly being improved. Technologies related to building evaluation for seismic conditions is maturing and is in its third generation. On the other hand, methods are just emerging for estimating infrastructure system performance and restoration times. Chapters 5 through 9 provide guidance on how to estimate the performance of existing buildings and infrastructure systems.

Architects and engineers generally design or evaluate buildings and infrastructure systems one building or system at a time without considering community-level functions or dependencies on other systems. Under a community resilience plan, each design should be compatible with the goals of the community resilience plan.

While it would be ideal to retrofit or replace all buildings and systems that do not meet the community resilience goals, it is neither necessary nor practical. As a starting point, a community should focus on having a critical mass of buildings and infrastructure systems to support short term recovery

The next step is to evaluate each of its designated clusters of buildings and infrastructure systems and estimate its anticipated recovery time for its current condition for each level of the hazard. This information, when compared to the performance goals previously set, defines the gaps that need to be addressed.

3.2.5. Summary Resilience Matrix

A matrix-based presentation of the many facets of a community resilience plan has been developed for use with this framework. It includes a Detailed Resilience Matrix for buildings and infrastructure systems. Example detailed matrices for the fictional community Centerville, USA are developed and shown in each of the infrastructure system chapters that follow and they include the recovery times for each recovery phase and estimated levels defined in Table 3-7 for each of the three hazard levels. The detailed example matrices for Centerville, USA are summarized in three Resilience Matrices, as shown in Table 3-10 through Table 3-12, to provide an overview of the desired and anticipated recovery goals estimated for the built environment. For purposes of providing a general overview, the summary matrix only shows the 90% restoration time needed for all elements within each phase for each infrastructure system.

Table 3-10: Example Summary Resilience Matrix for a Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	Overall Recovery Time for Hazard and Level Listed								
	Routine Hazard Level								
	Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
	Days	Days	Days	Wks	Wks	Wks	Mos	Mos	Mos
	0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities									
Buildings	90%	X							
Transportation	90%	X							
Energy	90%	X							
Water	90%		X						
Waste Water		90%	X						
Communication	90%		X						
Emergency Housing									
Buildings	90%		X						
Transportation	90%	X							
Energy	90%	X							
Water	90%		X						
Waste Water		90%	X						
Communication	90%			X					
Housing/Neighborhoods									
Buildings	90%		X						
Transportation		90%	X						
Energy		90%	X						
Water		90%		X					
Waste Water			90%	X					
Communication		90%		X					
Community Recovery									
Buildings		90%	X						
Transportation			90%	X					
Energy		90%	X						
Water			90%	X					
Waste Water			90%	X					
Communication		90%		X					

Footnotes:

1 Specify hazard being considered
Specify level – Routine, Expected, Extreme
Specify the size of the area affected – localized, community, regional
Specify severity of disruption – minor, moderate, severe

2 30% | 60% | 90% Restoration times relate to number of elements restored within the cluster

3 X Estimated 90% restoration time for current conditions based on design standards and current inventory

Table 3-11: Example Summary Resilience Matrix for an Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	Overall Recovery Time for Hazard and Level Listed								
	Expected Hazard Level								
	Phase 1 – Short-Term			Phase 1 – Short-Term			Phase 1 – Short-Term		
	Days	Days	Days	Wks	Wks	Wks	Mos	Mos	Mos
	0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities									
Buildings	90%							X	
Transportation		90%	X						
Energy		90%	X						
Water			90%		X				
Waste Water				90%				X	
Communication		90%		X					
Emergency Housing									
Buildings				90%					X
Transportation			90%	X					
Energy			90%	X					
Water			90%		X				
Waste Water				90%				X	
Communication				90%	X				
Housing/Neighborhoods									
Buildings						90%			X
Transportation			90%	X					
Energy			90%	X					
Water				90%				X	
Waste Water					90%			X	
Communication				90%			X		
Community Recovery									
Buildings								90%	X
Transportation				90%	X				
Energy			90%	X					
Water				90%				X	
Waste Water							90%	X	
Communication				90%			X		

Footnotes: See Table 3-10, page 16

Table 3-12: Example Summary Resilience Matrix for an Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	Overall Recovery Time for Hazard and Level Listed								
	Extreme Hazard Level								
	Phase 1 – Short-Term			Phase 1 – Short-Term			Phase 1 – Short-Term		
	Days	Days	Days	Wks	Wks	Wks	Mos	Mos	Mos
	0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Critical Facilities									
Buildings						90%			X
Transportation			90%		X				
Energy				90%					
Water							90%	X	
Waste Water					90%			X	
Communication	90%			X					
Emergency Housing									
Buildings						90%			X
Transportation				90%		X			
Energy				90%					
Water					90%		X		
Waste Water					90%			X	
Communication				90%			X		
Housing/Neighborhoods									
Buildings							90%		X
Transportation				90%		X			
Energy				90%	X				
Water					90%			X	
Waste Water						90%		X	
Communication					90%		X		
Community Recovery									
Buildings								90%	X
Transportation				90%		X			
Energy				90%	X				
Water							90%		X
Waste Water								90%	X
Communication					90%			X	

Footnotes: See Table 3-10, page 16

3.3. Mitigation and Recovery Strategies

Community disaster resilience planning provides a comprehensive picture of the gaps between desired and anticipated performance of the physical infrastructure to support recovery for the hazards and hazard levels considered. This information provides communities with the opportunity to develop short term plans for covering the most urgent gaps with emergency/interim facilities and supporting infrastructure systems as well as a comprehensive community-level basis for long term strategies that will eventually close the gaps.

Mitigation to derive long term solutions before the event costs money, but reduces demands during recovery and can speed up the overall recovery process. Streamlining recovery processes can also reduce the need for mitigation.

Mitigating the gaps can be addressed in a number of ways, from altering the expectations to relying on more external assistance, to adding redundancies, to retrofit and/or reconstruction programs that add robustness. For some hazards, such as flooding, the threat can be redirected.

Mitigation also provides the opportunity to build-back better. When a hazard event occurs, there is significant pressure to quickly restore the built environment to its pre-event condition. With advanced planning, reconstruction can be done to a “new normal” that includes addressing the needs of the social institutions and also improving sustainability, and resilience.

Cost is always an issue with regard to funding mitigation activities. While the initial planning is comprehensive and requires the interaction of a large number of people, it is the first and most cost effect step in the process, carrying out the needed retrofits before the hazard event occurs has significant long term benefits. A study of grants awarded by FEMA indicates “a dollar spent on disaster mitigation saves society an average of $4.” (MMC 2005) It is noteworthy that this study is being revisited as the benefit for investment is presumed to have increased dramatically since the study was last completed.

Unfortunately, most communities wait until after a hazard event occurs before they become serious about mitigation planning. This is not the most appropriate time to implement criteria to achieve a more resilient community. At this point the stressors on the community are overwhelming. Communities need to implement criteria for enhanced resiliency prior to any hazard event to achieve effective change and to achieve an acceptable level of community continuity should a hazard event occur. Fortunately, the FEMA requirements for mitigation planning are an incentive to initiate the process and this NIST Disaster Resilience Framework yield actionable information that can be implemented in the long term.

Once the plan is in place, a number of non-construction activities can be done at low cost for significant long-term benefit. There is also a series of construction related activities that can significantly improve community resilience in the long term.

3.3.1. Non-Construction Strategies

Implementing a community’s disaster resilience plan related to the physical infrastructure should begin with evaluating and validating the following activities or initiating them as needed. Each is a low-cost activity that is best done as an extensions to existing programs.

1. Organize and maintain a resilience office lead by a Chief Resilience Officer that collaborates with and learns from the Rockefeller 100 Resilience Cities program. Orchestrate community engagement through this office and solicit buy-in.
2. Incorporate the resilience plan in the Community Safety Element of the General Plan.
3. Incorporate the resilience plan in the communities FEMA Mitigation Plan
4. Adopting the latest national model building codes and standards for the physical infrastructure.
5. Insist on the development of codes and standards that are compatible with resilience planning and set transparent performance goals.

6. Adopt appropriate land use planning regulations that manage the green infrastructure, limit urban sprawl, and set design standards for construction in high hazard zones such as flood plains, coastal areas, areas susceptible to liquefaction, etc.
7. Assure the effectiveness of the building department in enforcing current codes and standards during permitting and construction inspection to assure that the latest processes are being followed.
8. Develop processes and guidelines to be deployed for post-event assessments and repairs.
9. Collaborate with adjacent communities to promote common understanding and opportunities for mutual aid during response and recovery.
10. Elevate the level of inter-system communication between the infrastructure community's providers and incorporating the interdependencies in their response and recovery plans.
11. Lobby for State and Federal owned and leased properties to be built and upgraded to resilient standards.
12. Develop and implement education and awareness programs for all stakeholders in the community to enhance understanding, preparedness, and opportunities for mitigation.

3.3.2. Construction-Related Strategies

1. Using the tools provided in Chapter 10, prioritize gaps identified between the desired and anticipated performance of infrastructure clusters, as summarized in the Resilience Matrix for the prevailing hazards.
2. Identify and implement opportunities for natural systems protection including sediment and erosion control, stream corridor restoration, forest management, conservation easements, and wetland restoration and preservation.
3. For each built environment gap, identify the guidelines and standards used to assess deficiencies in individual public and private buildings and infrastructure systems. Define the gap in a transparent and publicly available method and announce the result. This will trigger voluntary actions on the part of building owners and infrastructure system operators.
4. Include retrofitting of public buildings to achieve the resilience goals in the capital planning process and make it a part of the prioritization process.
5. Develop incentives to encourage new construction be built to the resilient standards and for deficient existing construction to be retrofitted as needed.
6. Support national efforts to improve code-based design standards that match the resilience metrics defined in this framework.
7. Identify building and infrastructure system clusters that need to be retrofitted under mandatory programs and implement the retrofitting through local ordinances. Develop and announce viable funding opportunities and include some level of public funding.

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4. Dependencies and Cascading Effects

The development of a specific community disaster resilience plan requires an understanding of the building and infrastructure system dependencies and the potential cascading effects that can occur. This chapter provides an overview of aspects of the physical interconnectedness of buildings and infrastructure systems to consider when setting performance goals for community recovery.

4.1. Introduction

To determine the performance needed for the selected clusters of the built environment and to protect a community from significant and non-reversible deterioration, an orderly and rapid process for managing recovery is needed that includes availability of a sufficient number of buildings in each of the designated clusters and infrastructure systems that support them. Each cluster's performance depends not only on its primary function, but also on the dependencies between clusters and the infrastructure systems that support them. These dependencies need to be addressed when setting performance goals to avoid potential cascading failures of multiple systems.

Cascading failures occur when a failure triggers failures of other components or systems. It can occur within one system, such as a power grid, when one component failure causes an overload and subsequent failure of other components in sequence. It can also occur between systems when the failure of one system causes the failure of other systems. For example, a multiple-hour loss of power in a community can cause failure in the cell phone system if there is no emergency power to maintain the cell towers.

Identifying the dependencies and potential cascading failures is the first step. Reducing the effect of dependencies and consequences, where possible, and setting performance goals that balance the role of dependent systems in community recovery is achieved through multiple approaches. For example, dependencies can be reduced by adding redundancy, increasing capacity, and installing weak links that constructively isolate portions of a system that do not need to be interconnected. Governance processes and public policies also play a key role in developing plans for mitigation, response, and recovery management of dependencies.

4.2. Dimensions of Dependency

Interactions within and between infrastructure systems are dependent on a number of factors. Traditionally, dependencies consider the physical and functional relationship between different systems (i.e., drinking water systems require electricity to operate pumps). However, this is only one dimension that illustrates system interaction. This section presents multiple dimensions of dependency considered in community resilience planning: internal and external, time, space, and source dependencies. It should be noted that due to the complex nature of infrastructure system interactions, these dimensions of dependency are not completely decoupled.

4.2.1. Internal and External Dependency

Disruption to the normal operating state of the built environment reveals that infrastructure systems are interconnected through a web of external dependencies. Additionally, within a given system (i.e., an individual service provider) operations are dependent on a similar web of internal dependencies. Failure of a single critical system component can result in cascading failures within an individual system, as in the case of lost electrical power to an estimated 50 million people in the 2003 Northeast Blackout (NERC 2004). External dependencies can also lead to cascading failures of other infrastructure systems, as in the shutdown of train service in and out of New York City and loss of cell sites after batteries were drained in the 2003 Northeast Blackout.

Internal Dependency

Within a given system, there are certain components that are critical to the successful operation of the system. An example of a critical component in a water system is a pump that delivers water to a water tower to distribute onto customers by gravity feed. If the pump stops working, then customers in the pressure zone served by that pump are without water – unless there is redundancy built into the system to supply water in another way. This pump example represents an infrastructure-related dependency internal to a single water utility. The pump would also be an internal dependency that affects operations within a single infrastructure system if it was part of a system that provided water to numerous water utilities from a wholesale water supplier. In addition to physical infrastructure-related internal dependencies, each infrastructure system depends on a number of other factors to sustain normal operations.

An example of infrastructure system interdependencies is shown in Figure 4-1 for emergency services. The example illustrates the dependencies that may exist between the services and buildings at the 'emergency services' level with the other infrastructure systems. Understanding of dependencies and potential cascading effects provides an informed basis for setting performance goals for community response and recovery.

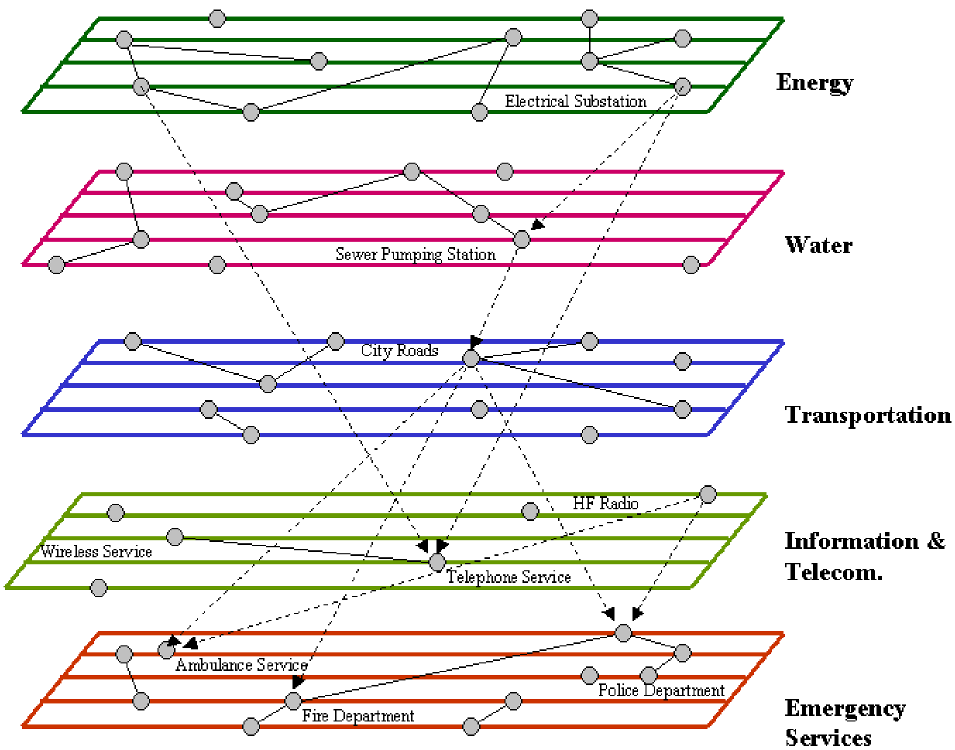

Figure 4-1. Example of Infrastructure Interdependencies for Emergency Services (Pederson et al 2006)

External Dependency

Infrastructure systems are typically dependent on other external systems for continued successful operation. The water pump described above is dependent on electrical power for operation; therefore, it is dependent on the energy system that is external to the water system. The pump may be able to operate for a short period with an emergency generator, but the generator would be dependent on refueling during an extended power outage. Refueling is in turn dependent on an available supply of fuel and a transportation system to deliver the fuel.

Figure 4-2 illustrates other examples of dependent relationship among infrastructure systems. These relationships can be characterized by multiple connections among infrastructure systems. The behavior of a given infrastructure system may be initially evaluated in isolation from other infrastructure systems, but community resilience planning requires understanding of the integraated performance of the physical infrastructure.

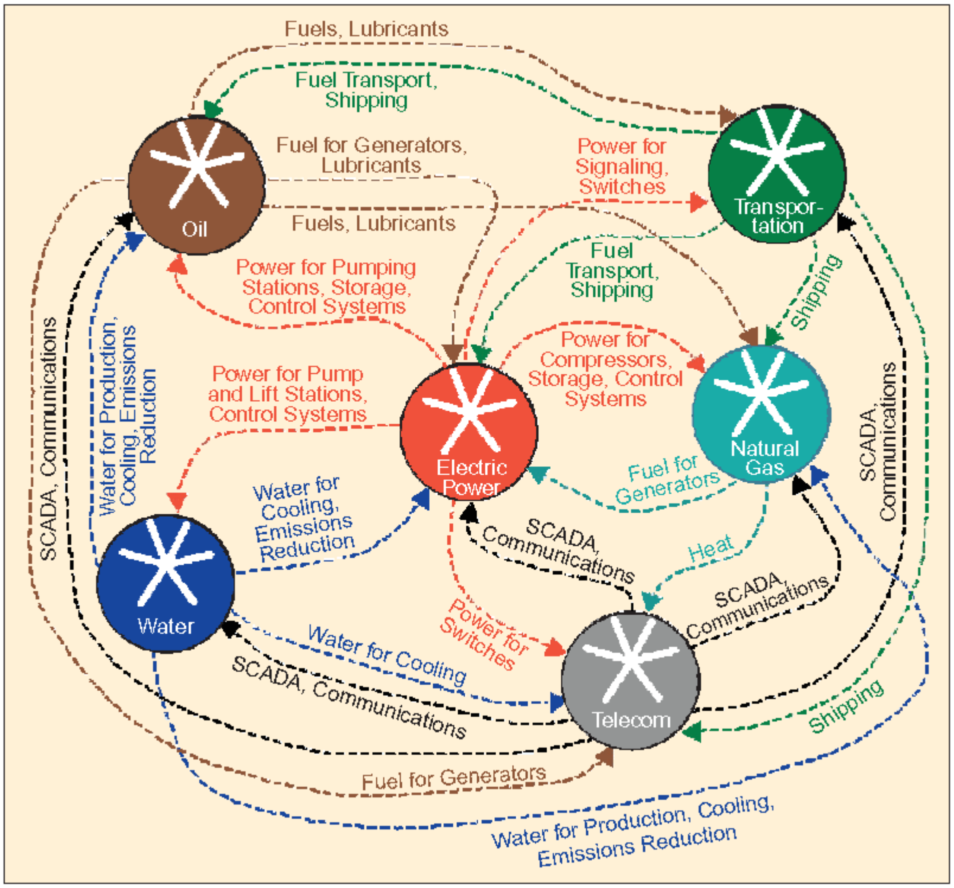

Figure 4-2. Example of External Dependency Relationship (Rinaldi et al 2001)

Cascading Failures

Internal dependency-related cascading failures can affect power transmission, computer networking, mechanical and structural systems, and communication systems. External dependency-related cascading failures can affect all buildings and systems. Figure 4-3 and Figure 4-4 illustrate how internal and external dependencies resulted in cascading failures in the 2003 Northeast Blackout. Failures in physical infrastructure can also have cascading impacts on social institutions. For example, prolonged loss of critical services following a disaster may drive small businesses to relocate or go out of business entirely.

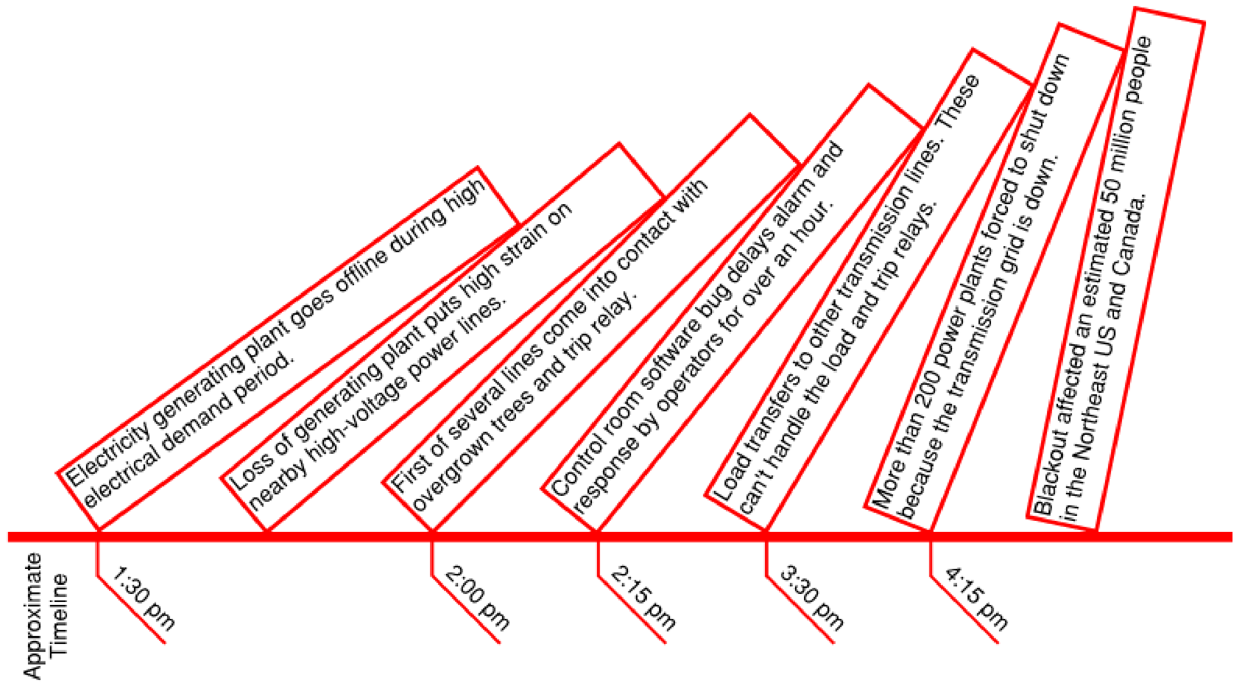

Figure 4-3: Power System Internal Dependence Cascading Failure in the 2003 Northeast Blackout

Figure 4-4: External Dependence Cascading Failure in the 2003 Northeast Blackout

4.2.2. Time Dependency

Recovery Phases

After a disaster, the time to restore critical services depends on how rapidly an infrastructure system and other systems required for its functioning can recover. Light-rail transportation systems, such as the Bay Area Rapid Transit (BART) system in the San Francisco Bay area, require electrical power for operation. No matter how resilient the light-rail infrastructure system, recovery of service depends on the restoration of electrical power.

There may also be operational dependencies that impact a utility provider's ability to perform repairs. Crews typically rely on the transportation network (roads and bridges) to access repair sites, liquid fuel for trucks and equipment, cellular phones for communication, availability of repair supplies through the supply chain, etc. Disruption in any one or a combination of these systems can increase delays in recovery of service.

The resilience framework defined in Chapter 3 organizes the community resilience plan around three phases of recovery using four categories of building clusters. The nature of the critical dependency issues is different for each of these phases. The first phase, focused on immediate response and labeled as "short-term", is expected to last for days and requires critical facilities and provisions for emergency housing. The second, intermediate recovery phase, is expected to last for weeks to months and includes restoration of housing and neighborhood-level services, such as schools. The third, the long-term recovery phase, focuses on full recovery of the community's economic and social base. Each phase has a unique set of dependencies, as is introduced below.

Short-Term Recovery Phase

During the short-term phase (days), the normal operation of infrastructure systems may be impaired. Individual system operators will activate their emergency response plans. Internal dependencies (such as staff, operations center, data, repair supplies, etc.) and key external dependencies (such as transportation) will be critical in defining the pace of the initial response. A well-defined governance process, between and among government emergency managers and system providers, will be essential to coordinate system restoration priorities that are best for the community, especially when the recommended restoration sequence might not be optimal for an individual system provider. A report by the City and County of San Francisco Lifelines Council indicated that a top planning and preparedness priority for system providers is to develop communication and employ priority decision-making strategies to aid in post-disaster response (CCSF Lifelines Council 2014).

Critical facilities, as defined in Chapter 3, are a small number of building clusters and supporting infrastructure systems that need to be functional immediately after an event to organize and direct the emergency response and provide a safe environment for emergency responders. During this early phase, the degree of dependence on other infrastructure systems depends on their ability to operate with emergency power, an independent communication network, and possibly onsite housing and subsistence for the staff. Critical transportation routes need to be established prior to the event and made a high priority in post-event cleanup and debris removal. Critical routes enable replenishment of onsite supplies including fuel, water, food, medical supplies, etc. Performance goals for recovery need to represent an appropriate balance between having the needed supplies on hand to operate independently for a short period and defining achievable restoration times.

For example, the stored water at some hospitals can only supply drinking water for three to four days. This supply may only represent about 5% of the total water usage, whereby some hospitals' total water usage may exceed 300,000 gal/day. Many hospitals do not currently have onsite storage capacity for wastewater and have limited storage capacity for medical waste. These dependencies would likely impair hospital functionality after a hazard event. In California, the Office of Statewide Health Planning and Development is implementing requirements to provide three days of an operational supply of water (including water for drinking, food preparation, sterilization, HVAC cooling towers, etc.), wastewater storage, and fuel for emergency generators (CBC 2013).

The timing of a disaster may also impact the resources available for response. Availability of hospital beds is often seasonally dependent. During the winter respiratory season, many hospitals operate at or near capacity, limiting the number of patient beds available for disaster response (even after discharge of less critical patients and canceling elective procedures).

The need for temporary housing for emergency responders and displaced individuals and animals, as discussed in Chapter 2, is often met by using schools, shelters, hotels, conference centers, residences that are safe to shelter-in-place, etc.. Food, water, security, and sanitation needed to protect public health are usually provided at centralized locations. During the short-term recovery phase, there is a limited need for transportation, power, and communication. For example, current thinking for earthquake resilience says that it is best for residents to shelter in their homes, neighborhoods, or within their community. Recovery performance goals should consider such options.

The inability to provide sufficient temporary housing can lead to a mass exodus from the community that could cascade into a loss of residents and ability to restore the economic base of the community. Performance goals need to realistically estimate the number of displaced residents and emergency responders that need to be accommodated, and the availability of adequate facilities within or adjacent to the community.

Intermediate Recovery Phase

In the intermediate recovery phase (weeks), the dependency focus is expected to shift more to external dependencies (electricity, liquid fuel, transportation, etc.) along with key internal dependencies (funding for payroll and repair supplies, contractors, etc.).

Restoring fully-functional neighborhoods is key to maintaining the workforce needed to restore the economic vitality of the community after a hazard event. During this period, special attention must be paid to the needs of the disadvantaged and at-risk populations who require a higher level of assistance. Functioning residences, schools, and businesses are needed rapidly enough to give the population confidence to stay and help to support community recovery. If people are unable to shelter in their neighborhoods, the small neighborhood businesses they depend on will likely lose their client base and have to be relocated or close. This, in turn, may cascade into delays for recovering the community's economy.

The needs of commercial services, such as banking, are critical to recovery of a community. If the primary economic engine of a region is based on a manufacturing plant that requires water, wastewater, and power operating within two weeks after an expected hazard, then the intermediate recovery phase must address these dependent systems. The intermediate recovery plans should consider other factors, such as for parents to return to their jobs, schools and daycare facilities will need to be back in operation.

The condition of the built environment that supports residences, neighborhoods, and businesses is one key factor that determines recovery time. Significant structural damage to buildings and infrastructure systems cannot be repaired within a few weeks; it takes months or longer, depending on the damage. Buildings need to be safe to use while being repaired for minor damage or temporary facilities will need to be provided, especially for damaged residences. The transportation, energy, water, wastewater, and communication systems that support these facilities need to be restored within the same timeframe.

Long-Term Recovery Phase

In the long-term recovery phase (months), it is anticipated that utility services will be restored (at least with temporary fixes). If a community is in the early stages of developing its resilience, the recovery time may take longer due to needed repairs or rebuilding. As a community develops a 'mature' resilience, a similar event should cause less damage and have shorter, less costly recovery times. The key dependencies at this point are related to supplies, equipment, and resource availability for repairs and reconstruction.

Restoring a community after a major event will provide a significant, short-term stimulus to the economy from the accelerated construction activity and provide an opportunity to improve the built environment according to a community's resilience plan, financed by government, insurance companies, large businesses, private savings and developers. In order for the recovery process to successfully improve community resilience, a governance structure needs to be in place that approves reconstruction rapidly and in accordance with the community's interests. Any stall or stalemate in the decision-making process will delay the construction activities needed to restart the economy.

It is important that communities develop a plan before a disaster on how to manage the logistics of recovery. For example, logistics include an expedited building permit process and adequate resources for building inspections during a post-disaster construction boom. They also include land use planning decisions that will guide rebuilding. If the process is delayed, then people and businesses may move out of the region and the opportunity to build back a better, more resilient community is lost. The Oregon Resilience Plan indicated that businesses are only able to accommodate approximately two to four weeks of business interruption before they would need to relocate or go out of business. This is particularly troubling to a state like Oregon where a large portion of the economy relies on small businesses and where the current expected level of resilience for a Cascadia Subduction Zone earthquake does not meet this four-week time window. Japan experienced small business losses because of delayed decisions in land use planning to rebuild in the tsunami-impacted region after the 2011 Tohoku earthquake (Mochizuki 2014).

4.2.3. Space Dependency

Disaster Impact Region

Different types of disasters result in variation in the geographic area of impact. Hurricanes or a Cascadia Subduction Zone earthquake may impact a large multi-state region, while tornados may only impact a portion of a community. Communities need to consider the potential geographic area of impact for their expected hazards as part of the planning process. The Oregon Resilience Plan (OSSPAC 2013) was developed for a scenario Cascadia Subduction Zone earthquake that would likely impact a region including Northern California, Oregon, Washington, and British Columbia. The plan discusses a strategy where the central and eastern portions of the state would provide assistance to the Willamette Valley/I-5 Corridor region (area including the state's largest population centers) and then the Willamette Valley/I-5 Corridor would provide assistance to the coastal region. Other mutual aid assistance would likely be mobilized from Idaho, Montana, and other adjacent states. This is in contrast to a Midwest tornado, which may cause significant devastation to a particular community, but assistance in response and recovery is available from the surrounding communities.

Location of Critical Infrastructure

The physical location of infrastructure within a community impacts how it is expected to perform in a disaster. For example, wastewater treatment plants are often located close to rivers or the ocean for system operation reasons, but this makes them particularly vulnerable to flooding, sea level rise, and tsunami hazards. In the resilience planning process, communities need to consider how the expected hazard and location of existing infrastructure impacts expected system performance. Communities should also adopt land use planning policies that consider the dependence between physical location and system performance, when evaluating upgrades to existing facilities, construction of new infrastructure, and rebuilding after a disaster.

Co-location

Infrastructure systems are often co-located along transportation or other utility corridors. The close proximity of these different systems can lead to unintended damage to these co-located systems. Infrastructure system pipelines and conduits are often co-located on bridges at river or other crossings and can be significantly impacted by earthquake and inundation (flood and tsunami) hazards. Figure 4-5 shows an example of where bridge support settlement during the 2011 Christchurch New Zealand earthquake caused a sewer pipeline, supported by the bridge, to break and spill raw sewage into the river below. Telecommunications wires are often supported by electrical power poles, so if the pole breaks, both systems are impacted. Water and wastewater pipelines are often co-located near other buried infrastructure under or adjacent to roadways. Failure of pipelines may result in damage to the roadway (i.e. sinkhole from water main break or collapsed sewer pipeline) and impacts to traffic when repairs are being made. Co-located infrastructure not only results in potential damage to multiple systems, but also often requires significantly more coordination between service providers during repair.

Figure 4-5: Example of Infrastructure Co-location (Source: Eidinger & Tang, 2014)

4.2.4. Source Dependency

Communities depend on goods and services that may or may not be available locally. Disasters that impact the source of these goods and services can have far-reaching downstream impacts.

In the Pacific Northwest, Oregon is dependent on refineries in the State of Washington for a supply of liquid fuel. A Cascadia Subduction Zone earthquake would likely disrupt refinery operation and limit available liquid fuel supplies in Washington and Oregon. Similarly, a Gulf Coast hurricane could damage offshore drilling platforms and oil refinery facilities, disrupting the liquid fuel supply for the hurricane-impacted region and larger portions of the US.

Regional utility systems provide another example of source dependency. The Tennessee Valley Authority (TVA) supplies power to over 150 municipal utility companies and several large industrial users in Alabama, Kentucky, Mississippi, and Tennessee. A disaster, such as an ice storm, impacting one or more TVA power generation facilities or transmission lines, has the potential to disrupt electricity over a large geographic area.

A disaster, such as a wildfire, can impact the drinking water supply due to high post-fire sediment loads. These sediment loads can cause damage to reservoirs and treatment plants that result in higher treatment costs to remove suspended solids from drinking water. The impact of sediment is highest in the burned area, but data from the Southern California wildfires in the fall of 2003 indicated increased sediment loads at treatment plants up to 100 miles from the fire (Meixner and Wohlgemuth 2004).

4.3. Planning for Infrastructure System Dependencies

As part of the community resilience planning process, utility providers, businesses, and others should be encouraged to refresh or develop their own emergency and continuity of operations plans and identify internal dependencies. As organizations are conducting internal resilience planning activities, they should also compile a list of external dependencies and they impact their operations. After each infrastructure system identifies their external dependencies, the next step is to engage all infrastructure systems along with community and business leaders to discuss the current expected performance of infrastructure for the range of disasters expected, external dependencies, and expected service restoration times for each infrastructure system.

It is critical that all stakeholders are in these discussions, including elected officials, emergency managers, first responders, service providers, business leaders, civic organizations, and disaster services organizations, etc. For discussion of external dependencies, the definition of community might need to be broadened, as utilities often serve a larger area than just one local population.

Understanding the dependencies within and between physical infrastructure systems is a new and developing area of planning related to resilience and recovery from significant disruptions. However, there is an immediate need for a process to identify the interdependencies for a resilience framework and an empirical method based on historical data seems to be the most achievable at this point. Such a method was used by the City and County of San Francisco Lifelines Council in 2013 and it can be applied to other communities. San Francisco reported their findings and recommendations in February 2014 (CCSF Lifelines Council 2014). Their process followed these steps:

1. Form a service provider council of private and public infrastructure owners and provide a quarterly forum for them to meet, share current planning activities, and discuss response and recovery issues, their interdependencies, and methods to improve the existing conditions.
2. For the extreme level of all prevailing hazards, characterize the expected level of damage in terms related to infrastructure system performance from the view of the infrastructure provider. Figure 4-6 illustrates the restoration times estimated by the providers in the San Francisco study.
3. For each infrastructure system, document the planned response and restoration process, likely dependencies on other systems, and the understanding of other system dependencies on them.
4. Process the information and determine overall interactions between systems and the related dependencies. Identify areas with potential for cascading effects, occurrences of co-location, overlaps, and hindrances related to restoration and recovery plans. Table 4-1 illustrates the dependencies identified in the San Francisco Study.
5. Develop a series of recommendations related to the next steps needed to better define the needs, advance collaborative planning where needed, prioritize the needed mitigation projects and identify funding sources for pre- and post-event needs.

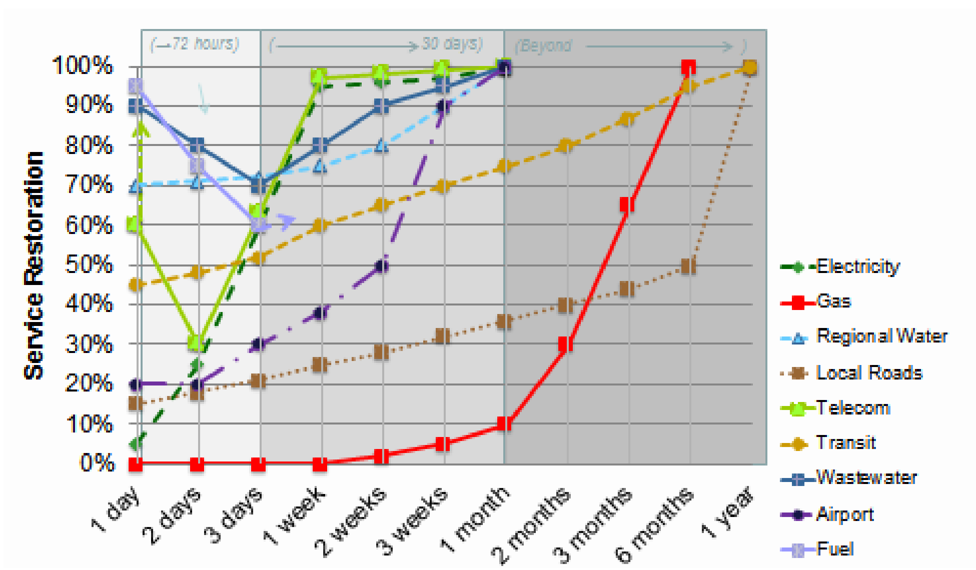

Figure 4-6: Potential Service Restoration Timeframes following a Scenario M 7.9 Earthquake on the San Andreas Fault. (CCSF Lifelines Council, 2014)

Table 4-1: Infrastructure System Dependencies following a scenario M7.9 earthquake on the San Andreas Fault. (CCSF Lifelines Council, 2014)

The overall interaction and dependency on a particular system (read down each column)

Infrastructure System Operators' dependency on other Infrastructure systems (read across each row)

	Regional Roads	City Streets	Electric Power	Natural Gas	Telecom	Water	Auxiliary Water	Waste-Water	Transit	Port	Airport	Fuel
Regional Roads	General	Restoration Substitute	Restoration	Restoration	Restoration	Restoration		Restoration	Substitute		Restoration	Restoration
City Streets	Substitute Restoration	General	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration		Restoration
Electric Power	Restoration	Co-location, Restoration	General		Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration		Co-location	Restoration	Restoration
Natural Gas	Restoration	Functional, Co-location, Restoration	Substitute	General	Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration		Co-location	Restoration	Restoration
Telecom	Restoration	Co-location, Restoration	Functional, Restoration	Restoration	General	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration			Restoration	Restoration
Water	Restoration	Restoration	Restoration		Restoration	General				Co-location		Restoration
Auxiliary Water	Restoration	Functional, Restoration	Restoration		Restoration	Functional, Restoration	General			Co-location, Restoration		Restoration
Waste-Water	Restoration	Co-location, Restoration	Functional, Restoration		Restoration	Functional, Restoration		General		Co-location, Restoration		Restoration
Transit	Substitute, Restoration	Functional, Substitute, Co-location, Restoration	Functional, Restoration		Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, Restoration	Co-location, General	Co-location, Restoration		Functional, Restoration
Port	Restoration	Co-location, Restoration	Co-location, Restoration		Co-location, Restoration	Co-location, Restoration	Co-location	Co-location	Co-location	General		Restoration
Airport	Restoration		Restoration		Restoration	Restoration		Restoration	Co-location, Restoration		General	Functional, Restoration
Fuel	Restoration	Restoration	Functional, Restoration		Restoration	Restoration				Restoration	Restoration	General

Legend:

- Significant interaction and dependency on this infrastructure system for service delivery and restoration efforts
- Moderate interaction and dependency on this infrastructure system for service delivery and restoration efforts
- Limited interaction and dependency on this infrastructure system for service delivery and restoration efforts

Key to terms used in the matrix:

Functional disaster propagation and cascading interactions from one system to another due to interdependence

Co-location interaction, physical disaster propagation among infrastructure systems

Restoration interaction, various hindrances in the restoration and recovery stages

Substitute interaction, one system's disruption influences dependencies on alternative systems

General interaction between components of the same system. (All systems would have general interaction issues, but some issues are more crucial for the system's potential disruption and restoration.)

Figure 4-7 shows a map of Portland, Oregon with a GIS overlay of infrastructure systems that are contained in the Earthquake Response Appendix to the City's Basic Emergency Operations Plan (City of Portland 2012). The city used this information to coordinate the potential spatial dependencies of the city's infrastructure. Eventually these tools may include systems modeling functionality that could enable scenario-based assessment of infrastructure system depencencies or be used as a tool to prioritize post-disaster infrastructure repairs and optomize restoration of all infrastructure systems.

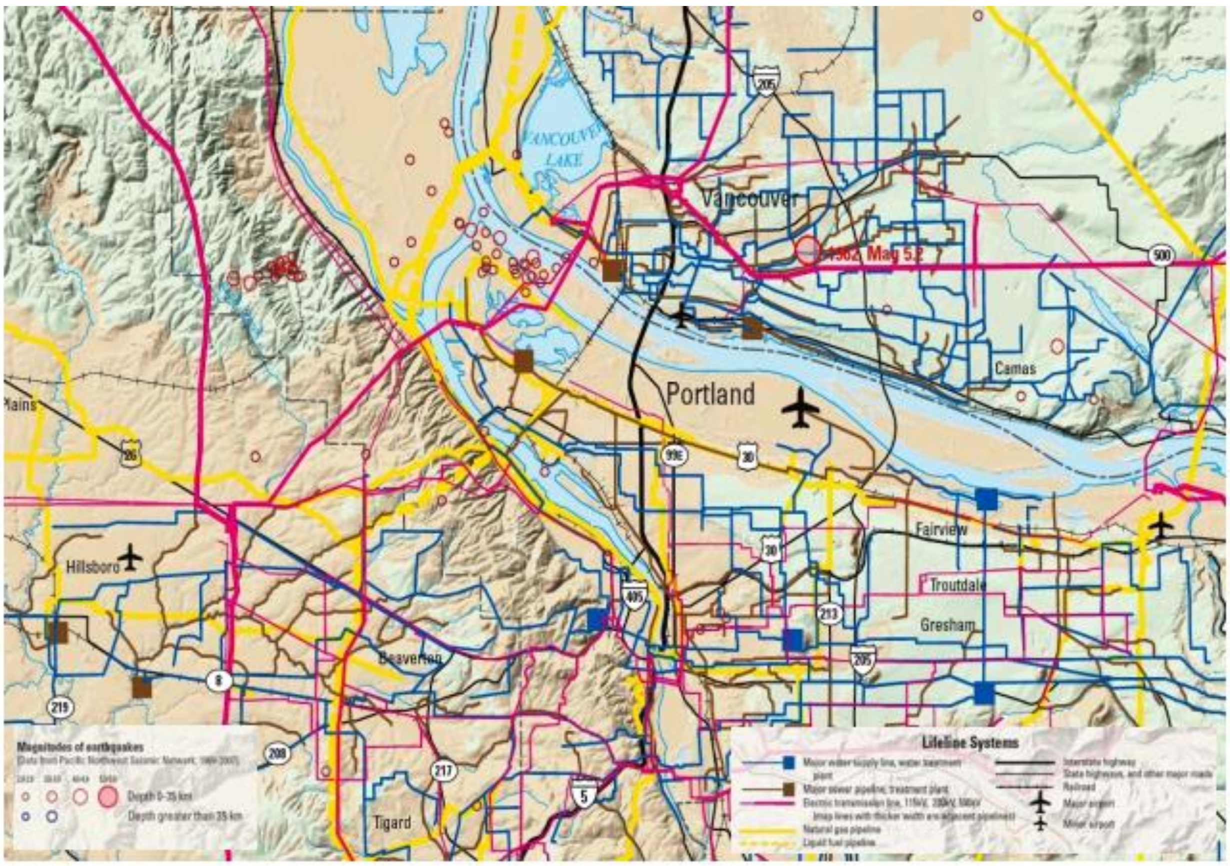

Figure 4-7: GIS Map of Infrastructure Systems around Portland, Oregon (City of Portland, 2012)

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5. Buildings

5.1. Introduction

This chapter presents guidance for setting performance goals for buildings in a community resilience plan. Building stock within a community varies widely, in terms of use, occupancy, ownership, age, construction type and condition. The variability in occupancy and use leads to different performance goals between buildings; variability in age and condition results in different performance levels, even within the same class of building; and variability in ownership, such as public or private, can present challenges in implementing minimum performance goals, particularly for existing buildings. This chapter discusses the various classes and uses of buildings, performance goals, and past and current codes and standards that support community resilience.

5.1.1. Social Needs and Systems Performance Goals

Buildings fulfill a multitude of social needs from the most basic, such as providing shelter, to housing necessary services like medical care and food. Many buildings also house goods or businesses that can be closed following a hazard event; but such buildings will hopefully require only modest repairs. Therefore, performance goals for buildings depend specifically on what each individual building houses or the function it serves. Some buildings must be functional immediately, or soon after, the disaster, while other buldings need to be stable so they do not collapse or place the life safety of the occupants at risk. Because buildings fulfill a wide variety of social needs, the recovery time and sequence of recovery must be evaluated at the community level. Section 5.2 discusses building classes and uses; Section 5.3 provides guidance for developing performance goals based on the methodology in Chapter 3.

5.1.2. Reliability v. Resilience

Buildings are an integrated set of systems – structural, architectural, utilities, etc. – that perform together to serve the intended function of the building. When discussing building performance, each of these systems must perform adequately because each system supports the building function in different ways. Structural systems provide a stable system that carries gravity loads based on building construction and contents and must resist forces imposed by hazard events. Architectural systems supply protection from outside elements through the cladding systems (e.g., roof, exterior walls or panels, doors, windows, etc.) and interior finishes. Utility systems deliver needed services that support the building function.

Buildings designs focus on the building's intended purpose and on occupant safety for fires and natural hazard events. Building designs are based on provisions in building codes and standards, though some designs are performance-based and allow alternative solutions. Structural systems for buildings are typically designed for a minimum required level of hazard intensity, based on a target reliability level for building performance. For buildings, structural reliability refers to the probability that a structural member or system will not fail. For gravity, wind, snow, and flood loads, structures are designed for member reliability, with a low probability of failure, so that structural members are not expected to fail during a design event. For seismic events, structures are designed for system reliability conditional on the design seismic event, where the structural system is not expected to fail or collapse, but individual members may fail. Thus, for wind, snow, and flood events, the structural system is expected to sustain little or no damage under a design hazard event. For seismic hazard events, the structure is expected to afford life safety to the occupants, such that while structural damage may occur, the building will not collapse. Therefore, while a building is expected to protect its occupants during a seismic event, it may not be functional afterwards and may even need to be demolished.

Wind, floods and winter storm events may also disrupt services, such as water supply, and create power outages, which also affect building functionality. If water pressure cannot be maintained, then fire hydrants and fire suppression systems are out of service, and buildings cannot be occupied. If fuel for generators is depleted during long term power outages, buildings are not functional.

While structural reliability is important, it is not synonymous with resilience. If a building has sustained damage such that, following a hazard event, it cannot perform its pre-disaster function, that may negatively affect a community's resilience. An example is a fire station where the building itself has sustained little or no structural damage, but the doors cannot open, preventing fire trucks from exiting to fight fires. Some buildings may need to be functional sooner than others. Providing a minimum level of reliability ensures buildings do not collapse, but does not ensure they will remain functional after a design-level hazard event.

Designing a resilient building requires understanding the functions that building supports in the community, and the performance required to ensure those functions during or after a hazard event. Some requirements may actually exceed those required by model building codes and standards.

5.1.3. Interdependencies

A community's resilience depends on the performance of its buildings. The functionality of most buildings depends, in turn, on the utilities that supply power, communication, water/wastewater, and the local transportation system. Alternatively, some buildings support the utility systems. Buildings and supporting infrastructure systems must have compatible performance goals to support community resilience. Refer to other chapters of this framework for infrastructure system resilience recommendations.

In many instances, infrastructure systems are unavailable immediately after a hazard event to support specific buildings when they must be operational. For example, emergency operation centers and hospitals must function immediately after a hazard event. However, power and water infrastructure systems may be damaged. Therefore, during short-term recovery, critical facilities should plan to operate without external power and water until those services are expected to be recovered.

In many instances, the functionality of specific buildings depends on the occupants as well as the physical building. First responders need to reach the buildings where equipment is housed to provide emergency services. Therefore, community resilience requires the buildings and supporting infrastructure systems consider dependencies that must be addressed to be functional.

5.2. Buildings Classes and Uses

5.2.1. Government

In most communities, the emergency operations centers, first responder facilities, airports, penitentiaries, and water and wastewater treatment facilities are government-owned buildings. These buildings provide essential services and shelter occupants and equipment that must remain operational during and after a major disaster event. Therefore, essential buildings should remain operational, as defined by Category A (safe and operational) in Chapter 3 and Table 5-1.

Other government buildings may not need to be functional immediately following a hazard event (e.g., City Hall or county administrative building, public schools, mass transit stations and garages, judicial courts, and community centers). However, these buildings may be needed during the intermediate recovery phase following the hazard event. A performance goal for these types of buildings might be either Category A or Category B, safe and usable during repair, depending on their role in the community recovery plan.

Categories C and D are provided to help communities evaluate the anticipated performance of their existing buildings for a hazard event. Older construction that is poorly maintained, or has features known to be prone to failure, such as unreinforced masonry walls and a lack of continuous load path to the foundation, need to be documented as part of the community resilience plan.

Typically, buildings are designed according to risk categories in the *American Society of Civil Engineers Standard 7* (ASCE 7) and *International Building Code*. Risk categories relate the criteria for design loads or resulting deformations to the consequence of failure for the structure and its occupants. Risk categories are distinct from *occupancy category*, which relates primarily to issues associated with fire and life safety protection, as opposed to risks associated with structural failure. Risk categories rank building performance with a progression of the anticipated seriousness of the consequence of failure from lowest risk to human life (Risk Category I) to the highest (Risk Category IV).

Essential buildings fall under Risk Category IV, which has the highest level of reliability, and provisions for seismic events that require nonstructural systems to remain operable. Some buildings that may be deemed essential are classified as Risk Category III, which includes buildings and structures that house a large number of people in one place or those having limited mobility or ability to escape to a safe haven in the event of failure, including elementary schools, prisons, and healthcare facilities. This category has also includes structures associated with utilities required to protect the health and safety of a community, including power-generating stations and water treatment and sewage treatment plants. Risk Category III requires a higher level of reliability than a typical building associated with Risk Category II, but there are fewer nonstructural system requirements for seismic events than a Risk Category IV building.

Table 5-1. Building Performance Categories

Category	Performance Standard
A. Safe and operational	These are facilities that suffer only minor damage and have the ability to function without interruption. Essential facilities such as hospitals and emergency operations centers need to have this level of function.
B. Safe and usable during repair	These are facilities that experience moderate damage to their finishes, contents and support systems. They will receive green tags when inspected and will be safe to occupy after the hazard event. This level of performance is suitable for shelter-in-place residential buildings, neighborhood businesses and services, and other businesses or services deemed important to community recovery.
C. Safe and not usable	These facilities meet the minimum safety goals, but a significant number will remain closed until they are repaired. These facilities will receive yellow tags. This performance may be suitable for some of the facilities that support the community's economy. Demand for business and market factors will determine when they should be repaired or replaced.
D. Unsafe – partial or complete collapse	These facilities are dangerous because the extent of damage may lead to casualties.

5.2.2. Healthcare

Emergency medical facilities are critical to response and recovery efforts following a major disaster. Therefore hospitals, essential healthcare facilities, and their supporting infrastructure, must be functional (Category A) during and following a hazard event. This does not mean the entire facility has to be fully operational, but critical functions, such as the emergency room and life support systems, should be operational until other functions can be restored. Currently, hospitals are designed to Risk Category IV requirements, with some local communities or federal agencies imposing additional requirements. For example, California requires that all hospital designs, regardless of location or ownership (municipal or private), be reviewed and construction overseen by a state agency.

Nursing homes and residential treatment facilities that house patients who cannot care for themselves may also need to be immediately functional after a hazard event. Other healthcare facilities, such as doctors' offices, pharmacies, and outpatient clinics, may not all need to be immediately available. Communities should determine if a subset of these buildings will be needed shortly after the event. Medical office buildings and pharmacies may need to be designed to suffer limited damage that can be repaired in a reasonable period of time, either Category A or Category B, depending on their role in community recovery and resilience. In most cases, buildings for these types of medical offices are currently designed as Risk Category II buildings.

5.2.3. Schools and Daycare Centers

Many communities have primary (K-12) schools that are designed to a higher performance level (Risk Category III) because they have large assemblies of children. Often, school gymnasiums or entire school buildings are designated to serve as emergency shelters during the hazard event and as emergency staging areas after the event. Additionally, the research that went into the SPUR Resilience City Initiative found a perception that when children can return to school, things are returning to normal and parents can return to work. Thus, expeditious resumption of function is important for primary schools across a community.

There can be a dichotomy of performance requirements for a school. On the one hand, providing enhanced performance and returning to operation quickly places a school in Category B, stable with moderate damage. However, if the school or some portion of the school is used as an emergency shelter, that requires Category A, stable with minor damage. Depending on the hazard, the Risk Category III provisions to which most primary schools are designed may provide Category A or B performance. Therefore, any school that will be designated as an emergency shelter should be evaluated to determine its intended role in the community and that it is appropriately designed for Category A or B performance. Evaluation would determine which schools are anticipated to perform adequately and which may need to be upgraded to a higher performance level.

Higher education facilities are generally regulated as business or assembly occupancies with exceptions for specific uses, such as laboratory and other research uses. Research universities are also often concerned with protecting their research facilities, long-term experiments, associated specimens and data.

Daycare centers house young children that require mobility assistance and are unable to make decisions; but daycare populations may not meet assembly requirements. Therefore, such centers may be located in buildings that meet either Risk Category II or III performance requirements and code requirements for these types of facilities vary. In some cases there are heightened requirements; and in other instances there are few constraints beyond basic code requirements for Risk Category II buildings. Communities may require daycare centers to be designed to a higher level of performance, similar to school buildings.

5.2.4. Religious and Spiritual Centers

Religious and spiritual centers play a special role in many communities. They can offer a safe haven for people with emotional distress following a hazard event. Logistically, these buildings are often critical nodes in the post-disaster recovery network. Many religious organizations operate charity networks that provide supplies to people following a hazard event. In past disasters, many religious institutions opened their doors to provide temporary housing. In most cases, however, these buildings are designed as typical Risk Category II buildings. Compounding the issue, these buildings are often among the oldest in a community and are built with materials and construction methods that perform poorly in hazard events.

If these facilities fill an important role in the community recovery plan, Category B would be a desired performance. However, a number of factors could influence a community to accept a lesser performance goal. First, most of these institutions are nonprofit entities, with little funding for infrastructure improvement. Second, many historic buildings would have to be modified, unacceptably disrupting their historic fabric to meet this higher performance category. Therefore, a community should understand the anticipated performance of its churches and spiritual centers and their role in community recovery.

5.2.5. Residential and Hospitality

Communities should consider whether residential buildings and neighborhoods will shelter a significant portion of the population following a hazard event. Houses, apartment buildings, and condominiums need not be fully functional, like a hospital or emergency operation center, but they should safely house occupants to support recovery and re-opening of businesses and schools. Not being fully functional could mean that a house or apartment is without power or water for a reasonable period of time, but can safely shelter its inhabitants. The significant destruction of housing stock led to the migration of a significant portion of the population following Hurricane Katrina’s impact on New Orleans. Such a shelter-in-place performance level is - key to the SPUR Resilient City initiative and prompted the City of San Francisco to mandate a retrofit ordinance for vulnerable multi-family housing.

Currently multi-unit residential structures are designed to Risk Category II provisions, except where the number of occupants is quite large (e.g., > 5,000 people); then they designs meet Risk Category III criteria. For multi-family residential structures, there are two dominant construction types: light frame (wood and cold formed steel light frame) construction and steel or reinforced concrete construction. Light frame residential structures have different performance issues than steel or reinforced concrete structures, which are typically larger.

Most one and two-family dwellings are constructed based on pre-engineered standards using the prescriptive requirements of the *International Residential Code*. There has been debate as to whether the IRC provides comparable performance to the *International Building Code.* In some cases, such as the Loma Prieta and Northridge earthquakes, one and two-family dwellings performed as well as or better than engineered buildings. Further investigation regarding a possible discrepancy in requirements between the IBC and the IRC is essential, because of the importance of residential housing.

In addition, an effective response to most hazard events may require supplemental first responders and personnel from outside the community. If most residential buildings are not functional or safe to occupy, demand for temporary shelter may compete with the need to temporarily house response and recovery workers. Hotels and motels can support response and recovery efforts if they are back in operation shortly after the event. Typically these buildings are designed to meet Risk Category II criteria, like multi-family residential structures.

5.2.6. Business and Services

While it would be ideal to have all community businesses open shortly after a hazard event, such an outcome is not economically practicable. Many business offices, retail stores, and manufacturing plants are located in older buildings that may not perform well during a hazard event or, if constructed more recently, are designed to Risk Category II criteria. Not all commercial buildings are designed to the code minimum requirements, and they may have higher performance capabilities.

Each community should select design and recovery performance goals for its businesses and services, depending on their role in the community during recovery. Certain types of commercial buildings may be critical to the recovery effort. The community needs to designate businesses and their buildings that are critical retail and able to meet a higher performance level. Some businesses and services are commonly essential to recovery:

- ***Grocery stores and pharmacies.*** People need food, water, medication, and first aid supplies following a hazard event. Regional or national grocery stores and pharmacies typically have robust distribution networks outside the affected area that can bring supplies immediately after the hazard event. Although the common preparedness recommendation is for people to have 72 hours of food and water on hand, the potential for disruption beyond the first three days should be evaluated for a community's hazards. For example, the Oregon Resilience Plan recommends two weeks of food and water for a Cascadia earthquake event.
- ***Banks or financial institutions.*** Banks or structures that house automated teller machines provide access to money.
- ***Hardware and home improvement stores.*** These businesses provide building materials for repairs, reconstruction, and emergency shoring of damaged buildings.
- ***Gas stations and petroleum refineries.*** Many communities are arranged so residents need automobiles to carryout basic functions, like shopping and commuting to work. A disruptive event may impact fuel delivery systems and gasoline may be difficult to obtain for a period of time.
- ***Buildings that house industrial and hazardous materials or processes.*** Buildings and other structures containing toxic, highly toxic, or explosive substances may be classified as Risk Category II structures if it can be demonstrated that the risk to the public from a release of these materials is minimal. However, communities need to verify that the risk management plan address community hazards, and any potential releases that may occur during or after a hazard event.

The resilience needs of other types of businesses and the buildings that house them depend to a large extent on the business and community's tolerance for those businesses to be delayed in reopening or closed. Many professional service businesses rely on employees working remotely from home or alternate office spaces. Conversely, manufacturing businesses, retail, and food service businesses do not have that luxury. Their location is critical to the ability of the business to function. If a restaurant or store cannot serve the public or a factory is unable to manufacture its product, then the business may fail. Losing these businesses can adversely impact the community's recovery and long-term resilience because of lost jobs and other economic impacts.

5.2.7. Conference and Event Venues

Convention centers, stadiums, and other large even venues are important for the long term recovery of many communities because of the revenue that these types of events typically generate. Additionally, a venue hosting major events following a hazard event can uplift morale for a community, like hosting the Super Bowl in New Orleans following Hurricane Katrina. Typically these venues are designed to Risk Category III because of the large number of occupants, so they have a greater performance capability than typical buildings.

5.2.8. Detention and Correctional Facilities

Many communities have standalone detention and correctional facilities (prisons). Building codes typically require some higher design requirements on these types of facilities because the people housed in them cannot evacuate without supervision. The level of enhanced design requirements varies based on the facility requirements and state or local jurisdiction. Within this framework, it is suggested that these types of facilities be designed to Category A or B.

5.3. Performance Goals

The resilience matrices in Chapter 3 provide examples of performance goals for buildings and infrastructure systems at the community level for fictional community, Centerville, USA. The example matrices provide a visual method communities can use to determine their desired performance goals in

Table 5-2 through Table 5-4 address each of the three hazard levels discussed in Chapter 3 – routine, expected, and extreme – for Centerville, USA. An individual community may start with one or more of the hazard levels. Some communities may decide that for routine events the infrastructure should have little to no disruption and the extreme event is too much to plan for, so they base their planning on the expected event. However, examining the response of the physical infrastructure to three levels of a hazard can provide insight and understanding regarding system performance. One or more systems may not perform well at the routine level, and cause cascading effects. Such performance indicates that frequent repairs may be required for that system. Alternatively, if there are substantial differences between the desired and anticipated performance of one or more systems, the performance at several hazard levels may help a community prioritize retrofit or mitigation strategies.

A community first needs to identify clusters, or groupings, of buildings for which the same performance goals are desired. The cluster groups and assignment of buildings within each cluster may be unique to each community. The types of buildings selected by Centerville are listed in the left column, and are categorized under critical facilities, emergency housing, housing/neighborhoods, and community recovery. The categories also reflect the sequence of building types that need to be functional following a hazard event. Each building cluster then needs to be evaluated for its role in the community recovery. The rate of recovery is indicated by percentages, 30 %, 60%, and 90%, to show how many buildings within the cluster are recovered and functioning during the three recovery phases in the top row of the table.

The examples in Table 5-2 through Table 5-4 illustrate a large urban/suburban community. Smaller or more distributed communities may elect to create different clusters, while major metropolitan areas may create even finer clusters of buildings. The Centerville example shows that, for a routine hazard in Table

5-2, almost all buildings are desired to be functioning within one to two days, and anticipated to be fully functional within one to three days. For the expected hazard in Table 5-3, only critical buildings and emergency housing are desired to be functioning within one day of the event, but these facilities are not anticipated to be functional for more than four months to two years. For the extreme hazard in Table 5-4, only emergency operation centers and first responder facilities are desired to be functional within a day, but the anticipated performance is that they will not be functional for more than three years.

Recovery of function may not initially be full recovery of function, but a minimum or interim level necessary to perform the essential tasks of that specific building to start the recovery process. For example, a city hall that has an emergency operation center may only provide for enough power to support lighting, phones, and computers for the EOC room, but not the entire building. The building's structure and exterior cladding would also need to be stable and intact to provide a safe environment and allow the EOC to be occupied.

Table 5-2. Example Building Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities	**….**	**A**									
Emergency Operation Centers			90%	X							
First Responder Facilities			90%	X							
Acute Care Hospitals			90%	X							
Non-ambulatory Occupants (prisons, nursing homes, etc.)			90%	X							
Emergency Housing		**B**									
Temporary Emergency Shelters			90%		X						
Single and Multi-family Housing (Shelter in place)			90%		X						
Housing/Neighborhoods		**B**									
Critical Retail			90%		X						
Religious and Spiritual Centers			90%		X						
Single and Multi-family Housing (Full Function)			90%		X						
Schools			90%		X						
Hotels & Motels			90%		X						
Community Recovery		**C**									
Businesses - Manufacturing			60%	90%	X						
Businesses - Commodity Services			60%	90%	X						
Businesses - Service Professions			60%	90%	X						
Conference & Event Venues			60%	90%	X						

Footnotes:

1 Specify hazard being considered
Specify level – Routine, Expected, Extreme
Specify the size of the area affected – localized, community, regional
Specify severity of disruption – minor, moderate, severe

2 30% | 60% | 90% Restoration times relate to number of elements restored within the cluster

3 X Estimated 90% restoration time for current conditions based on design standards and current inventory
Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan
R Regional
S State
MS Multi-state
C Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

Table 5-3. Example Building Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities	**….**	**A**									
Emergency Operation Centers			90%							X	
First Responder Facilities			90%							X	
Acute Care Hospitals			90%							X	
Non-ambulatory Occupants (prisons, nursing homes, etc.)			90%							X	
Emergency Housing		**B**									
Temporary Emergency Shelters			30%	90%							X
Single and Multi-family Housing (Shelter in place)			60%			90%					X
Housing/Neighborhoods		**B**									
Critical Retail				30%	60%	90%					X
Religious and Spiritual Centers					30%	60%	90%				X
Single and Multi-family Housing (Full Function)					30%		60%		90%		X
Schools					30%	60%	90%				X
Hotels & Motels					30%		60%	90%			X
Community Recovery		**C**									
Businesses - Manufacturing						30%	60%	90%			X
Businesses - Commodity Services						30%	60%		90%		X
Businesses - Service Professions						30%		60%		90%	X
Conference & Event Venues						30%		60%		90%	X

Footnotes: See Table 5-2, page 8.

Table 5-4. Example Building Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Critical Facilities	**….**	**A**									
Emergency Operation Centers			90%								X
First Responder Facilities			90%								X
Acute Care Hospitals			30%		60%		90%				X
Non-ambulatory Occupants (prisons, nursing homes, etc.)			30%			60%		90%			X
Emergency Housing		**B**									
Temporary Emergency Shelters			30%		60%	90%					X
Single and Multi-family Housing (Shelter in place)			30%			60%		90%			X
Housing/Neighborhoods		**B**									
Critical Retail					30%	60%	90%				X
Religious and Spiritual Centers					30%		60%	90%			X
Single and Multi-family Housing (Full Function)						30%		60%	90%		X
Schools						30%	60%	90%			X
Hotels & Motels						30%		60%	90%		X
Community Recovery		**C**									
Businesses - Manufacturing						30%		60%		90%	X
Businesses - Commodity Services						30%		60%		90%	X
Businesses - Service Professions							30%		60%	90%	X
Conference & Event Venues							30%		60%	90%	X

Footnotes: See Table 5-2, page 8.

It is difficult for designers to specifically target an amount of damage that can be repaired in a given timeframe, as there are numerous sources of uncertainty. However, it is possible to design for estimated levels of damage and based on that, assign a likelihood that the buildings within a cluster will be functional.

Communities primarily consist of existing buildings that have been designed and constructed under the building code at that time, potentially creating a range of expected performance levels for the same category of buildings. Sometimes, older buildings were designed using provisions that were later found to be inadequate, but rarely were the new provisions retroactively applied. Figure 5-1 shows a partially collapsed unreinforced masonry building following a major earthquake. This type of construction is unsafe in earthquakes, but many communities have not mandated retrofitting these types of buildings to avoid damage or collapse.

As part of developing performance goals for building clusters, the community should identify if any types of buildings or construction pose a significant safety hazard to occupants or the public. Mitigation or retrofit programs can be developed to address buildings that pose a significant safety hazard, such as unreinforced masonry building retrofit ordinances that have been adopted by many California cities, requirements for elevated construction in a flood plan, or requiring storm shelters in new homes.

When selecting recovery goals, a community must decide which performance category is appropriate for buildings within each cluster.

Category A buildings should require little repair to return to function. Often recovery is limited by outside factors such as power or water not being available, which is why onsite power and water is often required by communities for essential facilities. There may be some damage to a Category A building, but the damage can easily be cleaned up (i.e., toppled shelves or cosmetic damage to the structure) as shown in Figure 5-2.

Figure 5-1: Failure of unreinforced masonry wall during an earthquake event. (Photo courtesy of Degenkolb Engineers)

Figure 5-2: Non-structural damage to interior finishes following an earthquake event. (Photo Courtesy of Degenkolb Engineers)

Similarly, for flood events, buildings that sustain minor damage and thus fall into Category A are expected to have damage limited primarily to the exposed portions of the building exterior. If buildings are properly elevated, floodwaters may reach subflooring and building infrastructure systems but should not overtop the first floor or wet the interior. However, if the building has a basement, there could be damage to power sources, utilities and appliances located there. Buildings subject even to low flood depths may need some drying to remove residual moisture and cleaning to prevent mold growth and may not be safe for occupants until this process has occurred. Figure 5-3 shows an example of minor flood damage.

Figure 5-3: Floodwaters reached just under the first floor on this building (photo courtesy of AECOM)

Buildings that have experienced minor damage as the result of wind will generally have some roof covering damage, a limited amount of damage to openings (e.g., less than 10 % of doors and windows broken) and minimal exterior finish damage. Figure 5-4 illustrates minor damage as the result of wind.

Category B buildings are expected to sustain damage, but the damage should not affect the building's structural stability. There may be significant nonstructural damage, but the building can be used while the repairs are made. Figure 5-5 shows pictures of significant nonstructural damage inside a building that is structurally stable following an earthquake event. In such cases, the amount of work required to clean up the fallen contents or fix the damaged to the walls may take a couple days to a couple weeks.

Figure 5-4: Damage to roof covering, vinyl siding and fascia as the result of wind (courtesy AECOM)

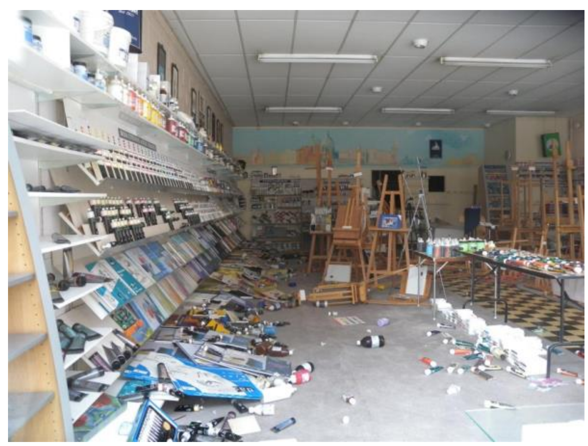

Figure 5-5: Significant nonstructural damage inside a building that is structurally stable after an earthquake event. (Photo Courtesy of Degenkolb Engineers)

Buildings that have been damaged by flooding and sustained moderate damage may experience a limited depth of flooding over the first floor; the foundation may be inundated or have minor undermining or scour; exterior and interior walls may have water stains and possible contamination that requires replacement. Subflooring and floor finishes may also require replacement along with some electrical wiring. While the building may be structurally stable, it may not be safe for habitants until properly dried and cleaned due to the potential for mold blooms and growth. Figure 5-6 show examples of moderate damage as the result of flooding.

Moderate damage sustained as the result of wind events may include moderate to major roof covering damage, some minor instances of roof sheathing failure, and some interior water damage, and damage to the exterior finish. Figure 5-7 shows moderate damage as the result of wind.

Figure 5-6: As a result of an estimated 3-4 feet of flooding, interior walls had to be replaced in this building as well as an exterior door and window (photo courtesy of FEMA) [getting a better quality version]

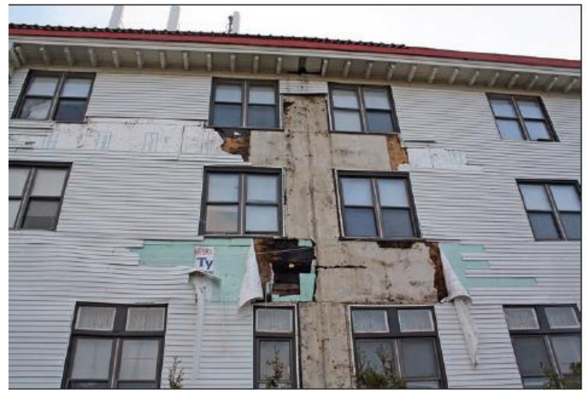

Figure 5-7: Siding loss and minor envelope damage on low-rise building from a wind event. (photo courtesy of FEMA) [getting a better quality version]

Category C buildings are expected to have significant nonstructural and some structural damage. The structural damage should not cause a loss of structural stability, but may require shoring while repairs are conducted. It is assumed that damage such as this would take weeks to months to repair. Figure 5-8 shows structural damage, but the global structure is stable. Figure 5-9 shows a fractured brace connection in a building damaged in an earthquake. There were about ten of these damaged braces on one story of a four story building and it took over three months from the disaster until the repairs were completed and the building could be reoccupied.

Figure 5-8: Apartment building with damaged structural members that is globally stable. (courtesy of Degenkolb Engineers)

Figure 5-9: Fractured brace connection in a building damaged in an earthquake (courtesy of Degenkolb Engineers)

For buildings severely damaged by flooding, flood depths will likely be several feet above the first floor and may result in foundation damage that could include settlement and severe scour and undermining.

Exterior walls may be severely damaged with large missing sections. Interior floor and wall finishes e will need replacement. Limited deformation of the structural frame may be evident. As with less severely flood damaged buildings, proper drying and cleaning is necessary prior to re-occupation of the building due to the potential for mold growth. Figure 5-10 shows severe damage as the result of flooding.

Severe damage incurred due to a wind event may include major roof sheathing loss, extensive interior water damage, and minor to major envelope damage. Additionally, roof uplift damage may be evident. In instances where significant water intrusion damage has occurred, buildings may not be safe for use until adequate drying and cleaning has occurred due to the potential for mold bloom. Figure 5-11 demonstrates severe wind damage to buildings.

Figure 5-10: Foundation wall collapse due to hydrostatic pressure from floodwaters (courtesy of FEMA) [getting a better quality version]

Figure 5-11: Wind and wind-borne debris resulted in considerable damage to glazing on this building (courtesy of FEMA) [getting a better quality version]

Category D buildings cannot be used or occupied after a hazard event. Destruction or collapse of buildings may occur because the building was not designed and constructed to withstand the severity of a particular event, or because a building was constructed to older building codes, or no codes at all, or because the codes were not properly followed or enforced. Figure 5-12 shows examples of destruction and collapse as the result of flood and wind events.

Figure 5-12: Collapse of 5-story building due to undermining (from flooding) of shallow foundation (courtesy of FEMA)

5.4. Regulatory Environment

Model building codes are developed at the national level for adoption across the country, and adopted by states or local jurisdictions. However, federal buildings are designed and constructed to federal government standards. In the U.S., two organizations publish model building codes for adoption by federal agencies or state and local governments. One is published by the International Code Council, which formed as a merger of three organizations that published regional model building codes. The other code is published by the National Fire Protection Association. The ICC's *International Building Code* is the most widely adopted model building codes; and the *National Fire Protection Code* is the most widely adopted model fire code in the U.S. Most federal agencies also use these codes, with agency-specific amendments, as the basis for their building requirements. These codes contain many reference standards that are typically published by not-for-profit standards development organizations, professional societies, and industry groups. Model building codes and the referenced standards are typically modified by federal, state, and local agencies for their specific purposes.

While the model building codes specify minimum requirements that are applicable throughout the country, states and local municipalities may modify the model building codes to achieve specific goals for local or regional hazards. For example, in areas of Florida, building codes were changed to require more hurricane-resilient construction following Hurricane Andrew, requiring certain types of roofing materials, stronger windows and doors, and greater inspection and enforcement.

Some states and localities adopt, but remove requirements in model building codes, to make them less stringent. Some jurisdictions only adopt the model code for government owned or specific occupancy buildings, but not for all buildings in their community. Some communities do not adopt or enforce any building code.

Enforcing building codes and construction standards is as important as adopting building codes and standards. The level of enforcement can significantly impact resilience. Even if the most up-to-date building code and standards are in effect, buildings designed and constructed in a substandard manner negatively impact community resilience. Therefore, having a properly trained building department to review designs for code conformance and inspect construction for conformance with the approved plans, is an essential component of community resilience.

5.5. Standards and Codes

The *International Building Code*, a commonly adopted model building code, was developed to provide design requirements that "safeguard public health, safety and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, safety to life and property from fire and other hazards attributed to the building environment, and to provide safety to fire fighters and emergency responders during emergency operations."

The expected performance of each building depends upon the codes and standards in-force at the time of construction, as well as the level of enforcement and maintenance. Building codes and standards are dynamic and ever-changing. Many changes come in response to disasters, while others come from a perceived weakness to natural disasters brought about by research on the subject. The evolving nature of building codes and enforcement, combined with the degradation that occurs over time, results in a building stock with variable capacities to resist hazard events.

Building codes and standards primarily regulate new construction and are based on the current consensus of best practices and design methods at the time they are written. After a significant hazard event, the building code may be modified based on observed damage or failures. Some provisions, when changed, become retroactive or are enforced during renovations. Examples of these are egress protection, accessibility for differently abled persons, and fire suppression system requirements.

Communities primarily consist of existing buildings, and most do not conform to current code standards. The mix of building types, construction, and age can create significant challenges when developing plans for a resilient community. Construction materials, construction quality, structural configuration, architectural finishes, redundancy of the mechanical and electrical systems can all affect the resilience of one building compared to another.

5.5.1. New Construction

Design criteria for new construction form the foundation for future resilience planning. Additions to the model codes may be desired to support a community's performance goals for resilience. Such changes typically add modest, incremental costs, whereas trying to require retrofit of existing construction after an event can be prohibitively expensive.

Building codes and standards have primarily focused on life safety of occupants during major natural hazard events, specifically in their structural design criteria. Early building codes addressed routine environmental design loads for frequent hazards such as wind and snow. The hazard design load and self-weight and occupancy live loads were used to design a structure. This approach produced structures that withstood routine, moderate hazards. However, the 1906 San Francisco Earthquake demonstrated that in particular seismic hazards induced large forces that were difficult to resist without any structural damage. This realization led to a philosophy of designing buildings for seismic hazards so buildings remained stable during the event with some structural damage, but did not collapse. The same concept applies to fire safety. By limiting fire spread with passive compartmentation, areas of the building outside the area of fire origin and adjacent buildings can often be saved from damage. Reduced fire damage allows more rapid recovery of functionality in the building.

Building codes provide design loads based on return periods for various hazards. In addition to design loads, there are often design provisions associated with the specific hazard. Table 5-5 (copied from Chapter 3) lists the various return periods for the routine, expected (design level), and extreme hazards.

Table 5-5: Design Loads for Buildings and Facilities (ASCE 7-10)

Hazard	Routine	Expected	Extreme
Ground Snow	50 year	300 to 500 year[1]	TBD
Rain	[2]	[2]	[2]
Wind – Extratropical	50 year	700 year	3,000 year[3]
Wind – Hurricane	50 to 100 year	700 year	3,000 year[3]
Wind – Tornado	[3]	[3]	[3]
Earthquake4	50 year	500 year	2,500 year
Tsunami	50 year	500 year	2,500 year
Flood	100 year	100 to 500 year	TBD
Fire – Wildfire	[4]	[4]	[4]
Fire –Urban/Manmade	[4]	[4]	[4]
Blast / Terrorism	[5]	[5]	[5]

[1] For the northeast, 1.6 (the LRFD factor on snow load) times the 50-year ground snow load is equivalent to the 300 to 500 year snow load.

[2] Rain is designed by rainfall intensity of inches per hour or mm/h, as specified by the local code.

[3] Tornado and tsunami loads are not addressed in ASCE 7-10. Tornadoes are presently classified by the EF scale. Tsunami loads are based on a proposal for ASCE 7-16.

[4] Hazards to be determined in conjunction with design professionals based on deterministic scenarios.

[5] Hazards to be determined based on deterministic scenarios. Reference UFC 03-020-01 for examples of deterministic scenarios.

Wind hazards. ASCE 7-10 prescribes design wind speeds for each Risk Category with different return periods. For Risk Category I, the mean return period is 300 years for facilities that have a low risk to human life and are typically unoccupied buildings. For Risk Category II facilities, that include typical buildings and other structures, the return period is 700 years. For Risk Category III and IV facilities, the return period is 1,300 years. The wind speeds derived from these return periods are based on extratropical winds and hurricane winds. Tornadic wind speeds are not currently addressed.

The majority of the wind design requirements are for the structural frame and the cladding. There are some requirements for attachment strength of nonstructural components. Requirements for serviceability and functionality are not explicitly codified, but are indirectly addressed through elastic design methods at specified wind speeds for desired performance levels. The International Building Code requires consideration of a drift limit under a reduced wind load (the factor used intends to approximate the 100-year return period wind). There are no explicit structural design requirements to preserve the building envelope so post-disaster function is not impacted, but there are some prescriptive requirements on the requirements of doors and windows. Nor are there requirements that exterior equipment, fire pumps, or generators must be functional following the design windstorm.

Snow hazards. Snow design uses a 50-year mean recurrence interval for ground snow loads. It is increased with an importance factor for higher Risk Category structures.

Rain hazards. Rain design uses a 100-year rain storm as the design hazard, with loads increased by 60% to account for uncertainty in predicting rainfall in a major event. However, the majority of rain design provisions relate to providing proper drainage and stiffness to the roof to prevent ponding. There are no code requirements in a design rain event that the building envelope must maintain its ability to keep water out. In many instances this is accomplished without explicit code requirements because of the liability seen with water intrusion and its adverse effects, such as mold.

Flood hazards. Flood design provisions for all buildings are typically based on a 100-year mean recurrence interval for flood elevation, though 500-year flood elevations are recommended for design of critical facilities. Recommended practice is to locate buildings out of the 100-year flood zone. If they must be within this flood zone, floodplain management provisions and building codes require that they be elevated to or above the design flood elevation which is, at a minimum, the elevation of the 100-year flood. Buildings with nonresidential uses may also be dry flood-proofed up to the design flood elevation if they are not subject to coastal flood forces or high velocity flooding. For structures subject to flood forces, the current provisions provide methods to avoid or resist flood forces, but are not necessarily meant to preserve functionality of the building during a flood event. Evacuation of flood prone areas during flood events is expected especially with days or even weeks of warning.

Flood design provisions are neither fully prescriptive or performance based. Instead, they are a mixture of the two. Elevation requirements are considered prescriptive because they elevation is mandated by flood maps and local codes. Other requirements that require design and vary between structures are considered performance based, such as building designs that resist flotation, collapse, and lateral movement.

Seismic hazards. Since the beginning of earthquake design, it has been recognized that designing for the hazard in the same way as other hazards would not be practical or economical. Therefore, the approach adopted prescribes forces and design requirements that allow buildings to be damaged, but not collapse. Following the 1971 San Fernando earthquake, hospitals were required to be designed to a higher standard, significantly improving their likelihood of remaining functional following the design earthquake.

The emphasis placed on the design of nonstructural systems is a very important distinction between seismic design provisions and design provisions for other hazards. All nonstructural systems have bracing requirements. In addition to the bracing requirements, nonstructural systems in essential facilities or those systems that relate to the life-safety system of the facility are required to maintain function or return to function following the design earthquake shaking hazard. The design earthquake shaking level is currently defined as 67% of the Risk Targeted Maximum Considered Earthquake shaking level.

Fire hazards. The performance of new and existing buildings during fires is addressed specifically through fire codes and in a complementary manner by building codes. Typically, fire prevention officers within local fire departments enforce the fire code, in conjunction with building inspectors. A fire code is primarily intended for preventing and containing fires and making certain that necessary training and equipment is on hand if a fire occurs. Fire codes also address inspection and maintenance requirements of passive and active fire protection systems.

The codes originated as life safety documents; but after the WTC disaster, many requirements establish additional redundancy, robustness and resilience. The (IBC) building code has been expanded to include protection for emergency responders following a major event.

Another key requirement is for automatic sprinkler systems in residential, healthcare, and assembly buildings as well as most other types of structures. Sprinklers limit the fire to the area of origin and can significantly reduce the level of smoke and fire damage.

There are currently very few, if any, code requirements for design of buildings in wild fire hazard areas. Some methods of construction could provide greater resilience than conventional construction in those regions, but nothing has been mandated.

Man-made hazards. Codes and standards do not have explicit structural design requirements for man-made hazards (e.g., arson, explosions or impact events), although some nominal provisions attempt to provide robustness to arrest the spread of damage so disproportionate collapse does not occur. Many requirements in the IBC require facility layout and hazard mitigation measures to prevent explosions of building contents. Guidelines for design of man-made hazards do exist for specific classes of buildings, like federal buildings and industrial facilities. Often these guidelines are restricted because they contain proprietary or security-sensitive information.

5.5.2. Existing Buildings

Existing buildings pose an even greater challenge than new buildings. For new buildings, codes can be amended or re-written. Although construction costs may increase, new buildings would be designed for the state-of-the-practice. Retrofit of existing buildings to the state-of-the-practice level of resilience, in contrast, can require significant financial commitment and necessitate major disruption to the building's function, which tends to dissuade building owners from retrofit.

The cost and disruption associated with retrofit has made mandating retrofit measures a politically unpopular decision. In California, only the class of building deemed most prone to collapse in an earthquake – Unreinforced Masonry Buildings – has had widespread, albeit not universal, acceptance as something that should be mandated for retrofit.

For buildings constructed prior to development of flood provisions or a community's adoption of flood provisions, there is a trigger for requiring that they be retrofit to meet current flood provisions. Buildings within designated flood hazard areas (generally the 100-year floodplain) that sustain damage of any origin, for which the cost to repair the building to its pre-damage conditions equals or exceeds 50 percent of the market value of the building, must be brought into compliance with current flood provisions. The same is true for improvements or rehabilitation of buildings when the cost equals or exceeds this threshold. However, enforcement of this requirement can be challenging, particularly in a post-disaster environment when communities are anxious to support building owners in reconstruction.

When existing buildings are evaluated for expected performance relative to resilience goals and required retrofit actions, standards for new construction are typically applied to the structural design. This application often leads to excessive requirements for improvements to obtain the desired performance. However, recent advancement in performance-based engineering has led to development of specific standards for existing buildings with regards to evaluation and retrofit.

One of the biggest impediments to retrofit of existing buildings lies in the conservatism embedded in current engineering codes and standards. Under-predicting a building's performance in a given hazard because the standards are conservative can lead to significant retrofit requirements. Those requirements can make the retrofit economically unappealing to building owners.

5.6. Strategies for Implementing Community Resilience Plans

5.6.1. Available Guidance

Current engineering standards provide tools to support assessment of the structural safety of buildings. ASCE 41, the existing building seismic standard, provides a methodology to assess the performance of buildings for both safety and the ability to be reoccupied following an earthquake. ATC 45 provides an assessment methodology for flood and wind events. Similar standards do not exist for other hazards.

Building code provisions can be used to determine whether a building has sufficient fire resistance, egress, and other occupant safety-related issues. These methodologies are useful for individual buildings safety, but do not address damage versus recovery time to function.

HAZUS provides a platform for communities to assess vulnerabilities to earthquakes, hurricanes, and other hazards. HAZUS is useful for assessing effects of a disaster on a community. However, the existing building stock must be adequately reflected in the model, which can require significant data gathering.

Several existing resources exist for property owners, designers and communities to use to better understand best practices for flood resistant design and construction including:

- FEMA P-55 (Volume I and II), Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas
- FEMA P-499, Home Builder's Guide to Coastal Construction: Technical Fact Sheet Series
- FEMA P-550, Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations

Existing resources addressing wind include the ATC Design Guide 2, Basic Wind Engineering for Low-Rise Buildings.

5.6.2. Strategies for New/Future Construction

For new and future construction, desired performance goals and anticipated performance for adopted building codes needs to be evaluated to determine if additional local requirements are required. Risk categories currently in the building codes can support the desired levels of performance and resilience goals. By clearly defining the desired building performance for a hazard event in terms of performance and recovery time for return of function, communities can tailor local building codes and standards to support specific resilience goals.

For flood-resistant design and construction, best practices exist for communities or individuals to implement in addition to code minimum requirements. One basic but effective practice is locating all new construction outside of flood zones. Additionally, using additional height, or freeboard, in building design is also effective.

Stronger design and construction practices for wind resistance are encouraged through a variety of existing resources with primary goals of improving continuous load path connections, strengthening building envelopes, and protecting openings.

For fire hazards, sole reliance on active fire protection through automatic extinguishing systems (AES) to provide property protection in combustible construction is not appropriate for communities with hazards that compromise the performance of the AES, such as seismic events.

5.6.3. Strategies for Existing Construction

Building codes and standards evolve, but little retroactive compliance is required. This is a major issue in communities because the cost of retrofit exceeds, by orders of magnitude, the cost of adding resilience to a new building. A strong resistance to building retrofit because of cost, inconvenience to the building occupants, and disruption of operations creates a significant challenge for community resilience planning.

A strategy to prioritize retrofit requirements is to identify the most significant hazards posed by potential failures by various types of buildings and to mandate retrofit or demolition of those buildings. There have also been programs specifically aimed at critical facilities (e.g., hospitals and fire stations), where those buildings must be retrofit or replaced.

Given the aforementioned challenges with existing construction, community resilience planning should take a long-term view to achieve resilience. For example, the City of Los Angeles just instituted an ordinance requiring older concrete buildings that present significant collapse hazard in major earthquake be retrofit within the next 30 years.

The risk associated with existing flood-prone construction can be addressed primarily through retrofitting:

- ***Elevation –*** Elevation is one of the most common flood retrofitting techniques because it provides a high level of protection and does not require the owner to relocate. Elevation involves raising an existing building so the lowest floor or lowest horizontal structural member is at or above the regulated flood level. Common elevation techniques include elevation on piles, piers or columns, and elevation on extended foundation walls. Other elevation techniques involve leaving the home in place and building a new elevated floor system within the building or adding a new upper story and wet floodproofing the ground level.
- ***Relocation –*** Relocation offers the greatest security from flooding. It involves moving an existing building to an area that is less vulnerable to flooding or completely outside the floodplain. The building owner usually selects the new site, often in consultation with a designer to ensure factors such as accessibility, utility service, cost, and owner preferences meet engineering and local regulatory requirements. Relocation includes lifting a building off its foundation, placing it on heavy-duty moving dollies, hauling it to a new site, and lowering it onto a pre-constructed foundation.
- ***Floodproofing –*** There are two types of floodproofing: wet floodproofing and dry floodproofing. Wet floodproofing allows floodwaters to enter the building and quickly reach the same level as the floodwaters on the building exterior. Equalizing the water level greatly reduces the effects of hydrostatic pressure and buoyancy. Wet floodproofing is generally used to limit damage to enclosures below elevated buildings, basements, crawlspaces, or garages. Wet floodproofing is not practical for areas used as habitable space. Dry floodproofing involves completely sealing the exterior of a building to prevent entry of floodwaters. All openings below the flood level are sealed and the walls of the building are relied on to keep water out. Internal drainage systems, such as sump pumps, remove any seepage. Due to large hydrostatic pressures, dry floodproofing is practical only for buildings with reinforced concrete or masonry walls; it is typically not practical for residential buildings or for buildings where flood depths exceed 2 to 3 feet.

Additional information on these techniques is found in FEMA P-259, Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures and FEMA P-936, Floodproofing Non-Residential Buildings.

For buildings subject to a wind hazard, the following strategies are widely accepted as among the most effective to address potential damage.

- ***Improving roof and wall coverings –*** Roof and wall coverings are important components of the building envelope. If the building envelope is breached during a storm, wind pressures can drastically increase internal pressures and fail the structural system of the building. Wind driven rain may cause extensive water damage to interior contents. Improving roof coverings may involve reinforcing the roof deck or removing the existing covering, securing the roof deck, and installing a new roof covering. Improving wall coverings may involve installing moisture barriers and ensuring proper fastener spacing is used or removing the existing covering and installing a new wall covering that is rated for high winds.
- ***Protecting openings –*** Openings (e.g., windows, doors, skylights, soffits, and vents) are an important component of the building envelope. Glazed openings, such as windows, are often vulnerable to debris impact and wind driven rain intrusion. Protecting openings usually involves installing an impact-resistant covering (such as a storm shutter) over an existing unprotected opening or installing impact-resistant products (such as a new window or door assembly).
- ***Continuous load path –*** The term "continuous load path" refers to the structural condition required to resist all loads – such as lateral and uplift wind pressures – applied to a building. A continuous load path starts at the point or surface where loads are applied, moves through the building, continues through the foundation, and terminates where the loads are transferred to the soils that support the building. To be effective, each link in the load path – from the roof to the foundation – must be strong enough to transfer loads without breaking. An existing building may be retrofitted if load paths are incomplete or if the load path connections are not adequate. Continuous load path design or retrofit

considerations typically involve several connections such as the roof sheathing to roof framing; roof framing to wall; wall to floor; and floor to foundation.

In some states, existing programs reward wind retrofit measures via homeowners' insurance discounts. FEMA P-804, Wind Retrofit Guide for Residential Buildings provides additional information on specific techniques for wind retrofitting residential buildings. Additionally, the Insurance Institute for Business and Home Safety developed a program called "Fortified" that encourages wind retrofits for both new and existing construction.

Many resources are available that describe seismic retrofit methods and performance-based methods. Examples are:

- **ASCE 41-13:** Seismic Evaluation and Retrofit of Existing Buildings. This is a consensus standard that allows users to perform and evaluation and retrofit using performance-based provisions which match a selected earthquake shaking intensity with a specific performance level. It is referenced by many building codes and jurisdictions.
- **FEMA 549:** Techniques for Seismic Retrofit. This publication provides examples of methods to seismically retrofit various types of construction materials and structural configurations. It contains example retrofit strategies and details to address identified deficiencies based on structural material.

5.7. References

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6. Transportation Systems

6.1. Introduction

Transportation systems are critical to our daily lives. People use various systems of transportation on a daily basis to travel to and from work, school, visits to family and friends, attend business meetings, and medical emergency sites. However, the transportation network meets much more than just an individual's needs. Businesses use trucks, ships, trains, and airplanes to transport goods from their point of production to their point of use or consumption. For example, food is often transported from the producer (e.g., a farm) to a processing and packing plant, then a regional or national distribution center, and finally to the local stores where it can be purchased by consumers. All of these steps in this example of product distribution rely heavily on the transportation system.

Traditionally, people think about the transportation system as using roads and bridges to move both goods and people. While roads and bridges are a critical part of the transportation network, communities[1] also rely upon other systems of transportation, including:

- Airports to transport people and goods long distances in a short period of time
- Passenger and freight rail lines to transport people and goods regionally/nationally
- Subway lines or light rail corridors in large urban centers (e.g., New York, DC, Chicago, Los Angeles) to transport people to/from work and entertainment/leisure activities
- Harbors and ports to import/export goods from/to the globally and distribute them on inland waterways
- Ferry terminals and waterways to transport the workforce to/from work (e.g., San Francisco, New York)
- Pipelines[2] to transport natural gas and petroleum nationally and regionally to utilities and refineries

The transportation system is a very complex system with multiple modes each with their own complexities that make coordinating activities to build resilience of the system and the communities they support very challenging. Examples of the complexity include:

- Within a small geographical area (i.e., a community) there may be many stakeholders responsible for the design, operation, maintenance and funding of the road network including federal, state, and local public agencies, as well as private operators of toll ways.
- The rail system includes private freight networks that are key to supporting economic activity and passenger rail services operating within cities and across states with multiple stakeholders.
- Marine transportation includes domestic and international movement of passengers and goods across regions that may have their own standards and guidelines for design, operation and maintenance. In the case of passenger ferries, a lack of standardization limits the transferability of vessels to support recovery from hazard events.
- The aviation system includes public and private airports of varying sizes that support air freight and commercial air passenger services.

Many people rely on multiple modes of transportation (i.e., intermodal transportation) every day. Businesses use multiple systems of transportation to move goods efficiently and cost effectively.

[1] For the purposes of this framework, a community is defined as an area under the jurisdiction of a local governance structure, such as incorporated cities and counties.
[2] Pipelines are included in the transportation chapter because they are regulated by the Department of Transportation. Water pipelines are discussed in Chapter 9.

Similarly, goods may be imported using ships; however, to get the goods from the ship to the next step in the supply chain requires trucks or rail. More discussion on intermodal transportation is in Section 6.1.2.

This chapter addresses disaster resilience of the transportation system. To address resilience of their infrastructure, communities need to first identify the regulatory bodies, parties responsible for the condition and maintenance of the infrastructure, and other key stakeholders. Communities should work with the stakeholders to determine the performance goals of the transportation infrastructure, evaluate the existing infrastructure, identify weak nodes and links in the network, and prioritize upgrades to improve resilience of individual network components and, consequently, the transportation network as a whole. This chapter provides an exemplary performance goal table. Communities can also use the performance goals table to identify the anticipated performance of existing infrastructure and their largest resilience gaps, and prioritize improvements.

6.1.1. Societal Needs and System Performance Goals

As discussed in Chapters 2 and 3, the social needs of the community drive the performance goals to be defined by each community, infrastructure owner, and its stakeholders. The social needs of the community include those of citizens, local businesses, supply chains of large national and multi-national businesses, industry, and government. Each community should define its own performance goals by the time needed for its critical infrastructure to be restored following a hazard event for three levels of hazard: routine, expected, and extreme, as defined in Chapter 3.

Transportation systems are a large part of our daily lives in the United States and are often taken for granted. While not all natural hazard events can be forecasted, the transportation system is even more important when a natural hazard event has advanced warning (i.e., hurricane) and after of a natural hazard event. When a hazard event is forecast, transportation systems permit:

1. Parents to convey their children home from school or daycare
2. Residents in evacuation zones to travel to shelters or distant safe communities
3. State officials to close transportation systems that pose a danger to travelers during a hazard event

Following a hazard event, the community has short-term (0-3 days), intermediate (1-12 weeks), and long term (4-36+ months) recovery needs. Currently, communities think about recovery in terms of emergency response and management goals. For transportation these include:

1. Access for emergency responders (firefighters, paramedics, police) to reach people in need
2. Access for those that restore critical infrastructure (energy, communications, water/wastewater)
3. Access to facilities for shelter, medical care, banks/commerce, and food
4. Egress/evacuation from a community immediately after a hazard event, if needed
5. Ingress of goods and supplies immediately after event to provide aid

However, when addressing resilience, communities must also consider any inherent vulnerability in the transportation network that may seriously affect the ability of the community to achieve full recovery in the longer term and also consider improving the level of transportation network performance in the next hazard event. The intermediate and longer term needs of communities for the transportation infrastructure include:

1. Ability of public sector employees who run government, direct traffic, respond to emergencies, run transit systems, and teach/work in schools to get to their posts
2. Ability for citizens to get to work, school, and sports/entertainment facilities
3. Ability to re-establish access to businesses (both small and large), banks, retail, manufacturing, etc., so they can serve their customers
4. Ability to re-establish access to key transportation facilities (airports, ports/harbors, railway stations), so goods can be transported and supply chain disruption is limited

5. Need to restore, retrofit, and improve transportation infrastructure and rolling stock, so they will not be damaged or fail in the same way in a future event
6. Strengthen mass transportation, such as airports, passenger and freight rail, subways, light rail, and ferry systems to relieve stress on the roads and bridges components of the transportation network

In the long term, communities should strive to go beyond simply recovering by prioritizing and making improvements to parts of the transportation network that failed in the disaster or were the source of stress on the network (e.g., failure of the subway system in New York City puts millions more people on the already-congested road network, or worse, at home).

6.1.2. Interdependencies

Chapter 4 details the interdependencies of all critical infrastructure systems in a community. As the built environment within communities grows more complex and different systems become (more) dependent on one another to provide services, addressing the issue of interdependencies becomes an increasingly critical aspect of resilience.

Transportation systems play a critical role in supporting each other, as well as critical services and other infrastructure systems. Hospitals, fire stations, police, and other emergency response systems depend on transportation before, during, and after a hazard event. Evacuation depends on the capacity of roads, waterways, airports, and rail, as well as the government's ability to manage them. Relief efforts are hindered until damage to transportation systems is repaired.

Specific dependencies on the transportation system include:

1. ***Power Energy*** – A significant number of power plants rely on bulk shipments of coal or fuel via barge and freight rail for their operation. Gas fired plants rely on natural gas pipelines. Resource recovery plants rely on bulk shipments of refuse via truck. Interruption to barge, freight rail, and truck routes from a hazard event can affect power generation if fuel at these power plants is not stockpiled in advance.
2. ***Communication and Information*** – As fiber networks are expanded, many are routed through leased conduits over bridges and through tunnels to cross waterways or other geographic features**.** This makes them vulnerable to damage of those transportation assets in a hazard event from flooding, earthquakes, or storm surge, which can knock out portions of the fiber communications network. Postal services delivering letters, documents, and packages are also entirely reliant on the transportation network.
3. ***Buildings/Facilities*** – Large transportation terminals or stations, airline terminals, and port cargo facilities cease to function when transportation systems are shut down by a hazard event. Mixed use transportation facilities that are integrated with retail, businesses, and hotels are also impacted when transportation stops.
4. ***Water/Wastewater*** – The pipelines used by these systems are considered part of the transportation system.

Specific interdependencies of transportations systems with the other infrastructure systems addressed in this framework include:

1. ***Power/Energy*** – The transportation system depends on the power and energy grid. Gas stations need electricity for vehicle owners to access fuel. As seen in Hurricane Sandy, without power, gas stations, utilities, and other entities that fuel transportation vehicles could not operate, which hindered both evacuation and recovery. Electric energy is also needed for traffic signals to function. As seen during the northeast blackout of 2003, New York City's 11,600 traffic signals were inoperable due to the loss of power, resulting in mass gridlock (DeBlasio et al. 2004). Airports, rail stations, moveable bridges, vehicular tunnels and ports rely on electric energy for

lighting, functionality of mechanical components (e.g., loading equipment at a port), fire/life safety and for functionality of the buildings themselves (see Chapter 5). Regional passenger rail, subways, and light rail rely on electric energy to function as well as for fire/life safety inside the tunnels. However, the energy industry also relies on transportation systems, so repair crews can reach areas where failures have occurred and bring services online quickly. The logistics of deploying repair crews after disasters often starts with filling in washouts and clearing debris and fallen trees from roads to provide access to utility repair crews.

Transportation systems also include natural gas and petroleum pipelines that feed the power/energy fuel storage, generation, and distribution systems. Pipelines also transport jet fuel to major airports. Most pipelines in the continental United States are buried beneath the ground and can rupture from earthquakes or wash out by flooding.

2. ***Communication*** – The communications system relies on roads and bridges so repair crews can get into areas with failures of telephone and cable lines, cell towers, and fiber optic networks to repair services. Conversely, transportation systems depend on communications to relay information. Airports use communications for instrument-controlled aircraft operations to relay logistical and scheduling information to passengers (e.g., flight status times, gate changes, etc.) and to communicate with other air traffic via air traffic control. Light rail, train, and bus stations rely on communication systems to coordinate and schedule inbound/outbound times for users. Highways depend on Intelligent Transportation Systems (ITS) to monitor traffic levels, direct traffic around areas of congestion, and respond to accidents and emergencies. ITS cameras, sensors, and variable message signs are supported on fiber networks, some owned and some leased by DOTs. Tolled highways and bridges rely on communication systems for electronic toll collection.
3. ***Building/Facilities –*** Buildings are rendered useless if people cannot reach them. Transportation systems allow people to travel to critical facilities, businesses, and to other homes/facilities to check on the safety of friends, family and vulnerable populations. When transportation systems are not available to get citizens to buildings and facilities, such structures cannot also contribute to the recovery.
4. ***Water and Wastewater –*** Water and wastewater lines are often buried beneath roads (i.e., below grade). Consequently, access to roads is needed to access points of failure. Moreover, leaks and failure of waterlines under roads can damage road foundations and sinkholes may form. Conversely, critical facilities in the transportation system (e.g., airports, bus, train, subway, and light rail stations) require water and wastewater for maintenance, sanitation, disposal, and emergency services (e.g., firefighting).

Intermodal Transportation. Due to the nature of our large, diverse transportation network and how it is used today, intermodal transportation is a key consideration for communities. Intermodal transportation varies by community, depending on the community's size, needs, structure, and complexity. Individual citizens in some communities may function well using only the road network on a daily basis. However, the community needs access to the larger transportation network, and thus other methods of transportation are needed to get food and supplies to local retailers in these communities.

In today's global environment, goods are often imported via airplane, ship, truck, or train. If goods are imported by airplane or ship, they are then loaded onto either trains or trucks. Depending on the goods being transported, the next stop in the supply chain may be a manufacturing or processing plant, national/regional distribution center, or a warehouse. Retailers often use warehouses or regional distribution centers to manage their products and provide goods to local stores via truck in a short time period. Therefore, coordination is needed between the different methods of transportation used by businesses to ensure that their products can be delivered to the customer. If one of the systems fails, there may not be a need for the others (e.g., if ships can't import goods, there will not be any goods for the rail system to transfer to the next stop in the supply chain).

People also use multiple methods of transportation on a daily basis, particularly in large urban centers, to get to/from work, school, entertainment facilities, homes, banks, etc. People who work in large cities often rely on mass rapid transit, such as bus transit for most of their commutes. However, to get to their bus stop or rail station, or final destination, individuals may rely on the roadway system, including buses, taxis, bicycles or walking.

Although several methods of transportation are available to citizens and businesses, hence, providing redundancy to the overall network, failures in one of the systems can put significant stress on other transportation systems. For example, even partial loss of use of the subway system in Chicago, New York, or DC would cause significant congestion and gridlock in the roadway network.

Freight transportation systems in the U.S. have less redundancy than systems that transport people. The freight rail lines currently have little redundancy with detours of hundreds of miles around certain critical routes that follow river beds and cross large rivers. With the reduced number of freight trains and the high costs for maintaining the right of way of freight tracks, railroads have abandoned redundant lines and many have been converted to recreational paths for pedestrians and cyclists.

Freight transportation by barge moves very large volumes at relatively low energy costs but has very limited system redundancy since it is dependent on navigable waterways. River flooding or a damaged or collapsed river crossing can lead to major delays of large volumes of freight.

Freight transported by truck has more redundancy than rail or barge freight; however, the national highway system has certain critical river crossings, which if damaged in a hazard event, can lead to long detours and heavily congested highway bottlenecks.

6.2. Transportation Infrastructure

Transportation systems in the United States are extremely large and complex. This section is divided into five main categories:

- Section 6.2.1 – Roads, Bridges, Highways, and Road Tunnels
- Section 6.2.2 – Rail
- Section 6.2.3 – Air
- Section 6.2.4 – Ports, Harbors, and Waterways
- Section 6.2.5 – Pipelines

These sections discuss the components of their network, potential vulnerabilities, and strategies used in the past to successfully mitigate failures. The first four sections deal with systems of the larger transportation network used to move both people and goods. The fifth section, Pipelines, discusses a system used to move resources alone (e.g., natural gas).

6.2.1. Roads, Bridges, Highways, and Road Tunnels

Roads and Highways. Roads and highways are vital to the nation's transportation infrastructure. The nation's four million miles of public roadways endured three trillion miles of vehicle travel in 2011 (ASCE 2013). The large network of roads and highways serves as the primary transportation infrastructure used by most people and businesses. Although other methods of transportation, such as subways and airplanes, which are discussed later in this chapter, are used to move mass amount of people and goods to specific hubs (i.e., nodes in the transportation network), roads and highways are used to get people and goods to their final destinations. A loss of a road, bridge, or tunnel can dramatically increase the time it takes for emergency responders to get to the disaster area or reduce the ability for citizens to evacuate immediately following a disaster.

When considering the road network, communities need to think about not only cars and trucks, but other methods of transportation, including buses, bicycles, and pedestrians. Locally, communities (particularly large communities with a stressed road system) should develop a long-term transportation plan that encourages citizens to use other methods of transportation (e.g., bicycles and buses) in addition to personal vehicles. Bicycle lanes, for example, can be added by widening the road in a planned construction project by approximately 4 feet. It is noted; however, that the usefulness of making such changes will vary by community based on average commute time and accessibility to alternative methods of transportation. Regardless, the goal of a road system for a community should be to encourage and support as many methods of transportation as possible to make it more efficient, rather than relying on just cars and trucks.

In addition to moving people and goods on roads and highways, essential utilities distribute services either along-side, above, or below the grade of roads. Therefore, when roads and highways fail, it not only disrupts the ability to move people and goods, it can leave the necessary utility services vulnerable to both initial and secondary hazards (e.g., uprooting of a tree or other debris falling on a power or communication line). For example, flooding can result in undercutting road beds. In Figure 6-1, a pipe (an example of interdependency) that lay directly underneath the road shoulder was vulnerable to damage as a result of road failure.

Figure 6-1: Road undercutting in the aftermath of Hurricane Irene (FEMA, Photo by Elissa Jun, 2011)

Roads are also susceptible to damage from earthquakes. The force of earthquakes can cause roads to split, as seen after the Loma Prieta earthquake (FHWA 2010). Moreover, secondary effects of earthquakes, such as landslides and fires can also damage roadways. In fact, liquefaction is a major vulnerability for all transportation infrastructure (tunnels, bridges, railways, etc.), whereas roads are especially susceptible to landslides (Meyer et al. 2014).

Failure or loss of service of individual roads does not typically cause a major disruption for a community, because redundancy is built into the road network. Major disruptions occur when a significant portion or critical component of the road/highway network fails, such that people and goods cannot get to their destination. Flash flooding in mountain communities where roads typically follow river beds with multiple bridge crossings have left entire communities cut off when roads and bridges collapsed from scour. For example, a dozen towns in Vermont were completely cut off from emergency aid in 2011 when Hurricane Irene dumped 11 inches of rain over a weekend that washed out roads and bridges. Similarly, in Boulder, Colorado search and rescue teams were prevented from reaching stranded communities after 6 inches of rain fell over 12 hours in September 2013, cutting off mountain towns after recent wildfires depleted the terrain of vegetation. Large areas of the road/highway system can be impacted by debris from high wind events (hurricanes, extra-tropical storms, tornadoes), flooding, as was seen in Hurricane Sandy, earthquakes, and ice storms. In the short term, tree fall (see Figure 6-2) on roads slows-down emergency response and repair crews from getting to

Figure 6-2: Local Road Blocked by Fallen Trees after Remnants of Extra-tropical Storm Struck Kentucky (Kentucky Public Service Commission 2009)

locations where their assistance is needed.

Ice storms, as previously discussed, can also cause road blocks by tree fall, as seen after the January 2009 ice storm in Kentucky (Kentucky Public Service Commission 2009). However, ice itself can also shut down the road network because even relatively small amounts of ice make driving conditions dangerous, particularly in areas of the United States where communities are not well prepared for snow and ice storms due to their infrequent occurrence. In states that are well prepared for these events and experience them regularly, ice storms or large snowfall events do not typically cause significant disruptions to transportation.

Bridges. Bridges are important components of the road/highway and railway networks, because they traverse significant geological features such as canyons, rivers, and bodies of water that interrupt the roadway path. Bridge structures are the most costly part of a roadway or railway system to build and maintain, so they are strategically placed and the temporary closure of one may lead to significant detour travel distances. The number of bridges, their length, and their location within a community depends on the local geography and social needs of the community. Bridges, like roads, are impacted by the harshness of their respective environmental conditions (e.g., freeze thaw cycles). Traditionally bridges include expansion joints, which allow rainwater, ice, snow, and other debris to get beneath the road surface. Though this is a maintenance issue, water and debris infiltration leads to corrosion and deterioration of both the superstructure (i.e., beams and deck) and substructure (e.g., piers, bearings, and abutments), which can impact bridge performance when a hazard event occurs. However, some short bridges (i.e., less than 300 feet) are now being designed using integral abutments so expansion joints are eliminated, reducing this deterioration in the future (Johnson 2012).

Scour (i.e., erosion of bank material around bridge foundations) is a leading cause of bridge failures (FHWA 2011). Scour is most often caused by flooding and wave action. Flooding and wave action from hurricane storm surge (or tsunamis) can also damage bridges in other ways. For example, during Hurricane Katrina, wave-induced forces pushed multiple spans of the I-10 twin bridges over Lake Pontchartrain off their bearings (Figure 6-3) (FHWA 2010). Earthquakes in San Fernando Valley, Loma Prieta, and Northridge, CA showed that bridges can collapse due to failure of piers and decks (FHWA 2010).

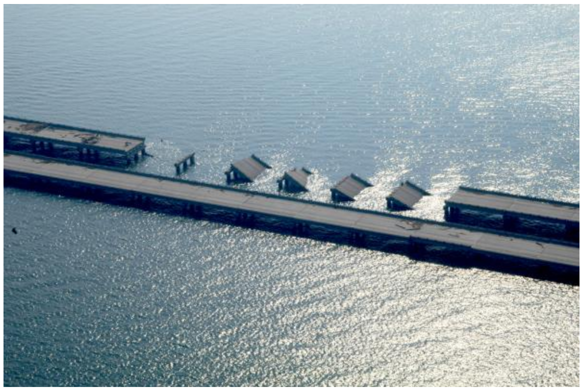

Figure 6-3: Bridge sections slid off their supports during Hurricane Katrina due to wave action (FEMA, 2005)

Longer bridges tend to have relatively lightweight superstructures (decks and girders), so they can span long distances. Historically, their relatively low natural frequencies made some of these bridges susceptible to high winds, because their low natural frequencies could be matched by the high winds. Thus resonance of the bridge could occur, producing large oscillations and failure in some cases. However, modern long span bridges are mostly subjected to aeroelastic wind tunnel testing to understand the dynamics of the structure and make changes in design (e.g., adding dampers or changing aerodynamic properties) to avoid failure during high wind events (FHWA 2011). Moreover, some older long span bridges were tested and retrofitted to ensure that they were not vulnerable to wind failures.

Similar to roads, failure of an individual bridge causes a disruption to the local road network, but does not always cause a major disruption of an entire community's road network. Because there are often alternative routes, the driver's commute time might increase. Failure of a bridge puts additional stress on other parts of the road network locally, because the bridge is a choke point, which could cause people to avoid certain areas and thus businesses. Therefore, when communities consider the design and functionality of their bridges, they should consider the purpose of the structure and redundancy of the surrounding road network. For example, if the bridge is the only way commuters and goods can access, via the road network, an area of the community that has many businesses and critical facilities, the bridge should be designed for the "extreme" event, as defined in Chapter 3. However, given that bridge failures are not common even in hazard events; most bridges should be designed and built for the "expected" event.

Road Tunnels. Road tunnels serve a similar purpose to bridges in the road network. They connect links of the road network by passing under water, through mountains, or under other roads/highways. In general, tunnels present more risk to life safety when failures occur than other transportation systems, which have easily accessible methods of egress. Fires in tunnels are the most deadly hazards because the enclosed space causes decreased oxygen levels, contains toxic gasses, and channels heat like a furnace (Meng and Qu 2010). Precipitation is another threat: flooding in surrounding areas can lead to dangerously high soil moisture levels that compromise structural integrity of tunnels through mountains (Meyer et al. 2014). Tunnels beneath rivers are not affected by moisture through the walls but by surrounding flooding through the tunnel portal. During long-term inundation inside a tunnel, corrosion is a major mode of damage, especially to any ventilation, electrical, or communications systems within in the tunnel structure. More resilient designs and different protection measures, such as inflatable tunnel plugs, may need to be employed to adequately mitigate the individual risk associated with tunnels (U.S. DHS 2013).

6.2.2. Rail

Rail systems consist of mass transit systems, such as subways, that operate within large high-density cities, regional commuter rail systems, which connect suburban communities to the city core, intercity passenger rail systems, like Amtrak, and freight rail systems that transport cargo both regionally and across the nation. Also included are light rail systems that operate within cities and airports.

Rail systems, which typically carry bulk commodities and assist in commuter services, have seen a boom in recent years. Amtrak reported more than 31.2 million passengers in 2012, double the reported figure from 2000. Freight railroads transport almost half the nation's intercity freight and approximately a third of its exports with both numbers projected to increase. Freight and passenger railroads increased investing in their infrastructure, even in the face of the recent recession, putting $75 billion back into the tracks since 2009. In 2010, freight railroads renewed enough miles of track to go from coast to coast. This aggressive investment policy gives the rail system the capacity to meet future needs and represents an opportune time to build resilience into the system (ASCE 2013).

Since rail systems tend to be less interconnected than roadway systems, more key points serve as bottlenecks to different areas that could be severely affected by a failure (Lazo 2013). One example is the failing Virginia Avenue tunnel in Washington D.C., through which 20 to 30 cargo trains travel each day. The tunnel, now 110 years old and facing structural issues that would cost $200 million to repair, has a single rail line, forcing many freight trains to wait while others pass through. Bottlenecks like this cost the U.S. about $200 billion annually, or 1.6% of GDP, and are projected to cost more without adding capacity along nationally significant corridors (ASCE 2013). Any disruption to these points in the system could cause significant economic disruptions, indicating a need to build in alternate routes that would increase redundancy in the system.

Another example of the lack of redundancy of the national freight rail system was the replacement of the critical 120-year-old Burlington Bridge in Iowa. It was determined that the two-track bridge – which had loading restrictions – was one of the three most important freight rail bridges spanning the Upper Mississippi River, based on train volume. The bridge is also part of Amtrak's national intercity passenger rail network and a key route for major coal traffic that brings low sulfur coal to the east, enough to supply electricity to nine million households annually.

Freight rail systems in the U.S. also play an important role in the intermodal transportation of containerized cargo and imported automobiles from ports on both coasts to points in the Midwest. Containers are double stacked on rail cars and transported to interior distribution hubs that then transfer cargo to trucks and taken to their final destinations.

Figure 6-4: A railroad bridge in New Orleans is washed out by flooding (Photo by Marvin Nauman)

Railways do face similar natural hazards as roads (e.g., flood and earthquake). Moreover, the railway network has similar infrastructure, including bridges and tunnels. However, the railway network in not nearly as redundant as local road networks. Thus disruptions in the railway network can have a significant impact. During Hurricane Katrina, flooding caused railway tracks to be impassible and some railway bridges failed, as shown in Figure 6-4. Careful planning can ensure that tracks are placed along high elevations and away from potential natural hazards. Relocating transit lines to newer tracks that are placed with more consideration of natural hazard risks reduces vulnerability, as does keeping older tracks in good repair for redundancy. Since railways, like roadways, are replaced every 20 years on average, resilience can be built into the system (Field et al. 2012).

Rail systems have other vulnerabilities. Most regional and intercity passenger rail systems either rely on electrified overhead catenaries or on third-rail traction power. While overhead catenary systems are more vulnerable to damage in storms from winds, falling trees, and branches, both are vulnerable to flooding, ice storms, and blizzards. Passenger rail in rural areas is powered by diesel locomotives and is more resilient. Some railroads have invested in hybrid locomotives that can be powered by diesel or electricity and be redeployed to restore limited service to lines where there may be loss of electric power. Freight rail cargo is transported by diesel powered locomotives that are not dependent on the energy grid and are less affected by storms, ice and flooding. Freight trains are more dependent on moveable bridges, which require electric power and are used for freight rail lines, because fixed bridges require elevated approaches to achieve higher under clearances.

A focus on early warning systems prior to a hazard event, whether that system is implemented by the weather service or by the rail companies, is essential if trains are to be moved to safer locations to protect train cars from flooding, which damages electrical components. As with other forms of transportation, adding forms of damage assessment will enable better prioritization of resources and lead to faster recovery in a post-disaster environment (The World Bank 2012).

Subway Systems. Subway systems move mass amounts of people for work, school, entertainment events, or other leisure activities. Because subways are underground, flooding is especially problematic. During Hurricane Sandy, the New York City subway system experienced heavy flooding; some tunnels filled up entirely.

RESILIENCE EXAMPLE: The New York City Transit (NYCT) subway system, despite being one of the oldest transportation infrastructures in the city, showcased adaptability in its response to the 9/11 attacks. Decision making was dispersed throughout the system; station managers were used to closing down their stations and rerouting trains due to police action. As a result of empowered leadership throughout the system, critical decision making was fast and unhindered by a chain of command. Trains were rerouted around the disrupted area, and when the nature of the event became clear, the subway was able to bring more trains onto outgoing tracks for evacuation. During the recovery, the system once again adapted to provide a means of transporting emergency personnel and supplies into and around the city (PWC 2013).

The subway's pumps were overwhelmed by the combined rainfall and storm surge. When power went out, the lack of redundancy in power supply stopped the pumps completely and left the subways unable to recover. The lack of protective measures leaves the system vulnerable to water and the lack of pump capacity, combined with a frail power supply, makes it unable to recover quickly. These problems severely inhibit the resilience of the subway system to the point that it will still take years for every station to reopen (City of New York 2013). Therefore, when attempting to achieve the performance goals set by the community's stakeholders, it is imperative to involve representatives of the energy industry in decision making, because of subways' strong dependence on the power supply

6.2.3. Air

The nation's air infrastructure provides the fastest way for freight and people to travel long distances. The airport system moves $562 billion in cargo each year, in addition to providing 728 million passenger flights. Use of commercial planes increased by 33 million passengers from 2000 to 2011. By 2040, it is projected that cargo will triple and over a billion passenger flights will traverse the nation's skies. Studies already show that negative impacts to this massive system cause significant damage. The estimated cost of congestion and delays was almost $22 billion in 2012 and is projected to rise to $63 billion by 2040, if national spending levels on air infrastructure are stagnant (ASCE 2013). Only with additional investment can the aviation infrastructure rise to meet the demands being placed upon it.

Airports are a key component of supply chain for e-commerce activities. Internet purchases result in tons of overnight air cargo transferred to trucks at airports and delivered to communities. There is a great interdependency between airports and roadway systems for timely delivery of high priority and perishable goods. Airport closures cause re-routing to other airports with longer truck travel times, delaying goods.

Large airports are communities in themselves; there are many people employed there, significant retail business and real-estate development, such as hotels. When an airport is closed, it does not just impact air travelers. People employed there are significantly affected and may be out of work until it reopens.

There are many dependencies between airports and other modes of transport. Passengers access airports via roadways or rail. Freight services and the provision of fuel to airports are reliant on roadways. In addition, when airports are disrupted, people and cargo are typically re-routed to road and rail networks.

Military airbases support the use of aircraft for operations by branches of the armed forces. An airbase typically has facilities similar to those of a civilian airport, such as traffic control and firefighting. Airbases are widespread throughout the U.S. and its territories and they provide a variety of services for the military such as refueling, storage and maintenance, training centers, and mission launch points. As with civilian air infrastructure, military air infrastructure provides the fastest way to transport personnel, cargo, arms, supplies, and other physical assets. As such, airbases play a critical role in supporting national security.

Disaster response is not a primary role of the armed forces; however, after major disasters, military airbases may double as launch points and staging areas for disaster recovery operations. As federal, state, and local agencies respond to disasters, the military is often called on for air support. Increased air transportation capabilities are particularly needed after hazard events that hinder ground transportation, such as floods, earthquakes, and major snow storms, or after hazard events in areas with prohibitive terrain. Common disaster response-related uses for military aircraft, include evacuation, search and rescue, supply delivery, and personnel mobilization. Airbases are governed by the branch of the military they serve, though assets may be provided to civilian governments under civilian control after a disaster.

Unfortunately, airports are more sensitive to disruptions than other forms of transportation infrastructure. Seventy percent of airport delays are due to severe weather events, which are expected to become more frequent (ACRP 2012). This sensitivity is partly attributed to system complexity, which incorporates more opportunities to fail and more risks than are immediately obvious (PWC 2013). Thus, completely assessing all vulnerabilities in an airport is difficult. Nevertheless, valuable lessons can be learned from past disasters.

Flooding, debris, snow, lightning strikes, wind, and ice can all force airport closure. In 2011, the area around the Dallas Fort Worth airport received 2.6 inches of snow before the Super Bowl. The airport was underprepared and suffered significant disruptions. Their equipment could only clear a runway one hour after de-icer was applied, leading to cancellation of over 300 flights. In response, the airport invested over $13 million in equipment to clear three runways of 2 inches of snow in 14 minutes. Although this is a great example of an aggressive response to creating a more resilient airport, it also showcases how easy it is for an unexpected weather event to cause disruptions (TRB 2014).

Runways are vulnerable to the same hazards as roads, although typically they have a lower degree of tolerance regarding safe condition for use. Runways can be shut down by flooding (Figure 6-5), ice, and snow. Additionally, runways are exceptionally vulnerable to soil liquefaction during seismic events (ACRP 2012). Apart from storm events, heat waves can cause the tarmac to buckle under the heavy loading caused by takeoff and landing.

Figure 6-5: Flooding closed the Chester County Airport and moved planes (FEMA, Photo by Andrea Booher, 1993)

The airport terminals are vulnerable to the same hazards as other buildings, as discussed in Chapter 5. Energy, fuel, communications, water, and wastewater services are all critical to the safe operation of airports. Refer to Chapters 7, 8 and 9, respectively, for discussion on the resiliency of these infrastructure systems.

Airports play an integral role in moving people and supplies before and after a hazard event. Any major disaster is likely to lead to increased traffic from evacuation. Additionally, if airports in an area close, other airports must deal with redirected flights and increased loads (ACRP 2012). After a disaster, federal and state aid is most quickly administered by air. These factors mean that airports are most needed when they are most vulnerable – directly before and after a hazard event. Therefore, increasing disaster resilience in airports is essential to increasing overall community resilience.

6.2.4. Ports, Harbors, and Waterways

Ports, harbors, and waterways are used largely for import/export of goods and materials. The U.S. Army Corps of Engineers estimates that over 95% of our trade, by volume, moves through our ports. In 2010, the ports helped export $460 billion worth of goods and import $940 billion. The U.S. has over 300 commercial harbors that process over 2.3 billion tons of cargo per year and over 600 additional smaller harbors. Although most ports are in good condition, the terminals need further investment due to the scheduled 2015 Panama Canal expansion. Due to the increasing size of commercial ships, many ports with shallow waterways are already inaccessible. Once the canal expansion is complete, even more ports will be unable to take advantage of the commerce boom from servicing new, larger ships that will be double the size of large cargo ships in use today (NOAA 2014). The need for further investment, as with the other transportation systems, means that this is the perfect time to make sustainable, resilient improvements to this critical infrastructure (ASCE 2013).

Maritime infrastructure also allows for waterborne transportation of passengers and vehicles, which is another important component of domestic trade (MARAD 2015). Ferries provide a safe and reliable link across bodies of water for commuters in major metropolitan areas where tunnels and bridges are not available or are less reliable and more congested. Additionally, ferries can serve in emergency evacuations of metropolitan areas when other transportation networks are inundated, gridlocked, or otherwise non-functional. According to the Bureau of Transportation Statistics, there were 23 ferry operators across 37 states and territories in 2009. It is estimated that U.S. ferries carried close to 103 million passengers and over 37 million vehicles in 2009 (RITA 2015). In New York City, the Staten Island Ferry carries approximately 70,000 passengers on a typical weekday (NYC DOT 2015).

The very nature of water transportation systems demands that critical infrastructure be located in vulnerable areas. Although planning port placement will not generally avoid earthquakes, storms, landslides, and tsunamis, placing ports by shallow undersea slopes helps reduce the risk of storm surge damage. Strengthening the structures themselves and strengthening the ground adjacent to the water, where soil may be weak, can be beneficial. Early warning systems for ship owners and port authorities also give facilities and watercraft time to prepare or evacuate (The World Bank 2012).

Figure 6-6: Shipping containers are displaced by high winds and storm surge.

Hurricanes, storms, and other heavy precipitation events can lead to extreme flooding and overtopping via precipitation and storm surge. These damage structures, dislodge containers (see Figure 6-6), undermine foundations, and destroy buildings outright. When hazardous chemicals are transported, there is a risk of hazardous spills in addition to the risk of oil spills. Flooding can also deposit silt and debris, which may restrict or disable navigable channels. Overwhelmed or failed drainage systems can cause flooding in areas that would otherwise be unaffected by a storm surge or riverine flooding. This represents a vulnerability caused by existing infrastructure. High winds associated with these types of events can damage critical equipment, such as cranes and structures (URS 2012). Drought conditions contributing to reduced levels in waterways may affect the ability to move goods and people.

An interview with port managers after Hurricane Sandy revealed that storm surge was the biggest issue the ports faced. The storm surge, combined with debris, slammed facilities and equipment and made road and rail access impossible, even after the storm. Flooding was a major issue, because all administrative offices were located on the first floors of buildings, so the water shut down the port management. In addition, flooding damaged new technology. The port had recently installed electric motors to move cranes in an effort to be more environmentally friendly, but these were all rendered inoperable. The loss of electric power shut down night lighting, nuclear detection for incoming and outgoing cargo, and traffic signals around the port. When power did slowly return, the presence of generators, running a few critical systems, combined with the grid voltage and repeatedly tripped circuit breakers. In parking lots, approximately 16,000 cars belonging to cruise passengers were flooded because there was nowhere and no one to move them. Piers and wharves performed well, because they are designed to withstand a ship impact laterally and the weight of a shipping container vertically, which are both forces that far exceed loads imposed by the storm. Although there was no loss of life during the storm, this interview illustrated the sheer number of things that can go wrong during or after a hazard event. Details like moving offices to the second floor, raising crane motors up or constructing housing for them, and having a system for recovery coordination with key utilities are easily overlooked, yet can make a huge difference (Wakeman 2013).

Drought can also stress shipping routes and maritime infrastructure. Inland waterways are particularly susceptible to drought; as water recedes during a drought, the navigable portion of a waterway may be restricted or completely cut off. Shriveling waterways create bottlenecks for shipping traffic, which creates congestion (U.S. FTA 2013). Even when drought-affected waterways remain navigable, reduced depth may require shipping vessels to reduce loads and speed, which hampers efficiency and increases shipping costs. Drought can also threaten commercial and municipal infrastructure that is specifically designed for fresh water. As freshwater discharge from a river's mouth decreases, coastal salt water can encroach on upstream areas that are typically freshwater (NPR 2013).

A unique vulnerability of maritime infrastructure is associated with sea level rise (SLR). Globally, the sea level is expected to rise by 7 to 23 inches by 2099. When combined with high tides and storm surges, this is the most probable threat to port infrastructure. Resulting changes in sediment movement lead to siltation along channel entrances, affecting accessibility for some ships. The risk of corrosion increases as more surface area comes in contact with the water. Some susceptibility to scour and flooding is ever present and is exacerbated by SLR, though it is usually accounted for in port design. This climate change impact has the potential to exact disaster-like tolls from the maritime infrastructure (Wakeman 2013).

As with other transportation modes there are many interdependencies For example, road and rail infrastructure is used to transport goods and people to and from ports and harbors to their final destination. Ferries can also be used as a temporary replacement for bridge infrastructure that may fail as a result of a hazard event. However, the lack of standardization across the industry can limit the transferability of vessels and infrastructure to support efforts following a hazard event.

Inland navigable waterways are crucial to the health of the U.S. trade economy. Shallow draft navigation (e.g., barges) serves 87% of all major U.S. cities, which accounts for 79% of all domestic waterborne freight (MARAD 2015). In 2005, inland waterways handled over 624 million tons of freight valued over $70 billion (MARAD 2007). The U.S. Maritime Administration estimates that if inland waterways became unavailable for transport, truck traffic on rural highways would increase by approximately 33% (58 million truck trips annually) and rail transport, by tonnage, would increase by 25%. Increases of these magnitudes would put tremendous stress on land-based infrastructure, resulting in increased maintenance costs, fuel consumption, congestion, and decreased safety. As waterways are maintained and improved, resilience to lasting drought conditions should be a chief consideration.

Inland waterways in the U.S. are relied upon to move large volumes of bulk cargo through a system of rivers and lakes interconnected by locks. As shown in Figure 6-7, one barge which can carry 1,500 tons of cargo moves the equivalent tonnage of 15 jumbo freight rail hopper cars or 58 large semi-trucks. A large barge tow consisting of 15 barges can transport the equivalent of 870 large semi-trucks. When the inland waterways flood, or there is a bridge collapse blocking a key river on their route, there is tremendous delay to bulk cargo movement that cannot be made up by other modes of freight transportation (Iowa DOT).

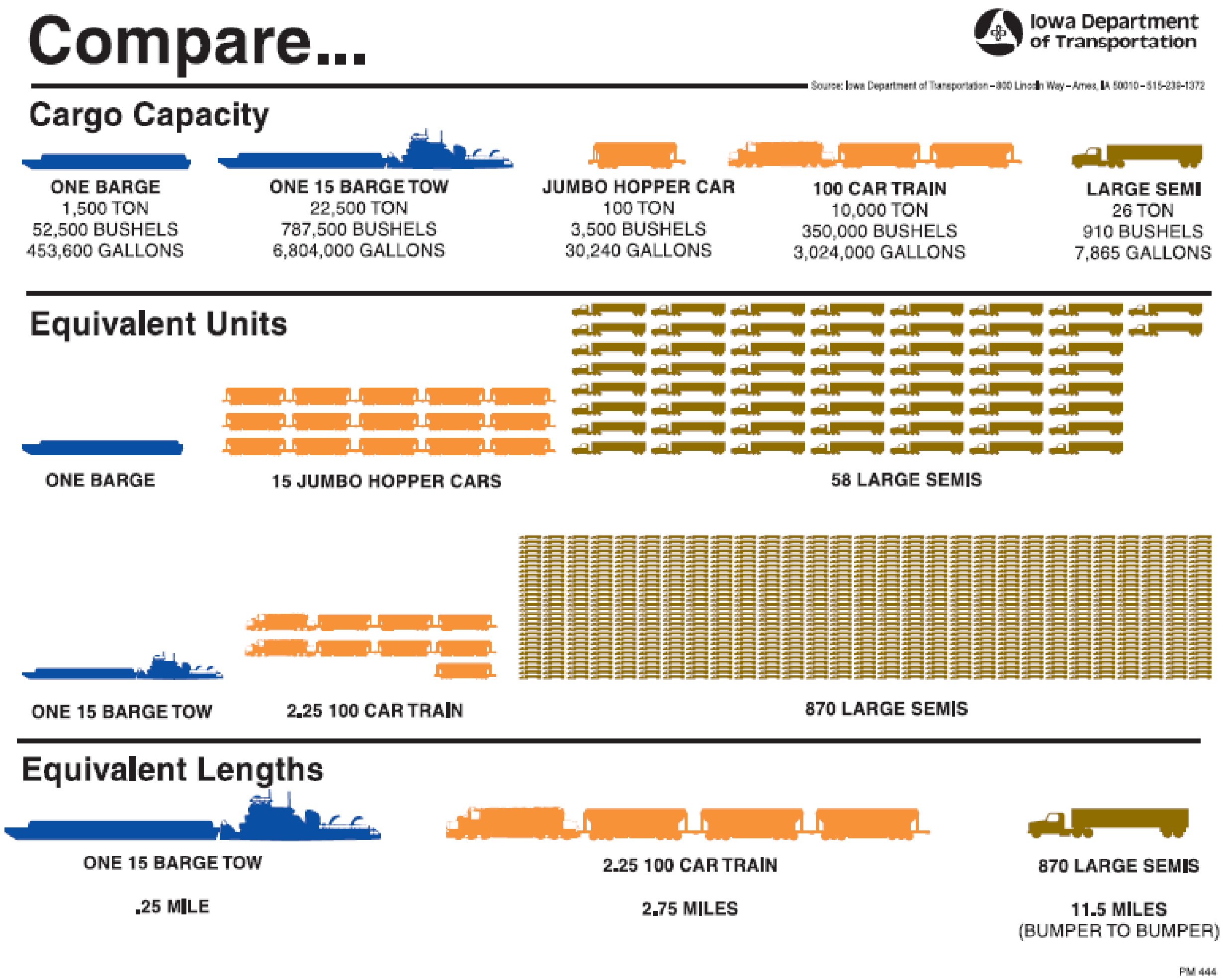

Figure 6-7: Iowa DOT Comparison Chart.

6.2.5. Pipelines

Pipelines are a key lifeline of the U.S. transportation and energy supply infrastructure, delivering natural gas, crude oil, refined products, such as gasoline and diesel, and natural gas liquids, such as ethane and propane. Because the engineering standards for pipeline safety and design are administered by the U.S. Department of Transportation's Pipeline and Hazardous Materials Administration (PHMSA), pipelines needed to transport natural gas and liquid fuels are discussed here as part of the transportation system.

The regulation and enforcement of pipeline safety for all types of pipelines are the responsibility of the PHMSA. A combination of federal, state, and local agencies are responsible for siting pipelines and their economic regulation (rates and tariffs).

Pipelines are generally grouped into three categories based on function: gathering (small pipelines in an oil or gas production area), transmission (larger, longer pipelines transporting products from supply areas to market areas), and distribution (pipelines delivering the product to residential, commercial or industrial end users). Including both onshore and offshore lines, there are approximately 300,000 miles of natural gas transmission pipelines, and 2.1 million miles of distribution pipelines in the U.S., delivering over 26 billion cubic feet of natural gas. Over 190,000 miles of liquids pipeline delivered nearly 15 billion barrels of crude oil and petroleum products in 2013. Over the last 10 years, liquids pipeline mileage is up 25,727 miles or 15.4%, with crude oil pipeline mileage growing 11,647 miles or 23.6% since 2004 (AOPL 2014).

The vast majority of liquid and gas pipelines are located underground, on land, or offshore; however, portions of the liquid pipeline network are located above ground along the Trans-Alaska Pipeline System, for example, which transports crude oil (DOT 2014).

Pipelines connect to compression/pumping stations, processing facilities, production platforms, wells, and storage facilities upstream and to end users, such as power plants and residential/commercial customers, downstream. Figure 6-8, showing the critical elements of the supply chain for oil, is equally illustrative of other types of pipeline systems and shows how these systems are inter-related with energy and other transportation systems. Short-term disruptions of the pipeline system by natural hazards complicate, hinder, and prolong disaster response and recovery. Long -term disruptions have a negative impact on the national economy, national security, and ecology.

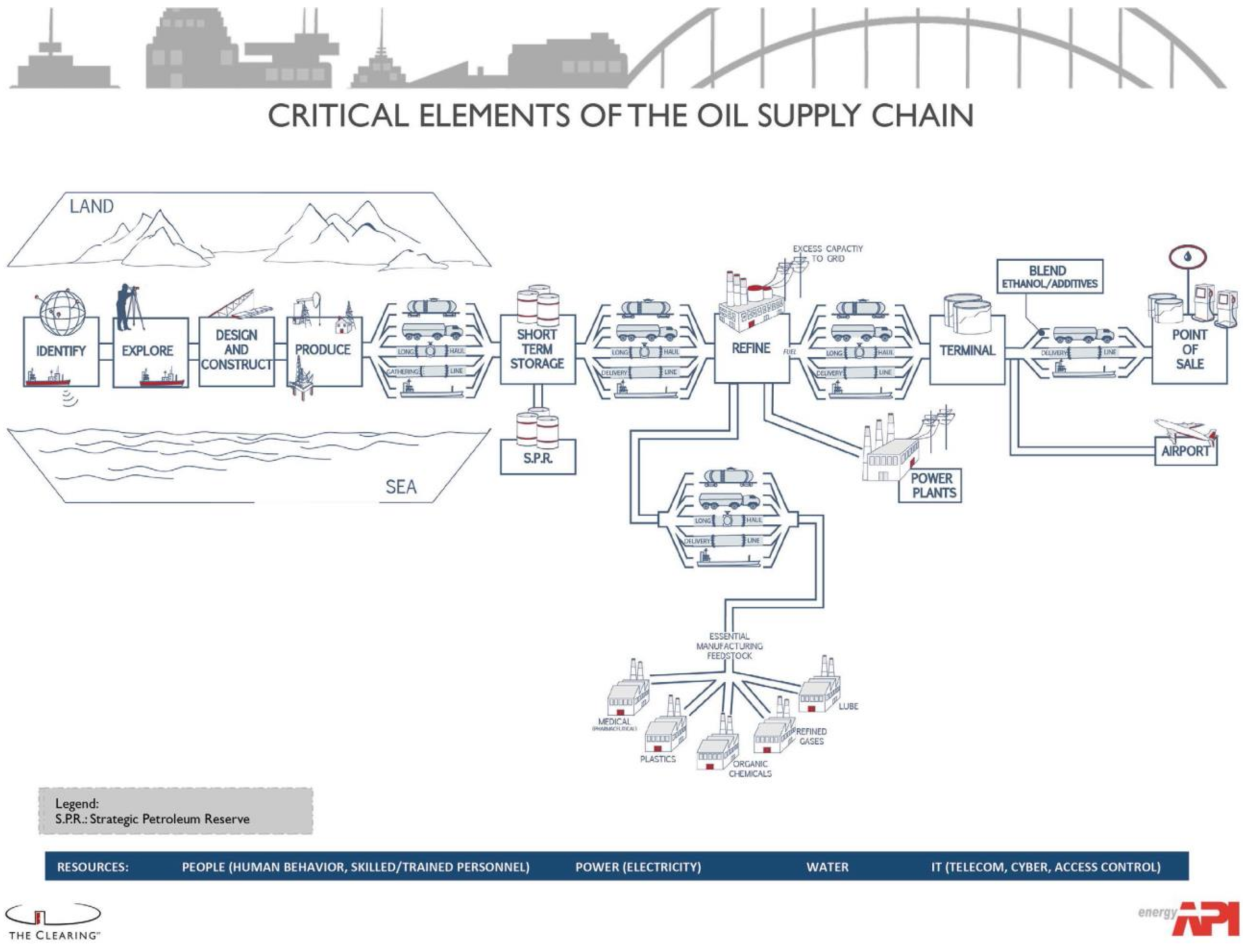

Figure 6-8: Critical Elements of the Oil Supply Chain

Pipelines and their associated aboveground facilities are vulnerable to damage by flooding and storm surge, impact from flood or windborne debris, and movement of land both on and offshore (earthquakes, subsidence, mudslides). Impacts to, or movement of, a pipeline can cause the line to rupture and that may ignite or explode into the air, soil, or a body of water. Secondary effects of pipeline disruptions include delays and fuel supply loss for the transportation system and natural gas to the energy infrastructure, which affects 1) the movement of responders and goods into affected areas and around the country if disruptions are prolonged and 2) power distribution to residents, businesses, and industry, which delays recovery and causes additional distress and life safety threats to residents.

Hurricanes can cause offshore pipes to be displaced laterally or become exposed, which can cause leaks at clamps, welds, flanges, and fittings or be pulled apart, rupturing pipelines. Earthquakes damage pipes by ground deformation – landslides, liquefaction and lateral movement of pipes – and by wave propagation or shaking (Ballantyne 2008, 3). These types of impacts result in pipe compression or wrinkling, cracking and separation at joints, welds, flanges, and fittings, and bending and shear (Ballantyne 2008, 3).

Hurricane Katrina caused extensive damage to offshore natural gas facilities that resulted in releases of gas from damaged or leaking pipelines in 72 locations (DNV 2007, 29). Damages to fuel refining and natural gas processing facilities caused by Hurricanes Katrina and Rita resulted in a loss of about 8% of the nation's capability to refine andprocess fuels, which significantly reduced the domestic supply (DNV 2007, 28). In addition, the damages also caused the equivalent of nearly an 11% loss of an average day's total gas consumption for the entire county (DNV 2007, 28). By comparison, Hurricane Sandy damaged petroleum refineries, not pipelines. Because the refineries were offline, although petroleum could still be moved through the pipeline, the movement was significantly slowed throughout the entire pipeline to compensate the loss of the supporting facilities, which affected areas from the Gulf Coast up the East Coast to New Jersey and New York, creating a supply chain problem in New Jersey and New York. Yet, this delay lacked the long term effects that Hurricane Katrina caused in 2005 (EIA 2012, 1). The Northridge (1994), Washington State (1997), and the Napa, California (2014) earthquakes damaged pipelines, which leaked natural gas that ignited, resulting in a fire (Northridge, Napa) and an explosion (Washington State) causing additional property damage (Ballantyne 2008, 1). Figure 6-10 shows an example of property damage caused by fire from broken gas lines.

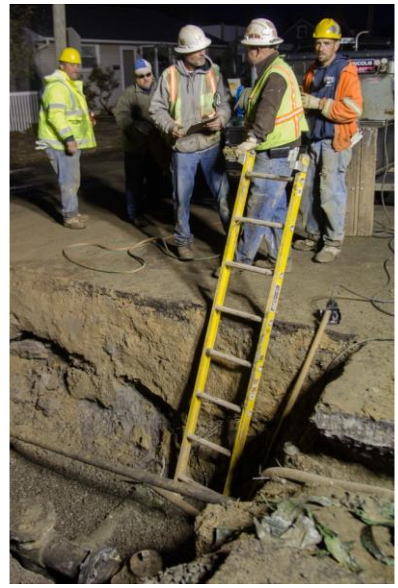

Figure 6-9: Natural gas crew shuts off gas after Hurricane Sandy (Photographer: Liz Roll, 2012)

Figure 6-10: Fire damage from broken gas lines (Photographer: Christopher Mardorf, 2014)

The PHMSA identified five areas for local governments to develop mitigation strategies to improve protection of pipelines and increase the resiliency of the transmission system: 1) pipeline awareness (education and outreach), 2) pipeline mapping, 3) excavation damage prevention, 4) land use and development planning near transmission pipelines, and 5) emergency response to pipeline emergencies (DOT 2013, 3). Identifying pipeline locations and entering the information into the National Pipeline Mapping System is a first step toward resiliency. Knowing where pipelines are located and making that information available is important to comprehensive and hazard mitigation planning, and preparedness, response, and recovery activities. Redesign or realignment of pipes to avoid liquefaction zones, faults, areas of subsidence, and floodplains are only possible if the location of both the pipeline alignment and the hazards are known and mapped. Similarly, local government can create a buffer zone around pipelines to provide an extra margin of safety for nearby residents and businesses and to provide greater access for repair or emergency response equipment. In addition to non-structural mitigation, structural mitigation measures help to mitigate damages to pipes due to earthquakes. These measures include replacing older pipes with modern steel piping with electric arc welded joints, avoiding use of anchors to allow the pipe to move with the ground, installing a coating/covering over piping to minimize soil friction and allow easy pipe movement, installing an automated control system to allow quick shutdown of damaged pipeline systems, and constructing parallel pipelines to build redundancy in the pipeline system (Ballantyne 2008, 6).

The American Lifelines Association (ALA 2005) identified the high-level performance measures and performance metrics for pipeline systems shown in Table 6-1.

Table 6-1: The American Lifelines Association High-Level Performance Measures and Performance Metrics for Pipeline Systems (ALA 2005).

Desired Outcomes (Performance Targets)	System Performance Metrics					
	Capital Losses ($)	Revenue Losses ($)	Service Disruption (% Service Population)	Downtime (hours)	Casualties (Deaths, Injuries)	Lost Product
Protect public and utility personnel safety					X	X
Maintain system reliability			X	X		
Prevent monetary loss	X	X	X	X		X
Prevent environmental damage						X

A qualitative ranking of hazards to typical pipeline system components and facilities from the ALA (2005) study is reproduced in Table 6-2.

Table 6-2: Qualitative Ranking of Hazards to Typical Pipeline System Components and Facilities (ALA 2005).

Hazards	Degree of Vulnerability									
	Transmission Pipelines	Pump Stations	Compressor Stations	Processing Facilities	Storage Tanks	Control Systems	Maintenance Operations Buildings and Equipment	Pressure Regulations / Metering Stations	Distribution Pipelines	Service Lines or Connections
Natural Hazards										
Earthquake Shaking	L	M	M	M	H	M	H	L	L	M
Earthquake Permanent Ground Deformations (fault rupture, liquefaction, landslide and settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Ground Movements (landslide, frost heave, settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Flooding (riverine, storm surge, tsunami and seiche)	L	H	H	H	M	H	H	H	L	M
Wind (hurricane, tornado)	L (Aerial)	-	-	-	-	L	L	-	-	-
Icing	L	-	-	-	-	-	-	-	L	-
Collateral Hazard: Blast or Fire	M	H	H	H	H	M	L	L	L	M
Collateral Hazard: Dam Inundation	L	H	H	H	M	H	H	H	L	M
Collateral Hazard: Nearby Collapse	-	L	L	L	-	L	L	L	M	L
Human Threats										
Physical Attack (biological, chemical, radiological and blast)	M	M	M	M	-	M	M	-	M	-
Cyber Attack	-	L	L	L	-	H	L	-	L	-

Note: Degrees of vulnerability: H = High, M = Moderate, L = Low. When a component or system is located within a building the vulnerability of both the building and component should be considered. For example, where there is a potential for building collapse or mandatory evacuation, the equipment housed within is at risk. The entries in Table 4-2 assume that the component is of recent vintage, i.e., post 1945.

It should be noted that over the last several years cyber security issues with pipeline systems have become an increased concern. Federal agencies, including the Department of Homeland Security, work with companies to improve security of computer-based pipeline control systems.

6.3. Performance Goals

Performance goals in this framework are defined by how quickly the functionality of the infrastructure systems recover after a hazard event. Minimizing downtime can be achieved during design or by developing and implementing a well prepared recovery plan (ideally both). [3]

Performance goals for the transportation system should be established by a panel of key stakeholders within the community, including owners, engineers, planners, regulators, codes and standards representatives, and representatives of other infrastructure systems (e.g., power and water/wastewater). Community stakeholders include representatives of the transportation system users, including commuters, school districts, emergency response services, local businesses, and other private and commercial property owners. Transportation stakeholders come from the state DOT, city DOT, township engineer, transit authorities, highway authorities, airport authorities, Amtrak, freight and short line railroads, independent taxi, bus, marine, airline and truck operators, USACE, FHWA, FAA, FRA, FTA, USCG, state, city and township code officials, AASHTO, AREMA, state, city and township OEMs, and others, as applicable. Additional stakeholders from local critical facilities, businesses, and users of the transportation system should be included establishing performance goals. For transportation systems, in particular, it is imperative that other infrastructure industries are involved in establishing the performance goals, because several systems have strong interdependencies with transportation systems, as discussed in Section 6.1.2. For example, both overhead and underground distribution lines for the power transmission and communication systems are often within the right-of-way of roads and bridges, thus are subject to DOT requirements. Likewise, water, gas, wastewater utilities with buried lines beneath streets should also be involved. In the case of passenger and light rail, the method of transportation is heavily reliant on energy systems. Once a panel of stakeholders is established, they can work to establish the performance goals for transportation system of their community. Table 6-3 through Table 6-5 present examples of performance goals for the routine, expected, and extreme events (defined in Chapter 3) for the fictional community of Centerville, USA. These example performance goals are intended to be generic so that they can be used for a hurricane, earthquake, flood, etc. Although the loading on the infrastructure and failure modes will differ depending on the type of hazard event, the social needs that drive the establishment of performance goals remain the same. However, it is noted that the social needs, and thus performance goals will vary by community.

The matrices provide three functional categories that equate to general services that transportation provides: ingress, egress and community transportation. Ingress refers to transportation of goods, services and first responders into a community immediately after a disaster and in the period of rebuilding and recovery from the event. Egress refers to the need to evacuate the population before and immediately after a hazard event. The transportation network must be viable and sufficient to provide safe egress for all citizens of the affected community. Community transportation ensures that the community can withstand and come back, or be resilient, from the given disaster. It ensures that the transportation network is available to provide passage to the critical facilities directly after an event and is available to citizens when their businesses re-open several days or weeks after. A full discussion of the definitions of each level is provided in Chapter 3.

Recovery times are broken down into three main phases: Short-term, Intermediate, and Long-term. The short term phase (0-3 days) includes the needs/goals to support immediate recovery of the community in the wake of a hazard event. The intermediate recovery phase (1-12 weeks) includes the needs/goals to support to support citizens and businesses returning to their daily functionality. The long term recovery phase (4-36+ months) performance goals support the need to rebuild, retrofit, and strengthen the transportation network to become more resilient for future hazard events.

[3] A detailed discussion on performance goal metrics is provided in Chapter 3.

Table 6-3 through Table 6-5 can be used as guides by communities/owners to evaluate the vulnerabilities of their transportation infrastructure at the various hazard levels (routine, expected, and extreme). The tables should be used by communities/owners to establish performance goals based on local social needs. Tables similar to Table 6-3 through Table 6-5 can be developed for any community (rural or urban), and any type of hazard event.

The performance goals in Table 6-3 through Table 6-5 were based on the performance seen in previous disaster events, such as Hurricanes Sandy and Katrina. Although these performance goals are provided as an example, it is up to the individual community to prepare their own set of performance goals for their given hazards and infrastructure.

The affected area of a given hazard event can also be specified, which often depends on the type of hazard. For example, earthquake and hurricanes typically have large affected areas, whereas tornadoes and tsunamis have relatively small affected areas. The affected area is important for the infrastructure owner to consider because it will impact how much of the infrastructure may be damaged which will impact the duration of the recovery process.

The disruption level in the performance goals tables is based on the current state of the transportation infrastructure system as a whole, and should be specified as minor, moderate, or severe.

In the individual rows of Table 6-3 through Table 6-5 an "X" shows how an infrastructure owner can indicate the anticipated performance and recovery of the infrastructure in their evaluation. As seen in these tables, there are significant gaps between the desired level of performance and what is seen in reality. This difference is a resilience gap. Once a community completes this table based on their local social needs and current anticipated performance, they can prioritize which gaps to address first.

Example performance goals for pipelines during the expected event in Centerville, USA are presented in Table 6-6. These example performance goals are similarly based on the performance seen in previous hazard events. The portions of the pipeline system most likely to have community impacts are liquid fuels and natural gas distribution systems, rather than production or transmission. This is because the interconnectivity of the pipeline grid is generally sufficient to adjust to localized incidents. Further, because natural gas and oil serve similar functions as electricity in the residential and commercial markets, the functional categories listed in Table 6-6 are essentially the same as the corresponding performance goal tables for electric transmission and distribution in Chapter 7. Much of the current infrastructure and response efforts managed by larger utilities may meet the 90% restored metric identified and therefore the blue shaded box is marked with 90% are to show that they are "overlapping."

To establish performance goals for transportation systems, it is necessary to first prioritize the transportation systems and components that are most critical to community response and recovery. Next, set the highest performance goals for those systems. Corresponding performance goals of a lesser degree will then be set for systems and components that play a lesser role. This will insure that efforts to improve resiliency will be focused first on actions that can bring the most benefit to the community. The priority for each transportation system to support ingress, egress, and community transportation is based on the degree the system contributes to the performance of that role for the community. The ability of each system to effectively serve these functions is a balance of the volume of people or goods that the system has the capacity to move and the interface of the system with the local community it serves. For example, highways are designed as networks for evacuation/egress. Local streets feed state county routes, which feed state highways, which feed interstate highways. The capacity of each branch is commensurate with the demand. If a local street is blocked, a detour to another street can be found and the impact on traffic congestion is small. If a major interstate highway is blocked, the consequences are significant since traffic jams will create gridlock, because the detour routes require large traffic volumes to take local routes that cannot handle them.

In turn, design standards for highways are the highest for interstate highways, because they are the most critical for the movement of people and goods. They are graded to be above flood plains, trees are cut back from the shoulders, rock slopes are well back of shoulders, and they are well maintained. State highways are next in the level of performance standards and numbered county routes follow.

Highway bridges and road tunnels are part of the highway infrastructure and cannot be prioritized separately from the highway they connect. Bridges on interstate highways are more important than bridges on state highways and county routes when it comes to egress and ingress. Similarly, bridges or tunnels that are part of a subway or rail system that relies on them cannot be prioritized separately.

1. Designated evacuation routes and emergency access routes should have highest priority. They were designated such, because they can function as a network collecting vehicles from local streets, to county routes, state highways, and interstate highways, moving travelers to higher ground or away from other hazards such as a nuclear power plant alert. Highways may have intelligent transportation systems (ITS) to alert travelers of travel times, detours, and potential traffic congestion that can be avoided. Evacuation plans may reverse the direction of highways, so that all travel lanes are outbound, away from the hazard. ITS devices like cameras, sensors and variable message signs let traffic command centers communicate with travelers in vehicles to direct them.
2. Interstate Highways are next, since they are constructed to higher standards. They also carry the highest volume of vehicles, which makes them critical in evacuations.
3. State Highways are next for similar reasons to the above.
4. Numbered County Routes should be next (they are numbered parts of complete systems).
5. Pipelines serving power and energy systems in the community are next. In the short-term phase, ruptured natural gas, fuel, water, and wastewater lines need to be repaired to support recovery.
6. Buses use all the highway routes described above. Bus fleets should be protected, fueled, and strategically located and staged to support egress. They can move the greatest volumes of people, especially those in communities who do not own vehicles or have people they can rely on for a ride. In the short-term phase, they can also move the largest volume of relief and recovery workers to a disaster area. In evacuation planning it is preferable to have people who do not have access to automobiles to use buses instead of taxis or livery vehicles, since it results in less highway congestion.
7. In large cities subway mass transit systems are generally designed to collect commuters traveling to the city center from their local community via walking, bicycle, bus, regional rail, park and ride lots, and livery vehicles. The subway lines also connect at transfer stations, which serve as hubs to allow commuters to get to the specific destination station closest to where they work. At the end of the business day they perform these functions in reverse. Subway systems are capable of moving large volumes of people for egress purposes away from a hazard in the city center. When used for ingress purposes, the subway routes will likely allow passengers to use the transfer stations to get to a point close to their destination if their normal destination station is closed due to a disaster. Subways may not be useful for egress or ingress for disasters other than those described here. For this reason they are placed after buses in priority order.
8. Large ferry vessels are capable of moving significant volumes of people across bodies of water that otherwise would require long travel distances by other modes of transportation. Examples are the ferry system in San Francisco and the Staten Island Ferry in New York City. They can perform this function well on an emergency basis for egress or ingress. Their operation; however, is limited in storm conditions when they are required to shut down. Large ferry systems have robust ferry terminal docking systems that are less likely to suffer damage during an expected storm event; however, for more extreme storm events they may suffer significant damage.

9. Light rail transit systems are often found to be a link between communities, the town center, and other modes of transportation, such as airports or passenger rail stations. They transport much lower volumes of passengers at lower speeds than mass transit systems, but provide more frequent service with shorter headways between trains. In general, light rail systems are not as resilient as other rail systems; they do not operate in high winds and have problems with icing, since they are either powered by overhead electric catenaries or have electric bus bars similar to, but less robust than, third rails.

10. Regional rail is generally designed to collect commuters traveling to the city center from local suburban communities via local stations or distribute them in the reverse direction. Travel to stations is by automobile, taxi, livery car, walking, or bicycle. Some stations are hubs with larger park and ride lots or garages. Regional rail usually feeds a multimodal train terminal station in the city or town center where passengers extend their trip to their ultimate destination by intercity rail, subway, bus transit systems, or taxis. Examples of regional rail are Penn Station in New York City and Union Station in Washington, DC. Regional rail can serve for egress or ingress; however, travelers evacuating from the suburbs need to be wary that the other transportation systems they will rely on for connections are functioning.

11. National or international airports can be used for egress of travelers who need to return to their home airport, or community residents evacuating to other cities. In the ingress mode, it can receive large volumes of emergency aid as air cargo and bring recovery workers from large distances unaffected by the hazard event. Airports are generally well connected to the regional highway network, which is likely to be the first local transportation system that is functioning after a hazard event. They may also be connected to regional rail, subway systems, or light rail systems.

12. Intercity rail, such as Amtrak, can be used for egress of travelers who need to return to their community, or residents evacuating to other communities. In the ingress mode, it can bring recovery workers from distant cities unaffected by the hazard event. Intercity rail stations are generally in the town center or city center and are well connected to the regional rail or local subway or bus transit system with taxi and rental car service.

13. Regional airports can function similar to national or international airports to serve communities that are outside of large cities. The highway networks that support these airports should be sized according to the lower volumes of cargo and passengers they transport.

14. Marine ports are comprised of docks, waterways, locks, and supporting upland facilities, which include cargo storage and distribution centers, cargo and container cranes, intermodal freight rail yards, and truck transfer and inspection facilities. Egress at these facilities involves scheduling large container ships and cargo vessels to divert to other ports, and diverting rail and truck exports to other ports. Ingress for recovery supplies and bulk and container cargo can only take place after restoration of the docks, waterways, locks, supporting upland facilities, and the connecting highways and rail yards.

15. Freight rail lines connect to major distribution centers in inland cities and to major port facilities on the coasts. Use for egress would include removal of debris and refuse. Use for ingress would include recovery supplies, bulk cargo, and heavy equipment.

16. Ferry terminals for smaller vessels carrying lower volumes of travelers do not have a big impact on egress, except where they may serve waterfront communities that are otherwise isolated (island communities). In addition, during the recovery phases, temporary ferry operations can be quickly established to serve communities cut off by bodies of water after the wash out of roads and bridges.

Table 6-3: Example Transportation Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels			90%	X							
State Highways, Bridges and Tunnels			90%	X							
National Highways, Bridges and Tunnels			90%	X							
Regional Airport			60%	90%	X						
National/International Airport			60%	90%	X						
Military Airports			60%	90%	X						
Marine Port			60%	90%	X						
Ferry Terminal			60%	90%	X						
Subway Station			60%	90%	X						
Rail Station, Local			60%	90%	X						
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National				30%	60%	90%	X				
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels			90%	X							
State Highways, Bridges and Tunnels			90%	X							
National Highways, Bridges and Tunnels			90%	X							
Regional Airport			60%	90%	X						
National/Int'l Airport			30%	60%	90%	X					
Military Airports			60%	90%	X						
Subway Station			60%	90%	X						
Ferry Terminal			60%	90%	X						
Rail Station, Local			90%		X						
Rail Station, Regional			60%	90%	X						
Rail Station, National			30%	60%	90%		X				
Community resilience											
Critical Facilities		**A**									
Hospitals			90%	X							
Police and Fire Stations			90%	X							
Emergency Operational Centers			90%	X							
Emergency Housing		**B**									
Residences			90%	X							
Emergency Responder Housing			90%	X							
Public Shelters			90%	X							
Housing/Neighborhoods		**B**									
Essential City Service Facilities			60%	90%	X						
Schools			60%	90%	X						
Medical Provider Offices			60%	90%	X						
Retail			60%	90%	X						
Community Recovery		**C**									
Residences			60%	90%	X						
Neighborhood retail			60%	90%	X						
Offices and work places			60%	90%	X						
Non-emergency City Services			60%	90%	X						
All businesses			30%	60%	90%	X					

Footnotes:

1 Specify hazard being considered

Specify level – Routine, Expected, Extreme
Specify the size of the area affected – localized, community, regional
Specify severity of disruption – minor, moderate, severe

2	30%	60%	90%	
3	X	Estimated restoration time for current conditions based on design standards and current inventory		

Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan

R	Regional
S	State
MS	Multi-state
C	Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

Table 6-4: Example Transportation Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels			60%	90%	X						
State Highways, Bridges and Tunnels			60%	90%		X					
National Highways, Bridges and Tunnels			90%		X						
Regional Airport				30%	60%	90%		X			
National/International Airport			30%	60%	90%	X					
Military Airports			30%	60%	90%	X					
Marine Port				30%	60%	90%	X				
Ferry Terminal			30%	60%	90%	X					
Subway Station			30%	60%	90%		X				
Rail Station, Local			30%	60%	90%	X					
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National				30%	60%	90%	X				
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels			60%	90%	X						
State Highways, Bridges and Tunnels			60%	90%		X					
National Highways, Bridges and Tunnels			90%		X						
Regional Airport				30%	60%	90%		X			
National/Int'l Airport				30%	60%	90%	X				
Military Airports				30%	60%	90%	X				
Subway Station			30%	60%	90%	X					
Ferry Terminal			60%	90%	X						
Rail Station, Local				30%	60%	90%	X				
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National			30%	60%	90%	X					
Community resilience											
Critical Facilities		**A**									
Hospitals			60%	90%	X						
Police and Fire Stations			60%	90%	X						
Emergency Operational Centers			60%	90%	X						
Emergency Housing		**B**									
Residences			30%	60%	90%	X					
Emergency Responder Housing			30%	60%	90%	X					
Public Shelters			90%		X						
Housing/Neighborhoods		**B**									
Essential City Service Facilities			30%	60%	90%	X					
Schools			30%	60%	90%	X					
Medical Provider Offices			30%	60%	90%	X					
Retail			30%	60%	90%	X					
Community Recovery		**C**									
Residences			30%	60%	90%	X					
Neighborhood retail			30%	60%	90%	X					
Offices and work places			30%	60%	90%	X					
Non-emergency City Services			30%	60%	90%	X					
All businesses				30%	60%	90%	X				

Footnotes: See Table 6-3, page 22.

Table 6-5: Example Transportation Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels					30%	60%	90%	X			
State Highways, Bridges and Tunnels					30%	60%	90%	X			
National Highways, Bridges and Tunnels				30%	60%	90%	X				
Regional Airport					30%	60%	90%	X			
National/International Airport				30%	60%	90%		X			
Military Airports					30%	60%	90%	X			
Marine Port					30%	60%	90%	X			
Ferry Terminal					30%	60%	90%	X			
Subway Station					30%	60%	90%	X			
Rail Station, Local					30%	60%	90%	X			
Rail Station, Regional					30%	60%	90%	X			
Rail Station, National					30%	60%	90%	X			
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels					30%	60%	90%	X			
State Highways, Bridges and Tunnels					30%	60%	90%	X			
National Highways, Bridges and Tunnels				30%	60%	90%	X				
Regional Airport					30%	60%	90%	X			
National/Int'l Airport				30%	60%	90%		X			
Military Airports					30%	60%	90%	X			
Subway Station					30%	60%	90%	X			
Ferry Terminal					30%	60%	90%	X			
Rail Station, Local					30%	60%	90%	X			
Rail Station, Regional					30%	60%	90%	X			
Rail Station, National					30%	60%	90%	X			
Community resilience											
Critical Facilities		**A**									
Hospitals			30%	60%	90%		X				
Police and Fire Stations			30%	60%	90%		X				
Emergency Operational Centers			30%	60%	90%		X				
Emergency Housing		**B**									
Residences					30%	60%	90%	X			
Emergency Responder Housing			30%	60%	90%	X					
Public Shelters			30%	60%	90%	X					
Housing/Neighborhoods		**B**									
Essential City Service Facilities					30%	60%	90%	X			
Schools					30%	60%	90%	X			
Medical Provider Offices					30%	60%	90%	X			
Retail					30%	60%	90%	X			
Community Recovery		C									
Residences					30%	60%	90%	X			
Neighborhood retail					30%	60%	90%	X			
Offices and work places					30%	60%	90%	X			
Non-emergency City Services					30%	60%	90%	X			
All businesses					30%	60%	90%	X			

Footnotes: See Table 6-3, page 22.

Table 6-6. Example Pipeline Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current (note: 90% used if desired equal to anticipated)

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Phase 1 -- Response			Phase 2 -- Workforce			Phase 3 -- Community		
			Days 0	Days 1	Days 1-3	Wks 1-4	Wks 4-8	Wks 8-12	Mos 4	Mos 4-36	Mos 36+
Pipelines											
Distribution											
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations				30%	60%	90%					
Emergency Operations Centers				30%	60%	90%					
Disaster debris/recycling centers				30%	60%	90%					
Related lifeline systems				30%	60%	90%					
Emergency Housing and Support Systems											
Public Shelters (General Population, Animal, etc.)					30%	60%	90%				
Food distribution centers					30%	60%	90%				
Nursing homes, transitional housing					30%	60%	90%				
Emergency shelter for response/recovery workforce				30%	60%	90%					
Related lifeline systems				30%	60%	90%					
Housing and Neighborhood infrastructure											
Essential city services facilities							30%	60%	90%		
Schools							30%	60%	90%		
Medical provider offices							30%	60%	90%		
Houses of worship/meditation/ exercise											
Buildings/space for social services (e.g., child services) and prosecution activities											
Food distribution from local grocery stores (location known by community)						30%	60%	90%	X		
Community Recovery Infrastructure											
Residential housing restoration							30%	60%	90%		
Commercial and industrial businesses							30%	60%	90%		
Non-emergency city services							30%	60%	90%		
Community Recovery Infrastructure											
Residential housing restoration							30%	60%	90%		
Commercial and industrial businesses							30%	60%	90%		
Non-emergency city services							30%	60%	90%		
Related lifeline systems							30%	60%	90%		

Footnotes: See Table 6-3, page 22.

6.4. Regulatory Environment

There are multiple regulatory bodies at the various levels of government (federal, state, and local) that have authority over the transportation system. The transportation system is not regulated by a single regulatory body, even within a single transportation mode. This section discusses regulatory bodies of communications infrastructure at the federal, state, and local levels.

6.4.1. Federal

Federal regulatory agencies oversee the transportation network and methods of transportation used within those networks. These agencies have promulgated policies and regulations that maintain the safety and security of infrastructure and operations. As the transportation industry features a diverse range of methods and operating environments, is overseen by a myriad of regulatory agencies, and funded by disparate streams that are subject to variability in direction of different political administrations, efforts to assess and address resilience across the transportation industry varies in scope. Some of the key regulatory agencies are discussed in the following sections.

Table 6-7 presents a summary of the methods of transportation used and the oversight authorities involved in their regulation.

Table 6-7: Transportation Infrastructure Code and Standards Governing Agencies

Industry	Infrastructure	Type	Method of Transportation	Public	Private	Oversight Authority													
						DHS	FEMA	NTSB	USDOT	FRA	FTA	TSA	FMCSA	FHWA	USCG	EPA	FAA	1+ state agencies
Surface Transport	Rail	Passenger	Inter-City Rail (Amtrak)	X		X	X	X	X	X		X						X
			Commuter Rail	X		X	X	X	X	X	X	X	X					X
			Subway	X		X	X	X	X		X	X						X
			Light Rail	X		X	X	X	X		X	X						X
			Inclined Plane	X		X	X	X	X		X	X						X
			Trolley/Cable Car	X		X	X	X	X		X	X						X
		Freight	Class 1 Freight Carriers		X	X	X	X	X	X		X						X
	Roads, Bridges and Tunnels	Passenger	Inter-City Motor coach	X	X	X	X	X	X			X	X	X				X
			Intra-City Bus/Motor coach	X	X	X	X	X	X		X	X	X	X				X
			Paratransit/Jitneys	X	X	X	X	X	X		X	X	X	X				X
			Taxis	X	X	X	X	X	X			X	X	X				X
			Personal Cars		X				X									X
		Freight	Commercial Trucking		X	X		X	X		X	X	X	X				X
	Maritime	Passenger	Ocean Lines		X			X	X			X			X	X		X
			Ferries	X		X	X	X	X		X	X		X	X	X		X
			Commercial Boats		X			X	X			X			X	X		X
			Personal Boats		X			X	X			X			X	X		X
		Freight	Freighters		X	X	X	X	X			X			X	X		X
			Barges		X	X	X	X	X			X			X	X		X
Air	Air	Passenger	Commercial Airplanes		X			X	X			X				X	X	X
			Blimps		X			X	X			X				X	X	X
			Drones	X	X			X	X			X				X	X	X
		Freight	Commercial Air Freight		X			X	X			X				X	X	X

6.4.1.1. U.S. Department of Transportation

The United States Department of Transportation (DOT) is a federal agency concerned with transportation. It was created in 1966 and governed by the U.S. Secretary of Transportation. Its mission is to "Serve the United States by ensuring a fast, safe, efficient, accessible, and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future." The following agencies are housed within the DOT:

- National Highway Traffic Safety Administration
- Federal Aviation Administration
- Office of Inspector General
- Federal Highway Administration
- Pipeline and Hazardous Materials Safety Administration
- Federal Motor Carrier Safety Administration
- Federal Railroad Administration
- Saint Lawrence Seaway Development Corporation
- Federal Transit Administration
- Surface Transportation Board
- Maritime Administration

6.4.1.2. Federal Highway Administration

The Federal Highway Administration (FHWA) is an agency within the U.S. Department of Transportation. The FHWA supports state and local governments in the design, construction, and maintenance of the roadway system. The FHWA provides funding to state and local DOTs to ensure that roadways remain safe and operable. It also conducts research and advances the technology of the transportation system including bridges, pavements, and materials through facilities such as the Turner Fairbanks Highway Research Center in McLean, Virginia.

The FHWA partners with state and local DOTs by funding pilot projects in an attempt to relieve congestion in the existing transportation network and improve commuter time for both citizens and business (FHWA 2009). One pilot program is the Freight Intermodal Distribution Pilot Grant Program, which funded six programs around the country to make improvements to their infrastructure, so that intermodal transportation of people and goods becomes more efficient (FHWA 2009). One of these six programs improves the transfer area of the Fairbanks, AK Freight Yard, so trucks can make pick-ups/drop-offs in a shorter period (FHWA 2009). The current pick-up/drop-off location does not provide enough room for the trucks to get to the trains, thus creating bottlenecks even without a hazard event occuring.

The FHWA also attempted to relieve congestion in road networks by funding pilot programs in four cities that encourage non-motorized methods of transportation in the road network (i.e., walking and bicycles). These programs provide infrastructure for other forms of transportation in the road network and encourage people to use the infrastructure, so the road network is more diverse (FHWA 2012). Increasing the diversity of how the road network is used relieves congestion, which is especially helpful after a hazard event.

6.4.1.3. Federal Transit Administration

The Federal Transit Administration (FTA) is an agency within the U.S. Department of Transportation, which provides financial and technical support to local public transit systems (i.e., buses, subways, light rail, commuter rail, monorail, passenger ferryboats, trolleys, inclined railways, and people movers). FTA programs assist state, regional, and local transit operators in developing and maintaining transit systems.

In 1990, the FTA promulgated 49 CFR Part 659, Fixed Guide way Rail State Safety Oversight, which mandated that rail transit agencies that do not run on the national railroad network develop a system safety management organization guided and documented in a System Safety Program Plan (SSPP), which covered revenue service operations. It later released 49 CFR Part 633 to cover system safety issues in design and construction of major capital projects. Later, after 9/11, the FTA developed requirements to cover security issues. However, these regulations did not cover the preponderance of transit systems that offered transit bus and paratransit operations. Nor did these, in general, cover capital projects of under $100M in value. Some of these capital design requirements do impact ferry grantees that operate under the USCG if the operation uses FTA grant funding. These programs potentially cover climate change issues, since transit systems are required to perform design and operational risk assessments at this time.[4] However, the FTA does not have a systematic regulatory program to address climate change or resilience. Instead, the FTA has developed guidance and a pilot program for agencies to investigate the issues.

6.4.1.4. Federal Railroad Administration (FRA)

The Federal Railroad Administration (FRA) is an agency within the U.S. Department of Transportation responsible for heavy rail freight systems, commuter and inter-city passenger rail systems. The primary FRA programs organize around safety, rail network development, research and development, regulations, and grants and loans.

FRA's core mission is railroad safety, and their programs reflect this focus. The safety programs address hazardous materials, motive power and equipment, operating practices, signal and train control, and track. FRA's Track Division provides evaluation, direction, and technical advice for rail safety enforcement programs for FRA and State safety programs. The Track Division participates in accident investigations and directly investigates reports concerning track conditions. Most relevant to resiliency, the Track Division actively participates in development of industry and consensual standards useful for enhancement of railroad safety. Industry design standards relevant to resiliency are developed primarily by the American Railway Engineering and Maintenance-of-Way Association (AREMA). Additionally, for policy matters and operations-related standards, the leading organization is the Association of American Railroads (AAR).

FRA's R&D mission is to ensure the safe, efficient and reliable movement of people and goods by rail through basic and applied research, and development of innovations and solutions. Safety is the DOT's primary strategic goal and the principal driver of FRA's R&D program. FRA's R&D program also contributes to other DOT strategic goals because safety-focused projects typically yield solutions towards the state of good repair, economic competitiveness, and environmental sustainability goals.

FRA's R&D program is founded on an understanding of safety risks in the industry. Hazard identification and risk analysis allows FRA to identify opportunities to reduce the likelihood of accidents and incidents, and to limit the consequences of hazardous events should they occur. Key strategies include stakeholder engagement and partnerships with other researchers, such as the AAR, prioritization of projects and conducting research through cost-effective procurement.

For roadway systems, federal regulation often leaves room for interpretation, while states often issue more specific guides and manuals building on federal regulation. For example, in each subsection of the FHWA's Manual on Uniform Traffic Control Devices (MUTCD) there is a "Standard" section followed by multiple "Guidance" sections, providing further details that are recommended, but not required, depending on specific conditions. States are allowed, and even encouraged, to make modifications to the MUTCD that fit specific state needs. California found so many such modifications that it issues its own California MUTCD that supersedes the federal version.

[4] The latter is not a mandated and necessarily enforced by a standardized framework but the former is more so.

6.4.1.5. Federal Aviation Administration (FAA)

The Federal Aviation Administration (FAA) is an agency of the U.S. Department of Transportation that oversees all civil aviation in the country. The major roles of the FAA include regulating U.S. commercial airspace, regulating flight inspection standards, and promoting air safety. The Transportation Security Administration (TSA) also has an active role in the security of air freight and commercial air passenger service.

The FAA supports public and private airports within the National Plan of Integrated Airport Systems (NPIAS) in the design, construction, and maintenance of the airport system with grants through the Airport Improvement Program (AIP). The FAA has undertaken a study to review facility, service, and equipment profile (FSEP) data and its vulnerability to various climate responses, such as storm surge. This data will result in publicly available climate models that will be accessible by airport operators and managers.

6.4.1.6. Federal Emergency Management Agency (FEMA)

FEMA is an agency of the United States Department of Homeland Security with a primary purpose to coordinate the response to a disaster that has occurred in the United States and that overwhelms the resources of local and state authorities. FEMA supports the recovery of infrastructure systems after a disaster event, including the transportation system, and the specific authorities and programs within the jurisdiction of participating departments and agencies.

As one of their mission is to recover from all hazards and provide funding for recovery and hazard mitigation, FEMA identifies transportation modes and capabilities for all populations, including individuals located in hospitals and nursing homes and individuals with disabilities and others with access and functional needs.

6.4.1.7. U.S. Coast Guard (USCG)

The USCG covers the safety and security of the national waterways, overseeing commercial freight and passenger service, as well as public transportation (e.g., municipal ferry service, boaters, and kayakers). The USGS works to prevent import of illegal or unwanted goods that may harm communities and provides escorts of exported cargo for national security (e.g., military cargo).

6.4.1.8. Transportation Security Administration (TSA)

The Transportation Security Administration (TSA), an agency within the U.S. Department of Homeland Security (DHS), is responsible for prevention of the intentional destruction or disablement of transportation systems in all modes of transport. Formed after the events of 9/11, TSA immediately imposed security oversight and regulation in the aviation community and subsequently established divisions in all other modes, including highway, mass transit, passenger and freight rail, pipeline and maritime where it shares oversight with the U.S. Coast Guard. TSA established direct interaction and partnerships with private and public transportation operators to review and assess modal security preparedness, training and enhancement through both regulatory and voluntary steps. TSA has focused its attentions on prevention of intentional disruption and improved resilience in all modal systems.

6.4.1.9. United States Corps of Engineers (USACE)

The USACE provides support in the emergency operation and restoration of inland waterways, ports, and harbors under the supervision of DOD/USACE, including dredging operations and assists in restoring the transportation infrastructure.

The USACE is a U.S. federal agency under the Department of Defense, with environmental sustainability as a guiding principle. By building and maintaining America’s infrastructure and by devising hurricane and storm damage reduction infrastructure, the USACE is reducing risks from hazard events.

The USACE regulates water under “Section 404 clean Water Act” and “Section 10 Rivers and Harbors” permits. As the lead federal regulatory agency, USACE assesses potential impacts to marine navigation in the federal-maintained channels in the USA.

USACE is addressing climate issues identified in the National Ocean Policy Implementation Plan (NOPIP) and taking actions. The USACE climate programs incorporate collaborative efforts to develop and disseminate methods, best practices, and standards for assessing coastal resilience in a changing climate. In response to Executive Orders 13514 and 13653, the USACE released its Climate Change Adaptation Plan and annual Strategic Sustainability Plan.

As it relates to the maritime industry, the USACE is working on the following actions in response to climate change related issues: **[3]**

- Develop an interagency plan for topographic and shallow bathymetric mapping to ensure comprehensive and accurate elevation information for coastlines that will eventually include acoustic bathymetry mapping.
- Provide and integrate county-level coastal and ocean job trends data via NOAA’s Digital Coast to enable decision-makers and planners to better assess the economic impacts of climate change and ocean acidification.
- Support NOAA’s Economics: National Ocean Watch (ENOW) will provide data on six economic sectors that directly depend on the resources of the oceans and Great Lakes: Living Resources (includes commercial fishing), Tourism and Recreation, Marine Transportation, Ship and Boat Building, Marine Construction (includes harbor dredging and beach nourishment), and Offshore Minerals (exploration and production, sand, gravel, oil, gas).
- Provide coastal inundation and sea-level change decision-support tools to local, state, tribal, and federal managers.
- Build on the USACE-developed sea level change calculator used in the interagency Sea Level Rise Tool for Sandy Recovery in the North Atlantic Coast. The USACE, NOAA, and FEMA are working on two pilot programs to test the application of this tool in the gulf coast and west coast. USACE, NOAA, and the Department of the Interior are working on a Sea Level Rise and Coastal Flooding Impacts Viewer and associated datasets including Digital Elevation Models. Being able to visualize potential impacts from sea level rise and coastal flooding is a powerful teaching and planning tool, and the Sea Level Rise Viewer, map services, and data brings this capability to coastal communities.

6.4.1.10. United States Environmental Protection Agency (EPA)

The EPA is an agency of the U.S. federal government created to protect human health and the environment by writing and enforcing regulations based on laws passed by Congress.

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. These regulations are important from the perspective that most marine infrastructure design and construction process are required to comply.

The EPA’s Program and Regional Offices produced a final Climate Change Adaptation Plan and the Climate Change Adaptation Implementation Plans. These plans describe how the agency will integrate considerations of climate change into its programs, policies, rules, and operations to ensure they are effective, even as the climate changes. On June 30, 2014, the EPA issued a new policy statement on climate change adaptation. This statement updates the initial policy statement issued in June of 2011. Climate Ready Estuaries is a partnership between EPA and the National Estuary Program to assess climate change vulnerabilities in coastal areas, develop and implement adaptation strategies, engage and educate stakeholders, and share the lessons learned with other coastal managers. **[4, 5]**

6.4.1.11. Council on Environmental Quality (CEQ)

CEQ was established within the Executive Office of the President by Congress as part of the National Environmental Policy Act of 1969 (NEPA) and additional responsibilities were provided by the Environmental Quality Improvement Act of 1970. NEPA assigns CEQ the task of ensuring that federal agencies meet their obligations under the Act. The challenge of harmonizing our economic, environmental and social aspirations puts NEPA and CEQ at the forefront of our nation's efforts to protect the environment. NEPA advanced an interdisciplinary approach to federal project planning and decision-making through environmental impact assessment. This approach requires federal officials to consider environmental values alongside the technical and economic considerations that are inherent factors in federal decision-making. They also require agencies to create their own NEPA implementing procedures. These procedures must meet the CEQ standard, while reflecting each agency's unique mandate and mission. Consequently, NEPA procedures vary from agency to agency. Further procedural differences may derive from other statutory requirements and the extent to which federal agencies use NEPA analyses to satisfy other review requirements. These include environmental requirements under statutes like the Endangered Species Act and Coastal Zone Management Act, Executive Orders on Environmental Justice, and other federal, state, tribal, and local laws and regulations.

6.4.1.12. National Ocean and Atmospheric Administration

Coastal Zone Management Act (CZMA) of 1972, administered by NOAA, provides for the management of the nation's coastal resources, including the Great Lakes. The National Coastal Zone Management Program works with coastal states and territories to address some of today's most pressing coastal issues, including climate change, ocean planning, and planning for energy facilities and development. The federal consistency component ensures that federal actions with reasonably foreseeable effects on coastal uses and resources must be consistent with the enforceable policies of a state's approved coastal management program. This also applies to federally authorized and funded non-federal actions.

6.4.1.13. Pipeline and Hazardous Materials Administration (PHMSA)

PHMSA is one of ten operating administrations within the U.S. Department of Transportation. PHMSA leads two national safety programs related to transportation. It is responsible for identifying and evaluating safety risks, developing and enforcing standards for transporting hazardous materials and for the design, construction, operations, and maintenance of pipelines carrying natural gas or hazardous liquids. PHMSA is also responsible for educating shippers, carriers, state partners and the public, as well as investigating hazmat and pipeline incidents and failures, reviewing oil spill response plans, conducting research, and providing grants to support state pipeline safety programs and improve emergency response to incidents. PHMSA also works with the Federal Aviation Administration (FAA), Federal Railroad Administration (FRA), Federal Motor Carrier Safety Administration (FMCSA), and U.S. Coast Guard to help them administer their hazardous materials safety programs effectively.

6.4.1.14. Federal Energy Regulatory Commission (FERC)

FERC is an independent regulatory agency for transmission and wholesale of electricity and natural gas in interstate commerce and regulates the transportation of oil by pipeline in interstate commerce. FERC also reviews proposals to build interstate natural gas pipelines, natural gas storage projects, and liquefied natural gas (LNG) terminals. FERC also licenses nonfederal hydropower projects and is responsible for protecting the reliability and cyber security of the bulk power system through the establishment and enforcement of mandatory standards.

FERC has comprehensive regulations implementing the National Environmental Policy Act (NEPA) that apply to interstate natural gas pipelines, natural gas storage facilities, and liquefied natural gas facilities. In evaluating applications for new facilities or modifications of existing facilities, FERC will issue an environmental assessment (EA) or environmental impact statement (EIS). If FERC approves the project and the routing, pipeline companies must comply with all environmental conditions that are attached to FERC orders.

6.4.2. Regional, State, and Local

Metropolitan Planning Organizations (MPO) were encouraged to review the safety and security of the regional transportation network, since the enactment of SAFETEA-LU in 2005. FHWA funded and encouraged MPOs across the U.S. to look into ways they can foster considerations of safety and security planning, including resilience efforts in the long-term capital plans that MPOs develop and fund.

For airports, FAA can accept state standards for construction materials and methods. Under certain conditions[5], the use of state dimensional standards that differ from the standards in FAA Advisory Circulars are not acceptable for federally obligated or certificated airports.

Many communities have zoning ordinances, building codes, and fire regulations that may place additional requirements on airport development and operations. For example, if a new hangar or other structure is to be built at an existing airport, approval and/or permits must be received from the local building department or planning authority (e.g., Borough of Lincoln Park, New Jersey has strict storm water management requirements due to high flood hazard potential).

State regulatory agencies oversee the ports, harbors, and waterways industry/infrastructure for methods of design and construction. Using New York as an example, the New York Department of State (NYSDOS) [6] regulates water under "Coastal Consistency Concurrence" permit. Coastal Zone Management Federal Consistency is a process that requires federal agencies to follow State coastal management policies when conducting a project or issuing a permit that could affect coastal resources. It also enables increased coordination between government agencies. The Department of State provides both technical assistance and grant funding to waterfront communities to facilitate disaster resilience.

6.5. Standards and Codes

Codes and standards are used by the transportation industry to establish the minimum acceptable criteria for design and construction. To maintain adequate robustness, each state and locality must adopt appropriate codes and standards as a minimum requirement. Although adoption of codes is important, enforcement is a key factor in ensuring compliance of the built environment with codes and standards.

Roads, Bridges, Highways and Road Tunnels. Moving Ahead for Progress in the 21st Century (MAP-21) is a bill signed into law by FHWA in July, 2012. MAP-21 makes funds available for studies of climate change vulnerability, to improve the dissemination of research products, and to accelerate deployment of new technologies and ensure existing programs are kept intact. Authorization is given to create programs granting financial awards for transportation research. MAP-21 requires the USDOT to create a bureau of transportation statistics that will oversee a national transportation library, an advisory council on statistics, and a national electronic atlas database. Although climate change statistics are not specified, this act at the very least, gives the option for a centralized data center useful for transportation agencies gaining access to climate information and using this information for the development of codes and standards.

AASHTO is a standards-setting body that publishes specifications, test protocols, and guidelines used in highway and bridge design and construction throughout the United States. AASHTO specifications for design of bridges consider waterfront effects, since bridges often span waterways. Hence, the provisions of these specifications are often used in the design of similar waterfront structures.

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[5] Applies to airports with 10,000 passengers or less boarding per year and runways 5,000 feet or shorter, serving aircraft of 60,000 pounds gross weight and under, and standards not related to the safety of airport approaches or airport geometric standards. Reference AC 150/5100-13, Development of State Standards for Nonprimary Airports.

Rail. The American Railway Engineering and Maintenance-of-Way Association (AREMA) authors a Manual for Railway Engineering (MRE) and a Communications and Signals Manual, among other guides. The MRE is updated annually with new design standards for fixed railway. Chapter 13 covers environmental aspects including water, air quality, and waste management and sites environmental acts pertaining to regulations. For example, Section 404 of the Clean Water Act discusses the regulatory limit for tidal waters and states that a project including placement of fill material within a body of water between ordinary high water marks requires a Section 404 permit from the USACE (see 6.4.1.6). Additionally, Section 401 of the CWA pertains to water quality certifications and provides a statutory basis for federally-designated states to regulate their state's water quality. This flexibility of state-issued certification allows for a more tailored response to disaster resilience needs. For example, Section 401 regulatory limit for tidal waters extends to the mean high water limit, which is influenced by changing sea levels.

The American Society of Civil Engineers, ASCE, is a professional body representing members of the civil engineering profession worldwide. The following standards, published by ASCE are of interest to facilities with a risk of natural hazards. These standards do not include specific reference to adaptation/resilience policies.

- ASCE 24 Flood Resistant Design and Construction: This standard is also referenced by the International Building Code, with any building or structure proposed to be located in a flood hazard area is to be designed in accordance with ASCE 24. Also, the International Residential Code (IRC) allows homes in coastal high hazard areas to be designed in accordance with ASCE 24, as an alternative to the prescriptive requirements therein. [**12**]
- ASCE 7 Minimum Design Loads for Buildings and Other Structures: This standard is referenced by the International Building Code (IBC). It includes the consideration and calculation of flood loads.[**13**]
- ASCE 61 Seismic Design Standard for Piers and Wharves: This defines a displacement-based design method to establish guidelines for piers and wharves to withstand the effects of earthquakes.[**14**]

The American Concrete Institute, ACI, is a leading authority and resource for the development and distribution of consensus-based standards for individuals and organizations involved in concrete design, construction, and materials. The ACI codes typically used where the flood risk is greatest are:

- ACI 318 Building Code Requirements for Structural Concrete and Commentary: This covers the materials, design, and construction of structural concrete used in buildings and where applicable in non-building structures. The code also covers the strength evaluation of existing concrete structures.
- ACI 350 Code Requirements for Environmental Engineering Concrete Structures: This code provides design requirements more stringent than ACI 318 for concrete structures intended to contain highly corrosive liquids used for environmental engineering. Waterfront structures exposed to aggressive saltwater environments are often designed to meet these more exacting standards.
- ACI 357.3R Guide for Design and Construction of Waterfront and Coastal Concrete Marine Structures: This is a relatively new guide, covering durability and serviceability of concrete waterfront structures, as well as analysis techniques and design methodologies unique to them.

The American Institute of Steel Construction's (AISC) mission is to provide specification and code development, research, education, technical assistance, quality certification, standardization, and market development for steel construction. Most building codes reference American National Standards Institute (ANSI)/AISC standard 360, Specification for Structural Steel Buildings.

Air. The FAA regulates commercial service airports under 14 CFR Part 139, Certification of Airports. This regulation prescribes rules governing the certification and operation of airports in any state of the United States, the District of Columbia, or any territory or possession of the United States that serve scheduled or unscheduled passenger service. Advisory Circulars (ACs) contain methods and procedures that certificate holders use to comply with the requirements of Part 139.

FAA's AC 150/5200-31C, Airport Emergency Plan, provides guidance to the airport operator in the development and implementation of an Airport Emergency Plan (AEP) that should address essential actions in the event of possible emergencies, including natural disasters. The guidance includes mitigation, such as zoning and earthquake-resistant construction, as an important phase of comprehensive emergency management.

Ports, Harbors, and Waterways. Codes and standards are used by the ports, harbors and waterways to establish minimum acceptable criteria for design and construction. To mandate adequate robustness, each jurisdiction adopts appropriate codes and standards to set these minimum requirements. Climate change adaptation would be in the form of local regulations, independent of the codes and standards selected. These regulations would be similar for a project, such as a pier or bulkhead, whether it is proposed as part of development of upland property or to protect upland property from sea level rise for an extended period. Therefore, the application of regulations to maritime infrastructure would be similar to those developments mentioned above. In the purpose and need statement for a proposed project, the basis of design should state the standards and codes used, and the regulations and guidelines followed; that part of the justification for the project includes risk for natural hazard, if appropriate.

The World Association for Waterborne Transport Infrastructure, PIANC, provides expert guidance, recommendations and technical advice for design, development, and maintenance of ports, waterways and coastal areas. Two guidelines of frequent interest in port design are:

- Seismic Guidelines for Port Construction
- Guidelines for the Design of Fender Systems

The following organizations provide codes, standards, and guidelines commonly used in maritime infrastructure design and construction:

- American Association of State Highway Officials (AASHTO)
- Permanent International Association of Navigation Congress PIANC 2002
- American Society of Civil Engineers (ASCE)
- American Concrete Institute (ACI)
- USA Department of Defense (DoD)
- U.S. Army Corps of Engineers (USACE)
- American Institute of Steel Construction (AISC)
- British Standards Institution (BSI)
- Overseas Coastal Area Development Institute of Japan (OCDI).

The DoD initiated the Unified Facilities Criteria (UFC) program to unify all technical criteria and standards pertaining to planning, design, and construction, which was previously issued by individual Defense agencies. The following UFC documents are often used for waterfront design – none specifically refer to adaptation/resilience policies.

- UFC 4-150-06 Military Harbors and Coastal Facilities
- UFC 4-151-10 General Criteria for Waterfront Construction
- UFC 4-150-01 Design: Piers and Wharves
- UFC 4-152-07N Design: Small Craft Berthing Facilities

- UFC 4-159-03 Design: Mooring

The USACE published an extensive library of Engineering Manuals covering the design of a variety of major civil works. The manuals typically used for waterfront design include the following – none of which specifically incorporate adaptation policies regarding resilience. **[18]**

- EM 1110-2-2502 Retaining and Flood Walls
- EM 1110-2-2602 Planning and Design of Navigation Locks
- EM 1110-2-2504 Design of Sheet Pile Walls
- EM 1110-2-2503 Design of Sheet Pile Cellular Structural Cofferdams and Retaining Structures
- EM-1110-2-1614 Design of Coastal Revetments Seawalls and Bulkheads
- EM-1110-2-1100 Coastal Engineering Manual

The standards from this institution used for waterfront construction are contained in the following parts of BSI 6349, Maritime Structures.

- Part 1: General Criteria
- Part 1-4: Materials
- Part 2: Design of Quay Walls, Jetties and Dolphins
- Part 3: Design of Shipyards and Sea Locks
- Part 4: Code of Practice for Design of Fendering and Mooring Systems
- Part 8: Design of RO/RO Ramps, Linkspans and Walkways

Pipelines. The nation's pipeline safety programs are overseen by Congress and administered by PHMSA. However, PHMSA delegates the majority of these responsibilities for intrastate (generally the gathering and distribution pipelines) lines to the states. PHMSA retains the role as primary safety inspector for interstate pipelines (generally, the transmission pipelines), except in 11 states (Arizona, California, Connecticut, Iowa, Michigan, Minnesota, New York, Ohio, Washington, Virginia and West Virginia). State pipeline safety personnel represent more than 75% of the state/federal inspection workforce, although state employees account for less than 40% of the federal pipeline safety budget. This means that the bulk of the safety and inspection responsibility lies at the state level. Under existing law, states opt into this relationship with PHMSA. If a state decides not to participate, PHMSA does the safety inspection on its own. At present, this applies only to Alaska and Hawaii.

All state programs must certify to DOT that they will adopt regulations that are as stringent as the Federal Pipeline Safety Regulations. States are allowed to adopt pipeline safety regulations that are stricter than federal government regulations and the overwhelming majority of states do have more stringent requirements. State regulations were developed over the years based on specific results of state inspections, changing public priorities, and increased safety expectations of the local public. A 2013 report issued by the National Association of Pipeline Safety Representatives (NAPSR), with assistance and support from the National Association of Regulatory Utility Commissioners (NARUC), found that most states have adopted pipeline safety regulations more stringent than the federal regulations. The report also contains a compendium of state regulations and identifies those that exceed federal requirements. (NASPSR, 2013).

PHMSA has separate safety and design standards for natural gas and liquids pipelines (49 CFR Part 192 for natural gas and 49 CFR Part 195 for liquids). The regulations also provide guidance for proper management and operation of these pipelines. PHMSA employees also participate in more than 25 national voluntary consensus standards-setting organizations that address pipeline design, construction, maintenance, inspection, and repair. PHMSA then reviews and approves standards for incorporation by reference into its regulations. PHMSA currently incorporates by reference all or parts of more than 60 voluntary standards and specifications developed and published by technical organizations, including consensus engineering standards from the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), the American Gas Association, the National Fire Protection Association, and the American Society for Testing and Materials. For example, ASME Standard B31.8S establishes risk assessment practices for identifying pipelines (primarily older pipelines) that could possibly be susceptible to material and construction-related integrity concerns. In addition, many agencies – federal, state and local – share responsibility for developing and enforcing other codes and standards applicable to pipeline infrastructure, such as erosion control requirements, noise ordinances, and building codes.

6.5.1. New Construction

Current federal and state project development guidelines require an environmental study at the early stages of transportation projects to identify potential environmental impacts and identify state and federal permitting requirements. The study must provide a sufficient level of understanding of the projected alignment of the facility to enable engineers and planners to identify likely impacts. If federal funding is to be used for the project, it will be subject to environmental review under the National Environmental Policy Act (NEPA). Projects go through a scoping process to establish general parameters of the work and the potential for impact. The scoping process leads to a Class of Action determination establishing whether the project is Categorically Exempt from NEPA review, or will need either an Environmental Assessment (EA) or the highest level of review, which is an Environmental Impact Statement (EIS).

Roads, Bridges, Highways and Road Tunnels. The interstate roads, bridges, highways, road tunnels system, and virtually all other state and local roadways and bridges in the United States are owned and operated by the public sector. Toll roads are typically owned and operated by public/private partnerships, but are subject to the same federal and state design standards issued primarily by FHWA and state Departments of Transportation. The state DOTs establish standards within the framework of the American Association of State Highway and Transportation Officials (AASHTO). AASHTO's most recent bridge design manual, the Load Factor and Resistance Design (LFRD) Bridge Design Specifications, incorporates a risk factor into load bearing calculations. This includes effects due to deflection, cracking, fatigue, flexure, shear, torsion, buckling, settlement, bearing, and sliding. Effects of climate change are able to influence the uncertainty variables in the load equation (Myers).

After Hurricane Katrina, FHWA began recommending a design standard for major interstate structures to consider a combination of wave and surge effects, as well as the likelihood of pressure scour during an overtopping event. Additionally, FHWA recommended that a flood frequency surge and wave action (500-year storm) be considered. (Myers). Some of the codes, standards, and guidelines for surface transportation are shown in Table 6-8.

Table 6-8: Surface Transport Codes, Standards, or Guidelines

Component	Organization	Codes, Standards or Guideline
General	AASHTO	Roadside Design Guide, 4^{th} Edition, 2011
		A Policy on Geometric Design of Highways and Streets, 6^{th} Edition, 2011
General	AASHTO	LRFD Bridge Design Specifications, 7^{th} Edition, 2014
		AASHTO Highway Drainage Guidelines, 2007
	FHWA	Guide for Design of Pavement Structures, 4^{th} Edition, 1998
		Design Standards Interstate System
		Highways in the Coastal Environment, 2^{nd} Edition, June 2008
		A Policy on Design Standards – Interstate Systems, January 2005
Specific to Severe Weather/Hazards	AASHTO	Guide Specifications for Bridges Vulnerable to Coastal Storms (2008)
		Transportation Asset Management Guide, January 2011
		Integrating Extreme Weather Risk into Transportation Asset Management
	NCHRP	Climate Change, Extreme Weather Events, and the Highway System
	FHWA	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure, The Gulf Coast Study, Phase 2, Task 3.2 (Aug 2014)
	United States DOT	2014 DOT Climate Adaptation Plan
	U.S. Global Change Research Program	National Climate Assessment

Rail. The rail network in the United States is primarily owned and operated by the private sector. The few exceptions are in densely developed urban corridors where Amtrak and public transit agencies operate over the privately owned freight lines under trackage rights. In some areas, such as the Northeast Corridor and cities with commuter rail service the tracks and other infrastructure may be owned and maintained by Amtrak, the regional transit authority, or its contract operator. In the railroad industry, AREMA establishes and updates design standards for track, structures, and facilities. Operating standards in the rail industry pertaining to safety are under the jurisdiction of FRA. Additionally, the industry trade organization AAR has a role in the development of operating standards and policies pertaining to railroad operations. Some of the codes, standards, and guidelines for rail are shown in Table 6-9.

Table 6-9: Rail Surface Transport Codes, Standards, or Guidelines

Component	Organization	Codes, Standards or Guideline
General	AREMA	Manual for Railway Engineering, 2014
		Communications and Signal Manual, 2014
		Portfolio of Track Work Plans
General	AREMA	Practical Guide to Railway Engineering
		Bridge Inspection Handbook
		Design of Modern Steel Railway Bridges
	AAR	Guide for Design of Pavement Structures
General	AAR	Design Standards Interstate System
		A Policy on Design Standards – Interstate Systems
Specific to Climate Change	AREMA	None identified
	AAR	None identified
	United States DOT	2014 DOT Climate Adaptation Plan
	U.S. Global Change Research Program	National Climate Assessment

Ports. As stated elsewhere in this document, new maritime construction needs to follow the local codes and standards for design and construction. Climate change impacts are usually incorporated by local authorities by utilizing the guidance documents issued by various local and federal authorities (such as USACE, IPCC). For example, the City of New York adopted specific guidelines in regards to climate change through an authorized panel, New York Panel on Climate Change (NPCC).

The following return periods from current industry standards can serve as a starting point to guide an agency towards a comfortable level of risk for current and projected scenarios. A return period or recurrence interval is an estimate of the likelihood of an event, such as a flood, to occur.

- Wind on facilities (ASCE-7): Varies depending on occupancy category – up to 1700 year return
- Coastal Flooding (USACE): 50 year return
- Inland Flooding (AASHTO): 100 year return plus a percentage depending on agency
- Inland Flooding for other facilities (ASCE-7): 100-year return

Pipelines. New pipelines are subject to current federal and state design and safety guidelines. Liquids pipelines and intrastate natural gas pipelines are regulated at the state level; therefore, regulations and risk evaluations for assessment of hazards will vary depending on location.

The failure modes discussed in this chapter may represent key vulnerabilities in the codes that are exposed during hazard events. Table 6-10 presents a summary of the methods of transportation used, whether they are used for public or private transportation, and the oversight authorities involved in their regulation.

Table 6-10: Transportation Infrastructure Code and Standards Governing Agencies

Industry	Infrastructure	Type	Method of Transportation	Public	Private	Oversight Authority													
						DHS	FEMA	NTSB	USDOT	FRA	FTA	TSA	FMCSA	FHWA	USCG	EPA	FAA	1+ state agencies
Surface Transport	Rail	Passenger	Inter-City Rail (Amtrak)	X		X	X	X	X	X		X						X
			Commuter Rail	X		X	X	X	X	X	X	X	X					X
			Subway	X		X	X	X	X		X	X						X
			Light Rail	X		X	X	X	X		X	X						X
			Inclined Plane	X		X	X	X	X		X	X						X
			Trolley/Cable Car	X		X	X	X	X		X	X						X
		Freight	Class 1 Freight Carriers		X	X	X	X	X	X		X						X
	Roads, Bridges and Tunnels	Passenger	Inter-City Motor coach	X	X	X	X	X	X			X	X	X				X
			Intra-City Bus/Motor coach	X	X	X	X	X	X		X	X	X	X				X
			Paratransit/Jitneys	X	X	X	X	X	X		X	X	X	X				X
			Taxis	X	X	X	X	X	X			X	X	X				X
			Personal Cars		X				X									X
		Freight	Commercial Trucking		X	X		X	X		X	X	X	X				X
	Maritime	Passenger	Ocean Lines		X			X	X			X			X	X		X
			Ferries	X		X	X	X	X		X	X		X	X	X		X
			Commercial Boats		X			X	X			X			X	X		X
			Personal Boats		X			X	X			X			X	X		X
		Freight	Freighters		X	X	X	X	X			X			X	X		X
			Barges		X	X	X	X	X			X			X	X		X
Air	Air	Passenger	Commercial Airplanes		X			X	X			X				X	X	X
			Blimps		X			X	X			X				X	X	X
			Drones	X	X			X	X			X				X	X	X
		Freight	Commercial Air Freight		X			X	X			X				X	X	X

6.5.1.1. Implied or stated Performance Levels for Expected Hazard Levels

When defining standards for hazards for roads, bridges, highways, and road tunnels, federal regulations tend to use general language for performance levels. For example, when describing Drainage Channels, the AASHTO Roadside Design Guide states that “channels should be designed to carry the design runoff and to accommodate excessive storm water with minimal highway flooding or damage.” No specific levels are mentioned, leaving specific implementation up to state regulations and engineering judgment.

Although federal documentation does not give specifics on hazard mitigation levels for the entire country, it often gives guidance on how more locally-based regulation should be formed. For example, in Highways in the Coastal Environment, the FHWA gives three approaches for determining site-specific design water levels. These consist of 1) use of available analyses, 2) historical analysis, and 3) numerical simulations with historic inputs. These are only general guidelines, but they apply to all regions of the country and ensure the process is data driven.

AREMA provides more specific regulations than AASHTO in regards to hazard levels, but still leaves room for site-specific engineering. To continue the draining example, the Manual for Railway Engineering states that, “typically, the 100-year base flood elevation is the most commonly regulated storm water elevation associated with rivers, streams and concentrated flow areas.” It goes on to describe how, “any change to the flood plain will generally result in extensive studies and computer modeling to be submitted for approval.” Again, these regulations are not specific numeric regulations, but a guidance that ensures proper steps are taken by the appropriate agency to mitigate risk.

The National Cooperative Highway Research Program conducted a study on climate change adaptation strategies in 2013 that provided some specific examples of dealing with increasing severity of weather events. For example, precipitation events may consider estimating second -order recurrence intervals (if two 100-year storms happened in two consecutive years) and updating variables accordingly in the Clausius-Clapeyron relationship for relative precipitation increases (NCHRP 2013).

The Advisory Circulars (AC) define design criteria for most details of an ***airport’s*** facilities – runway/taxiways, terminal buildings, lighting, and navigational aids. These documents define standard criteria for construction, but do not specifically address climate extreme weather events beyond potentially constructing drainage for a 50-year storm. The following is a subset of the available Acs.

- AC 150/5300-13A, Airport Design (9/28/12)
- AC 150/5370-10G, Standards for Specifying Construction of Airports (7/21/14)
- AC 150/5340/30H, Design and Installation Details for Airport Visual Aids (7/21/14)
- AC 150/5320-5D, Airport Drainage Design (8/15/13)
- AC 150/5345-53D, Airport Lighting Equipment Certification Program (9/26/12)
- AC 150/5345-28G, Precision Approach Path Indicator (PAPI) Systems (9/29/11)
- AC 150/5320-6E, Airport Pavement Design and Evaluation (9/30/09)
- AC 150/5200-30C, Airport Winter Safety and Operations (12/9/08)
- AC 150/5345-46D, Specification for Runway and Taxiway Light Fixtures (5/19/09)
- AC 150/5360-13, Planning and Design Guidelines for Airport Terminals and Facilities (4/22/88)

Performance levels addressed include a recommended 5-year storm event be used with no encroachment of runoff on taxiway and runway pavements when designing storm water drainage (including paved shoulders). Airport pavements should provide a skid-resistant surface that will provide good traction during any weather conditions (with provisions for frost and permafrost). And, airport terminal buildings should be structurally designed to appropriate seismic standards (Executive Order 12699, Seismic Safety of Federally Assisted or Regulated New Building Construction, January 5, 1990).

State and local legislative bodies are not obligated to adopt model building codes and may write their own code or portions of a code. A model code does not have legal standing until it is adopted as law by a legislative body (state legislature, county board, city council, etc.). When adopted as law, owners of property within the boundaries of the adopting jurisdiction are required to comply with the referred codes.

Because codes are updated regularly, existing structures are traditionally only required to meet the code that was enforced when the property was built unless the building undergoes reconstruction, rehabilitation, alteration, or if the occupancy of the existing building changes. In that case, provisions are included in the code to require partial to full compliance depending on the extent of construction. [ASCE Policy Statement 525 – Model Building Codes]. For example, New York City Building code describes the requirement for flood-resistant construction, referencing FEMA flood maps and ASCE 24 for "dry flood-proofing." The Design Flood Elevation for certain structures, such as terminals, air traffic control towers, and electrical substations, is the 100-year floodplain plus one-foot.

Except for wind and seismic loading, rail codes do not provide specifics regarding natural hazards (e.g., the codes may stipulate various flood levels for which a structure may need to be designed, but they will not specifically set what that level is). Rather, they set event-based criteria, e.g., 50 or 100-year event. Similarly for wave loads, various codes (e.g., USACE Coastal Engineering Manual) may advise that waves should be considered, but it's usually up to the design professional to determine what wave characteristics should be considered.

Each agency's tolerance for risk (note that risk tolerance could include interests beyond an agency's immediate jurisdiction particularly if other utilities within the asset right of way, such as water, sewer, or electrical may be impacted). An agency with a higher risk tolerance would plan for less extreme changes. An agency with a lower risk tolerance could be expected to plan for more extreme change.

Interstate natural gas infrastructure is regulated by FERC, which is responsible for compliance with NEPA. The NEPA document will address potential impacts of climate change: impacts resulting from the project and impacts on the project. As stated previously, impacts on pipelines are generally limited because they are buried, but aboveground facilities such as compressor stations could be affected by storm-related incidents. Input from state and local governments is a key component of the review process at FERC. Local knowledge of environmental conditions and concerns about inter-relationships with other critical infrastructure should be identified to FERC at the earliest point in any project review. For example, there may be resiliency and reliability concerns if a new pipeline's proposed route would be adjacent to a critical electric transmission line.

6.5.1.2. Recovery Levels

For roadway and rail transportation, no specific requirements were identified in codes or standards. However, at state and local levels there may be operational goals or performance standards. For example, a state may issue a severe weather warning, mandating that all drivers remain home until authorities deem roads are safe enough to be traveled. Similarly for rail, administrative and inspection personnel decide when a system is safe to operate.

There is minimal description of required recovery levels for extreme events for airports. Language for storm water drainage requires surface runoff from the selected design storm be disposed of without damage to facilities, undue saturation of the subsoil, or significant interruption of normal traffic. "The drainage system will have the maximum reliability of operation practicable under all conditions, with due consideration given to abnormal requirements, such as debris and annual periods of snowmelt and ice jam breakup."

Marine infrastructure is critical to the transportation industry (commercial, public, and private) and the full recovery will be necessary for proper functionality. However, no specific guidance or performance levels were identified.

6.5.2. Existing Construction

The design of transportation systems has been refined over time; however, incorporating resiliency into the design is a relatively new concept. For existing transportation systems, they are bound by the codes and standards for which they were initially designed. Typically, transportation infrastructure is not required to meet the new codes as they develop. As the codes and standards incorporate resiliency, a significant portion of transportation system will not be covered under these new more restrictive codes and standards.

For rail and roadways, documented codes or standards have not been identified specifically for existing construction.

Airport codes and standards do not address retrofitting existing construction to adjust for climate change or extreme weather events. Several advisory circulars outline procedures for maintaining existing facilities only.

- AC 150/5380-6C, Guidelines and Procedures for Maintenance of Airport Pavements (10/10/14)
- AC 150/5380-7B, Airport Pavement Management Program (PMP) (10/10/14)
- AC 150/5340-26C, Maintenance of Airport Visual Aid Facilities (6/20/14)
- AC 150/5200-33, Hazardous Wildlife Attractants on or Near Airports

In relation to Prevailing Design Standards for the maritime industry, only sections of the local or national codes and standards that govern design of the component would be required. Information collected will allow for the assessment of the existing asset to determine if it adheres to current design standards. This will assist in determining vulnerabilities and the selection and prioritization of adaptation strategies for the marine infrastructure in question.

Reviewing existing design codes and standards will guide the engineer to determine the design parameters required to perform a check of the condition of the marine infrastructure. Using the selected code or design standards and the parameter values to perform an engineering calculation to determine if the asset satisfies the requirements. The degree to which the component is affected by the stressor will serve to assist in determining appropriate adaptation strategies.

Figure 6-11 illustrates a comparison of transportation timeframes against the climate impacts. According to Moritz (2012), infrastructure planned and built with past climate and weather in mind may not be adequate for future resilience and operation. Hence, there is a strong need to re-consider or adopt the long-range transportation planning process.

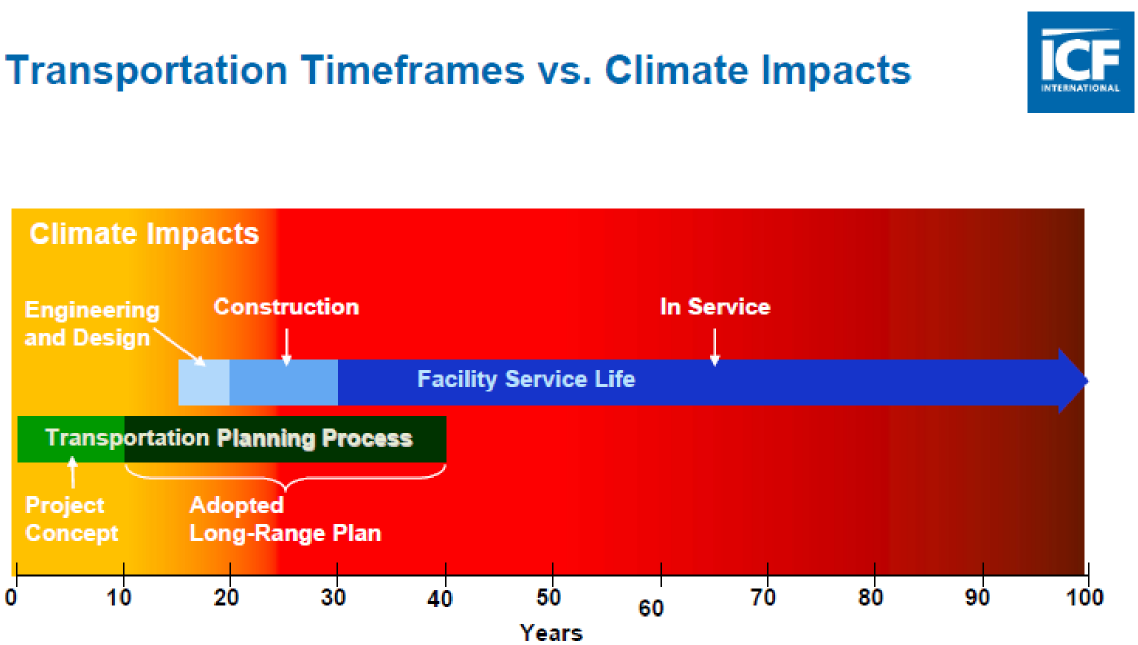

Figure 6-11: Procedures to Evaluate Sea Level Change Impacts, Responses, and Adaptation Corps of Engineers' Approach, Naval Facilities Engineering Command Port Hueneme, CA 24 October 2012

6.5.2.1. Implied or stated Performance Levels for Expected Hazard Levels

The performance levels for new/future and existing transportation infrastructure are anticipated to be the same. Therefore, the reader is referred to the previous discussion in Section 6.5.1.1.

6.5.2.2. Recovery Levels

Since the performance levels anticipated for new/future and existing construction are the same, the recovery levels are also anticipated to be similar. The reader is referred to the previous discussion in Section 6.5.1.2.

6.6. Strategies for Implementing Community Resilience Plans

6.6.1. Available Guidance

Section 6.2 describes the various components of the transportation systems and case studies of where these systems may have failed in the past. The performance of the transportation system is highly dependent on the age of the system, the type of natural hazard, the standard to which it was designed, and the basic decisions made immediately before and after the hazard event. Current engineering standards and guidelines provide tools to assess the performance of bridges and roadways, such as the (AASHTO) *Manual for Bridge Evaluation.* Similar standards exist for other transportation nodes, such as airports, rail, subways, etc.

AASHTO's Transportation Asset Management Guide applies to both roads and rail, as it encourages agencies to include operations and maintenance into state and local resource management programs. This includes considering life-cycle planning, including frequency of maintenance and repair based on weather conditions. The guide asks, "What allowance should be made for climate change when designing a new asset or facility with a long life? For example, should expanded storm water drainage capacity be provided, should route planning decisions consider the risks of sea level changes in coastal areas?" The guide goes on to recommend processes and tools for life cycle management, incorporating effects due to climate change. In addition to processes, it is necessary to continue to monitor the assets to continually improve the model's forecasting.

ISO 31000:2009, *Risk management – Principles and guidelines*, provides principles, a framework, and a process for managing risk. It can be used by any organization regardless of its size, activity, or sector. Using ISO 31000 can help organizations increase the likelihood of achieving objectives, improve the identification of opportunities and threats, and effectively allocate and use resources for risk treatment. ISO 31000 cannot be used for certification purposes, but does provide guidance for internal or external audit programs. Organizations using it can compare their risk management practices with an internationally-recognized benchmark, providing sound principles for effective management and corporate governance. The guidelines for establishment of sound risk assessment programs can be applied to the development of resilience assessment and mitigation (http://www.iso.org/iso/home/standards/iso31000.htm).

FAA issued a memorandum titled "Considering Greenhouse Gases and Climate Under the National Environmental Policy Act (NEPA): Interim Guidance" (January 12, 2012). The memo indicates that an estimate of GHG emissions can serve as a "reasonable proxy for assessing potential climate change impacts" and provide information for decision-making. The amount of carbon dioxide and/or fuel burn from aircraft operations should be calculated for FAA NEPA evaluations. Consideration should be given to reducing GHG emissions as a part of the project; however, reduction is not mandated. The memo does not reference assessing vulnerability to extreme weather as a result of climate change.[6] FAA's AC

[6] CEQ recently issued the "Draft Guidance on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change" (December 2014), which suggests agencies focus quantitative greenhouse gas analysis on the projects and actions with 25,000 metric tons of CO2-equivalent emissions on an annual basis or more, and counsels

150/5200-31C, Airport Emergency Plan, provides guidance on conducting a hazard/risk analysis to help determine what hazards exist and how to address them. In addition, the scope of work for FAA's Airport Sustainable Master Plan Pilot Program included a baseline inventory or assessment of each defined sustainability category (which will vary by airport), establishment of measurable goals, and development of specific sustainability initiatives to help the airport achieve each goal.

Several of the larger airport authorities, such as Port Authority of New York and New Jersey (PANYNJ), Los Angeles World Airports (LAWA) and Philadelphia International Airport, have established assessment methodologies, either alone or as part of larger citywide or regional efforts. PANYNJ became involved in a climate change assessment led by New York City's Long-Term Planning and Sustainability Office, which was conducted between August 2008 and March 2010. The team was called the Climate Change Adaptation Task Force, and its work was part of a comprehensive sustainability plan for New York City called PlanNYC. The assessment process comprised six major tasks: defining the climate change variables and projections, developing asset inventories, assessing vulnerabilities, analyzing risks, prioritizing the assets, and developing adaptation strategies.

The Greater Toronto Airports Authority (GTAA) uses the PIEVC (Public Infrastructure Engineering Vulnerability Committee) Protocol from Engineers Canada to assess risk and identify preliminary needs (such as storm water facilities).

The ASCE and Coasts, Oceans Ports and Rivers Institute (COPRI) established special committees on climate change to identify, gather, and organize information on potential infrastructure impacts due to climate change; to develop partnerships and collaborations of relevant and interested committees and organizations for responsible understanding and planning of potential climate change impacts; to develop strategies and recommendations addressing climate change impacts [**22**]. The Sea Level Change Committee provides a more systematic approach to estimating and including sea level change in marine/coastal projects. [**23**]

6.6.2. Strategies for New/Future Construction

The Canadian Council of Professional Engineers developed a risk based vulnerability assessment framework to evaluate climate change risks in building, roadway asset, stormwater–wastewater systems, and water resource management infrastructures. The protocol involves project definition, data gathering and sufficiency, risk assessment, engineering analysis, and recommendations. It covers the categories of buildings, roads and associated structures, stormwater/wastewater, and water resource systems (PIEVC 2009).

In the United Kingdom, the Highway Agency has a Climate Change Adaptation Strategy and framework that addresses specific climate risks for highway infrastructure and agency practices (UK, 2009). Transport Asset Management Plans (TMAPs) are mandatory in the UK, and some incorporate specific sections on climate change (Myers).

Transit New Zealand has incorporated climate change into its asset management inventory. Standards for assets have the ability to change with newly developed climate change predictions. An economic analysis shows that existing assets with a lifespan of 25 years or less did not require changes in design or maintenance, but new construction can be modified as needed. Additionally, Transit NZ modified its bridge manual, including a new design factor for climate change (Myers).

Rail. The FTA advocates for designs including larger drainage capacity, stronger structures to withstand winds, and materials suited for higher temperatures. For subway systems, flooding is a primary climate change affected concern. Potential strategies include requiring flood gates, high elevation entrances, and

agencies to use the information developed during the NEPA review to consider alternatives that are more resilient to the effects of a changing climate.

closable ventilation gates (requiring new fan-driven ventilation). A FEMA-commissioned study determined that that flood protection savings are, on average, four times greater than prevention costs.

Localized flooding for transit and other transportation facilities can be prevented by establishing proper stormwater management. Best practices include rain gardens, stormwater ponds, increased vegetation, green roofs, rain barrels, and pervious pavements. These allow stormwater to be absorbed through natural processes, reducing, or preventing flooding altogether (FTA 2011).

Port Authority of NY and NJ, PANYNJ, has an organization-wide "Sustainable Infrastructure Guidelines" that is implemented for projects including terminal building construction, building demolition, electronics systems, communications systems, airfield construction or rehabilitation, and landscaping. The guidelines require the protection of the ecological health of wetlands, floodplains, and riparian buffers, protection and maintenance of absorbent landscapes, mitigation of the heat island effect, and implementation of stormwater best management practice strategies, implementation of sustainable landscape maintenance. LAWA's Sustainable Airport Planning, Design, and Construction Guidelines are similar, identifying many technical approaches to climate change adaptation planning such as increasing the capacity of stormwater conveyance and storage (e.g., design for 100-year and 500-year storms) and utilizing heat-resistant paving materials.

New buildings, particularly those adjacent to coastal resources or within a floodplain, should implement flood hazard mitigation as part of the design. PANYNJ sets forth an elevation of 18 inches higher than the current code requirements, based on an anticipated increase of the mean sea level, for the lowest floor of buildings to be considered for all project elements. If that is not feasible, then the standard should at least be met for all critical project elements (electrical equipment, communications, etc.).

San Diego International Airport has incorporated low impact development strategies (e.g., pervious pavement, infiltration storage chambers, bio-retention swales, modular wetlands, riprap energy dissipater) into their north side improvements in order to reduce flooding risks.

The American Society of Civil Engineers (ASCE) issued a series of policy statements (a list is provided at the end of this document for those relevant to this study) defining the Societies role in the industry by supporting the sustainable and resilient reconstruction of affected areas devastated by accidental, intentional and/or natural disaster events. Collaboration with ASCE and its technical Institutes would promote development of national codes and standards for the changing world.

ASCE specifically supports the following activities:

- *Redesign and reconstruction of disaster protection systems for affected communities at a level appropriate for protection of the population, critical infrastructure and the environment; and*
- *Reconstruction that incorporates appropriate studies, urban design, application of technology, land use, zoning, and utilization of natural systems to recreate communities that are resilient, sustainable, more livable and less vulnerable to accidental, intentional and/or natural disaster events.*

The challenges include evaluation of the prior conditions and effects caused by the hazard(s) to determine if reconstruction of the affected infrastructure is viable, feasible and beneficial to facilitate the task of protecting life, property, and national critical infrastructure.

To better protect American lives, property, and infrastructure, the affected areas cannot always be rebuilt to match prior conditions. Reconstruction and recovery includes consideration of the existing conditions, which may have facilitated the destruction. It also includes consideration of the principles of sustainability and resilience.

There are many federal, state and local agencies that have been working on strategies for the maritime industry, including USDOT (FHWA) USACE and ASCE. Additional research including a more detailed review of the TRB 2013 report, *Assessment Of The Body Of Knowledge On Incorporating Climate Change Adaptation Measures Into Transportation Projects.*

From a European perspective, resilience or adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise (EU Adaptation Policy).

Adaptation strategies are needed at all levels of administration: at the local, regional, national, EU and also the international level. Due to the varying severity and nature of climate impacts between regions in U.S. and Europe, most climate adaptation initiatives will be taken at the regional or local levels. The ability to cope and adapt also differs across populations, economic sectors and regions within Europe.

6.6.3. Strategies for Existing Construction

The Transportation Research Board, TRB, reviewed operation and maintenance practice to mitigate the effects of future climate change conditions. They cite the example of an airport operator purchasing additional snow removal equipment to minimize operational out-of-service time. Agencies should be prepared for increased extreme weather incidents of all types and obtain the necessary equipment to minimize the operational disruption time (TRB, 2013).

PANYNJ's climate change assessment found that capital investments could take the form of permanent improvements that could include installing new flood barriers, elevating certain elements of critical infrastructure so that they would be above the projected flood elevations, moving entire facilities to higher ground, and designing new assets for quick restoration after an extreme event. Regulatory strategies could include modifying city building codes and design standards.

Key West International Airport in Florida is already vulnerable to hurricanes and sea level rise. They have been retrofitting existing infrastructure, such as installing flapper valves inside drainage structures to avoid standing water on runways and taxiways. In addition, they have had to adapt their wildlife hazard mitigation strategies to handle new animals that are encroaching on the airport as a result of changing habitat. Additional strategies are outlined in the "Monroe County Climate Action Plan" (March 2013).

Climate adaptation strategies in the maritime industry must be applied to existing buildings as well as new building projects. Borrowing from the ICLEI process, the steps below describe how a project team can integrate adaptation strategies to existing buildings and sites. **[24]**

1. Understand regional impacts: Identify climate impacts for the facility's region.
2. Evaluate current operation and maintenance targets: Understand how the maintenance and operations perform under current peak climate conditions.
3. Conduct a scenario analysis: Analyze how the facility will respond to projected climate impacts, modeling different system options under a variety of climatic conditions. Implement adaptation strategies: Install adaptation strategies that provide passive or efficient responses to more extreme climate events in order to maintain occupant comfort while preventing increased energy use.

Similar to the process above, USACE employs a 3 tier process for screening out the projects (Moritz, 2012). Tier 1 Establish Strategic Decision Context, Tier 2 involves Project Area Vulnerability and Tier 3 for Alternative Development, Evaluation, and Adaptability. Future storm tides will reach higher elevations than past storms and will do so more frequently impacting both flooding and structural loading.

- As part of the Tier 2 process, structural loading and processes needs to be evaluated from technical perfective:
- Natural variability of loading factors
- Tidal and wave height range
- Local sea level change rate

- Extreme lows and highs
- Frequency of events
- Key project processes
- Short and Long-term erosion/recession
- Rate of change of exposure
- Cumulative impacts with other climate or natural Drivers
- Example of Inventory & Forecast Qualitative Matrix (describes study area's and parallel system's susceptibility to sea level change (Moritz, 2012)

Table 6-11: Risks from Sea Level Rise

Critical Resources in Study Area	Density of Resource (3=high, 2=medium, 1=low, X=none)	Relevance	Risk from Sea Level Rise (3=high,2=medium, l=low, X=none present)
Length and type of primary federal navigation	3	The length and type of navigation structure will determine stability and maintenance impacts.(age, last maintained)	3
Length and type of secondary federal navigation structures (groins, spur jetties,dikes, etc.)	2	The length and type of navigation structure will determine stability and maintenance impacts.(age, last maintained)	2
Length and type of federal shoreline protection structures	1	The length and type of shoreline protection structure will determine stability and maintenance impacts. (age, last maintained)	2
Channel length and authorized depth, mooring areas and basins	3	SLR may impact this favorably; SLF may require adjustments to authorized lengths and depths. Harbor and entrance resonance and performance issues may arise. (length, area)	1
Dredged material management sites	1	DMMP sites may become more or less dispersive and/or have changes in capacity. (number, area)	1
Port facilities- bulkheads, wharves, docks, piers	3	Performance of existing federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts. (length, type, seasons of use)	3
Commercial Infrastructure	3	Performance of existing federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts. (type, value)	2
Transportation infrastructure	2	Impacts to transportation infrastructure (roads, rail, etc.) can impact benefits realized. (length, type)	2
Utilities, drainage systems, communication	2	Connectivity and support systems may be affected resulting in decreased project benefits.(length, type)	2
Environmental and habitat areas	1	Assessment of any environmental systems in project area. (type, sensitivity)	1

The FTA identifies four categories pertaining to adaptation strategies. They are broad enough that they apply to a range of transportation facilities (FTA 2011):

- ***Maintain and manage*** – adjust budgets for increased maintenance cost and improve severe event response times. Utilize technologies that detect changes such as pressure and temperature in materials as a precaution against structure damage or rising water levels.
- ***Strengthen and protect*** – existing infrastructure should be retrofitted to withstand future climate conditions. Ensure facilities can stand up against high winds and extreme temperatures, and assure flood prevention and adequate drainage.
- ***Enhance redundancy*** – identify system alternatives in the event of service interruption and develop a regional mobility perspective that includes all transportation modes.

- ***Retreat*** – Abandon at risk infrastructure located in vulnerable or indefensible areas. Potentially relocate in a less vulnerable location.

In regards to subways, many strategies have been implemented to combat heavier rains that would otherwise result in flooding. Many cities have increased the number of pumps or pump capacity. New York City has implemented raised ventilation grates to prevent runoff into subway lines. Tokyo ventilation shafts are designed to close when a heavy rain warning is issued, and can be closed by remote control or automatically in response to a flood sensor. The Port Authority of New York and New Jersey raised the floodgates at the top of stairs leading to station platforms to account for sea level rise and sealed all gates below the 100-year floodplain.

For open railway, track buckling results from increased temperatures and are costly to the railroad industry as well as an important derailment safety hazard. Slow orders (mandated speed reductions) are typically issued on sections of track in areas where an elevated rail temperature is expected and risk of track buckling is increased. Replacement track has a higher lateral resistance to combat buckling forces. FRA has created a model for predicting rail temperatures, allowing proper replacement before an incident occurs (FRA 2014).

Increased temperatures also have an effect on electrical equipment, worker exhaustion, and passenger comfort. Increased ventilation and cooling rooms may be required to maintain adequate temperatures for electronics and computers. Workers may need better air conditioning or shorter shifts to combat heat exhaustion. Transit stops and other shelter facilities should be designed with proper shading and ventilation. Heat resistant materials and reflective paints should also be considered (FTA 2011).

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7. Energy Systems

7.1. Introduction

The electricity performance expectations and needs of society have increased dramatically over the past 25 years. In fact, the demand for electricity has increased by over 25% since 1990. However, the aging United States infrastructure is a major issue for all communities. The energy system is making progress in upgrading the existing electric infrastructure with a focused effort to make the system less vulnerable to large catastrophic events. For example, many utility providers are installing smart grid technologies; and grid modernization improvement is a major effort nationwide that is projected to continue for years to come. This translates to a need to upgrade all elements of the energy infrastructure system and build for resiliency. In an effort to build resilient and flexible energy infrastructure there needs to be an understanding and balance of the desired level of resilience, the expected benefits resilience may bring, and the estimated costs associated with improving and replacing this infrastructure.

Electricity and fuel are interdependent, essential, and cross-cutting services for community resilience and reliability. They support society's most basic human needs for food, water, and shelter. In a hazard event, electricity and fuel supply are critical to supporting human life and restoration of service is a critical activity no matter what the cause or where the event occurred. Post-disaster fuel supply is also critical to electricity generation and transportation. Having available fuel is essential for local generators in managing recovery and for emergency service and supply vehicles.

This section discusses the natural gas and liquid fuels subsystems only as they relate to the reliability and resilience of the electric power system. The pipelines needed to transport natural gas and liquid fuels are discussed as part of the Transportation System (Chapter 6) because the engineering standards for pipeline safety and design are administered by the USDOT.

7.1.1. Social Needs and System Performance Goals

The electrical and fuel supply societal needs of the 21st century are much different from what these needs were a century ago. High quality, high availability, inexpensive power has become a basic societal necessity. Even in day-to-day power delivery, utilities struggle to meet these conflicting consumer expectations. Preparing for and responding to hazard events becomes an even larger challenge when utilities need to pay for necessary infrastructure repairs while experiencing revenue losses when electricity delivery is suspended. This difficult challenge requires careful consideration, especially from regulatory authorities, when addressing utility rate recovery cases and setting public expectations for post-disaster recovery timelines and quality of service expectations.

As communities address issues related to their expectations of energy system performance, improving grid resilience and the costs associated with the associated improvements, communicates must prioritize and balance end user (public safety, hospitals, businesses, and residences) resiliency and restoration requirements. As much as practical, systems need to adapt to the ever-changing environment and be built to either minimize damage and impacts to the system, or rapidly restore the system after hazard events occur. Communities must strike a balance that enables utilities, municipalities and co-operatives to protect, maintain, and recover the system while controlling costs. Involving additional community partners may be necessary if performance or restoration expectations are greater than the energy service provider(s) can economically or practically support.

Electricity consumers should be informed and educated on the costs and benefits of facility and infrastructure hardening and resiliency planning and resulting performance expectations. Generation facilities (including renewable energy and storage options) and substations may need to be located into the communities they serve to ensure these facilities are sited and constructed to be resistant to potential hazards (e.g., flooding, storm surge, wildfire, etc.).

When events occur and recovery efforts are required, the priorities and restoration efforts should address emergency-related societal needs first, and then progress through a tiered response. Although this model of recovery can be complex, for simplicity, the three general tiers on which to focus restoration of services are: 1) emergency facilities and services (Critical and Essential Facilities), 2) critical public works and right of way (access) for critical infrastructure restoration crews, and then 3) systematic restoration of the community at large. Later in this chapter (Section 7.3), these tiers are further investigated for energy systems (by system element such as generation, transmission, and distribution) in example performance goals matrices. These tiers are discussed in Section 7.5, and are related to recovery levels for new and existing infrastructure (Sections 7.5.1.2 and 7.5.2.2, respectively).

7.1.2. Reliability, Energy Assurance, and Resilience

Reliability and resilience are related, but distinct, concepts with different performance goals or metrics. In many cases, the projects and investments to improve day-to-day reliability contribute to resilience; however there is not a one-to-one correspondence. In August 2012, the President's Council of Economic Advisers released a study on the benefits of investing in grid resilience. The study explained the difference between resilience and reliability as:

> *"A more resilient grid is one that is better able to sustain and recover from adverse events like severe weather – a more reliable grid is one with fewer and shorter power interruptions."*

In September 2012, Maryland's Grid Resiliency Task Force adopted similar definitions for resilience and reliability.

> *"[R]eliability [was defined] as the ability of the bulk power and distribution systems to deliver electricity to customer during normal 'blue sky' operations. . . . Resiliency was defined as the ability of the distribution system to absorb stresses without experiencing a sustained outage."*

The Public Service Enterprise Group (PSEG) in New Jersey states in its Energy Strong Program:

> *"Reliability remains fundamental but is no longer enough now that extreme storms have become increasingly common and people are more dependent on electricity than ever before."*

PSEG is looking for a different set of performance metrics for all conditions; performance metrics that have commonality with resilience metrics presented in this framework.

For the purposes of this framework, NIST will use the definition of "resilience" from Presidential Policy Directive/PPD-21: Presidential Policy Directive – Critical Infrastructure Security and Resilience:

> *The term "resilience" means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.*

Quantitative statistics have not yet been compiled to illustrate the effort the electricity system has put into resilience, but those in the industry have thought a great deal about resilience. In recent industry studies (NARUC 2013), NERC defines resilience of the bulk electric system via two main responsibilities – adequacy and security. <u>Adequacy</u> in this context is "the ability of the bulk power system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements." <u>Security</u> is the "ability of the bulk power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements from credible contingencies." This definition of security may be applied to the bulk electric system, but is not applicable to the distribution system, nor does it address infrastructures of other systems (e.g., gas/fuels, telecommunications and water).

The purpose of this discussion is not to resolve the issue of which term is most appropriate or which approach will make the infrastructure of the grid least susceptible to damage and outages during all types of events. Rather, the purpose is to look at the infrastructure elements of the energy system (generation facilities, substations, transmission and distribution elements) and provide guidelines and performance objectives for design and construction of an electrical grid that is more reliable and also more hazard resistant so as to perform with the least impact or interruption when events (routine, expected, or extreme) occur. Using the terms related to resilience that are used by the other systems will simplify defining performance metrics for resilience in this and the other systems, allowing us to identify and understand interdependencies between the different systems.

The Four R's. When applying the PPD-21 to the energy system to define resilience, a number of scholarly articles and reports on resilience provide an energy industry specific evaluation of what resilience can look like. One article, the NASEO State Energy Assurance Guidelines[1] refer to the 4 Rs of resilience with respect to infrastructural qualities:

1. ***Robustness -*** the inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality
2. ***Redundancy -*** system properties that allow for alternate options, choices, and substitutions when the system is under stress
3. ***Resourcefulness -*** the capacity to mobilize needed resources and services in emergencies
4. ***Rapidity -*** the speed with which disruption can be overcome and safety, services, and financial stability restored

An overall energy resilience strategy is one that actively manages each of these qualities to achieve the desired performance of an energy system. In addition, it can be used to help quantify the following measures of resilience for various types of physical and organizational systems:

1. ***Technical -*** the ability of physical systems (including all interconnected components) to perform to acceptable/desired levels when subject to hazard events
2. ***Organizational -*** the capacity of organizations - especially those managing critical facilities and hazard event-related functions - to make decisions and take actions that contribute to resilience
3. ***Social -*** consisting of measures specifically designed to lessen the extent to which communities and governmental jurisdictions suffer negative consequences due to loss of critical services due to a hazard event
4. ***Economic -*** the capacity to reduce both direct and indirect economic losses resulting from a hazard event

To explore some differences between reliability and resilience, look at recent events. In the wake of Hurricane Sandy, widespread power outages had cascading and disastrous consequences across the New York and New Jersey region, but specifically in lower Manhattan in New York City. The tidal surge flooded a substation in lower Manhattan and knocked out power for customers below 39th Street for nearly five days. "[It was] the largest storm-related outage in our history," according to an October 30, 2012, press release from John Miksad, Senior Vice President for Electric Operations at Consolidated Edison.

The lights in lower Manhattan were hardly back on before Consolidated Edison asked state utility regulators to approve a very large, multi-year capital investment program to harden the electric power grid for future storms. Note, resilience hardening is programmed and funded at lower levels than reliability funding over the same period of time (taken from Pentland 2013) at this utility.

[1] This report can be found at : http://www.naseo.org/Data/Sites/1/documents/publications/State_Energy_Assurance_Guidelines_Version_3.1.pdf

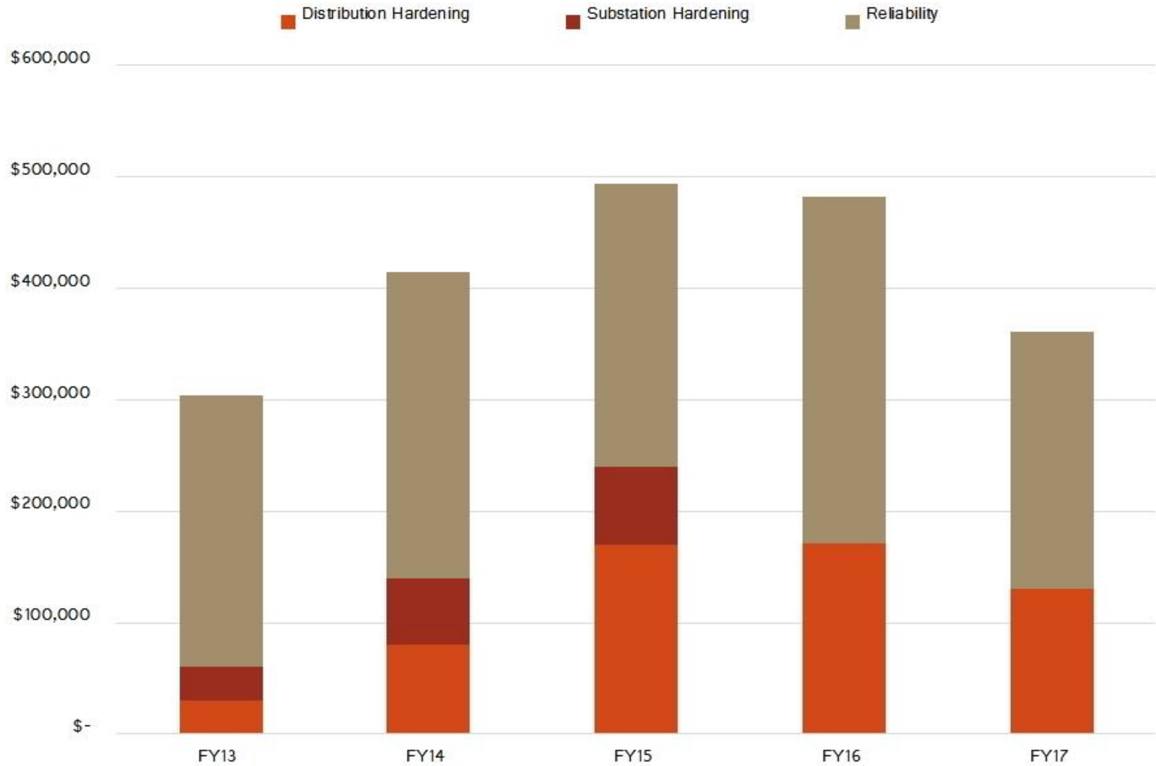

Figure 7-1. Con Edison's Proposed Capital Budget

This spending demonstrates that even a very large commitment to hardening is still not at the same levels as reliability spending for this one entity. Is this a trend? Is it representative of the industry as a whole? The answer to both questions is "no." Nevertheless the spending plan provides a recent example to help our understanding of these two initiatives. Reliability can be stated as a "core goal" of electric service. It can be argued that resilience is a new and growing goal, but is secondary to reliability. There is no clear formula to designate the appropriate balance between the two; and assigning or measuring expenditures as attributable to only reliability or resiliency is not always easy. For example, reliability expenditures, particularly in automation of operations, positively benefit resiliency, so where should these expenditures be tracked?

7.1.3. Interdependencies

Energy is a key aspect of resilience. In fact, every other system presented in this framework depends upon the energy system for the power required to provide a functioning level of resilience for their system. For example, although a hospital or emergency operations center may not be physically damaged by a hurricane, flood, or earthquake (a resilience success for buildings), it still may not be functional without power or electricity for sustained and complete operations of all systems and services (presuming the emergency and backup power systems on site have limitations on the duration and the number of systems they can power when electricity from the grid is unavailable).

Energy systems also have interdependencies with other systems that reduce effectiveness or resilience. Some examples are:

1. Operations and control centers of utilities rely on the communications and information system to send and receive operational information to the generation, transmission, and distribution components within the grid. While the deployment of automated systems to control the switches and controls within the grid will improve resilience, operational control must still be maintained at some level or the resilience of the grid will be affected.

2. Liquid fuels rely on the transportation system to ensure the ability to distribute liquid and natural gas over land (via truck and rail). Disruptions to the transportation system negatively affect the supply chain and resilience of the energy system (see also 6.2.5 Pipelines for additional information).

3. The ability to recover electricity infrastructure in the electrical subsystem can be seriously hampered if buildings or transportation system damage is sustained. The response teams, who are integral to the recovery (and resilience) of the electrical Subsystem, must be able to mobilize and reach impacted areas. If buildings are destroyed and block access or if roads are impassable due to catastrophic events, they cannot perform response and recovery activities, making the energy system less resilient.

Where possible, interdependencies including, but not limited to, those presented here were considered in preparing the example performance goals presented in Section 7.3.

7.2. Energy Infrastructure

Our national infrastructure systems are designed for reliable service with some intent to build a stronger system due to potential hazard events. While these systems are designed to minimum NESC codes (and in many areas, beyond the minimum criteria set forth in the codes), the level or magnitude of the event these systems can withstand without damage is not clearly defined. Over the years, improvements in technology have addressed some vulnerabilities or risks in the system. However, these improvements in technology may have also inadvertently introduced new vulnerabilities or risks. Recent post-disaster studies and reports on climate change shed light on why damage and impacts to these systems from the natural hazard events occurred in the past several years.

The electricity subsystem has spent a great deal of time and money planning, building, rebuilding, and re-planning for reliability and to support energy assurance goals. While much of that effort pre-dates current definitions of resiliency, it should still be stated that the electricity subsystem is working to create and ensure some level of resiliency for communities. The infrastructure continues to improve, with some improvement actually due to hazard events.

The Characteristics of a Resilient Energy System include:

1. Planned, modeled, and prepared; ready for immediate and reliable deployment; robust (hardened) where appropriate
2. Supports emergency response, life safety, restoration effectiveness, and socio-economic continuity during a major event
3. Recovers rapidly after catastrophic events
4. Incorporates redundancy and spare capacity
5. Supports a diversity of energy sources
6. Modular or loosely-coupled architecture
7. Aware and responsive to electrical and environmental conditions
8. Actively monitored and maintained
9. Operates efficiently in non-emergency conditions
10. Provides economic and societal benefits to the communities and stakeholders served

When designing energy infrastructure, resiliency performance metrics should use common vocabulary, understood by both providers and consumers, to ensure clear communication, reduce risk, and increase resilience from different threat and hazard events. Some questions to consider when (re)designing and establishing performance criteria for the critical components of the energy infrastructure include:

1. Why did failures occur?
2. Were the design criteria not correct to account for these hazard events?
3. Can and should higher criteria be used? Or were these hazard events truly rare or extreme events for which it is not feasible to design the systems to resist with minimal to no impact to the services they provide?
4. Was the extent and impact of the failures disproportionate to the magnitude of the event that occurred? And if so, was the degree of the failure or impact due to the design and construction of the infrastructure or was it a result of, or exacerbated by, the inability to respond/repair the damage that was caused by the event (i.e., a poor operational response)?

These important questions need to be discussed and answered to create a framework that provides design and construction guidance in the energy industry so generators, distributors, and users of the bulk power system can set and achieve performance goals. The performance metrics discussed in this guidance must be discussed in a common vocabulary by both providers and consumers within this industry to have a chance to reduce our risk and increase our resilience from these different threat and hazard events.

7.2.1. Electric Power

The electric power subsystem provides production and delivery of electric energy, often known as power, or electricity, in sufficient quantities to areas that need electricity through a grid connection, which distributes electrical energy to customers. Electric power is generated by central power stations or by distributed generation. The other main processes are transmission and distribution. This was illustrated in the *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2*.0, shown in Figure 7-2 below.

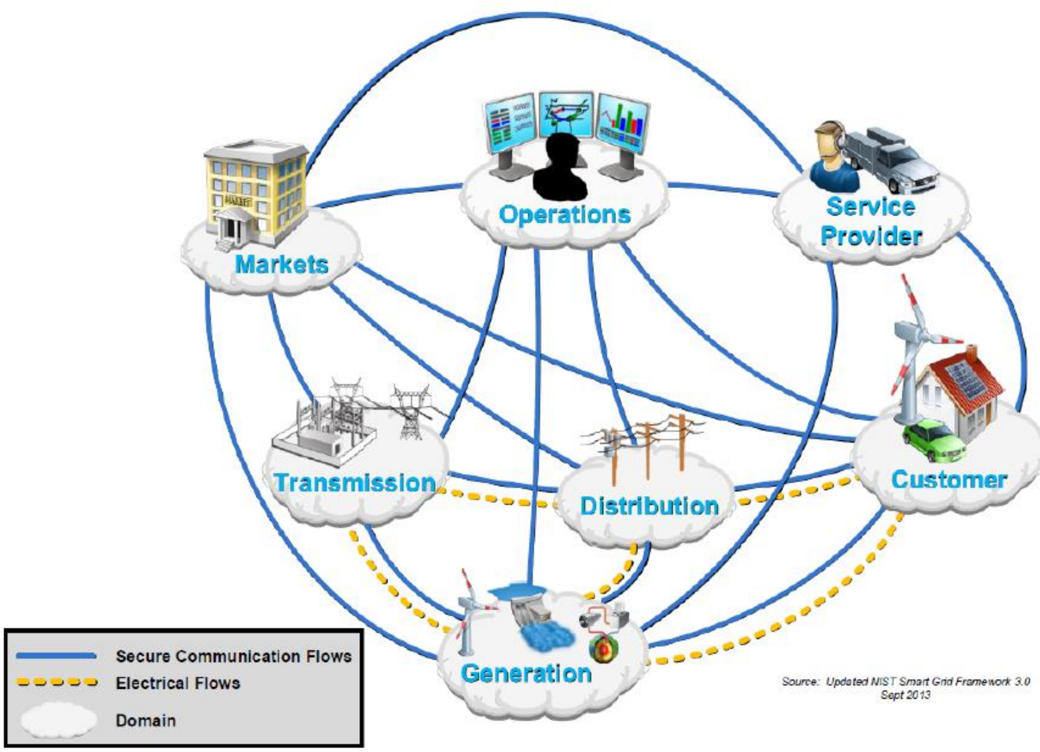

Figure 7-2: NIST Smart Grid Conceptual Model (NIST 2012)

In 2009, NIST established the Smart Grid Interoperability Panel (SGIP) and developed the Smart Grid Conceptual Model. This model is used worldwide as a simple mechanism for graphically describing the different domains within the Smart Grid. The model is fully described in the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0, which reflects advances in smart grid technologies and developments from NIST's collaborative work with industry stakeholders.

For simplicity, and to remain focused on the primary resilience components within the bulk power electrical network, this document will focus primarily on generation, transmission, and distribution. Note that the natural gas delivery system is very similar in architecture and much of the terminology is interchangeable with the electricity network when describing the domains.

7.2.1.1. Generation

Traditional power generation is supported through bulk power plants that incorporate large spinning electrical generators. In the US, this power is 3-Phase Alternating Current (AC). However, the generation system is evolving and has been for some time. Prior to deregulation of electricity in certain US states, the public utilities owned and managed both the generation (power plants) and the transmission grid over which electricity was delivered. Deregulation separated generation and transmission, with most deregulated states allowing independent power producers (IPPs) to competitively develop generation projects. The term "deregulation" does not imply these utilities are not highly regulated, simply that consumer choice exists, although IPP developers must still negotiate contracts to sell power to the utilities who maintain their responsibility to manage and deliver the electricity via the grid. The US today is a patchwork of regulated and deregulated states so, depending on the state, the utility could control transmission, generation, or both. This patchwork of regulation and deregulation at the state level also applies to the distribution of natural gas by utilities.

In addition, renewable power projects, distributed generation by commercial entities, and demand-side management (such as demand response and energy efficiency and energy storage) are becoming more pervasive. Today the term "generation" increasingly includes "virtual generation," resulting from using load-reduction to offset power demand or the use of storage rather than developing new generation (power plants). Additionally, more of this activity is evolving to be located behind the meter at homes and businesses (rooftop solar, smart meters, etc.).

Renewable power comes in many forms – wind, solar, biomass, hydropower. In some states energy-from-waste (waste-to-energy) plants also meets the definition of renewable power. The public is well-versed in the term "renewable power," but does not typically understand that the rules vary from state to state in the same way the Renewable Portfolio Standards (RPS) or goals for the percentage of power to be generated from renewables vary by state.

"Distributed generation" is an umbrella term typically describing power plants developed for a specific company or industrial location, also known as "in-the-fence" power, which serve the needs of a particular commercial plant, manufacturing facility or industrial park. These plants must be developed in accordance with requirements for their particular state, but are typically single or small group load-serving entities. An example might be an industrial facility that builds its own on-site power plant to serve its electric power supply needs. Often these generating plants are also cogeneration facilities, providing steam for a host establishment or a neighboring industrial/commercial facility for heat or another industrial process use. Many of these smaller facilities are also referred to as Combined-Heat and Power or CHP plants.

In regulated states Demand Side Management (DSM) is best defined by the Energy Information Administration: "the planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand." Thus, DSM can include both Energy Efficiency (EE) or Demand Response (DR) to reduce electric demand.

Energy Efficiency at the utility level is a method or program by which the utility manages or reduces the demand for power rather than building or contracting for new generation (power plants) or having to purchase additional power on the spot market, which can be extremely expensive. These programs can be high-level state-wide improvements to public buildings (efficient light bulbs, improved insulation, etc.) or can entail distribution of energy efficient light-bulbs or sophisticated meters and thermostats for residential users.

Demand Response (DR) is sometimes implemented by a non-utility company that enters into a contract with electric users, usually large users such as universities, high-rise office buildings, chains of retail stores etc., and pays those users to lower their electric use during times of peak demand such as hot summer days. In doing so, the DR company sells that reduced-load to the utility during peak demand periods. This allows large users of electricity to lower their annual electric costs via the DR payment and allows the utility to avoid brown-outs or black-outs and avoid spot market purchases or the need to develop new generation.

Energy Storage comes in many forms, from large-scale batteries, to pump storage, to fuel cells. In the case of pump storage, which has a long history, water is pumped up to a dam or holding basin during periods of low electric demand (non-peak-periods) so it can be released during periods of high demand to meet load. This historical use of pump storage is now being expanded to use compressed air and other technical methods of delayed release of energy, such as flywheels, during peak periods.

As noted earlier, the belief that generation satisfies electric demand is only partly true. Using alternative methods to reduce, offset, or delay peak electric demand plays a larger role and, as such, needs to be considered as a key part of the system by which reliable and efficient power to the US population is ensured.

7.2.1.2. Transmission

In the traditional bulk power system, 3-Phase power exits the generator and enters a transmission substation. Voltages are transformed to very high voltages to travel long distances along three separate transmission lines, each carrying a single phase. The transmission infrastructure is primarily wire and towers carrying high voltage power from generators to distribution substations. It is the “middle-man” of the electric power delivery network.

The overarching issues surrounding the vulnerabilities of the transmission infrastructure stem from the aging physical assets today. As overall customer load requirements grow and the various federal and state regulations change, there is a need for more robust and flexible electric power delivery systems to keep up with demand. The emergence of the renewable generation market, and the transition from coal generation to natural gas generation, has begun new stresses on the power grid beyond its original design. Electrical flows that were designed to be in one direction are now in multiple directions, depending on the generation available at any particular time of day. Transmission constraints, which affect cost and reliability, have become common in operations.

Recently (over the last 10 years), transmission planning has evolved from relatively few new transmission lines being built nationwide to many new transmission lines being planned by most major utilities. The cost and time to build new transmission lines have also increased significantly over the years due to public routing, regulatory and environmental restrictions. But the performance of these transmission lines has improved with the passage and implementation of FAC-003-3 Transmission Vegetation Management Program. The purpose of FAC 003-3 is to provide the guidance needed “*to maintain a reliable electric transmission system by using a defense-in-depth strategy to manage vegetation located on transmission rights of way (ROW) and minimize encroachments from vegetation located adjacent to the ROW, thus preventing the risk of those vegetation-related outages that could lead to Cascading.”*

All of these demands impact electric transmission system reliability. Ever-increasing cyber-based monitoring systems are being developed to reduce the impact of any potential hazard. As new systems are engineered and constructed there is also a need to evaluate ongoing maintenance. Many efforts are underway to strengthen our nation’s transmission systems. Several major Smart Grid transmission projects have been initiated and, in some cases, recently completed to supply power across the nation. Other efforts to increase the power grid's resiliency and efficiency include developing and deploying new technologies (e.g., Demand Response, Micro-grid/Islanding, Synchrophasers (PMU), Dynamic Transfer, Energy Imbalance Markets (EIM) and Dynamic Line Rating (DLR)). The FERC also issued Order 1000, meant to reduce capital costs of transmission for end consumers by introducing competition between utilities and transmission developers.

Transmission infrastructure is vulnerable to a number of hazards. Storms with heavy rain (e.g., hurricanes) can cause flooding of low-lying electrical infrastructure including substations as was the case with Hurricanes Sandy and Irene[2]. The heavy rain that accompanies many thunderstorms and hurricanes adds to the hazards from debris, by potentially washing away the foundations of poles on the sides of hills and exposing underground cabling to the movement of water. There are other examples of flood hazards and events, (ranging from tsunamis, to dam failures, to large water main breaks) that can also cause water to follow electrical lines back to underground electrical conduits and vaults and will have a negative impact on underground substations and splices.

Flooding is not the only hazard that threatens damage and failures of the electric power infrastructure. Strong winds, such as those from tornadoes, hurricanes, and even thunderstorms, can damage electrical infrastructure. Large thunderstorms tend to have strong straight line wind and can destroy trees and structures quickly.

Another potential hazard that can impact electrical power infrastructure is wildfire. Wildfires are a routine part of life in some communities across the country. Depending upon the wildfire risk, communities may need energy resiliency measures to protect against them. Every year, wildfires burn thousands of acres and destroy homes and other structures. Electrical lines have been implicated in starting wildfires, as was the case in the 2007 San Diego Witch Creek, Guejito and Rice wildfires[3].

7.2.1.3. Distribution

In the traditional power delivery system, the distribution system begins at the distribution substation. The substation takes power that is normally delivered at 10s or 100s of thousands of volts and transforms the voltage to less than 10k volts (typically 7200 volts). The distribution substation is a critical piece of the overall power delivery system and is a focus area for resiliency hardening and post-disaster repair. It supports a variety of Operations Technology (OT) and Information Technology (IT) equipment and systems that connect the endpoint loads to the utility's operation center. The distribution system is by far the largest component of the electricity network. With regard to recovery operations, the majority of focus is normally within the distribution network.

Given the aging infrastructure, some real vulnerabilities exist in the energy distribution systems. The distribution systems are typically built and constructed along roadsides but, in some cases, they run through less accessible back lots and other right-of-ways. As overall customer load requirements grow and the changes in regulations continue, there is a need for more robust electric systems; but the ability to provide these robust electric systems is struggling to keep up with the demand.

Maintaining the designed distribution systems is also a challenge. The poles and equipment that are key elements of the distribution system are subject to overloading with additional wire and system components by local service providers who add lines and equipment to existing poles. These additions may directly overload the components that make up the electrical system or increase their vulnerability to wind and ice during storm events.

[2] United Illuminating announces $11M flood prevention project for substations, July 23, 2013, http://connecticut.news12.com/features/sandy/united-illuminating-announces-11m-flood-prevention-project-for-substations-1.5753215, retrieved 27-July-2013

[3] Power lines cited as cause of largest wildfires". *SAN DIEGO UNION-TRIBUNE*. 2007-11-16. Retrieved 2013-7-27.

Further, as new systems are engineered and constructed there is a need to evaluate the ongoing maintenance. One element of maintenance in the forefront along the distribution system is tree coverage. Most, if not all, utility entities have well-established and adequate tree management programs; but failure to implement these programs has been a leading cause of outages. The reason for this failure is not always simple. Even though the utility may have an established and programmed vegetation management program, public and private land owners may not allow removal of any trees or limbs. Other jurisdictions and environmental entities (state, local, or activist) have also succeeded in stopping tree trimming and clearing programs. Further, the health of trees and vegetation (as well as insect infestation and other natural scenarios that can diminish the performance of trees) should be anticipated and addressed in planning and maintenance programs. The aggregate impact of these actions results in failed implementation of the tree trimming programs, which creates a critical failure point where system vulnerability continues to worsen instead of being mitigated. These tree maintenance programs should consider local factors that can also impact the performance of trees and vegetation and result in localized areas of poor performance during storm events that, if not accounted for, would directly impact the performance of the Distribution Systems.

As discussed for transmission, many cyber-based monitoring systems are being developed annually to reduce the impact of any potential natural hazard such as the hurricanes and flooding.

Many efforts are underway to strengthen our nation's distribution systems. There are major feeder hardening program/projects underway across the nation. These projects have been focusing on dead-end cross arms, lightning arresters at any identified weak points. In California there is a push for strengthening the systems from fires. They are now "boxing in" fuses so no hot metal will hit the ground and potentially cause fires. Dependent on the location nationally, there has also been a movement away from wood poles. Where wooden poles are still being used, they are increasing the size and class to accommodate the overall design constraints.

The electric energy distribution system is vulnerable to a number of hazard events. Overhead distribution lines are particularly vulnerable to high wind hazards, such as hurricanes and tornadoes. However, most infrastructure failures from wind storms are not from the wind loading directly. Trees often fall onto infrastructure, causing damage and failures to the distribution network. Many neighborhoods have large trees that parallel the overhead infrastructure; and in many cases conductors may actually run through the trees. Therefore, vegetation management is critical to minimizing vulnerability of distribution lines to high wind events[4]. It only takes one property owner resisting a utility tree trimming program to trigger a power outage affecting a large number of people.

The constant push of high winds on utility poles can slowly cause them to lean. Pole toppling events can occur several days after a storm. Heavily loaded poles can be braced if they are likely to be exposed to high straight line winds. Winds that change direction around the clock, such as those experienced in Florida at the end of the 2007 hurricane season, can do more damage than storms where the wind comes from one direction. If it is solidly packed, the pole can crack off at ground level or another weak point. As a result of the observations after the 2007 hurricane season, Florida now requires more pole inspections to look for overloaded poles and poles that show rot at the interface with the ground or other weakness. Instead of a 15-year pole inspection cycle, Florida is considering a 7-year inspection cycle. Poles that look perfectly fine from a visual inspection may not be fine internally or underground. Therefore, new inspection tools and techniques have been developed to help with pole inspection.

Another hazard associated with high wind events such as hurricanes, tornadoes, and thunderstorms is lightning, which is a particular concern for electrical energy infrastructure. When a transformer is overloaded, either by a direct lightning strike or by an overload on the circuit, it typically flashes to a

[4] EPRI Report 1026889, Enhancing Distribution Resiliency, Opportunities for Applying Innovative Technologies, January 2013

roaring blaze quickly. The resulting blaze can consume not only the transformer, but the pole it is on and the close vegetation as flaming oil falls to the ground. Lines can come down from direct lightning strikes, especially on poles that have hollowed out over time and filled with water. These poles literally explode when the water inside flashes to steam.

Lightning will travel down a conductor until it finds an easier path to travel. Even when a line is already down and de-energized, lightning can strike it traveling the remaining path, until it finds a lightning arrestor or a fusible link. Damage to home appliances and consumer electronics is common when lightning strikes a line beyond an outage point. Reminding people to unplug appliances and other equipment in a major storm is the best way for them to protect this equipment. Having back up or standby power for critical communications needs and data gathering in emergency centers that are fully up to date on software and data is important, even in mobile command posts. Having that back up equipment that is simply stored and not connected to the grid is a good approach to redundancy and resiliency. Too often, backup equipment is used to provide additional capacity on a day-to-day basis, only to leave the location with no working equipment after lightning strikes. Surge protectors, uninterruptible power supply (UPS) systems, and other protection equipment is helpful, but only having the equipment unplugged from the wall is 100% insurance that a lightning strike will not disable it.

Earthquakes can also cause damage to electrical infrastructure. Earthquakes can do widespread damage to the electrical infrastructure with little or no warning. In addition to directly damaging electrical infrastructure, they can cause other failures, such as fires and ruptured water mains, which may in turn cause damage to electrical infrastructure.

Earthquakes that cause ground movement in close proximity to the fault may damage towers and poles or break electrical lines that cross the fault or run parallel to the fault line. Those lines tend to snap because there is not enough slack in the line to allow it to flex with the movement of the fault line, or the movement is so rapid that the line’s slack cannot move quickly enough. Overhead lines on proper structures tend to perform better than underground lines near major earthquakes because the lines all have some slack (the sag of the centenary) in them and their supporting structures flex as well.

Top loaded poles (those with transformers, voltage regulators, etc.) tend to fail first in an earthquake, all things being equal with the footing of the pole and the quality of the pole. It is better to ground mount this type of equipment if the poles are close to a fault line.

7.2.1.4. Emerging Technologies

Many smart grid technologies available today are targeted to help the electric utility significantly in improving reliability, operating efficiency, and power quality, and in identifying potential opportunities to harden the current circuits from a resiliency standpoint. Many technologies, considered “plug and play,” are working together nicely with the right infrastructure. Many utilities are also evaluating their smart grid plans and working on full integration to allow for predictability as well as corrective action.

Technology has also allowed the utilities to rapidly correct power outage situations. Many utilities have implemented some form of distribution automation with very good results. These results have led to further technological advancements, being implemented today. Today’s utilities recognize the real need to build a resilient, safe, and economical electrical network. As the utilities computerize the electric grid, they are opening additional opportunities for predictability and better understanding of communities’ usage.

Microgrids

With regards to energy resiliency, one of the most profound emerging technology opportunities is microgrids. Microgrids connect loads with Distributed Energy Resources (DERs) within a defined boundary. The “macro” grid treats the DER as a single entity; the microgrid manages the DERs and loads independently. Microgrids can be connected or disconnected from the grid and can operate independently in an islanded mode. They offer a variety of compelling business opportunities to help meet organizational mission requirements, participate in electricity markets, increase energy surety/resiliency, and incorporate renewable energy resources.

Microgrids can be implemented at numerous points in the electric power system physical hierarchy – transmission, subtransmission, substation, distribution, and consumer. The most fundamental division of location however is customer-side or utility-side implementation. Customer-side microgrids can be designed and implemented with the specific operational and business requirements of the facility in mind. Customer-side microgrids can be thought of as an extensive, highly managed extension of an emergency generator backup system. The difference is that a microgrid is designed to provide full energy services for an extended period of time. A customer-side microgrid can be implemented to ensure business continuity during a major natural hazard. Recently a major Fortune 100 corporation included a microgrid as part of their new company campus headquarters design to allow full operation of the facility for an unlimited time in the aftermath of an earthquake. A clear business case could be made for implementing such a microgrid by extracting value from the technology during normal operations. In contrast, a utility-side microgrid has the challenge of being funded using the existing utility regulatory model for technology investment. Many more stakeholders are involved in deciding whether the investment required is prudent.

Microgrids have been studied as a potential grid hardening solutions by New York, Connecticut, and California, as well as the U.S. Department of Energy. These studies also consider some of the current regulatory frameworks hindering widespread deployment.

There are 6 primary requirement areas to consider when designing a microgrid, which are substantially different for customer-side versus utility-side implementations:

1. ***Mission:*** What is the organization's mission? How will a microgrid help support the mission?
2. ***Loads and Generation:*** What are the existing and future loads that will need to be addressed by the microgrid? What are the existing suitable generation resources available?
3. ***Infrastructure:*** How is the current grid configured? How will the microgrid interact and take advantage of what is already there? How do the infrastructure elements need to be monitored and controlled to ensure stable operation and meet operational goals?
4. ***Scenarios:*** What are likely events (typical, emergency, opportunistic) that a microgrid can support?
5. ***Policy:*** What policies, incentives, and constraints need to be considered?
6. ***Costs:*** What are current and projected costs of the system?

Microgrids are not simple, interchangeable systems. They require a good business case, should operate and provide value when the grid is operational, and require long-term operational expertise and maintenance commitment. However, in some cases the economic and business value for microgrids may pencil out when loss of critical operations poses a significant risk to public safety or security. Resiliency-related candidates to consider microgrid solutions include:

- Critical facilities for critical events (City Hall, Police, Fire, 911, etc.)
- Hospitals and medical centers
- Local government facilities
- Federal facilities and military bases
- Key businesses including grocery stores, drug stores, large employers, gas stations
- Schools, colleges, and universities

Each of these candidates could be serviced by a customer-side or a utility-side microgrid – or a hybrid approach where the customer side is integrated with a utility-side system to provide enhanced flexibility. All of the following technologies are potential elements of a utility or customer side microgrid:

Renewable Energy Generation

Renewable energy comes from natural sources that are constantly and sustainably replenished. When power is interrupted, renewable energy generation can continue to support uninterrupted or reduced capacity service to energy consumers. Although it is arguable that renewable energy is not emerging technology, the equipment, software, and systems are rapidly becoming pervasive and are maturing at a very accelerated pace. The two primary emerging renewable energy generation resources are solar and wind.

- ***Solar Photovoltaic (PV) -*** The photovoltaic process converts light into electricity. Solar cell modules supply DC electricity at a certain voltage (e.g. 12 VDC). The amount of current is directly dependent on the amount of light that enters the module. When multiple modules are strung together, a solar (or PV) array is constructed that can produce larger quantities of electricity. PV arrays are configured in series or in parallel in order to provide different voltage and current combinations. PV systems are being used in a variety of scenarios, ranging from small rooftop supplemental power all the way to large solar farms providing many megawatts (MW) of power. The technology continues to improve with higher efficiency conversions of light into electricity and stronger, lighter, more flexible materials.
- ***Wind Power -*** Wind power is one of the oldest forms of renewable energy and has been harnessed by man for many centuries. The basic process uses turbines to capture the wind's energy, convert to kinetic, spinning energy, and convert the energy into mechanical power. The resulting mechanical power has been used historically to pump and move water, and in mills to grind grain and corn. It can also be used to create electricity through a generator. Although the same basic principles are at work, wind generation today is significantly different than those of our ancestors, primarily due to scale. Farms of wind generators are found throughout the Midwest, Texas, the coasts, and deserts. Some wind farms produce many megawatts (MW) of power. The technology trend is better aerodynamics for more efficient conversion of kinetic wind energy to electricity, more efficient and smarter generators, and larger, more powerful wind turbines.

Fuel Cells and Storage

- ***Fuel Cells -*** Fuel cells create electricity through chemical reactions. The reaction is controllable and can be tuned to manage the amount of electricity produced. The types of fuels vary, but require oxygen and hydrogen in their chemistry. The waste from fuel cells is clean, producing H2O. Fuel cells have a variety of uses and have been popular concepts in the automotive industry to support environmentally-friendly hydrogen vehicles. The technology continues to involve with different fuel sources, cheaper solutions, and higher capacities.
- ***Battery Energy Storage -*** Battery storage systems are the next "killer app" for energy resiliency, power quality, and energy efficiency. The concept is simple: when demand is low, charge the batteries; when demand is high or the system is stressed, use battery power. Battery power today is in the same place technologically that solar power was in the 1990s. Batteries are too big, too expensive, and don't last long enough. Also, there are very few incentives for investment in battery technology. The landscape is slowly changing and states like California are performing battery studies and pilots. This emerging technology could have an enormous impact on how the grid is managed and combined with renewable energy generation, simple microgrids become viable, affordable solutions and our energy becomes more resilient.

Demand-Side Management

The ability for customer-side loads to respond to external controls during an energy system emergency is a key element of energy system resiliency during the event while restorative actions are underway. This is especially important when microgrids are used on the customer side and/or utility side of the meter. A key challenge in managing a microgrid is maintaining load/generation balance to keep the system stable.

Simple customer side backup generation solutions that are not intended for long term operation and support of normal business operations typically only supply emergency loads. More sophisticated systems that integrate renewable energy sources, fuel cells, and energy storage may utilize a building automation system to control building loads to optimize the performance of the system for short or long term operation. Utility-side microgrids may also use demand side management systems (DMS) to effectively manage feeder and substation level microgrids to ensure system stability and maximize the number of customers that can be served by those portions of the system that remain intact after a major event and come on line during restoration. DSM techniques can also be used at the bulk level to manage temporary transmission and subtransmission loading constraints that may exist during a major event.

7.2.2. Liquid Fuel

The most common liquid fuels are gasoline, diesel, and kerosene-based products, such as jet fuels, which are produced from petroleum. Other liquid fuels include compressed natural gas, liquefied petroleum gas (LPG), synthetic fuels produced from natural gas or coal, biodiesel, and alcohols. For resiliency, liquid fuels are critical to back-up power generation and nearly all modes of transportation. In addition, 11% of U.S. homes rely on heating oil or propane, with heating oil usage concentrated primarily in the Northeast and propane usage concentrated in rural areas (USEIA 2009).

Although less than 1% of all electricity in the U.S. is generated in oil-fired plants, there are some isolated markets in which petroleum remains the primary fuel. The leading example is Hawaii, where more than 70% of electricity generation is fueled by petroleum (USEIA 2014a).

Potential failure points for liquid fuel production, storage, and distribution include:

1. Catastrophic loss of major production fields
   - Fires
   - Blowouts
   - Spills
2. Transport of crude oil from production sites to refineries
   - Ports
   - Pipelines
   - Rail
3. Processing at refineries into finished products
   - Onsite storage of raw materials
   - Onsite piping
   - Processing reactors vessels
   - Power supply (grid or backup)
   - Onsite storage of finished products and by-products
4. Transport from refineries to regional distribution centers
   - Ports
   - Pipelines
   - Rail
5. Storage at regional distribution centers
   - Aboveground tank farms are the most common storage systems used at permanent depots
6. Regional distribution
   - Pipelines (e.g., pipeline from Oregon's CEI Hub to Portland International Airport)
   - Trucks (e.g., distribution from Port of Tampa to Orlando-area fuel stations)

7. End user or retail sale
   - Onsite storage (e.g., above ground tanks at an airport or buried tanks at a retail fuel station)
   - Power for pumps at retail distributors (e.g., New Jersey retail fuel station grant program described below in Section 7.3.4)

Maintaining production of crude oil and safely transporting it to refining centers (Steps 1 and 2) are major national and international security issues that are beyond the scope of this framework.

US refineries (Step 3) tend to be geographically concentrated and operate at 90% or more of capacity during periods of strong economic growth (USEIA 2014b). The reliability and resiliency of US refinery capacity is both a national security issue and a major regional economic issue in those areas of the US where refinery capacity is concentrated.

Regardless of where production and refinery capacity are located, all communities should assess their resiliency with respect to Steps 4-7. Damage to ports, tank farms, pipelines, railways or roadways can cause serious delays to the distribution of liquid fuels which, in turn, can lead to loss of backup power generation when onsite fuel supplies are exhausted and disruptions to all modes of transportation. In cold weather scenarios, an extended disruption to heating fuel supplies also has the potential of becoming a significant issue.

Steps 4-7 focus on the energy portion of the Oregon Resilience Plan, which was developed for a magnitude 9.0 earthquake scenario on the Cascadia subduction zone. The Oregon study identifies the northwest industrial area of Portland along the Willamette River as Oregon's Critical Energy Infrastructure (CEI) Hub. More than 90 percent of Oregon's refined petroleum products pass through this six-mile stretch along the lower Willamette River before being distributed throughout the state. For the Cascadia earthquake and tsunami scenario, potential hazards to liquid fuel storage and distribution networks include ground shaking, sloshing, liquefaction, lateral spreading, landslides, settlement, bearing capacity failures, fire, or seiches in the CEI Hub area and tsunami damage at the coast. Fuel is transported to the site via a liquid fuel transmission pipeline from the north and marine vessels. Alternative modes of transporting fuel from the east or south or by air are very limited. Key recommendations for improving the resiliency of the Oregon energy system include conducting vulnerability assessments, developing mitigation plans, diversifying transportation corridors and storage locations, providing alternate means of delivering fuels to end users, and coordinated planning (OSSPAC 2013).

The American Lifelines Association (ALA 2005) identified the high-level performance measures and performance metrics for pipeline systems shown in Table 7-1.

Table 7-1. The American Lifelines Association High-Level Performance Measures and Performance Metrics for Pipeline Systems (ALA 2005).

Desired Outcomes (Performance Targets)	System Performance Metrics					
	Capital Losses ($)	Revenue Losses ($)	Service Disruption (% service population)	Downtime (hours)	Casualties (deaths, injuries)	Lost Product
Protect public and utility personnel safety					X	X
Maintain system reliability			X	X		
Prevent monetary loss	X	X	X	X		X
Prevent environmental damage						X

A qualitative ranking of hazards to typical pipeline system components and facilities from the ALA (2005) study is reproduced in Table 7-2.

Table 7-2. Qualitative Ranking of Hazards to Typical Pipeline System Components and Facilities (ALA 2005).

Hazards	Degree of Vulnerability									
	Transmission Pipelines	Pump Stations	Compressor Stations	Processing Facilities	Storage Tanks	Control Systems	Maintenance Operations Buildings and Equipment	Pressure Regulations / Metering Stations	Distribution Pipelines	Service Lines or Connections
Natural Hazards										
Earthquake Shaking	L	M	M	M	H	M	H	L	L	M
Earthquake Permanent Ground Deformations (fault rupture, liquefaction, landslide and settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Ground Movements (landslide, frost heave, settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Flooding (riverine, storm surge, tsunami and seiche)	L	H	H	H	M	H	H	H	L	M
Wind (hurricane, tornado)	L (Aerial)	-	-	-	-	L	L	-	-	-
Icing	L	-	-	-	-	-	-	-	L	-
Collateral Hazard: Blast or Fire	M	H	H	H	H	M	L	L	L	M
Collateral Hazard: Dam Inundation	L	H	H	H	M	H	H	H	L	M
Collateral Hazard: Nearby Collapse	-	L	L	L	-	L	L	L	M	L
Human Threats										
Physical Attack (biological, chemical, radiological and blast)	M	M	M	M	-	M	M	-	M	-
Cyber Attack	-	L	L	L	-	H	L	-	L	-

Note: Degrees of vulnerability: H = High, M = Moderate, L = Low. When a component or system is located within a building the vulnerability of both the building and component should be considered. For example, where there is a potential for building collapse or mandatory evacuation, the equipment housed within is at risk. The entries in Table 7-2 assume that the component is of recent vintage, i.e., post 1945.

7.2.3. Natural Gas

Natural gas pipelines and storage facilities comprise a vast natural gas infrastructure that services 65 million homes, 5 million businesses, 193,000 factories and 5,500 electric generating facilities (McDonough 2013). There are nominally over 2.4 million miles of natural gas pipelines in the continental US, with pipelines running along roads and private easements under both urban and rural lands (McDonough 2013). Steps need to be taken to safeguard this massive and ubiquitous part of our energy infrastructure from disastrous events.

Natural gas pipelines can be damaged via ground shaking, liquefaction, and ground rupture. Specific points of failure may be predicted when rupture or liquefaction occurs; but the most damaging event on a wide scale is ground shaking (Nadeau 2007). Existing weaknesses, which serve as the first points of failure, can include corrosion, bad welds, and weak or strained material. Regular maintenance can have a beneficial effect, as can upgrading piping from iron (used in older pipeline) to plastic (used for low-pressure distribution lines) or even steel. Extensive work has been done to develop models that predict the impact of natural hazards on natural gas systems, which can help leaders determine the risk to their local facilities.

Generation, in addition to piping, needs to be resilient to hazard events. Fuel cells, which generate power via electrochemical reaction rather than combustion, are already being used as a means to achieve a more resilient natural gas infrastructure. Fuel cells provide a decentralized, reliable source of power that has proven useful in hazard events. They are considered a distributed resource by IEEE. For example, during Hurricane Sandy, one manufacturer put 60 fuel cells in place to provide backup power to cell phone towers. Thanks to the inherent resilience of underground natural gas systems to non-seismic events, these cell towers remained operational during and after the storm. Notably, they were the only cell towers in the area to remain operational throughout the event (Fuel Cell and Hydrogen Energy Association 2014).

Aboveground facilities (e.g., compressor stations, processing plants, meter stations, and wells) are the most vulnerable parts of the natural gas system. Natural gas pipes and storage facilities are inherently protected from many hazard events by being underground, but the facilities aboveground are subject to all the same risks as other commercial structures. For example, unusually cold weather in 2011 caused interruptions in natural gas service in the Southwest, which, in turn, caused outages at gas-fired electric generating facilities that were experiencing high demand for electricity. A joint report by FERC and NERC concluded these outages and disruptions of service were caused by weather-related mechanical problems such as frozen sensing lines, equipment, water lines and valves. The report recommended adopting minimum winterization standards for natural gas production and processing facilities, and suggested that additional underground natural gas storage capacity in the region could have ameliorated the impacts of natural gas supply shortages. In addition to the issues discussed in the section about structure resilience, there are vulnerabilities specific to natural gas facilities – flammability and high pressure hazards, and issues with the surrounding infrastructure. These special vulnerabilities should be recognized and accounted for in addition to the steps taken to mitigate inherent risks of aboveground buildings.

7.2.4. Emergency and Standby Power

Loss of offsite power delivered by the commercial power grid can be triggered by failures in power generation, transmission, or distribution systems or by disruptions to power plant fuel supplies. The vulnerability of offsite power to nearly all hazards and the dependence of nearly all buildings and infrastructure on offsite commercial power combine to make both emergency and standby power key requirements for improving disaster resilience.

IEEE (1995) defines an emergency power system as "an independent reserve source of electric energy that, upon failure or outage of the normal source, automatically provides reliable electric power within a specified time to critical devices and equipment whose failure to operate satisfactorily would jeopardize the health and safety of personnel or result in damage to property."

The National Electric Code (NFPA 2005) defines emergency systems as "those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life."

The NEC (NFPA 2005) divides standby power systems into two categories:

- ***"Legally Required Standby Systems:*** Those systems required and so classed as legally required standby by municipal, state, federal, and other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply power to selected load (other than those classed as emergency systems) in the event of failure of the normal source. Legally required standby systems are typically installed to serve loads, such as heating and refrigeration systems, communications systems, ventilation and smoke removal systems, sewage disposal, lighting systems, and industrial processes that, when stopped during any interruption of the normal electrical supply, could create hazards or hamper rescue and fire-fighting operations."
- ***"Optional Standby Systems:*** Those systems intended to supply power to public or private facilities or property where life safety does not depend on the performance of the system. Optional standby systems are intended to supply on-site generated power to selected loads either automatically or manually. Optional standby systems are typically installed to provide an alternate source of electric power for such facilities as industrial and commercial buildings,

farms, and residences and to serve loads such as heating and refrigeration systems, data processing and communications systems, and industrial processes that, when stopped during any power outage, could cause discomfort, serious interruption of the process, damage to the product or process, and the like."

Emergency and standby power systems are essential for continuous operation of critical facilities, such as hospitals and emergency operations centers. Emergency and standby power are also needed to mitigate cascading failures of transportation and infrastructure systems that depend on electric power, including: communications networks, waste water lift stations, waste water treatment plants, water treatment plants, water distribution pumps, transportation fueling stations, traffic signals, traffic monitoring systems, and railway signals (ALA 2006).

Important considerations for safe and reliable operation of onsite emergency and standby power include:

- Elevation of all electrical components, including generators, service panels, outlets, etc., above a design flood level that is appropriate to the importance/criticality of the facility
- Proper ventilation of combustion products and cooling system components
- Availability of adequate uninterruptable power supply (UPS) to support critical systems until emergency or standby power comes on line
- Ability to start emergency or standby power generation without power from the grid ("black start capability")
- Prioritization of power needs and proper sizing of generators and circuits to safely meet essential requirements
- Installation of permanent quick-connect hookups to accept power from temporary generators and label the hook up with the power requirement to enable generator size selection
- Ability to properly disconnect from the utility grid and to avoid feeding power back onto a de-energized grid ("islanding")
- Ability to safely transfer back to the grid when primary power is restored

> The US Army Corps of Engineers (USACE) had developed tool called the *Emergency Power Facility Assessment Tool* (EPFAT). The EPFAT allows public entities to input generator and bill of material requirements into an on-line database with the intention of expediting the support of temporary power installations after events. There are currently over 16,000 facilities in the database. The EPFAT database may be accessed at http://epfat.swf.usace.army.mil/

National Fire Protection Association Standards 110 and 111 provide performance standards for *Emergency and Standby Power Systems* (NFPA 2013a) and *Stored Electrical Energy Emergency and Standby Power Systems* (NFPA 2013b). NPFA 110 recognizes two classification levels: critical to life and safety (Level 1) and less critical (Level 2). Level 1 applications include life safety illumination, fire detection and alarm systems, elevators, fire pumps, public safety communications systems, industrial processes where current interruption would produce serious life safety or health hazards, and essential ventilating and smoke removal systems. Level 2 applications include heating and refrigerating systems, other communications systems, other ventilating and smoke removal systems, sewage disposal, lighting, and industrial processes.

Key considerations for emergency and standby power system fuels include:

- Providing sufficient on-site fuel supply to support essential power loads until an ongoing supply of fuel can be safely and reliably delivered to the site
- Selecting a fuel that is not dependent on electricity from the grid for delivery (e.g., pipe-delivered, natural gas or truck-delivered liquid fuels such as diesel fuel)
- Performing regular tests (at least monthly) and properly maintaining equipment

Alternative fuel sources, such as solar arrays with battery backups, can be considered as a means of maintaining lighting for emergency exit paths or providing water pressure in buildings or for operating transportation system signals or pumps at fueling stations (Andrews et al. 2013).

A partial listing of technologies used for generating emergency or standby power includes:

- Diesel generators
- Combined Heat and Power (CHP)
- Microturbines
- Reciprocating gas engines
- Fuel cells

Diesel generators range from small mobile generators to larger permanently installed systems. Small generators can be easily deployed to power traffic signals, rail crossing signals, or critical circuits in residential or small commercial buildings; but they require frequent refueling, pose safety hazards to inexperienced operators, and may not be reliable due to poor maintenance and infrequent use. Theft of generators is also a problem when left unattended to power transportation system signals, for example. Permanently installed generators may have more substantial fuel capacities and may be safer to operate and more reliable if tested and maintained on a regular schedule.

Following Superstorm Sandy, the State of New Jersey used FEMA HMGP funds to establish a Retail Fuel Station Energy Resiliency Program (NJOEM 2014). Eligibility requirements for the program include:

- Stations must be located within ¼-mile of an identified evacuation route
- Stations with gasoline storage capacity of 30,000 to 35,000 gallons eligible for up to $15,000 grant to purchase quick-connect technology or to offset a portion of the cost of purchasing a generator
- Stations with gasoline storage capacity of more than 35,000 gallons eligible for up to $65,000 grant toward the purchase and installation of an onsite generator
- Stations must sell both gasoline and diesel fuel (except in limited instances)

The program requires a maintenance contract be in place for at least five years from the date of final approval of municipal building inspector. New Jersey's Office of Homeland Security and Preparedness (OHSP) was also selected by the federal DHS to conduct the Regional Resiliency Assessment Program (RRAP) on the State's petroleum transportation and distribution system.

Combined Heat and Power (CHP) is a highly efficient method of providing uninterrupted power and thermal (heating or cooling) services to a host facility. CHP systems are typically powered by natural gas fueled turbines or reciprocating engines. Over a dozen case studies of successful CHP system performance during Superstorm Sandy and other recent large scale power outages have been documented by Hampson et al. (2013). Key advantages of CHP systems over conventional diesel generators include better reliability, lower fuel costs, lower emissions, and the ability to address thermal demands in addition to power demands. Texas and Louisiana now require that all state and local government entities identify which government-owned buildings are critical in an emergency and that a feasibility study on CHP is conducted prior to constructing or extensively renovating a critical government facility. In New York, the State Energy Research and Development Authority (NYSERDA) and the State Office of Emergency Management have partnered to educate emergency managers about the benefits of CHP systems in emergency facilities; and the governor has announced a $20 million investment towards CHP projects, with added incentives for projects serving critical infrastructure, including facilities of refuge (Hampson et al. 2013).

The technologies described in this section are mature and widely deployed. All of these technologies may be employed and coupled with a sophisticated control system to support a microgrid. As noted earlier in the emerging technologies section, microgrids can support normal or near-normal business operations depending on the application and implementation of the system.

7.3. Performance Goals

Examples of Performance Goals at the community level were presented in Chapter 3 for different elements of critical infrastructure. This section presents an example of performance goals for the energy system components in fictional community Centerville, USA. Previous work to develop and establish performance goals or levels of performance is found in the efforts undertaken by SPUR (San Francisco), the California Energy Assurance Planning (CaLEAP) program, and Oregon. While these efforts were first developed at the local and state levels, respectively, they represent the most recent examples of major urban centers and an entire state developing a resilience plan to improve hazard resistance and infrastructure performance.

Table 7-3 through Table 7-5 represent example performance goals for the electrical subsystem for **routine, expected, and extreme** events (the three event levels of routine, expected, and extreme events were presented and discussed in Chapter 3 – the expected event is generally synonymous with a “Design Level event” as defined by the relevant codes and standards.). This example is presented for the fictional community in and around Centerville, USA. Since the ability to provide services after a windstorm, ice storm, hurricane, or flood event allows a utility to win support from their customer base, many providers and entities for energy systems have been designing and rebuilding their infrastructure to consider more severe events to make their systems more resilient and reliable for their customers. As such, it is recognized that the 90% desired performance level is already at the existing or current performance level for most electric utilities in the example matrices. However, the target performance levels proposed may not currently be what are being achieved by all utilities and providers.

The example performance goals presented in Table 7-3 through Table 7-5 are based on anticipated performance to support a community in a manner that is considered resilient, based on recent actual events and response times after storm and hazard events that have occurred over the past several years, and anecdotal reporting of response times. It is important to understand that a community may be different than the example community used in the performance goal tables. A community may have different infrastructure (for example, it may not have power generation or transmission assets, just distribution assets that must be evaluated and hardened for improved performance). Also, both the community stakeholders and the utilities supporting them will have different levels of expectation and actual performance (response to outages or interruptions) depending upon their geographic locations and past history of dealing with events of different magnitudes (routine, expected, or extreme). Further, much of the current infrastructure and response efforts managed by larger utilities may meet the 90% restored metric identified and therefore the blue shaded box can be marked with the “X” and 90% are to show that they are “overlapping.” The Centerville, USA example energy performance goals in this chapter do not show this scenario. However, the example performance goals for pipelines in Centerville, USA in Chapter 6 so show this possibility. Again, an important and notable caveat to this is that Municipals and Cooperatives (Muni’s and Co-Ops) are not traditionally performing at this level and across the board they would likely be at least one box to the right of the current condition (X) mapped in the example matrix.

It is also important to note that, for this system, there is a slight difference in the presentation of information related to percent of the system restored. The reality is that the percentage of the infrastructure the utilities desire to get back on line immediately will vary from community to community and is focused on the sub element identified. If the performance goal is to have all Generation infrastructure operating and functional, but the reality is that the distribution sub elements may be damaged and not operational during the same time period, then each gets its own performance metric as shown (perhaps 90% (or 100%) for the generation, but only 30% of 60% for the other sub elements (such as transmission or distribution), and there may be further granularity in these sub elements based on the infrastructure in another community (see table). The sub elements presented and ranks here are a representative set, communities may have a greater or smaller number of sub elements and functions than what has been depicted here. The local planning process should evaluate and establish the sub elements and functions for which the community and the industries should look to set performance goals.

Lastly, these performance goals will not capture or reflect the inability of the generation or transmission capabilities to be easily re-established when critical infrastructure assets are completely destroyed by an event (e.g., a surge that completely destroys a generation station or major transmission substation). Major impact events such as these are generally considered in that the grid will be able to respond and absorb some level of infrastructure failure. However in communities where there is a generation, transmission, or substation single-point-of-failure condition, that impact is not well-reflected in these metrics at this time. Effort should be made to consider short- and long-term solutions to disruptions, outages, and interruptions. The ability of the sub elements and functions to be operational as soon as possible after an event can be achieved through a variety of solutions. Some may require capital investments, while others are operational responses that are labor and personnel dependent. Some solutions will be dependent on technology or even completely dependent upon the resilience of other supporting systems. Additional information on codes, standards, and recovery levels for new and existing construction presented later in this section should be reviewed prior to completing a performance goals matrix for a community.

Table 7-3. Example Electrical System Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	**(4) Support Needed**	**(5) Target Goal**	**Overall Recovery Time for Hazard and Level Listed**								
			Routine Hazard Level								
			Phase 1 – Short-Term			**Phase 2 -- Intermediate**			**Phase 3 – Long-Term**		
			Days			**Wks**			**Mos**		
			0	**1**	**1-3**	**1-4**	**4-8**	**8-12**	**4**	**4-24**	**24+**
Power - Electric Utilities											
Generation		**1**									
Critical Facilities and Infrastructure Systems	R/C		90%								
Emergency Housing and Support Systems	R/C		90%								
Housing and Neighborhood infrastructure	R/C		90%								
Community Recovery Infrastructure	R/C		90%								
Transmission (including Substations)		**1**									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%								
Disaster debris / recycling centers/ Related lifeline systems			90%								
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			90%								
Emergency shelter for response / recovery workforce/ Key Commercial and Finance			90%								
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices			90%	X							
Houses of worship/meditation/ exercise			90%	X							
Buildings/space for social services (e.g., child services) and prosecution activities			90%	X							
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services			90%	X							
Residential housing restoration			90%	X							
Distribution											
Critical Response Facilities and Support Systems		**1**									
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%	X							
Disaster debris / recycling centers/ Related lifeline systems			90%	X							
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			90%	X							
Emergency shelter for response / recovery workforce/ Key Commercial and Finance			90%	X							
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				90%	X						
Houses of worship/meditation/ exercise				90%	X						
Buildings/space for social services (e.g., child services) and prosecution activities				90%	X						
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services				90%	X						
Residential housing restoration				90%	X						

Footnotes:

1 Specify hazard being considered

Specify level -- Routine, Expected, Extreme
Specify the size of the area affected - localized, community, regional
Specify severity of disruption - minor, moderate, severe

2 30% 60%

3 X Estimated restoration time for current conditions based on design standards and current inventory
Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan

R	Regional
S	State
MS	Multi-state
C	Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

Table 7-4. Example Electrical System Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Power - Electric Utilities											
Generation		1									
Critical Facilities and Infrastructure Systems	R/C		90%	X							
Emergency Housing and Support Systems	R/C		90%	X							
Housing and Neighborhood infrastructure	R/C		90%		X						
Community Recovery Infrastructure	R/C		90%		X						
Transmission (including Substations)		1									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%	X							
Disaster debris / recycling centers/ Related lifeline systems			60%	90%	X						
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			60%	90%	X						
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				60%	90%	X					
Houses of worship/meditation/ exercise				60%	90%	X					
Buildings/space for social services (e.g., child services) and prosecution activities				60%	90%	X					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%	X				
Residential housing restoration					60%	90%	X				
Distribution											
Critical Response Facilities and Support Systems		1									
Hospitals, Police and Fire Stations / Emergency Operations Centers			60%	90%	X						
Disaster debris / recycling centers/ Related lifeline systems			60%	90%	X						
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers				60%	90%	X					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				60%	90%	X					
Houses of worship/meditation/ exercise				60%	90%	X					
Buildings/space for social services (e.g., child services) and prosecution activities				60%	90%	X					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					90%	X					
Residential housing restoration					90%	X					

Footnotes: See Table 7-3, page 22.

Table 7-5. Example Electrical System Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Power - Electric Utilities											
Generation		**1**									
Critical Facilities and Infrastructure Systems	R/C			90%	X						
Emergency Housing and Support Systems	R/C			90%	X						
Housing and Neighborhood infrastructure	R/C				90%	X					
Community Recovery Infrastructure	R/C				90%	X					
Transmission (including Substations)		**1**									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers				60%	90%	X					
Disaster debris / recycling centers/ Related lifeline systems				60%	90%	X					
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers				60%	90%	X					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices					60%	90%					
Houses of worship/meditation/ exercise					60%	90%					
Buildings/space for social services (e.g., child services) and prosecution activities					60%	90%					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%					
Residential housing restoration					60%	90%					
Distribution											
Critical Response Facilities and Support Systems		**1**									
Hospitals, Police and Fire Stations / Emergency Operations Centers					60%	90%					
Disaster debris / recycling centers/ Related lifeline systems					60%	90%					
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers					60%	90%					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance					60%	90%					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices					60%	90%	X				
Houses of worship/meditation/ exercise					60%	90%	X				
Buildings/space for social services (e.g., child services) and prosecution activities					60%	90%	X				
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%	X				
Residential housing restoration					60%	90%	X				

Footnotes: See Table 7-3, page 22.

7.4. Regulatory Environment

The electric utility and liquid fuel industries are highly regulated with the goal of keeping prices low, keeping delivery safe, and providing reliable, quality products to consumers. Regulation occurs at the federal and state levels.

The Federal Energy Regulatory Commission (FERC) is the US national regulatory body responsible for interstate transmission of oil, natural gas, and electricity. They are also responsible for reviewing interstate gas pipeline proposals, licensing hydropower plants, and reviewing proposals for developing liquefied natural gas terminals. FERC regulates the interstate wholesale sales and transmission of electricity, reviews and makes decisions on utility mergers and acquisitions, monitors and investigates energy markets, and provides rulings on transmission siting applications. FERC has the authority to provide civil penalties and fines for non-compliance to regulatory rules.

The Western Energy Crisis, the Enron scandal, and a historic East Coast blackout, led Congress to grant broad new authority to the FERC in 2005. After this third event, the Northeast Blackout, a joint US-Canada task force studied the causes and effects of the 2003 blackout and identified the need to make reliability standards mandatory and enforceable with penalties for noncompliance. So, in the Energy Policy Act of 2005 - Public Law 109-58 - (EPAct 2005), Congress entrusted FERC with a major new responsibility to oversee mandatory, enforceable reliability standards for the nation's Bulk Power System—that is, the wholesale power grid. The importance of this change cannot be overstated. The business of reliability became not just a set of industry best practices; it became a matter of national importance.

Through Section 215 of the Federal Power Act, Congress authorized FERC to certify a national electric reliability organization. That ERO is the North American Electric Reliability Corporation (NERC). NERC is a not-for-profit entity whose mission is to ensure the reliability of the Bulk Power System (BPS) in North America. This means that it is the responsibility of NERC to develop and enforce Reliability Standards. Further, they are to annually assess seasonal and long-term reliability, monitor the BPS through system awareness, and educate, train, and certify industry personnel.

Each state has a regulatory commission whose responsibility is to represent the electricity consumers in their jurisdiction. State commissions regulate retail electricity and gas, approve physical construction of infrastructure projects, provide rulings on local distribution of electricity and gas, and provide general regulatory oversight of local utilities and gas distribution companies. The commission meets regularly with state utilities and performs performance assessments. If performance metrics are not met, utilities may be punished or fined.

7.4.1. Federal

At the federal level there is regulation by FERC which is "an independent agency that regulates the interstate transmission of electricity, natural gas, and oil." FERC does not have siting authority for electric transmission facilities, but it does regulate reliability standards through NERC.

NERC is also at the federal level which, as defined, is "a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization for North America, subject to oversight by the Federal Energy Regulatory Commission and governmental authorities in Canada."

The Nuclear Regulatory Commission (NRC), another federal regulator, focuses primarily on nuclear power plants. The NRC is responsible for licensing and inspecting nuclear reactors, and providing regulations, guidelines, and best practices for their operation. They are also responsible for any nuclear fuel manufacturing oversight and for coordinating and participating in nuclear energy research and development.

Each of the various state and federal authorities regulates different and overlapping aspects of the electric system. The requirements, standards and codes for each are lengthy and complex and are ever evolving but it is these that must form the basis for future refinements to facilitate reliability and preparedness improvements.

7.4.2. State

The utilities are constantly in a complex regulatory dance with state public service commissions, regarding the rapidly changing rules governing their roles and responsibilities. Recently, one of the biggest issues for utilities and commercial generators, particularly rooftop solar companies, involves the regulation of "behind the meter" load (such as rooftop solar) and their ability to sell power back into the grid to the utility. This is referred to as "net metering" and, again, the rules vary from state to state. The concern from utilities is that they remain responsible for upgrade and maintenance of a grid interconnection system that would receive less revenue and would also need to handle the varying bi-directional load demands that can add complexity to an already stressed infrastructure.

Although the push to lower greenhouse gas emissions and increase self-reliance using on-site methods, such as roof-top solar (and potentially storage), has merit, so does improving the backbone and efficiency of our electric grid. Grid improvements can also dramatically reduce line loss, thereby increasing environmental benefits and reliability; but those improvements are expensive and require significant investment. The debate is escalating as additional unique and beneficial "generation" and "virtual generation" options arise.

This push-pull is being played out right now in the headlines and before state public service commissions (PSCs) and utilities across the country. It is therefore imperative that these evolving rules of conduct be formulated with an eye to cost, reliability, safety, disaster preparedness and environmental benefit. The rules themselves will be primarily administered by state PSCs and utilities; but the oversight roles of the regional Independent System Operators (ISOs) and the Regional Transmission Organizations (RTOs) is also key, particularly with respect to cost and reliability.

The ISOs and RTOs serve much the same function, though the RTOs have greater responsibility for their regional transmission network as established by FERC. However, both the ISOs and RTOs operate regional electricity grids, administer the wholesale electricity markets, and provide reliability planning for the bulk electric system. Some of these systems such as the New York ISO (NYISO) are single state systems, and some are more regional such as the ISO New England (ISO-NE) system and the Southwest Power Pool (SPP). Due to the inter-relatedness of the North American grid, the ISO/RTO systems are international and include for example, the Alberta Electric System Operator.

7.4.3. Local

At the State and Local levels, codes and standards are adopted by the State PSCs, PUCs, ISOs, and RTOs to govern design and construction of the infrastructure. There is a wide variation in the level of design guidance that is provided by the codes and standards adopted by these entities. While some have best-practices, others reference ANSI-approved, consensus codes and standards. But even when the codes and standards are adopted, there is an apparent lag in adopting the most current version of these standards.

7.5. Codes and Standards

A number of codes and standards are used in the power industry for design and construction of generation, transmission, stations/substations, and distribution assets. While ASCE 7 (mentioned earlier in this document) is now incorporated by reference and used more frequently than in the past, most of the Transmission and Distribution assets are designed to the National Electric Safety Code (NESC) or the Rural Utilities Service (RUS), respectively. There are many variables related to design and construction of these assets. As such, not all elements may be addressed here or will require additional cross checking with additional codes, standards, and regulations.

In 2009, NIST established the Smart Grid Interoperability Panel (SGIP). The SGIP is a private-public partnership that identifies electricity delivery standards gaps, fills the gaps through requirements analysis, and coordinates with Standards Setting Organizations (SSOs) to create or modify interoperability standards and guidelines. The SGIP maintains a Catalog of Standards (CoS) that lists many standards that have been vetted through a regimented process with regards to cybersecurity and architectural integrity.

The electric code that is adhered to by the Investor-Owned Utilities (IOUs), who design and construct the Transmission assets, is the National Electric Safety Code (NESC); Sections 24 (Grades of Construction), 25 (Loading Requirements) and 26 (Strength Requirements). NESC Rules 215 (grounding) and 218 (trees) present information important to vegetation management. While this is truly a safety code, it is used as a design code in lieu of other guidance. Each utility also has a Standards department that evaluates the various codes and standards (safety or design) that are applied during design and construction of their assets. They evaluate any new equipment to ensure it meets or exceeds these standards. From the baseline set forth in the NESC, it is important to note that all IOUs have developed their own standards for their respective systems. While most of these standards exceed the minimums set forth by the NESC, the question that exists is whether the baseline set forth in the NESC addresses the performance desired for resiliency when considering all hazards (flood, wind, seismic, ice, and other natural hazards and man-made threats).

In a similar fashion, but working from a different set of criteria, the Co-operatives and Municipalities responsible for Distribution assets use the design manuals/standards from the Rural Utilities Service (RUS). The RUS distribution line design manuals consist of RUS bulletins 1724-150 through 1724-154. These refer to the identification of critical loads/customers and poles/equipment. In all cases, each utility is applying more constringent wind and ice loading conditions from these codes.

The information in the following subsections is provided to help communities better develop their own performance metrics for new (or recent) construction by identifying some of the performance criteria that was likely considered in the design of these assets.

7.5.1. New Construction

For some elements of the energy system, the design criteria for hazards have been aligned with building standards such as ASCE 7 Minimum Design Loads for Buildings and Other Structures. However, performance goals for these systems for each event are less defined. Definitions are also less clear regarding what are considered “routine,” “expected,” “extreme,” or “catastrophic” events. As resilience becomes better defined, this framework is working to bring together different interpretations and definition of these events as they are defined and used in practice within the existing industries and codes/standards used in each industry.

The following is a summary of hazards considered by the NESC (Part 2, Section 25):

- ***250B – Combined Ice and Wind –*** This is the basic loading criteria and is known as the District Loading. It incorporates both wind and ice with overload and strength factors. This applies to all structures and references the map presented in Figure 250-1. The boundaries of the districts follow county lines. Data was obtained from a small number of weather stations which were far apart. While the industry has discussed replacing this map with appropriate maps from ASCE 7, this issue is still being evaluated.
- ***250C – Extreme Wind –*** These criteria account for the higher winds typically found along the coastline and during extreme events. These criteria are only used for structures that are higher than 60’ above ground (70’ pole and longer). Appropriate maps are Figures 250-2a through 250-2e. Due to their typical tower height, transmission lines are designed to these criteria. The overload and strength factors used are generally 1 since this is an extreme event map (note, the

nomenclature of “extreme wind” used here is not consistent with the extreme wind event used for the design and construction of buildings or storm shelters per the ICC-500 *Standard for the Design and Construction of Storm Shelters*). These criteria were first introduced into the NESC in 1977. The 2002 NESC incorporated the wind maps from ASCE 7-98; where the wind data was much more comprehensive. The 2012 NESC uses the wind maps from ASCE 7-05. The ASCE 7-10 wind maps were revised to better represent the wind hazard. The maps now are based on new modeling efforts, refinements to understanding of wind performance, and incorporation of the contribution of the Importance Factor [I] into the data presented by the maps. However, these maps are currently not used by the NESC based on a decision by their code committee to retain the use of the ASCE 7-05 wind maps.

Most distribution structures are lower than the 60 ft. height limitation; therefore, most utilities will not design their distribution lines to the ASCE 7 criteria (something that may need to be reconsidered depending upon performance of these systems during hurricanes and tornadoes over the past 2 decades).

- ***250D – Combined Ice and Wind –*** This criterion was added in the 2007 NESC to account for extreme ice events. This criterion is similar to the Extreme Wind loading. Most Transmission assets will be designed to this criterion while distribution assets will not. Over the years most utilities had their own extreme ice loading for the design of Transmission assets. The maps from ASCE 7-05 have been retained and referenced for this criterion.
- Additional Standards related to hazard-resistant design include:
    - ASCE 7-10 exempts electrical lines from seismic design
    - ASCE 113 applies design criteria for stations. Seismic design is addressed in this standard
    - ANSI O5 applies to wood poles
    - ANSI C29 applies to insulators

Some utilities on the east coast are now starting to look at station hardening due to hurricane Sandy. This includes raising structures and control buildings at existing stations, or relocating the station outside the flood zone. Much of this guidance is a result of state and local floodplain management practices and requirements as opposed to specific codes, standards, or regulations from the energy industry itself. And while NSEC rules exist for vegetation management, there is a lack of Codes, Standards, and industry-accepted Best Management Practices that consistently address maintenance requirements.

7.5.1.1. Implied or stated Performance Levels for Expected Hazard Level

As discussed in the previous section, structures greater than 60 feet tall are designed for ASCE 7 wind and ice hazards. Though the NESC defines these as an “extreme” loading case, these loads are consistent with the expected event as defined in this framework. Therefore, new/future energy infrastructure greater than 60 feet tall should experience very few failures in an expected event. However, energy infrastructure less than 60 feet tall (i.e., most distribution structures) is not required to be designed to the NESC “extreme” loads. Rather, they are designed to Rule 250B criteria, which is less than an expected event as defined in Chapter 3. Therefore, failures in the energy distribution system are likely to occur in an expected ice or wind event. As seen in the example performance goals in Section 7.3, it is anticipated that some failures in the distribution system would also occur to the routine wind or ice event, though these will likely be limited, resulting in less outages.

Many failures of the energy infrastructure are due to tree fall or debris impact rather than direct wind/ice loading itself. Therefore, the electric utility’s ability to maintain an effective tree-trimming program will greatly impact the performance levels of the infrastructure when a hazard event does occur.

7.5.1.2. Recovery levels

As discussed, failures of energy infrastructure less than 60 feet are likely to occur in an expected event, particularly wind and ice events. The time to recover and restore service so the system is fully functional will depend on a number of factors, such as whether distribution lines are overhead or underground, effectiveness of the energy utility tree-trimming program, mobility of emergency repair crews, availability of resources for repair, and size of the impacted area. Overhead distribution lines may fail more frequently due to wind or ice events. However, these failures are easier to access and repair than underground lines, which may occur due to other events.

For earthquakes, overhead structures would be anticipated to perform well due to their flexibility. However, buried distribution lines may fail due to liquefaction or if there is not enough slack in the lines to resist the forces from earthquakes. Flooding may also lead to failure of underground infrastructure if not adequately protected. As previously stated, underground infrastructure damage is more difficult to access and fix. Therefore, while overhead distribution infrastructure may have more widespread failures, it will only take days to weeks to recover, whereas only a few underground failures may result in the same recovery time. However, widespread underground failures may result in weeks (rather than days) of recovery time to achieve full functionality of the system.

7.5.2. Existing Construction

For the older infrastructure elements of the energy system, the design criteria used for hazards varies greatly. In many cases, little to no consideration was given to the forces and loads imparted onto this infrastructure because the infrastructure pre-dated the modern codes such as ASCE 7 Minimum Design Loads for Buildings and Other Structures that provide criteria to calculate and apply such loads. In some instances, most hazard resistance was incorporated through anecdotal information such as siting of critical infrastructure based on past-historical storms or it was provided through conservative design approaches and uses of materials that, by their nature, happen to provide some level of resilience. Further, performance goals for these systems were likely never considered or defined. As a result, old infrastructure has inherent vulnerabilities because many of the systems were not designed for these specific hazard loads. This section discusses the anticipated or implied performance from existing infrastructure elements to help develop better performance metrics for communities.

Existing infrastructure in the energy system was designed and constructed to codes and standards that did not address hazards to the level of current codes and standards. Because of this a number of vulnerabilities exist in both the electrical system, and the communications infrastructure used to control it. As a result, these older assets remain vulnerable (with existing equipment and systems) unless the equipment is replaced due to age or new codes/regulations or enforced internal utility best practices require an upgrade. Examples of these vulnerabilities are:

- ***Clustered, below grade transformers.*** Transformers tightly clustered in underground vaults and small substation yards – many at or below grade (to hide the ugly infrastructure). These below grade vaults often fill with water and debris during floods, mud slides, and earthquakes. Redundant means must be provided to mitigate these hazards to enjoy the otherwise substantial benefit of below grade, protected infrastructure.
- ***Single pole substation high and low voltage feeds.*** Using single poles to take both the incoming and outgoing lines from substations add a potential single point of failure. If separated and the incoming high voltage pole/tower fails, distributed generation may still be able to feed the station. If a low side feeder exit pole fails, the incoming high voltage feed remains as do other low voltage feeder poles.
- ***Fuses, not breakers in many locations.*** Using fuses rather than breakers/reclosers in different parts of a distribution system is cost based. Using more breakers and reclosers may be a new best practice when considering resiliency. Also, the lack of sectionalizers in many utility systems can mean that a single fault prevents all customers from having power turned back on while the damaged circuit is being repaired.
- ***Underground ducts run close together and crossing in many shallow manholes.*** A potential common mode failure challenge not generally considered in existing design practices.

- ***Lack of automation.*** Most switching in the distribution grid today is local and manual – meaning that to turn on power using alternate configurations, a person has to get to the gear when staff to do that is the most scarce.

Other vulnerabilities present in existing communications and control equipment include supporting the energy system:

- ***Single communications card/frequency in devices.*** Single point of failure issue and potential interference issue with increased radio traffic used in major disaster response scenarios.
- ***Single encryption key or worse (default passwords) for all devices in a system.*** This is a well-known security issue being addressed in critical infrastructure – but presently most distribution systems are not considered critical infrastructure.
- ***Very small batteries/super capacitors in devices.*** This leads to very short communications windows – on narrow channels – which progresses to notable numbers of dropped or missed communications during outages limiting the ability to optimize crew dispatch.
- ***Mesh networks performance on cold start.*** Some mesh network implementations being used for field area networks tend to be very fragile when the system starts to have outages, and take time to reform after an outage – while the mesh design is supposed to be highly resilient in the most critical moments – it can be its own worst enemy as implemented today (e.g. small batteries, deep mesh designs, lack of stored cold start parameters, etc.)
- ***Common right of ways.*** Fiber and other communication circuits tend to run in the same rights of ways (on the same poles) as the electrical service – breaking one normally breaks both.
- ***Telecommunications Route Diversity.*** This concept is often a myth because of the small number of telecomm switches/and actual central offices/as well as multiplexing thousands of VPNs in a single fiber
- ***Cellular Communications Emergency Operating Practices.*** While cellular towers offer dual coverage in many places, the tendency is to only put batteries at some and back up generation at fewer locations – so the towers revert to emergency calling only when the grid goes down – locking out grid communications that use cellular communications for backhaul.
- ***Digital Phone System Powering Requirements.*** Unlike the POTS system – the new digital phone systems requires power at each street box – in some cases there are batteries, in others there are not – Cable companies have the lowest installation of batteries in their VOIP = data systems compared to other telecomm providers
- ***Wireless Communications Spectrum Clustering and Frequency Agility.*** Wireless frequencies tend to be highly clustered, meaning that even low power jammers can disrupt all of the wireless related communications to the grid (e.g. Push to talk and DA/SA/AMI, etc.)
- ***Signaling System Security Vulnerabilities.*** SS7 vulnerabilities have not been closed for G3 or G4 cellular systems – meaning that they can be jammed or intercepted by a knowledgeable person with little in the way of specialized equipment in an unencrypted form.

Most of these issues do not have explicit codes and regulations – but some do. Most come under the category of best practices on both customer and utility sides of the meter. These vulnerabilities will remain until new construction undertaken using new codes and best practices that consider resilience replaces the older infrastructure.

7.5.2.1. Implied or stated Performance Levels for Expected Hazard Level

Some existing utility infrastructure is up to 30 years in age and most infrastructure 10 years or newer are highly dependent on communications and control networks to operate effectively in adverse conditions. This is especially true for those systems with some level of automation that permit automatic or remote controlled circuit switching, sectionalizing and reconfiguration. Situational awareness to know the availability and operational state of field assets is also directly impacted by the availability of communications equipment.

There are multiple failure modes for communications and control equipment. One that is addressed by codes and standards for new construction is the ability of this electronic equipment to operate correctly in harsh environmental conditions. Early implementations of network gear in substations were based on consumer gear (think LinkSys) that had very low tolerance for temperature, humidity, shock, vibration, and the electromagnetic environment. Even first generation industrial quality gear intended for utility applications did not consider the environment found in substation and feeder applications. New standards, such IEC 61850-3 and IEEE 1613, begin to address these concerns. The IEC standard used around the world, but especially in Europe, have good environmental (temperature, shock, and vibration) guidelines – but the equivalent IEEE standard used primarily in North America does not. In North America there is presently no code or regulation that requires communications and control equipment to comply with any standard – and utility enforced best practices are still emerging. The bottom line is that the system will be vulnerable to communications and control failures in extreme conditions for some time to come.

7.5.2.2. Recovery levels

When events do occur and recovery efforts are required, the priorities and restoration efforts should address emergency-related societal needs first and progress through a tiered response. While the model of recovery can be complex, for simplicity, three general tiers to focus on are the restoration of services for emergency facilities and services (Critical and Essential Facilities), for critical public works and right of way (access) for critical infrastructure restoration crews, and then the systematic restoration of the community at large. Samples of how the infrastructure elements may (and could) perform was discussed in Section 7.3. Additional suggestions for how the infrastructure and facilities should respond when impacted by a Routine, Expected, or Extreme event are also expanded upon below:

1. ***Emergency Facilities and Services Restoration:*** Technologies and systems that address core emergency services should be properly planned, tested, maintained, and restored first. These facilities normally include 911 call centers, police, fire, and emergency medical dispatch stations. They also include centers identified for emergency shelter, food, and water, such as community centers, schools, and stadiums. When planning for disaster responsiveness, also consider communication infrastructure that links critical emergency resources (wire line communications, cellular radio, and third party managed radio systems).

2. ***Critical Rights of Way and Infrastructure Restoration:*** The next priorities to address include systems necessary to dispatch and manage road and right of way clearing crews, electric repair crews, and other non-emergency yet vital restoration related organizations and services. This list includes critical government facilities and communications paths to allow government to function effectively, manage the crisis, and maintain civil order. Energy resiliency in this sense covers emergency power for utility crew dispatch centers, key city buildings such as city hall, public works crew facilities. It also covers the business processes in place to ensure generators and UPS systems in these facilities are sized appropriately and tested periodically.

3. ***Socio-Economic Continuity Restoration:*** The next priority is to support socio-economic continuity. Full restoration typically requires days or even weeks. This aspect of restoration is often unplanned and the biggest utility clients or loudest complainers often move to top of the priority list. This element should be carefully prioritized and integrated into a community resilience plan. First, ensure citizens outside of the community shelters have access to food, water, fuel/energy, and communications. After these immediate needs are met, identify businesses supporting the basic needs of citizens such as water and sewage utilities, grocery stores, gas stations, drug stores, internet and telephone service providers, and make them priorities for restoration.

4. Mitigation projects or resiliency efforts may include hardening distribution systems and employing technologies such as backup generation, renewable energy, or microgrids to ensure these facilities remain online throughout the event or can be rapidly restored. Key infrastructure

elements also need protecting, such as sewage lift stations and water pumping stations. All these equipment and systems should be periodically tested and properly maintained in order to achieve the economic and societal benefit of the investment.

7.6. Strategies for Implementation of Community Resilience Plans

Section 7.2 discusses components of the energy infrastructure system. The discussion includes some potential vulnerabilities observed in the past encouraging the reader to think about the different hazards that could impact the energy infrastructure in their community. The number, types, and magnitudes of hazards that need to be considered will vary from community to community.

Section 7.3 discusses the performance goals of the energy infrastructure strived for by the community. Section 7.3 does provide example performance goals for the routine, expected and extreme event. However, the performance goals should be adjusted by the community based on its social needs.

Sections 0 and 7.5 outline some of the regulatory levels and issues, and codes and standards that the reader should keep in mind when planning to make upgrades/changes to existing energy infrastructure. The objectives of this section are to use the information from Section 7.2 through 7.5 and provide guidance on how a community should work through the process of assessing their energy infrastructure, define strategies to make its infrastructure more resilient, and narrow the resilience gaps.

7.6.1. Available Guidance

Another term is often used to describe energy system resiliency and reliability – Energy Assurance. Energy Assurance refers to the entire process of managing all aspects of energy delivery, resiliency and reliability to ensure a desired outcome for how energy services will perform during normal and abnormal situations.

Energy Assurance is often focused on assisting local governments to become more resilient to loss of energy. Becoming more energy resilient will help local governments prepare for, respond to, recover from, and mitigate against potential emergencies that impact energy while minimizing economic loss and protecting public health and safety. For the purposes of this framework, Energy Assurance is about:

- Ensuring "key assets" are functional when needed;
- Fostering critical public-private partnerships before incidents happen;
- Gaining awareness of energy dependencies; and,
- Identifying actions and projects to move toward increased energy resiliency.

Examples of how Energy Assurance is used as a means to collect the multitude of disciplines, characteristics and dimensions of energy delivery, resilience, and reliability planning processes together include the DOE's Energy Assurance program (http://energy.gov/oe/services/energy-assurance), The National Association of State Energy Officials (NASEO) State Energy Assurance Guidelines (http://www.naseo.org/Data/Sites/1/documents/publications/State_Energy_Assurance_Guidelines_Version_3.1.pdf), and the California Local Energy Assurance Planning (CaLEAP) process (http://www.caleap.org).

Energy Assurance, as a whole, is about assuring that essential services are maintained in the event of an energy disruption. The first step is to identify the "key assets" of the essential services in the community and determine their vulnerabilities. The key assets could be as big as an entire building (e.g., Police or Fire Station) or as small as an element within a building (e.g., communications or HVAC system).

Building relationships is another part of Energy Assurance. Many emergency managers know that building partnerships after a disaster is too late. Attempting to identify who to reach and working around potential obstacles to reach them (e.g., limited or down telecommunications) is difficult. Establishing these relationships helps local governments anticipate actions and clarify roles and responsibilities prior to events; thus increasing the likelihood of a successful and efficient response and recovery.

Gaining an awareness and/or understanding of energy interdependencies is also a very important piece of energy assurance. Our communities have become very complex and many elements within them rely upon another element within the community. In some instances, water systems need energy for their services, but energy providers also need water to produce energy. Understanding these relationships is vital in decision making.

With a good understanding of the key assets and interdependencies, a local government, working with the local energy provider, can identify actions and projects to become more energy resilient.

Because resilience is new, there is a significant need for tools to help both the community and the industry assess resilience. Tools and methods exist to measure reliability, but again, these calculated values typically look at systems during blue sky events and not during natural hazard events.

An example of how resilience has been addressed during recent initiatives is found in energy assurance planning programs. A first step toward implementing resilience in the energy industry is to develop an Energy Assurance Plan tailored for a community. The flowchart developed by the CaLEAP program illustrates the overall approach for developing such a plan including forming an EAP team. Notice that this flowchart is similar to that shown in Chapter 3 of this document outlining the approach to achieve community resilience.

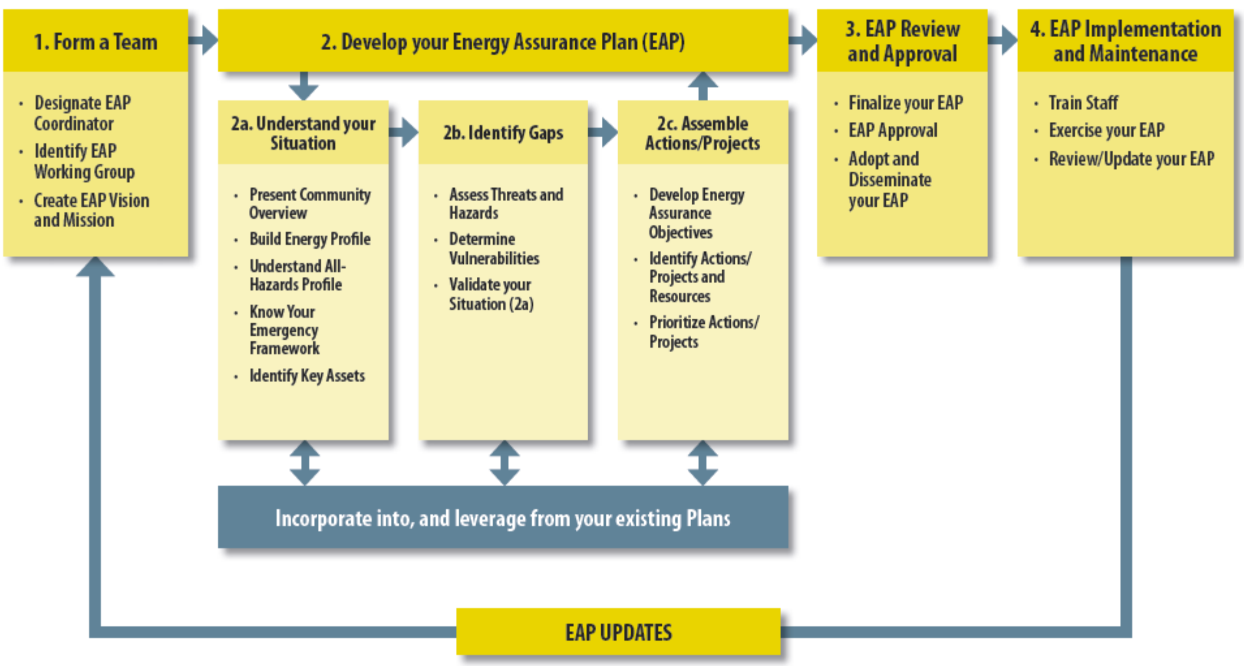

Figure 7-3: Energy Assurance Flowchart Developed by CaLEAP

Thinking about resilience as an aspect of reliability might be the quickest means to develop assessment methodologies to assess and score resilience – especially from the energy service provider perspective. It may allow the ability to explicitly consider large-scale events and non-traditional hazards that were sometimes neglected in previous assessments. It would also set up a means to consider resilience in the current industry mode that allows for variable pricing for duration and a better understanding of scale by adapting to risk-based frameworks that capture interdependencies and likelihood. By assimilating resilience into the factors that assure reliability, regulators might not be charged with setting new criteria for utility performance.

The length of time to restore electric service is a traditional metric of grid reliability. Similarly, the grid's ability to ride through minor disturbances or avoid cascading outages is already considered within existing grid reliability indices. While these metrics and indices (such as System Average Interruption

Duration Index [SAIDI], the Customer Average Interruption Duration Index [CAIDI], the System Average Interruption Frequency Index [SAIFI], the Customer Average Interruption Frequency Index [CAIFI], and others) exist, there are limitations to how these apply to the grid, including the fact that most reliability indices and metrics are blue-sky indicators. When looking at and defining resilience, the events that cause us to measure and evaluate the performance of the grid take place in much harsher and significant conditions (such as natural hazard events and acts of vandalism, crime, and terrorism). Performance goals tables, such as those in Section 7.3, can be used by communities and energy utility providers to set goals for recovery times during hazard events. However, these tables can also be used define to determine the anticipated performance of the infrastructure (i.e., the "X" in the performance goals tables) for a given event. The community or utility can then define the resilience gaps (i.e., the difference between the "90%" and "X" in the performance goals tables) and prioritize strategies for enhancing the resilience of the energy infrastructure system.

7.6.2. Strategies for new/future Construction

In general, when identifying equipment, and other components within the energy system, one of the qualifying criterion should focus on resiliency. When evaluating different vendors and system components, check their track record and references, and collaborate with others.

Construction Strategies. There are several construction strategies that can be used to help improve resilience of energy infrastructure from hazard events, including the following:

- Strengthening and reinforcing critical lines leading to population centers or other critical loads. For instance, adding line reinforcements to lines that serve a hospital or fire station makes them more resilient to wind, ice, and branch loads.
- Establish pole depth standards based on local soil conditions for each pole height. Ensure that poles are planted to the correct depth and the foundation will support the loads.
- Do not overload poles.
- Consider using National Electrical Safety Code (NESC) Grade B construction standards for critical distribution lines. This grade of construction is commonly used in the utility industry and utility surveys show that using Grade B for storm hardening is a popular and effective resiliency construction strategy.
- Consider undergrounding. There are definite pros and cons to using undergrounding. They are less vulnerable to weather, fire, and man-made hazards, but certainly not earthquakes. It is expensive and when faults do occur, they are difficult to locate, take much longer to get to, and are expensive to fix. For an event like Hurricane Sandy or the ice storms of 2012 and 2013, underground cables would have dramatically reduced the amount of damage and restoration times. For an earthquake in California, it could have the opposite effect. Due to the increased costs associated with undergrounding, some options include:
    - Underground circuits based on the largest number of customers services.
    - If there are circuits that will be difficult to access (especially during weather-related hazard events), underground those circuits.
    - If there are circuits whose terrain and surrounding environment make it relatively easy and inexpensive to install underground cable, underground those circuits.
- Consider Covered aerial medium-voltage (CAMV) systems. This hardware attaches to poles and overhead wires to add strength and stability to the wires. The added stability makes the distribution network more resilient to contact with trees and debris, and is especially useful in narrow rights of way with large concentrations of trees.
- Other potential solutions include various pole line configurations that can help minimize restoration efforts.

- In fire prone areas, consider using concrete, heavy steel, or other non-flammable and warp resistant structures to put conductors and equipment overhead. This makes the survival of the line more likely. However, consider driver safety in this upgrade. Because these structures are stronger, consider moving them further from the road rights-of-way so the likelihood of hitting a pole is reduced if an automobile leaves the road.

Non-Construction Strategies. As discussed in Section 7.2, the effects of a number of natural hazards can be mitigated without hardening or other construction strategies of the infrastructure. Some possible non-construction strategies for improving the resilience of energy infrastructure include the following:

- Trim trees and other potential obstructions as far as practical within the right of way.
- Use submersible equipment in underground substations, which can be accomplished in the case of city-run electric utilities or city-owned substations. Submersible equipment stops almost any water-based issue with substation operation, whether from weather events, water main breaks or flooding from other sources.
- Minimize the number of splices in conductors and in ducts that carry the splices. Where possible, position splices in conductors and ducts as far away from water mains as possible and in easily-accessible locations. Note: in high volume rain areas, storm drains can be as large an issue as water mains.
- Consider heavy wall insulation cables, type TC cables, and type MC cables. Heavy wall insulation cables are more resistant to physical damage and moisture, providing better resilience to severe weather conditions than thin wall insulation cables. Type TC cables are used in industrial applications for power and control applications. TC cables have a moisture-resistant jacket and are rated for use in wet conditions. Type MC cables are also moisture-resistant and rated for use in wet conditions. In addition, MC cables are also crush-resistant.

Electrical Infrastructure in Buildings. Specific to energy infrastructure in buildings, the National Institute of Building Sciences recommends that "during the facility design and/or re-build development process, building projects have a comprehensive, integrated perspective that seeks to:

- ***Reduce Heating, Cooling, and Lighting Loads through Climate-Responsive Design and Conservation Practices***
  - Use passive solar design; orient, size, and specify windows; and locate landscape elements with solar geometry and building load requirements in mind.
  - Use high-performance building envelopes; select walls, roofs, and other assemblies based on long-term insulation and durability requirements.
- ***Employ Renewable or High-Efficiency Energy Sources***
  - Renewable energy sources include solar water heating, photovoltaic (PV), wind, biomass, and geothermal.
  - Evaluate the use of building scale to take advantage of on-site renewable energy technologies such as day lighting, solar water heating, and geothermal heat pumps.
  - Consider the use of larger scale, on-site renewable energy technologies such as photovoltaics, solar thermal, and wind turbines.
  - Evaluate purchasing electricity generated from renewable sources or low polluting sources such as natural gas.
- ***Specify Efficient HVAC and Lighting Systems***
  - Use energy efficient HVAC equipment and systems that meet or exceed 10 CFR 434.
  - Use lighting systems that consume less than 1 watt/square foot for ambient lighting.

  - Use Energy Star® approved and/or FEMP-designated energy efficient products or products that meet or exceed Department of Energy standards.
  - Evaluate energy recovery systems that pre-heat or pre-cool incoming ventilation air in commercial and institutional buildings.
  - Investigate the use of integrated generation and delivery systems, such as co-generation, fuel cells, and off-peak thermal storage.

- ***Optimize Building Performance and System Control Strategies***
  - Employ energy modeling programs early in the design process.
  - Use sensors to control loads based on occupancy, schedule and/or the availability of natural resources such as daylight or natural ventilation.
  - Evaluate the use of modular components such as boilers or chillers to optimize part-load efficiency and maintenance requirements.
  - Evaluate the use of Smart Controls that merge building automation systems with information technology (IT) infrastructures.
  - Employ an interactive energy management tool that allows you to track and assess energy and water consumption." 5

The CaLEAP organization has identified additional recommendations for building and retail owners, including:

- Ensuring emergency, life safety, high priority, and general building circuits are well segregated in building wiring design and breaker panel layouts.
- Ensuring building automation systems take advantage of segregated load grouping mentioned above, are standards based (e.g. BACNet), and are capable of accepting utility load control signals (e.g. OpenADR).
- Key community facilities necessary to ensure socio-economic continuity without internal backup generation capability are configured to permit easy, safe connection to external mobile generation (e.g. through standardized connectors at the outside service entrance)

7.6.3. Strategies for Existing Construction

The previous section on strategies for new construction discussed recommendations by the National Institute of Building Sciences in detail. Most of the ideas expressed also apply to existing construction strategies. However, in new construction, there is a larger set of opportunities for energy efficiency and resiliency since nothing has been built yet.

In general, when replacing equipment, and other components within the energy system, each component should be considered and, where more resilient, better reliability choices are available, communities should not replace with the same equipment when practical.

Construction Strategies. Similarly to new/future infrastructure, construction strategies, including the following, can be used to enhance the resilience of existing infrastructure:

- Strengthen and reinforce critical lines leading to population centers or other critical loads. For instance, adding line reinforcements to lines that serve a hospital or fire station makes them more resilient to wind, ice, and branch loads.
- When adding new equipment to poles, perform loading assessment to ensure that the pole is not over-stressed.
- Consider Covered aerial medium-voltage (CAMV) systems.
- Consider replacing overhead lines with underground systems. As discussed previously, this requires careful consideration and a cost/benefit analysis. However, in many cases, the ability of

[5] Source: National Institute of Building Sciences, http://www.wbdg.org/design/minimize_consumption.php

underground systems to provide uninterrupted service (or service with limited outages) during severe weather events has societal and economic benefits that deserve consideration. Due to the increased costs associated with undergrounding, some options include:

- Underground only the worst performing circuits, or section(s) of a circuit.
- Underground circuits based on the largest number of customers services.
- Underground circuits that are difficult to access (especially during weather-related hazard events).

- Consider moving overhead equipment higher so the fire has to reach further to do significant damage.
- A second electrical system path to critical buildings is a resilient design. The alternative electrical path can be from local generation or from an independent path into the area that can be traced back to a power source without crossing the other path.
- Make sure the soil types and insulation properties of the soils are known when burying a line. If the line is buried too shallow, the line will end up out of commission as often as an overhead system and the resulting problems will take far longer to find and fix. Broken overhead infrastructure is typically found by simple visual inspection, while failed underground infrastructure requires investigation by digging or specialized equipment. In some instances, one costly option is to abandon in place and replace the whole distance of the splice to restore the system quickly.
- Use modern flexible fuel lines for the run between the fuel tank and the shelter or skid upon which the generator sit. This installation not only minimizes leaks from vibration, but keeps pipes with lower thermal tolerance away from hot parts of the generator. A cracked or broken insulated fuel line may take hours to detect in an emergency situation because of the chaos. Typically the leak gets worse as the generator vibrates, and the loss of fuel can become significant. A visual inspection of the fuel lines after an earthquake should be conducted as quickly as possible to prevent a hazmat event, fire, or an early shutdown of a back-up generator.

Non-Construction Strategies. In many cases, improving the resilience of existing infrastructure may be more easily accomplished through non-construction strategies. Some possible non-construction strategies for improving the resilience of existing energy infrastructure include the following:

- Trim trees and other potential obstructions as far as practical within the right of way.
- Perform regular tree trimming and line inspections.
- Perform regular pole inspections. Look for excessive pole loading due to telephone, cable (television), and internet-related equipment. If the pole is wooden, check for decay. Check the foundation of the poles to ensure they are properly embedded and stable. If there is erosion around the footing or the pole is leaning, add guy wires or reset/replace the pole. Consider heavy wall insulation cables, type TC cables, and type MC cables.
- Inspect underground splices and equipment on a scheduled basis to make sure seals are intact and that nothing has destroyed the waterproof capability of the connections.
- Using bulkheads that are strong enough to resist the water pressure on the other side in ducts can help protect equipment and minimize damage as well as close off a path of least resistance that will spread the damage from a break. If a duct runs down a 200 foot high hill and the main breaks at the top, the bulkhead would have to resist approximately 400 psi of pressure in the duct. Understanding this in inspection and design is useful. A strong bulkhead at the top of the hill can provide a simple solution that ensures the duct never fills with water.
- Have an adequate stock of spares (poles, transformers, line, etc.) on hand for fire prone areas, and do not use them for routine work. If emergency spares are used in routine work, then it will take even longer to do restoration.

- Aggressive vegetation management is critical to the safety of both overhead and underground infrastructure[6]. This includes removing trash that is illegally dumped on rights-of-way. Recently, over 200 tires were removed from an illegal dumping pile on a right-of-way. These tires would have burned hot enough to destroy the line if they had ignited.
- If possible, cutting off power before wildfire gets to the line allows equipment and lines time to cool and may save the system from destruction. If people have been removed from an area, do not hesitate to turn off power a couple of hours before the fire reaches the area, allowing equipment maximum time to cool. This proactive action can also avoid having fires start as the result of a power line going down or overheating equipment, thereby negating any perimeter that may have been created.
- Controlled burns for vegetation management and invasive species reduction can impact infrastructure if vegetation is close to rights of way. Ensure that precautions are taken prior to controlled burns – about 20% of electrical outages from fires are from controlled burns.
- Proper grounding and inspections of grounding equipment greatly minimize the chance transformer fire can occur from lightning. Standards exist both for how to ground and how to inspect the grounding. Poles in areas that are susceptible to fire should be inspected more often or, the use of non-flammable poles, like concrete, is an intelligent hardening mitigation effort.

Installing and maintaining lightning arrestors and cut outs in the distribution grid can minimize the area that a single lightning strike affects but, in the case of cut-outs, once it is triggered, manual fuse replacement is required. Replacing cutouts with sectionalizers means that the equipment has a chance to stop the lightning and automatically attempt a reset to restore power. On the customer side of the meter, existing construction can be readily retrofit with external generation support connectors as previously noted for new construction. If an existing facility is considering adding any form of self-generation systems, consider upgrading building circuits at the same time to segregate load types. If a building automation upgrade is being considered, ensure that it meets the suggestions previously noted for new construction. As noted previously, consider using the USACE Emergency Power Facility Assessment Tool (EPFAT), which allows public entities to input generator and bill of material requirements to expedite temporary power installation support services.

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8. Communication and Information Systems

8.1. Introduction

PPD-21 identifies "energy and communications systems as uniquely critical due to the enabling functions they provide across all critical infrastructure sectors." These two infrastructure systems are highly interdependent. Communication and information systems, the focus of this chapter, are increasingly critical parts of our daily lives. For example, the banking system relies on the Internet for financial transactions, documents are transferred via Internet between businesses, and e-mail is a primary means of communication. When Internet is not available, commerce is directly affected and economic output is reduced.

Communication and information systems have seen incredible development and use over the past 20-30 years. In terms of system types, functionality, and speed, some of the most notable changes of communication and information systems over the past few decades are:

- Moving from a society that relies on fixed line (i.e., landline) telephones as the primary means of two-way voice communication to one that relies heavily on mobile devices (e.g., cell phones) and Internet (Voice over Internet Protocol, VoIP) for voice communication, text messages, and e-mail. Many now have abandoned traditional landlines in favor of mobile phones and VoIP.
- Moving from a society where large personal computers were used to communicate via e-mail and access information via the Internet to a society where smaller mobile devices, such as laptops and cell phones, are used for the same purpose
- More and more people now use laptops, smart phones, and tablets to read news on the Internet and watch movies and television shows, instead of using traditional methods such as television
- More recently, businesses have begun to use social networking sites for collaboration, marketing, recruiting, etc.

As in many other developed countries, most people in the United States take these services for granted until they are unavailable. Unfortunately, communication and information systems are often lost in the wake of natural disasters—a time when they are needed most for:

- Relaying emergency and safety information to the public
- Coordinating recovery plans among first responders and community leaders
- Communication between family members and loved ones to check on each other's safety
- Communication between civilians and emergency responders

When addressing resilience, communities must also think about the longer term and improving performance of the built environment in the next hazard event. Intermediate and long-term communications and information infrastructure needs of communities include:

- The ability to communicate with employers, schools, and other aspects of individuals' daily lives
- Re-establishing operations of small businesses, banks, etc., via Internet and telecommunications so they can serve their clients
- Restoration, retrofits, and improvements to infrastructure components so it will not fail in the same way in future events (i.e., implement changes to make infrastructure more resilient).

To address resilience of communication and information infrastructure, service providers should work with other stakeholders in the community to establish performance goals for their infrastructure. Example performance goals for the fictional town of Centerville, USA are provided in this chapter to illustrate the process of setting performance goals, evaluating the state of existing communication and information infrastructure systems, identifying weak links in the infrastructure network, and prioritizing upgrades to improve resilience of the network. The example performance goals tables are for a generic hazard, but can be developed by a community/service provider for any type and magnitude of hazard in rural or urban communities.

The goal of this chapter is to provide guidance for the reader that can be used to understand the potential forms of damage to infrastructure and develop plans to improve communication and information infrastructure resilience. Damage observed in past events and success stories are used to show that service providers have many opportunities to become more resilient. Guidance for planning of logistics and personnel are outside the scope of this chapter. Communities and service providers have their own challenges and solutions to accomplish their goals.

8.1.1. Social Needs and System Performance Goals

As discussed in Chapter 2, the social needs of the community drive performance goals that are to be defined by each community and its stakeholders. Social needs of the community include those of citizens, businesses (both small/local and large/multi-national), industry, and government. Each community should define its performance goals in terms of the time it takes for its critical infrastructure to be restored following a hazard event for three levels of event: routine, expected, and extreme, as defined in Chapter 3.

The community has short (0-3 days), intermediate (1-12 weeks), and long-term (4-36+ months) recovery needs. Specific to communications, communities traditionally think about recovery in terms of emergency response and management goals, which include communication between:

- Citizens and emergency responders
- Family members and loved ones to check on each other’s safety
- Government and the public (e.g., providing emergency and safety information to the public)
- First responders
- Government agencies

However, as discussed in the introductory section, communities must think about their long-term social needs when addressing resilience. The community’s intermediate goal is to recover so people and businesses can return to their daily routine. To do this, people need to be able to communicate with their employers, their children’s schools, and other members of the community. Businesses need to have Internet and telephone service to communicate with their clients and suppliers. In the long term, communities should strive to go beyond simply recovering by prioritizing and making improvements to parts of the communications infrastructure that failed in the disaster.

8.1.2. Availability, Reliability, and Resilience

Availability and reliability are terms often used by industry when referring to communications networks. ***Availability*** refers to the percentage of time a communications system is accessible for use. The best telecommunications networks have 99.999 percent availability, which is referred to as “five 9’s availability” (CPNI 2006). This indicates a telecommunications network would be unavailable for only approximately five minutes/year.

Reliability is the probability of successfully performing an intended function for a given time period (Department of the Army 2007). Therefore, though reliability and availability are related, they are not the same. A telecommunications network, for example, may have a high availability with multiple short downtimes or failure during a year. This would mean the reliability is reduced due to incremental disruptions (i.e., failures) in service. Reliability will always be less than availability.

Whether the type of communications system is wireline or wireless telephone, or Internet, service providers market their reliability to potential customers. Service providers think about the communications system itself in terms of the services they provide to the end user rather than the infrastructure (i.e., built environment) that supports the service.

Resilience is closely related to availability and reliability. Like availability and reliability, resilience includes the ability to limit and withstand disruptions/downtime. However, resilience also involves preparing for and adapting to changing conditions to mitigate impacts of future events so disruptions occur less frequently, and, when they do occur, there is a plan to recover quickly. Resilience is also the ability to recover from a disaster event such that the infrastructure is rebuilt to a higher standard. Consequently, by enhancing the resilience of communications infrastructure, availability (amount of downtime) and reliability (frequency of downtime) can be improved. Note that availability will never reach 100 percent because maintenance, which requires downtime, will always be needed.

Capacity. Resilience of communications infrastructure is dependent on the network's capacity. As is often seen during and immediately after disaster events, there is an increase in demand of the communication and information systems (Jrad et al. 2005 and 2006). Section 8.1 points out that, during and immediately after a disaster event, the system is used extensively for communication between family and loved ones, communication with vulnerable populations (e.g., ill or elderly), civilians and first responders, and customers and service providers when outages occur.

Unfortunately, the capacity of a system is not immediately increased for disasters and so cellular phones, for example, may not appear to immediately function properly due to high volume use. This is especially true in densely populated areas, such as New York City, or around emergency shelter or evacuation areas. The latter is an especially important consideration, because some facilities used as emergency shelter and evacuation centers are not designed with that intent.

For example, the Superdome in New Orleans, LA was used as emergency shelter during Hurricane Katrina. Although this was an exceptionally large facility used for sporting and entertainment events, these facilities can be overwhelmed prior to, during, and after disaster events because of the influx of civilians seeking shelter. This results in increased demand on the wireless/cellular network.

With the expansion of technology and the massive growth of cellular phone use, the wireless telecommunications network around emergency shelter facilities will become more stressed in disaster events until augmented by additional capacity.

Jrad et al. (2005) found that for an overall telecommunications infrastructure network to be most resilient, an approximately equal user base for wireline and wireless communications was best. The study found that if one network is significantly greater than the other and the larger one experiences a disruption, increased demand will switch to the smaller network and lead to overload. As a simple example, if landline demand is 1,000,000 users, cellular network demand is 500,000 users, and the landline network experiences a disruption in a disaster event, some landline demand will transfer to the cellular network (Jrad et al. 2005). The increased demand would then stress the wireless network and likely result in perceived service disruptions due to overloading of the network when many calls cannot be completed.

Historically, network connectivity (e.g., reliability or availability) has been a primary concern for communications. However, because of the increased multiuse functionality of mobile communications devices (e.g., cellular phones and iPads), communications network resilience also needs to consider the type of data being used, and hence capacity of the network.

Capacity will become an even greater challenge for communications service providers in the wake of future hazard events. Additional capacity is needed to support service for non-traditional functionality of mobile devices such as sending photographs, watching movies on the Internet, etc. Furthermore, some 9-1-1 centers have the ability to receive photo submissions, which may require more capacity than a phone call. On the other hand, if 9-1-1 call centers can receive text messages, this may also be useful because text messages take up a very small amount of data (i.e., less capacity) and can persist until they get into the network and delivered.

8.1.3. Interdependencies

Chapter 4 provides details of the interdependencies of all critical infrastructure systems in a community. The built environment within communities is continually becoming more complex and different systems are becoming more dependent on one another to provide services. Specific to the communications and information system, the following interdependencies must be considered:

Power/Energy. The communication and information system is highly dependent on the power/energy system. For current high technology and data services, the end user needs external power for telecommunications, Internet, and cable. Loss of external power means loss of communication/information services, except for cellular phones which will likely be able to function until their battery is diminished in the absence of standby power. For use beyond the life of the battery, the cell phone must be charged using an external power source. Furthermore, distribution of communications and power service is often collocated (e.g., wires traveling along utility poles). Failure of these systems can happen simultaneously due to tree fall severing both types of lines. In the wake of a disaster event where external power is lost, communications infrastructure needs continuous standby power to ensure continued functionality.

External power is also critical for cooling critical equipment inside buildings. Air conditioning systems, which keep critical equipment from overheating, are not typically connected to standby power. Therefore, although critical communication equipment may continue to function when a power outage occurs, it may become overheated and shutdown (Kwasinski 2009).

Conversely, emergency repair crews for power utilities need to be able to communicate so they can prioritize and repair their network efficiently. The power provider controls the rights of the utility poles; therefore, the design, construction, routing, and maintenance of telecommunication lines are dependent on the requirements and regulations of the power utility provider.

Transportation. A common problem after disaster events is that roadways and other parts of the transportation system needed in recovery of infrastructure become impassible. Specifically, tree fall and other debris resulting from high wind events (e.g., hurricanes and tornadoes), storm surge/flooding, and ice storms prevent emergency crews from reaching the areas where they need to repair damaged communications infrastructure. Moreover, standby generators cannot be refueled because roads are impassible. Transportation repair crews, including those for traffic signals, need to be able to communicate to ensure their system is fixed. Traffic signals and transportation hubs also rely on communications systems. Traffic signals use communication systems for timing and synchronization of green lights to ensure smooth flow of traffic and transportation hubs use communications system to communicate schedules for inbound/outbound passenger traffic.

Building/Facilities. Buildings and facilities need their communications and information systems to function properly. Buildings used for business and industry communicate with clients, suppliers, and each other via telephone and e-mail. Residential buildings need these services to communicate with employers, loved ones, banks, and services. Currently, money is transferred between businesses, bills are paid to services/businesses and personal banking is completed online or, less commonly, by telephone.

Individuals inside buildings in the immediate aftermath of sudden, unexpected events (e.g., blast events) also need the communications network to learn what is happening.

In large urban centers, service providers often have cell towers on top of buildings. If these buildings fail, an interruption in service may occur due to the loss of the cell tower.

Water and Wastewater. Water and wastewater utilities rely on communications amongst operations staff and emergency workers in the recovery phase. If the communications network, including the cellular network, is down for an extended period of time following a disaster event, the recovery process can take longer since there will be limited coordination in the efforts.

Similar to power/energy, water is needed for cooling systems in buildings that house critical equipment for the communications and information systems. Furthermore, water and wastewater systems are needed in buildings that house critical equipment for technicians.

Security. Security is an important consideration, particularly in the immediate (emergency) recovery after a disaster event. Service providers will not endanger employees. In cases where power and communications systems fail, security becomes an issue because small groups of citizens may use it as an opportunity for looting and violence. Communication and information service providers must be able to work with security to control the situation and begin the recovery process in a timely manner.

8.2. Critical Communication and Information Infrastructure

This section discusses some of the critical components in the communication and information system infrastructure, their potential vulnerabilities, and strategies used in the past to successfully mitigate failures. Figure 8-1 presents components of a telecommunications system.

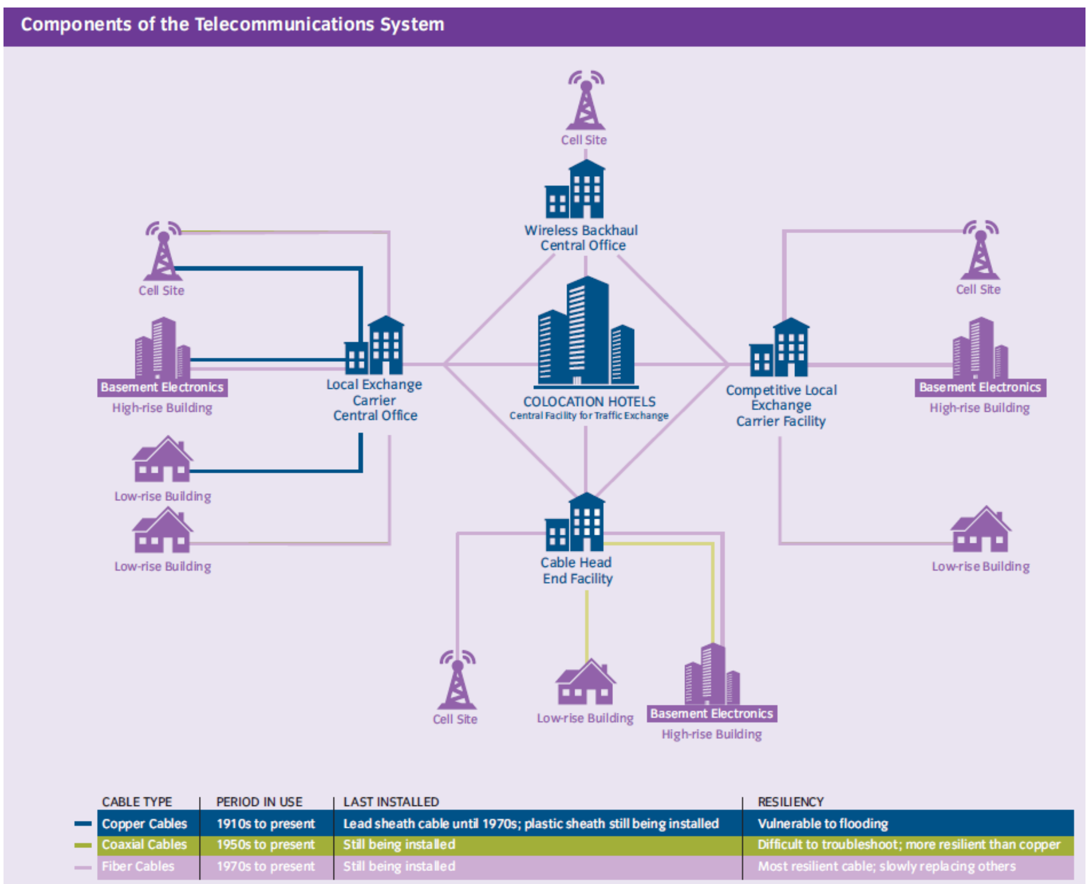

Figure 8-1. Components of the Communications System (City of New York, 2013)

8.2.1. Landline Telephone Systems

Most newer, high technology communication systems are heavily dependent on the performance of the electric power system. Consequently, these newer communication systems are dependent on the distribution of external power to end users, which often is interrupted during and after a disaster. Hence, reliable standby power is critical to the continued functionality of the end user's telecommunications.

Conventional analog landlines (i.e., not digital telephones) operate on a separate electric supply that may be impacted by the event, but service providers often use their own standby power to minimize disruption at end user locations. Hence, landline telephones are generally a more resilient option for telephone communication if commercial power loss is the only impact from a disaster event.

The American Lifelines Alliance (ALA 2006) recommends that landline systems should be retained or reinstated for standby service to reduce vulnerability. However, failure of utility poles or trees onto wires can result in lines for power, cable, and telecommunications being cut, resulting in loss of service.

8.2.1.1. Central Offices

Central Offices, also known as telephone exchanges, are buildings that house equipment used to direct and process telephone calls and data. Maintaining the functionality of these facilities is critical to the timely recovery from an event. These facilities are designed as occupancy Category III (in some cases IV) buildings in ASCE 7 and, consequently, are expected to be fully functional after an expected event.

The primary resiliency concerns for Central Offices are:

- Performance of the structure
- Redundancy of Central Offices/nodes within network
- Placement/protection of critical equipment
- Threat to/from interdependent services

Performance of the Structure. The design of Central Offices is extremely important for continued service of the telecommunications system. These buildings are to be designed as an Occupancy Category III building per ASCE 7, and consequently the design of equipment and standby power must be consistent with that of the building design.

Depending on the location of the community, the design considers different types and magnitudes of disasters. For example, the design of Central Offices in California may be mainly concerned with earthquake loading, whereas Central Offices on the east coast may be concerned mainly with hurricane force winds and/or flooding (especially if it is located in the floodplain as are many Central Offices in coastal communities). In place of providing redundancy of Central Offices, these structures should be designed to resist more severe environmental loads. In cases where Central Offices are located in older buildings that were built to codes and standards that are less stringent than current day standards, it is important to bring these buildings up to modern standards or harden the sections of the building containing critical telecommunications equipment to achieve the desired performance level.

Partial failure of a Central Office can result in the loss of switches and other critical equipment, which results in damage to the communications infrastructure network and loss of functionality. On September 11, 2001 (9/11), four switches were lost in the Verizon Central Office located at 140 West Street (Jrad et al. 2006).

Complete collapse of a Central Office or other building containing a node/exchange in the network would result in loss of all switches and critical equipment. On 9/11, two switches were lost in the World Trade Center Buildings that collapsed (Jrad et al 2006). Though these were not Central Offices, the loss of the nodes could not be recovered. The loss of an entire Central Office would bring the service provider's network to a halt, particularly if no redundancy or backup/restoration capability was built into the network of Central Offices.

Since communities are ultimately responsible for updating, enforcing, and making amendments to building codes, it is important that the most up-to-date building codes be used in the design of new buildings that are used as a part of the communication network. In cases where existing buildings house Central Offices, these buildings should be evaluated and hardened as needed to ensure the critical equipment within the structure is protected.

Redundancy of Central Offices. As learned after the 9/11 terrorist attacks on the World Trade Centers in New York City, redundancy of Central Offices is vital to continued service in the wake of a disaster. On September 11, almost all of Lower Manhattan (i.e., the community most immediately impacted by the disaster) lost the ability to communicate because World Trade Center Building 7 collapsed directly onto Verizon's Central Office at 140 West Street, seen in Figure 8-2 (Lower Manhattan Telecommunications Users' Working Group, 2002). At the time, Verizon did not offer Central Office redundancy as part of its standard service. Furthermore, customers of other service providers that leased Verizon's space lost service as well since they did not provide redundancy either.

Figure 8-2. Damage to Verizon Building on September 11, 2001 (FEMA 2002)

Verizon made a significant effort to restore their services rapidly after the attacks and have since improved their system to use multiple Central Offices for additional reliability. AT&T also endured problems as they had two transport nodes located in World Trade Tower 2, which collapsed and was restored in Jersey City, NJ with mobilized recovery equipment. Overall, almost $2 billion was spent on rebuilding and upgrading Lower Manhattan's telecom infrastructure after 9-11 (Lower Manhattan Telecommunications Users' Working Group, 2002).

Although this was an extremely expensive venture, it is an example that shows building a telecom system with redundancy can eliminate expensive upgrading/repair costs after a disaster event. However, this magnitude of expense is likely not necessary for many other communities.

Placement/Protection of Critical Equipment. Although construction of the building is important, placement and protection of equipment is also an essential consideration if functionality is to be maintained. For example, any electrical or standby power equipment, such as generators, should be placed above the extreme (as defined in Chapter 3) flood level scenario. They should also be located such that it is not susceptible to other environmental loads such as wind. Flooding produced by Hurricane Sandy exposed weaknesses in the location of standby power (e.g., generators). Generators and other electrical equipment that were placed in basements failed due to flooding (FEMA 2013).

Figure 8-3. Large Standby Portable Power Unit Used when Basement Generators Failed (FEMA 2013)

In recent events where in-situ standby power systems did not meet the desired level of performance and failed, portable standby power was brought in to help bring facilities back online until power was restored or on-site standby generators were restored. For example, Figure 8-3 shows a portable standby generator power unit used in place of basement standby generators that failed due to flooding of Verizon's Central Office at 104 Broad Street in Manhattan, NY after Hurricane Sandy (FEMA 2013).

After 9/11, the Verizon Central Office at 140 West Street (i.e., the one impacted by the collapse of WTC 7) was hardened to prevent loss of service in a disaster event (City of New York, 2013). Between 9/11 and Hurricane Sandy, the 140 West Street Central Office:

- Raised their standby power generators and electrical switchgear to higher elevations
- Used newer copper infrastructure (i.e., encased the copper wires in plastic casing)
- Provided pumps to protect against flooding

The City of New York (2013) compared the performance of this Central Office to the one at 104 Broad Street (also affected by Sandy) that had not been hardened. The 104 Broad Street Central Office positioned its standby power generators and electrical switchgear below grade (i.e., in a basement) and had old copper infrastructure in lead casing (City of New York 2013). While the 140 West Street Central Office (i.e., the hardened Central Office) was operational within 24 hours, the 104 Broad Street Central Office was not operational for 11 days.

The success story of the 140 West Street Central Office during and after Hurricane Sandy illustrates that making relatively simple changes in location of equipment can significantly improve infrastructure/equipment performance following a disaster event. This example shows careful planning of critical equipment location and protection is essential to achieving the performance goal of continued service in the wake of a disaster event.

An alternative to raising all critical equipment is to protect it so water does not enter the Central Office during a flood event. Sandbags are often used in North America to protect buildings or openings of buildings from flooding. However, these sandbag barriers are not always effective. After the 9.0 magnitude earthquake and tsunami in the Great Tohoku, Japan Region in 2011, Kwasinksi (2011) observed that watertight doors performed well in areas that experienced significant damage and prevented flooding of critical electronic equipment in Central Offices. Watertight doors, such as that shown in Figure 8-4, can be used in the United States to prevent water from entering a Central Office due to inland (riverine) or coastal (storm surge, tsunami) flooding. Note that other openings, such as windows, may also be vulnerable to flooding and need to be sealed effectively so other failures in the building envelope do not occur (Kwasinski 2011).

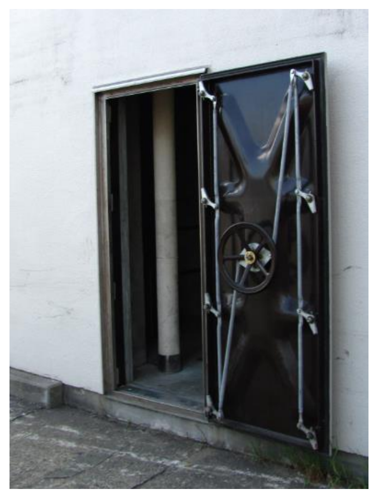

Figure 8-4. Watertight Door Used on Central Office in Kamaishi, Japan (Kwasinski 2011)

Placement and protection of critical equipment should be considered for all types of natural disasters a community may experience. As illustrated by the Hurricane Sandy example, different hazard types warrant different considerations. Equipment stability must be considered for earthquakes. Figure 8-5 shows an example of failure inside a telecommunications Central Office in the 1985 Mexico City Earthquake (OSSPAC 2013). The building itself did not collapse, but light fixtures and equipment failed. Critical equipment in earthquake prone regions should be designed and mounted such that shaking will not lead to equipment failure.

As indicated in Chapter 3 and presented in Table 8-1 through Table 8-3 (see Section 8.3), the desired performance of the communications system in the routine, expected, and extreme event (as defined in Chapter 3) is little or no interruption of service. These Central Office buildings are considered Risk Category III buildings in ASCE 7 and, consequently, should be designed to remain functional through the 1/100 year flood elevation + 1 ft, or the design-based elevation (whichever is higher), the 1,700 year wind event (based on ASCE 7-10), and the 0.2 percent earthquake. In the case of Hurricane Sandy, the desired performance with respect to flooding was not achieved.

***Figure 8-5. Light Fixture and Equipment Failure inside Central Office in Mexico City 1985 Earthquake** (Alex Tang, OSSPAC 2013)*

Although these facilities are less vulnerable to wind than flood, in the case of routine, expected, and extreme events it is critical that the building envelope performs as intended since failure of the building envelope can allow significant amounts of water to enter the building and damage components. Historically, few building envelopes actually meet anticipated performance levels.

Threat to/from Interdependent Services. As discussed in Section 8.1.3 and Chapter 4, interdependencies play a big role in the overall performance of communications infrastructure. Central Offices rely on external power for critical equipment and electrical switchgear. The transportation system is needed for workers to maintain and monitor the functionality of equipment. Functioning water is needed for technicians to enter a building, meaning that if water the water system is not functional, repairs cannot be made to critical equipment.

Electric power is the most obvious and important dependency of the communication and information system. For Central Offices, external electric power is needed to ensure the air conditioning system is functional so it can serve as a cooling system for critical electrical equipment. Although critical equipment is typically connected to backup batteries and/or standby generators, air conditioning systems are not connected to these standby systems. When there is a loss of electric power, critical telecommunications equipment can overheat and shut down as a result (Kwasinski 2009).

Intra-dependencies with the rest of the communications infrastructure network must be considered. A Central Office serves as a switching node in the network and if its functionality is lost, stress is put on the network because the links (distribution system) are not connected as intended.

8.2.1.2. Transmission and Distribution

While the Central Offices of the telecommunications systems play a key role in the functionality of the system, the transmission and distribution system must also be maintained and protected adequately for continued service. There are several components that must be considered for continued functionality:

- First/last mile transmission
- Type of cable (copper wires, coaxial cables, fiber optic cables)
- Overhead vs. Underground Wires
- Distributed Loop Carrier Remote Terminals (DLC RTs)
- Cable Television (CATV) Uninterruptible Power Supply (UPS)

First/Last Mile Transmission. The "first/last mile" is a term used in the communications industry that refers to the final leg of delivering services, via network cables, from a provider to a customer. The use of the term "last mile" implies the last leg of network cables delivering service to a customer, whereas "first mile" indicates the first leg of cables carrying data from the customer to the world (e.g., calling out or uploading data onto the Internet). Although the name implies it is one mile long, this is not always the case, especially in rural communities where it may be much longer (WV Broadband 2013).

As learned from the 9/11 attacks, the first/last mile is a key to resilience for telecommunications and information infrastructure, especially for downtown business telecom networks. In urban settings, service providers typically connect Central Offices in a ring, which connects to the Internet backbone at several points (Lower Manhattan Telecommunications Users' Working Group, 2002). Although the first/last mile is beyond this ring of Central Offices, the redundancy results in a resilient method that improves the likelihood that service providers will achieve their systems performance goal of continual service. Path diversity is built into the infrastructure system often using nodes that connect to the network backbone. However, as learned during workshops used to inform this framework, part of the last mile typically does not connect to the network backbone and, thus, is vulnerable to single-point failures. Furthermore, the location of the node failure also impacts service. If the failed node is between a Central Office and the buildings/facilities it services (i.e., first/last mile) the first/last mile customers will be of service.

There is likely to be less redundancy in the telecommunication and information network cable systems in rural communities. Historically, rural and remote communities have not used these services as frequently or relied as heavily on them as urban communities. This has been the case because:

- In the past, technology to send large amounts of data over a long distance had not been available
- The cost for service providers to expand into remote communities may be too high and have a low benefit-cost ratio

As a result of the lack of redundancy in rural and remote communities, a failure of one node in the service cables (single point of failure) may be all that is necessary for an outage to occur. Therefore, it may not be practical, currently, for rural and remote communities to expect the same performance goals as urban communities. As communications technology continues to grow and change, the level of redundancy (or path diversity) in communications infrastructure delivering services to rural/remote communities is likely to increase. In the case where the reason for loss of telecommunication services in the loss of external power rather than failure of the communications system itself, restoration of services may be quicker for rural communities. As learned in stakeholder workshops held to inform this framework, it was observed in Hurricanes Katrina and Sandy that power can be easier to restore in rural areas because in densely populated areas, components tend to be packed in tightly and other systems need to be repaired first before getting to the power supply system.

Copper Wires. Copper wires work by transmitting signals through electric pulses and carry the low power needed to operate a traditional landline telephone. The telephone company (i.e., service provider) that owns the wire provides the power rather than an electric company. Therefore, the use of traditional analog (i.e., plain old telephone service or POTS) landlines that use copper wire lessens the interdependency on external power (ALA 2006). As a result, in a natural hazard event resulting in loss of external power, communication may still be possible through the use of analog landlines (though this is not guaranteed).

Although copper wires perform well in many cases, they are being replaced by fiber optic cables because copper wires cannot support the large amount of data required for television and high-speed Internet, which has become the consumer expectation in the 21st century (Lower Manhattan Telecommunications Users' Working Group 2002).

Some service providers are interested in retiring their copper wires. Keeping both fiber optic and copper wires in service makes maintenance expensive for service providers and, hence, for customers (FTTH Council 2013). Copper wire is an aging infrastructure that becomes increasingly expensive to maintain. Verizon reported its operating expenses have been reduced by approximately 70 percent when it installed its FiOS (fiber optic) network and retired its copper plant in Central Offices (FTTH Council 2013).

Despite the advantages of traditional copper wire, there are also well-documented problems. As seen during and after Hurricane Sandy, copper wire is susceptible to salt water flooding. Once these metal wires are exposed to salt water, they fail (City of New York 2013). One solution to this problem is to ensure the copper wire is encased in a plastic or another non-saltwater-sensitive material. Furthermore, copper wires are older and generally no longer installed.

Coaxial Cables. Coaxial cable is a more modern material and commonly used for transmission. It offers more resistance to water and is, therefore, not as susceptible to flood damage as copper wires. After Hurricane Sandy, these coaxial wires generally performed well with failures typically associated with loss of power to the electrical equipment to which they were connected (City of New York 2013). Coaxial cable has been and continues to be primarily used for cable television and Internet services. However, coaxial cables are being replaced by fiber optic cable since fiber optics can carry all types of services.

Fiber Optic Cables. Fiber optic cables are more resistant to water damage than either coaxial cable or copper wire (City of New York 2013). Fiber optic cables are now commonly used to bundle home services (television, high-speed Internet, and telephone) into one system, and provide ultra-high speed Internet. The use of fiber optic cables allows for transmission of large amounts of data on a single fiber. These cables are fully water resistant (City of New York 2013). Unfortunately, these services rely more heavily on power provided by a power utility instead of the communications provider itself for the end user. Consequently, during and after a natural hazard event where power is frequently interrupted, landline communications using fiber optic cables are lost in the absence of end user standby power equipment (ALA 2006). In fact, some communities turn off the power prior to the arrival of hurricane force winds for safety purposes. This prevents "live" electric lines from falling on roads, homes, etc., but it also eliminates the external power source for telecommunications of the end user. Some service providers provide in-home battery backup for cable and telephone.

Overhead vs. Underground Wires. Distribution wire can be strung overhead using utility poles, or run underground. There are advantages and disadvantages for both options.

Overhead wire failures are relatively easily located and repaired in the wake of a natural hazard event. However, their exposure makes them especially susceptible to high wind (e.g., hurricanes and tornadoes) and ice hazards. In high wind events, overhead wires may fail due to the failure of poles by the direct action of wind acting on poles and cables, or trees falling onto the cables. Figure 8-6 shows an example of a failed cable television (CATV) line due to the direct action of wind during Hurricane Katrina.

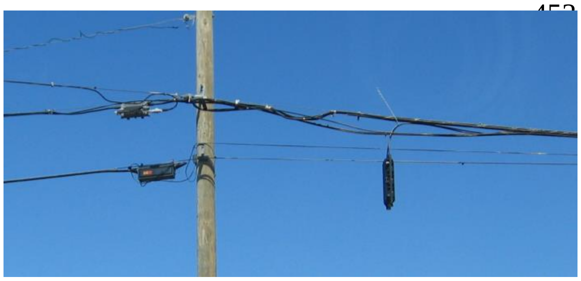

Figure 8-6. Failure of CATV cable due to the direct action of wind (Kwasinski 2006)

Widespread failure of the aboveground system in high winds and ice storms is common and often associated with the effects of tree blow-down and falling branches. This is difficult to mitigate without removing trees. Some improvement in performance can be achieved with continued trimming of branches, to reduce both the likelihood of branches falling on lines and wind-induced forces acting upon the trees, which reduces the blow-down probability. The electric utility that owns the poles performs the tree trimming. Chapter 7 discusses challenges associated with tree removal and trimming.

Ice storms can also result in failure of aboveground communication infrastructure. For example, in January 2009, Kentucky experienced an ice storm in which long distance telephone lines failed due to loss of power and icing on poles, lines, and towers (Kentucky Public Service Commission 2009). Similar to wind hazards, accumulation of ice seen in Kentucky, paired with snow and high winds, led to tree falling onto overhead telephone and power lines. However, unlike power lines, telecommunication lines that have limbs hanging on them or fall to the ground will continue to function unless severed (Kentucky Public Service Commission 2009). Since long distance telecommunications depend on power from another source (i.e., power providers), communication with those outside the local community was lost during the storm. Following the 2009 Kentucky ice storm, many communities became isolated and were unable to communicate their situation and emergency needs to regional or state disaster response officials (Kentucky Public Service Commission 2009). However, as learned in workshops held to inform this framework, long distance communications do have standby power capability.

Emergency response and restoration of the telecommunications infrastructure after a hazard event is an important consideration for which the challenges vary by hazard. In the cases of high wind and ice/snow events, tree fall on roads (Figure 8-7) slows down emergency repair crews from restoring power and overhead telecommunications. Ice storms have their own unique challenges in the recovery process. In addition to debris (e.g., trees) on roads, emergency restoration crews can be slowed down by ice-covered roads, and soft terrain (e.g., mud) in rural areas. Emergency restoration crews also face the difficulty of working for long periods of time in cold and windy conditions associated with these events. Communities should consider the conditions under which emergency restoration crews must work in establishing realistic performance goals of telecommunications infrastructure.

Figure 8-7. Trees Fallen Across Roads Due to Ice Storm in Kentucky Slowed Down Recovery Efforts (Kentucky Public Service Commission 2009)

Although installation of underground wires eliminates the concern of impacts from wind, ice, and tree fall, underground wires may be more susceptible to flood if not properly protected, or earthquake damage and liquefaction.

Communities in parts of the United States have debated converting their overhead wires to underground wires to eliminate the impacts from wind, ice, and tree fall. However, converting overhead to underground wires is both challenging and expensive (City of Urbana Public Works Department 2001). The main challenges/issues associated with converting from overhead to underground wires noted in the City of Urbana's Public Works Department Report (2001) are:

- Shorter design life of the underground system
- Lack of maintenance and repair accessibility of the underground facilities
- Aboveground hardware issues
- Converting all customers' wiring to accommodate underground in place of aboveground services

Service providers, like electric utility providers, would pass the cost associated with converting from overhead to underground wires to their customers (City of Urbana Public Works Department 2001). As discussed in Chapter 7 (Energy Systems), electric utility companies have tree trimming programs (and budgets) to reduce the risk of tree branches falling and damaging their distribution lines. The power utility is also reimbursed by telecommunications service providers since their services also benefit from the tree trimming program. The cost associated with maintaining a dedicated tree trimming program is significantly less than converting from overhead to underground wires because converting to an unground network involves many expensive efforts, including removing the existing system, lost cost resulting from not using the existing system for its design life, underground installation costs, and rewiring each building to accommodate underground utilities (City of Urbana Public Works Department 2001). Since telecommunications service providers and electric power utilities share infrastructure, they should work together to decide what is best for their distribution system.

Loop Digital Carrier Remote Terminals. Loop Digital Carrier Remote Terminals (DLC RTs) are nodes in the landline and Internet network that allow service to be distributed beyond the range for a given Central Office or exchange. Historically, copper wires provide service from a Central Office to a customer within approximately 4 kilometers of that Central Office (Kwasinski et al. 2006). The use of fiber optic cables and curbside DLC RTs can extend this range of service to approximately 10 km (Kwasinski et al. 2006). Therefore, DLC RTs provide a possible solution for service providers to reach customers further from their existing Central Offices or exchanges without having to invest in the construction of additional Central Offices. However, these nodes will not always allow sufficient capacity to replace the demand of a Central Office or node. Therefore, the service provider should consider how many customers it needs to serve (i.e., demand) with the node and if that number will grow (e.g., due to expansion of developments in area) or shrink (e.g., customers leave and do not come back as was the case after Hurricane Katrina).

DLC RTs can be used to rapidly replace smaller Central Offices or nodes as was done after Hurricane Katrina when less capacity than before the event was needed (Kwasinski 2011). This can help limit downtime of the network, but appropriate planning is needed to ensure the DLC RTs do not fail after the next hazard event. Perhaps the two most important things for service providers to consider when implementing DLC RTs are construction to limit vulnerability to hazards and standby power, which is a crucial consideration for any communications infrastructure.

A key lesson learned for DLC RTs from Hurricane Katrina was that nodes should be elevated in storm surge areas so they are not impacted in future hazard events (Kwasinski 2011). The former BellSouth in New Orleans implemented this practice in New Orleans and the surrounding region after Hurricane Katrina. Figure 8-8 shows a DLC RT elevated on a platform. The building in the background of the figure was a small Central Office in which all equipment was damaged during Hurricane Katrina, but never replaced (Kwasinski 2011). When the next set of storms (i.e., Hurricanes Gustav and Ike) passed through the region in 2008, many of the DLC RTs were not physically damaged due to storm surge.

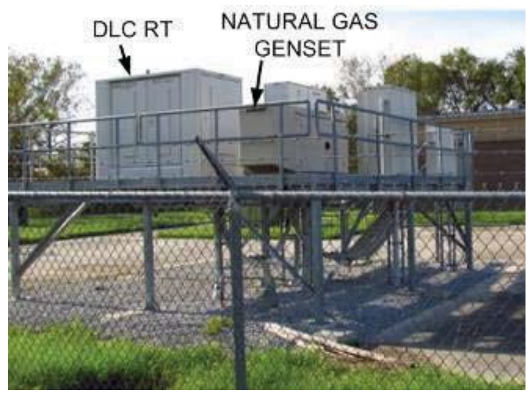

Figure 8-8. Elevated DLC RT with Natural Gas Standby Generator Installed After Hurricane Katrina (Kwasinski 2011)

Like cell towers, DLC RTs, need standby power to function when external power is disrupted as often occurs in a hazard event (see Section 8.2.3.1). Standby power generators can either be installed permanently, or deployed after a disruption in service. There are challenges associated with both options.

Waiting until after an event to deploy standby generators can be difficult because:

- It can require significant labor support and logistics to mobilize a large number of standby generators
- Fuel-operated standby generators require refueling during extended outages, which can be problematic due to access to fuel
- Transportation routes to reach nodes may be impassible due to debris

In contrast, permanent generators can be expensive to install and maintain for a large number of sites, and require periodic testing to ensure they will function when needed. Furthermore, permanent generators should also be placed such that they are less vulnerable to the hazards that face the community (e.g., raised above anticipated storm surge levels). The installation of permanent standby generators (and raising the DLC RTs) after Hurricane Katrina (see Figure 8-8), helped reduce the amount of telecommunications outages during the 2008 Hurricanes (Gustav and Ike) that struck the same region (Kwasinski 2011).

As discussed in other chapters of this document (e.g., Chapter 7), there are several energy options for standby generators. The most common is liquid fuel. Fuel is generally widely available, but may not be immediately after a disaster event which may make refueling challenging if outage times of external power extend for a long period of time. Permanent natural gas standby generators have also been used in the past. Natural gas standby generators performed well during Hurricane Gustav (Kwasinski 2011). However, natural gas generators are not the best option in general because natural gas distribution lines are often shut down prior to an anticipated hazard event to prevent fire and explosions. As a result, natural gas may not be the best option for standby power at critical nodes in the communications network.

Cable Television (CATV) Uninterruptible Power Supply (UPS). Many people receive landline telephone, Internet, and cable television through the same service provider. These services are bundled and distributed to the customers in a similar manner to the typical landline using coaxial cable. UPS systems are used to inject power into the coaxial cable so CATV service can be delivered to customers (Kwasinski et al. 2006). UPS systems are placed on a pedestal on the ground or on a utility pole. Kwasinski (2011) documented several of the challenges associated with this infrastructure, including the placement of UPS' on the ground or on utility poles, and providing adequate standby power. Like all of other critical equipment discussed in this chapter, it is important to place UPS systems such that their vulnerability to hazards is minimized. Figure 8-9 (left) shows two UPS systems after Hurricane Katrina: one that was mounted on a pedestal at ground level was destroyed due to storm surge, and another that was mounted to a utility pole was not damaged. However, Figure 8-9 (right) also shows that placing UPS systems too high on utility poles can interfere with regular maintenance (Kwasinksi 2011). As previously mentioned, providing adequate standby power is a challenge, particularly for a pole-mounted UPS, because the additional load on a utility pole to provide sufficient standby power may be more than the pole can withstand.

Figure 8-9. Placement of UPS Systems is an Important Consideration for Resilience and Periodic Maintenance (Kwasinski 2009)

8.2.2. Internet Systems

The Internet has become the most used source of communication over the past couple of decades. It is continually used for e-mail, online shopping, receiving/reading the news, telephony, and increasingly for use of social networking. Businesses rely heavily on the Internet for communication, sending and receiving documents, video conferencing, e-mail, and working with other team members using online collaboration tools. The Internet is heavily used by financial institutions for transferring funds, buying and selling stocks, etc. Connectivity is becoming more important in the healthcare industry as it moves towards electronic medical records.

High-speed Internet is often tied in with telephone and cable by service providers through coaxial or fiber optic wires. The Internet depends on the electric power system, and loss of power at any point along the chain from source to user prevents data reception. As a result, Internet dependency on the electric power system makes it vulnerable to the performance of the power system in a natural hazard event. A concern for Internet systems, as is the case for landlines, is single points of failure (i.e., an individual source of service where there is no alternative/redundancy).

8.2.2.1. Internet Exchange Points (IXP)

Internet Exchange Points are buildings that allow service providers to connect directly to each other. This is advantageous because it helps improve quality of service and reduce transmission costs. The development of IXPs has played a major role in advancing development of the Internet ecosystem across North America, Europe, and Asia (Kende and Hurpy, 2012). IXPs now stretch into several countries in Africa and continue to expand the reach of the Internet. IXPs facilitate local, regional, and international connectivity.

IXPs provide a way for members, including Internet Service Providers (ISPs), backbone providers, and content providers to connect their networks and exchange traffic directly (Kende and Hurpy 2012). Similar to Central Offices for landlines, this results in IXPs being a potential single point of failure.

The buildings housing the IXPs would be expected to meet the ASCE 7 requirements for critical buildings (Occupancy Category IV) and, consequently, would be expected to perform with no interruption of service for the “expected” event, or hazard level. The facilities would be expected to have sufficient standby power to function until external power to the facility is brought back online.

Location of Critical Equipment in IXPs. Another similarity to telecommunications Central Offices is that the location and protection of critical equipment is important. Critical equipment should be protected by placing it in locations where it will not be susceptible to expected hazards in the community. For example, inevitably some buildings are in floodplains because many large urban centers are centered around large bodies of water or on the coast. The owner, engineers, maintenance, and technical staff must all be aware of potential hazards that could impact the equipment within the structure. As should be done for telecommunications Central Offices, the following considerations should be taken into consideration for the critical equipment of IXPs:

- Electrical and emergency equipment should be located above the elevation of an “extreme” flood, which is to be defined by the community (see Chapter 3). Alternatively, tools such as Sea, Lake, and Overland Surges from Hurricanes (SLOSH) maps could be used to define the minimum elevation for electrical and critical equipment.
- Rooms housing critical equipment should be designed to resist extreme loads for the community, whether it is earthquake, high wind, blast, other hazards, or a combination of hazards. Remember that fire is often a secondary hazard that results from other hazard events.
- Where possible, redundancy and standby power for critical equipment should be provided.

All too often, communities see the same problems and damage in the wake of a natural hazard event (e.g., loss of power, loss of roof cover and wall cladding leading to rain infiltration in high wind events). Fortunately, many problems can be mitigated by sufficient planning and risk assessment (as previously discussed in the comparison of two telecommunications Central Offices in New York City after Hurricane Sandy). Careful placement and protection of critical equipment can help achieve performance goals of the Internet’s critical equipment. For example, in flood prone regions, critical equipment should be placed above the extreme flood level for the area. In earthquake regions, critical equipment should be designed and mounted such that shaking from earthquake events does not cause failure.

8.2.2.2. Internet Backbone

The Internet Backbone refers to the cables that connect the "network-of-networks." The Internet is a system of nodes connected by paths/links. These paths run all over the United States and the rest of the world. As a result, many of the same challenges identified for the landline cables for fiber optic cables exist for Internet, namely that it requires power to function. The heavy reliance on power impacts the performance and recovery goals of Internet service for service providers and their customers.

Path Diversity. Path diversity refers to the ability of information to travel along different paths to get to its destination should there be a failure in its originally intended path (i.e., path diversity is synonymous with redundancy). The more diversity that exists, the more reliable the system.

8.2.3. Cellular/Mobile Systems

The cellular telephone system has most of the same vulnerabilities as the landline system, including the local exchange offices, collocation hotels, and cable head facilities. Other possible failure points unique to the cellular network include the cell site (tower and power) and backhaul switches at Central Offices. Figure 8-1 (page 5) shows how the cellular phone network fits within the telecommunication network. At the base of a cell tower is switchgear (also known as Cell Site Electronics) and standby power. Damage of switchgear at the base of the tower prevents switching to standby power when commercial power fails.

8.2.3.1. Cell Towers

Virtually all natural hazards including earthquake, high wind, ice and flood affect the ability of an individual cell tower to function through loss of external power or failure of cell phone towers themselves.

Loss of External Power. Large scale loss of external power occurs relatively frequently in hurricanes (mainly due to high wind and flooding), large thunderstorm events (such as those associated with derechos and tornadoes), ice storms, and earthquakes. Some cell towers are equipped with batteries designed to provide four to eight hours of standby power after loss of external power (City of New York 2013). In the past, the FCC has attempted to mandate a minimum of eight hours of battery standby power, but the requirement was removed by the courts. However, adequate standby power should be provided for cell towers, particularly in areas that serve critical facilities. The functionality of the tower can be extended through use of permanent or portable diesel generators. Portable generators were used in New York following Hurricane Sandy in 2012. The installation of permanent diesel generators has been resisted by the providers due to the high cost and practicality (City of New York 2013).

Recalling that buildings and systems should remain fully functional during and after a routine event (Chapter 3), all cellular towers and attached equipment should remain operational. There is an expectation that the 9-1-1 emergency call system will remain functional during and after the event. Considering the poor performance of the electric grid experienced during recent hurricanes (which produced wind speeds less than the nominal 50 to 100-year values as specified in ASCE 7 [93, 95, 02 and 05]), external power is unlikely to remain functional during the expected, or even routine (as defined in Chapter 3) event. Consequently, adequate standby power is critical to ensure functionality. Recent experience with hurricanes and other disaster events suggest the standby power needs to last longer than the typical current practice of four to eight hours (City of New York 2013).

In flood prone areas, the standby power needs to be located, at a minimum, above the 100-year flood level to ensure functionality after the event. Similarly, the equipment must be resistant to the 50-year earthquake load.

The use of permanently located diesel electric standby power poses significant difficulties due to the initial and ongoing required maintenance costs. Diesel generators are often (though not always) loud and may generate complaints from nearby residents. In the case of events such as hurricanes and major ice storms where advanced warning is available, portable generators can be staged and deployed after the storm. However, for widespread hazard events, such as hurricanes and ice storms, the need often exceeds the ability to deploy all of the portable generators needed. When they are deployed, the portable generators usually require refueling about once per day so continued access is important. Permanent generators also require refueling, but the frequency is variable due to the different capacities of permanent generators. In events where there is little to no warning, such as earthquakes and tornadoes, staging of portable generators cannot be completed ahead of time. However, for localized events that are unpredictable and short duration (e.g., tornadoes, tsunamis), portable generators may be the best approach for quick recovery of the system's functionality.

In highly urbanized areas, such as New York City, cell towers are frequently located on top of buildings, preventing the placement of permanent diesel standby generators and making it difficult to supply power from portable generators because of impeded access.

Improvements in battery technology and the use of hydrogen fuel cell technologies may alleviate some of the standby power issues. Furthermore, newer cellular phone technologies require less power, potentially leading to longer battery life. Standby battery technology is a key consideration in establishing the performance goals of cellular phones in the wake of a hazard event.

Failure of Cell Phone Towers. Collapse of cell phone towers due to earthquake, high winds, or flooding should not be expected to occur when subject to a natural hazard event of magnitude less than or equal to the expected event. This was not the case in Hurricane Katrina (2005) where cell phone towers were reported to have failed (DHS, 2006), although many failed after being impacted by flood-borne debris (e.g., large boats, etc.), whose momentum was likely well beyond a typical design flood impact. After an event, failed towers can be replaced by temporary portable towers. Similarly, the January 2009 Kentucky ice storm had cell phone tower failures due to the combination of ice accumulation and winds over 40 mph (Kentucky Public Service Commission 2009).

Cell towers may be designed to either ASCE Category II or ASCE Category III occupancy requirements. The latter is used when the towers are used to support essential emergency equipment or located at a central emergency hub. Consequently, in the case of wind and flood, the towers and equipment located at the base of the tower should perform without any damage during both routine and expected events (Chapter 3).

More commonly, cell towers are designed to meet the criteria of TIA/EIT-222-G. Prior to the 2006 version of this standard (which is based on the ASCE 7 loading criteria), it used Allowable Stress Design (ASD) rather than Load and Resistance Factor Design, wind loads used fastest mile wind speeds rather 3-second gust, and seismic provisions were not provided. The ice provisions differ from version to version, but no major differences in methodology have been noted. Therefore, cell towers designed to meet the criteria of TIA/EIT-222-G should perform well in an expected wind, ice, or earthquake event. However, older cell towers that have not been retrofitted/upgraded to meet the 2006 version of TIA/EIT-222-G may not perform as well. Specifically, cell towers in earthquake-prone regions may have been designed and built without guidance on the loading, which may have resulted in either over- or under-designed cell towers in these regions.

Backhaul Facilities. Backhaul facilities serve a purpose similar to that of the Central Offices and consequently should meet the same performance goals, including proper design of the standby power system.

8.3. Performance Goals

Although the goal of communities, infrastructure owners, and businesses is to have continued operation at all times, 100 percent functionality is not always feasible in the wake of a hazard event given the current state of infrastructure in the United States. Depending on the magnitude and type of event, the levels of damage and functionality will vary. Most importantly, performance goals of the communications infrastructure will vary from community to community based upon its needs and should be defined by the community and its stakeholders. As discussed in Section 8.2, there are many examples of service providers and other infrastructure owners who have successfully made changes to their infrastructure system such that their downtime has been shortened or even eliminated after a hazard event.

This section provides examples of performance goals for the fictional town of Centerville, USA. Communication infrastructure stakeholders and communities can use performance goals tables to assess their infrastructure and take steps in improving their resilience to hazard events. Note that performance goals are specified in terms of recovery time. However, mitigation techniques, including improving design and code/standard enforcement, play significant roles in accomplishing performance goals. Therefore, both mitigation strategies and recovery plans can be used to achieve performance goals.

Before establishing performance goals, it is imperative to understand who the owners, regulatory bodies, and stakeholders of the communications infrastructure are and how they operate. All groups should be involved in establishing performance goals and working together to narrow gaps in resilience.

Infrastructure Owners, Regulatory Bodies, and Stakeholders. Ownership and regulation of communication and information infrastructure systems adds a layer of complexity for resilience. Governments typically do not own communication infrastructure other than in their own facilities. However, Federal, State, and Local government agencies are involved in the regulation of communications infrastructure. The Federal Communications Commission (FCC) has an advisory committee called the Communications Security, Reliability, and Interoperability Council (CSRIC) that promotes best practices, although there are limited requirements for compliance with the practices. However, best practices are often implemented by service providers (despite not being standards) because they help mitigate risks, which is a good idea in a competitive industry.

The FCC has authority over wireless, long-distance telephone, and Internet services, whereas state agencies have authority over local landlines and agencies at all levels have regulatory authority over cable (City of New York 2013). Within these three levels of government, there may be multiple agencies involved in overseeing infrastructure. State and local Departments of Transportation (DOTs) control access to roadway rights-of-way for construction. The local Department of Buildings (DOB) regulates the placement of electrical equipment, standby power, and fuel storage at critical telecommunications facilities as specified in their local Building Codes (City of New York 2013).

Service providers own communications infrastructure. The Telecommunications Act of 1996 was established to promote competition in the communications industry (FCC 2011), which would result in lower prices for customers. This has resulted in a growing number of industry players who share infrastructure to offer options for their services to customers more efficiently. Service providers can sometimes share infrastructure to provide their services. However, their infrastructure cannot always be shared because different providers use different technology that is not compatible.

Telecommunication and Cable/Internet Service Providers, such as AT&T and Verizon, often share infrastructure with providers in the energy industry. For example, utility poles for overhead wires typically serve to transport electric energy, telecommunications, and cable. It is, therefore, essential that key members from these service providers are involved in establishing, or agreeing to, the performance goals for the communications infrastructure. Improved performance of their infrastructure, much like the power industry, will result in improved service in the wake of a hazard event. Moreover, improvements made to achieve performance goals may result in better performance on a day-to-day basis. A service provider may benefit from excellent performance following a hazard event because customers frustrated with their own service may look for other options that are more reliable. Service providers may also experience different damage levels for the same quality infrastructure due to poor fortune, which can provide an inaccurate perception that it is not as reliable as another service provider. However, this may not always be true because some service providers share infrastructure and thus, failures may occur due to interdependencies. Moreover, in a competitive cost-driven industry, the cost to make a system more resilient, which is passed down to customers, may result in losing business. Therefore, including service providers in the group of stakeholders is key because their industry is quite complex.

After the AT&T divestiture of 1984, the end user became responsible for the voice and data cabling on its premises (Anixter Inc. 2013). Therefore, building owners are responsible for communications infrastructure within their facilities. As a result, standards have been developed by the American National Standards Institute/Telecommunications Industry Association (ANSI/TIA) for different types of premises, including:

- Commercial buildings (e.g., office and university campus buildings)
- Residential buildings (e.g., single and multi-unit homes)
- Industrial buildings (e.g., factories and testing laboratories)
- Healthcare facilities (e.g., hospitals)

Communications infrastructure has owners and stakeholders from multiple industries that must be included in establishing the performance goals and improving resilience of system components. For resilience of the distribution communication systems, service provider representatives, including designer professionals (engineers and architects for buildings owned by service providers such as Central Offices/data centers), planners, utility operators, and financial decision makers (i.e., financial analysts) for power service providers must be included in the process. Owners of buildings that are leased by service providers to house critical equipment and nodes in their system are important stakeholders. Additionally, representatives of end users from different industries should be included to establish performance goals and improve resilience of communications system transfer from provider to building owner. Specifically, transfer of telecommunications and Internet to a building is often through a single point of failure. Those involved in building design, such as planners, architects, engineers, and owners need to be aware of potential opportunities to increase redundancy and resiliency.

Performance Goals. Performance goals in this document are defined in terms of how quickly the infrastructure's functionality can be recovered after a hazard event. Minimizing downtime can be achieved during the design process and/or recovery plans. Example tables of performance goals for communications infrastructure, similar to the format presented in the Oregon Resilience Plan (OSSPAC 2013), are presented in Table 8-1 through Table 8-3. These tables of performance goals are examples for routine, expected, and extreme events, respectively. Note that these performance goals were developed based on wind events using current ASCE (ASCE 7-10) design criteria, performance seen in past high wind events, and engineering judgment. Thus, these goals can be adjusted by users as necessary for their community to meet its social needs, consider their state of infrastructure, and the type and magnitude of hazard. For example, an earthquake-prone region may have different performance goals because the design philosophy is for life safety as opposed to wind design which focuses on serviceability.

The performance goals tables (Table 8-1 to Table 8-3) are intended as a guide that communities/owners can use to evaluate the strengths and weaknesses of the resilience of their communications systems infrastructure. As previously discussed, the performance goals may vary from community-to-community based upon its social needs. Communities/owners and stakeholders should use the table as a tool to assess what their performance goals should be based on their local social needs. Tables similar to that of Table 8-1 to Table 8-3 can be developed for any community (urban or rural), any type of hazard event, and for the various levels of hazards (routine, expected and extreme) defined in Chapter 3 of the framework.

Representatives of the stakeholders in a given community should participate in establishing the performance goals and evaluating the current state of the systems. The City of San Francisco provides an excellent example of what bringing stakeholders together can accomplish. San Francisco has developed a lifelines council (The Lifelines Council of the City and County of San Francisco 2014), which unites different stakeholders to get input regarding the current state of infrastructure and how improvements can be made in practice. The lifelines council performs studies and provides recommendations as to where enhancements in infrastructure resilience and coordination are needed (The Lifelines Council of the City and County of San Francisco 2014). Their work has led to additional redundancy being implemented into the network in the Bay Area.

Granularity of Performance Goals. Table 8-1and Table 8-3 present examples of performance goals for different components of the communications infrastructure when subjected to each hazard level. The list of components for this example is not intended to be exhaustive. These lists vary by community based on its size and social needs. In terms of granularity of the performance goals table, the communications infrastructure system is broken down into three categories (see Table 8-2): 1) Core and Central Offices, 2) Distribution Nodes, and 3) Last Mile.

The Core and Central Offices could be split into two different functional categories by nationwide service providers. The Core refers to the backbone of service provider's network that includes facilities that store customer data and information. For larger service providers, these facilities may be geo-redundant and run in tandem so one widespread event, such as a hurricane or earthquake, cannot disrupt the entire network. Central Offices, discussed throughout this chapter, are regional nodes whose failure would result in widespread service disruptions. For this example of performance goals, the Core and Central Offices are treated as one functional category because the performance goals for Centerville, USA are the same (i.e., no failure of Central Offices or Core facilities).

Distribution nodes include the next tier in the communications network that collect and distribute communications at a more local (e.g., neighborhood) level. For Centerville, USA, this includes cell towers. For other communities, this may include DLC RTs and other local hubs/nodes.

The last mile refers to distribution of services to the customers. For landline, Internet, and cable, this is impacted by the performance of the distribution wires in a given hazard event. Wireless technology, such as cellular phones, operates using signals rather than physical infrastructure for distribution. Therefore, the last mile distribution is not needed. Although the system's components (e.g., underground cables, overhead cables, etc.) are not specifically included in the performance goals, they must be considered to achieve the performance goals specified by the community or service provider.

Developing Performance Goals Tables. The community/owners should work to establish their own performance goals. In the example tables (Table 8-1 to Table 8-3), performance goals are established for three levels of functionality. The orange shaded boxes indicate the desired time to reach 30 percent functionality of the component. Yellow indicates the time frame in which 60 percent operability is desired and green indicates greater than 90 percent operability. A goal is not set for 100 percent operability in this example because it may take significantly longer to reach this target and may not be necessary for communities to return to their normal daily lives. The performance of many of the components in the communication network, such as towers and buildings housing equipment are expected to perform according to their design criteria. Recent history, however, suggests this is frequently not the case.

The affected area of a given hazard can also be specified, which is often dependent on the type of hazard. For example, earthquake and hurricanes typically have large affected areas, whereas tornadoes and tsunamis have relatively small affected areas. The affected area is important for a community to consider because it will impact how much of the infrastructure may be damaged, which in turn will impact the duration of the recovery process. The disruption level based on the current state of the communications infrastructure system as a whole should be specified as usual, moderate or severe.

An "X" is placed in the each row of Table 8-1 through Table 8-3 as an example of how a community can indicate anticipated performance and recovery of the infrastructure in their evaluation. As seen in the tables, the hypothetical “X” indicates there is a significant gap between what is desired and what reality is for all of the components. This is a resilience gap. If the community decides that improving the resilience of their Central Offices is a top priority after its evaluation of their infrastructure, the next step would be to determine how to reduce this resilience gap. For Central Offices and their equipment, there are a number of solutions that can help narrow the gap in resilience, including hardening the building to resist extreme loads and protecting equipment from hazards such as flooding by elevating electrical equipment and emergency equipment above extreme flooding levels.

These lessons have been learned through past disasters, including the 9/11 terrorist attacks, Hurricanes Sandy and Katrina, etc. Section 8.6.1discusses potential methods to evaluate the anticipated performance of existing communications infrastructure. Sections 8.6.2 and 8.6.3 provide mitigation and recovery strategies that can be used to achieve the performance goals set by the community or service provider. The strategies in these sections also recognize it will take communities/owners time and money to invest in solutions, and provides possible long and short term solutions.

Emergency Responder Communication Systems. The performance goals include distribution infrastructure to critical facilities such as hospitals, fire and police stations, and emergency operation centers. However, the example performance goals for communication infrastructure do not include communication systems between emergency responders (fire/police/paramedics), which have their own communications networks and devices. Community emergency response providers should ensure their networks and devices remain functional in the immediate aftermath of a disaster event (i.e., there should not be any downtime of emergency responder communication networks). After a disaster event, functionality of critical services communication networks is essential to coordinating response to people who are injured, and fire or other hazard suppression.

Table 8-1. Example Communications Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Nodes/Exchange/Switching Points		**A**									
Central offices			90%		X						
Buildings containing exchanges			90%		X						
Internet Exchange Point (IXP)			90%		X						
Towers		**A**									
Free standing cell phone towers			90%		X						
Towers mounted on buildings			90%		X						
Distribution lines to …											
Critical Facilities		**1**									
Hospitals			90%		X						
Police and fire stations			90%		X						
Emergency operation center			90%		X						
Emergency Housing		**1**									
Residences			90%			X					
Emergency responder housing			90%			X					
Public shelters			90%			X					
Housing/Neighborhoods		**2**									
Essential city service facilities			60%	90%		X					
Schools			60%	90%		X					
Medical provider offices			60%	90%		X					
Retail			60%	90%		X					
Community Recovery Infrastructure		**3**									
Residences			60%	90%		X					
Neighborhood retail			60%	90%		X					
Offices and work places			60%	90%		X					
Non-emergency city services			60%	90%		X					
Businesses			60%	90%		X					

Notes: These performance goals are based on an expected wind event (using current ASCE design criteria) and performance seen in past high wind events.

Footnotes:

1 Specify hazard being considered
Specify level -- Routine, Expected, Extreme
Specify the size of the area affected - localized, community, regional
Specify severity of disruption - minor, moderate, severe

2 | 30% | 60% | 90% | Restoration times relate to number of elements of each cluster

3 | X | Estimated restoration time for current conditions based on design standards and current inventory
Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan
R Regional
S State
MS Multi-state
C Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

Table 8-2. Example Communications Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	**(4) Support Needed**	**(5) Target Goal**	**Overall Recovery Time for Hazard and Level Listed**								
			Expected Hazard Level								
			Phase 1 – Short-Term			**Phase 2 – Intermediate**			**Phase 3 – Long-Term**		
			Days			**Wks**			**Mos**		
			0	**1**	**1-3**	**1-4**	**4-8**	**8-12**	**4**	**4-36**	**36+**
Nodes/Exchange/Switching Points		**A**									
Central Offices			90%			X					
Buildings containing exchanges			90%			X					
Internet Exchange Point (IXP)			90%			X					
Towers		**A**									
Free standing cell phone towers			90%			X					
Towers mounted on buildings			90%			X					
Distribution lines to …											
Critical Facilities		**1**									
Hospitals			90%			X					
Police and fire stations			90%			X					
Emergency Operation Center			90%			X					
Emergency Housing		**1**									
Residences					60%	90%		X			
Emergency responder housing					60%	90%		X			
Public Shelters					60%	90%		X			
Housing/Neighborhoods		**2**									
Essential city service facilities					30%	90%		X			
Schools					30%	90%		X			
Medical provider offices					30%	90%		X			
Retail					30%	90%			X		
Community Recovery Infrastructure		**3**									
Residences					30%	90%		X			
Neighborhood retail					30%	90%			X		
Offices and work places					30%	90%		X			
Non-emergency city services					30%	90%			X		
Businesses					30%	90%			X		

Footnotes: See Table 8-1, page 22.

Table 8-3. Example Communications Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Nodes/Exchange/Switching Points		**A**									
Central Offices			90%			X					
Buildings containing exchanges			90%			X					
Internet Exchange Point (IXP)			90%			X					
Towers		**A**									
Free standing cell phone towers				90%		X					
Towers mounted on buildings				90%		X					
Distribution lines to …											
Critical Facilities		**1**									
Hospitals			90%			X					
Police and fire stations			90%			X					
Emergency operation center			90%			X					
Emergency Housing		**1**									
Residences					30%	90%			X		
Emergency responder housing					30%	90%			X		
Public shelters					30%	90%			X		
Housing/Neighborhoods		**2**									
Essential city service facilities					30%	60%	90%		X		
Schools					30%	60%	90%		X		
Medical provider offices					30%	60%	90%		X		
Retail					30%	60%	90%		X		
Community Recovery Infrastructure		**3**									
Residences					30%	60%	90%			X	
Neighborhood retail					30%	60%	90%			X	
Offices and work places					30%	60%	90%			X	
Non-emergency city services					30%	60%	90%			X	
Businesses					30%	60%	90%			X	

Footnotes: See Table 8-1, page 22.

8.4. Regulatory Environment

There are multiple regulatory bodies at the various levels of government (Federal, State, and Local) that have authority over communications infrastructure. There is no one regulatory body that oversees all communication infrastructure and is responsible for enforcement of the various standards and codes. The rapidly evolving technologies over the past 30 years have led to changes in regulatory jurisdiction, which adds complexity to the regulatory environment. This section discusses regulatory bodies of communications infrastructure at the Federal, State, and Local levels.

8.4.1. Federal

The regulatory body of communication services and, thus, infrastructure is the FCC. The FCC is a government agency that regulates interstate and international communications of telephone, cable, radio, and other forms of communication. It has jurisdiction over wireless, long-distance telephone, and the Internet (including VoIP).

As previously discussed, the FCC has an advisory group called the Communications Security, Reliability, and Interoperability Council (CSRIC) that promotes best practices. The council performs studies, including after disaster events (e.g., Hurricane Katrina), and recommends ways to improve disaster preparedness, network reliability, and communications among first responders (Victory et. al 2006). The recommended best practices are not required to be adopted and enforced since they are not standards. However, as learned in the stakeholder workshops held to inform this framework, industry considers best practices voluntary good things to do under appropriate circumstances. Furthermore, implementing best practices allows service providers to remain competitive in business.

8.4.2. State

State government agencies have authority over local landline telephone service. Most commonly, the agency responsible for overseeing communications infrastructure at the State level is known as the Public Service Commission (PSC). However, other State agencies have jurisdiction over telecommunications infrastructure as well. A prime example is the State DOT. The State DOT has jurisdiction over the right-of-way and, therefore, oversees construction of roads/highways where utility poles and wires are built. Utility poles and wires are commonly placed within the right-of-way of roads, whether it is aboveground or underground. The DOT has the ability to permit or deny planned paths of the utilities.

8.4.3. Local

Local government has jurisdiction over communication infrastructure through a number of agencies. The Department of Buildings (DOB), or equivalent, is responsible for enforcing the local Building Code. Therefore, the DOB regulates the placement of electrical equipment, standby power, and fuel storage at critical telecommunications facilities such as Central Offices (City of New York 2013).

Large cities, such as New York City, Chicago, Los Angeles, and Seattle have their own DOT (City of New York 2013). These local DOTs oversee road construction and the associated right-of-way for utilities (including communications infrastructure). Many smaller municipalities have an Office of Transportation Planning, which serves a similar function.

8.4.4. Overlapping Jurisdiction

Due to the complex bundling packages that service providers now offer customers, a number of regulatory bodies have jurisdiction over the various services provided in said bundle. For example, a bundled telephone, Internet and cable package functions under the jurisdiction of both Local (cable) and Federal (Internet and VoIP) agencies (City of New York 2013). Furthermore, changing from traditional landlines to VoIP shifts a customer's services from being regulated by State agencies to Federal agencies. As technology continues to evolve, jurisdiction over services may continue to shift from one level of government to another. Following the current trend of more and more services becoming Internet based, the shift of services may continue to move toward being under Federal agency regulations.

8.5. Standards and Codes

Codes and Standards are used by the communication and information industry to establish the minimum acceptable criteria for design and construction. The codes and standards shown in Table 8-4 were mainly developed by the American National Standards Institute/Telecommunications Industry Association (ANSI/TIA). This organization has developed many standards that are adopted at the state and local government levels as well as by individual organizations. In fact, many of the standards presented in Table 8-4 are referenced and adopted by universities, such as East Tennessee State University (ETSU 2014), in their communication and information systems design guidelines. Individual end users, such as a university campus or hospital, and levels of government may have additional standards/guidelines.

Table 8-4. Summary of Communication and Information Codes and Standards

Code/Standard	Description
ANSI/TIA-222-G Structural Standards for Antennae Supporting Structures and Antennas	Specifies the loading and strength requirements for antennas and their supporting structures (e.g., towers). The 2006 edition of the standard has significant changes from its previous editions including: changing from ASD to LRFD; change of wind loading to better match ASCE-7 (i.e., switch from use of fastest-mile to 3-second gust wind speeds); updating of ice provisions; and addition of seismic provisions (Erichsen 2014)
ANSI/TIA-568-C.0 Generic Telecommunications Cabling for Customer Premises	Used for planning and installation of a structured cabling system for all types of customer premises. This standard provides requirements in addition to those for specific types of premises (Anexter Inc. 2013)
ANSI/TIA-568-C.1 Commercial Building Telecommunications Cabling Standard	Used for planning and installation of a structured cabling system of commercial buildings (Anexter Inc. 2013)
ANSI/TIA-569-C Commercial Building Standard for Telecommunication Pathways and Spaces	Standard recognizes that buildings have a long life cycle and must be designed to support the changing telecommunications systems and media. Standardized pathways, space design and construction practices to support telecommunications media and equipment inside buildings (Anexter Inc. 2013)
ANSI/TIA-570-B Residential Telecommunications Cabling Standard	Standard specifies cabling infrastructure for distribution of telecommunications services in single or multi-tenant dwellings. Cabling for audio, security, and home are included in this standard (Hubbell Premise Wiring, Inc. 2014)
ANSI/TIA-606-B Administration Standard for Commercial Telecommunications Infrastructure	Provides guidelines for proper labeling and administration of telecommunications infrastructure (Anexter Inc. 2013).
ANSI/TIA-942-A Telecommunications Infrastructure Standard for Data Centers	Provides requirements specific to data centers. Data centers may be an entire building or a portion of a building (Hubbell Premise Wiring, Inc. 2014)
ANSI/TIA-1005 Telecommunications Infrastructure for Industrial Premises	Provides the minimum requirements and guidance for cabling infrastructure inside of and between industrial buildings (Anexter Inc. 2013)
ANSI/TIA-1019 Standard for Installation, Alteration & Maintenance of Antenna Supporting Structures and Antennas	Provides requirements for loading of structures under construction related to antenna supporting structures and the antennas themselves (Anexter Inc. 2013)
ANSI/TIA-1179 Healthcare Facility Telecommunications Infrastructure Standard	Provides minimum requirements and guidance for planning and installation of a structured cabling system for healthcare facilities and buildings. This standard also provides performance and technical criteria for different cabling system configurations (Anexter Inc. 2013)
ASCE 7-10 Minimum Design Loads for Buildings and Other Structures	Provides minimum loading criteria for buildings housing critical communications equipment. Also provides loading criteria for towers.
IEEE National Electrical Safety Code (NESC)	United States Standard providing requirements for safe installation, operation and maintenance of electrical power, standby power and telecommunication systems (both overhead and underground wiring).

8.5.1. New Construction

The standards listed in Table 8-4 are used in new construction for various parts of the communications infrastructure system. As discussed in Section 8.2.1.1, new Central Offices are designed using ASCE 7-10 Occupancy Category III buildings. Consequently, the design of equipment and standby power for Central Offices must be consistent with that of the building design. As discussed in Chapter 5 (Buildings), buildings (e.g., Central Offices) must be designed in accordance with ASCE loading criteria for the applicable hazards of the community, which may include flooding, snow/ice, earthquakes, and wind. Wind loading criteria used by ASCE 7-10 has been developed using hurricane and extratropical winds. Other natural loads that can cause significant damage such as wildfire, tsunami, and tornadoes are not explicitly considered in ASCE 7-10. However, as discussed in Chapter 5, fire protection standards are available and are used to mitigate potential building fire damage.

The ANSI/TIA-222-G standard is used for the design of new cell towers. This version of the standards, released in 2006, included the biggest set of changes since the standard's inception (TIA 2014). Some major changes include:

1. Using limits states design rather than allowable stress design
2. Changing the design wind speeds from fastest-mile to 3-second gust, as is done for ASCE 7, and using the wind maps from ASCE 7
3. Earthquake loading is addressed for the first time in the ANSI/TIA-222 standard (Wahba 2003)

Note that wind, ice, and storm surge are the predominant concerns for towers. However, earthquake loading was added so it would be considered in highly seismic regions (Wahba 2003).

Communication system distribution lines are subject to the design criteria in the National Electric Safety Code (NESC). As discussed in Chapter 7, Rule 250 contains the environmental hazard loading on the communication and electric power lines as well as their supporting structures (e.g., utility poles). Specifically, these criteria address combined ice and wind loading, which are provided in Rule 250B for three districts of the United States defined as: 1) Heavy; 2) Medium; and 3) Light. Rule 250C addresses "extreme" wind loading and Rule 250D provides design criteria for "extreme" ice with concurrent wind.

Use of the term "extreme" by NESC does not correspond to that used in this document. Rather, use of "extreme" by the current version of NESC-2012 indicates the use of the ASCE 7-05 maps for the 50 year return period, which, if used with the appropriate ASCE 7-05 load and resistance factors, corresponds to an expected event as defined in Chapter 3 of this document. However, the NESC "extreme" loads only apply to structures (in this case distribution lines) at least 60 feet above ground. Since most communication distribution lines in the last mile are below this height (i.e., 60 feet), the lines would be designed for Rule 250B, which has lower loading requirements than Rules 250C and D.

For communication distribution wires, the designer could use either the NESC or ASCE 7. Malmedal and Sen (2003) showed ASCE 7 loading of codes in the past have been more conservative than those of NESC, particularly for ice loading. Using ASCE 7 will provide a more conservative design, but a higher cost that is not desirable to utilities/service providers. When considering resilience, a more conservative design should be considered, particularly for communication distribution lines in the last-mile to critical facilities.

In the communications industry, codes and standards provide the baseline loading and design for infrastructure. However, the industry heavily relies on the development and implementation of best practices, rather than regulations, to improve their infrastructure resilience. The FCC's CSRIC provides an excellent example of a body that develops and publishes best practices for various network types (Internet/data, wireless and landline telephone) and industry roles, including service providers, network operators, equipment suppliers, property managers, and government (CSRIC 2014). Service providers often adapt these and/or develop their own best practices to help improve the infrastructure of which their business relies. The best practices developed by the CSRIC cover a wide array of topics ranging from training and awareness to cyber security and network operations. For the purposes of this document, only a handful of the best practices developed by the CSRIC (see Table 8-5) that relate to physical communications infrastructure are listed.

As shown in Table 8-5, the best practices list many suggestions discussed in this chapter, including:

- Adequate standby power for critical equipment and cell towers
- Backup strategies for cooling critical equipment in Central Offices
- Limiting exposure of distribution lines and critical equipment to hazards (important for standby equipment too)
- Minimizing single points of failure in Central Offices, and distribution network

The best practices (CSRIC 2014) have an emphasis on ensuring adequate power supply because the communications system is dependent on power systems to function. Innovative technologies and strategies for maintaining external power infrastructure continue to be developed and are discussed in Chapter 7.

1034 ***Table 8-5. Best Practices for Communications Infrastructure***

Best Practice Description (CSRIC 2014)	**Applicable Infrastructure**
Network Operators, Service Providers, Equipment Suppliers, and Property Managers should ensure the inclusion of fire stair returns in their physical security designs. Further, they should ensure there are no fire tower or stair re-entries into areas of critical infrastructure, where permitted by code.	Central Offices, nodes, critical equipment
Network Operators and Service Providers should prepare for HVAC or cabinet fan failures by ensuring conventional fans are available to cool heat-sensitive equipment, as appropriate.	Critical equipment
Network Operators and Service Providers should consult National Fire Prevention Association Standards (e.g., NFPA 75 and 76) for guidance in the design of fire suppression systems. When zoning regulations require sprinkler systems, an exemption should be sought for the use of non-destructive systems.	Central Offices, nodes, critical equipment
Network Operators should provide back-up power (e.g., some combination of batteries, generator, fuel cells) at cell sites and remote equipment locations, consistent with the site specific constraints, criticality of the site, expected load, and reliability of primary power.	Cell sites and DLC RTs
Network Operators and Property Managers should consider alternative measures for cooling network equipment facilities (e.g., powering HVAC on generator, deploying mobile HVAC units) in the event of a power outage.	Central Offices, nodes, critical equipment
Network Operators, Service Providers, and Property Managers together with the Power Company and other tenants in the location, should verify that aerial power lines are not in conflict with hazards that could produce a loss of service during high winds or icy conditions.	Distribution lines
Back-up Power: Network Operators, Service Providers, Equipment Suppliers, and Property Managers should ensure all critical infrastructure facilities, including security equipment, devices, and appliances protecting it are supported by backup power systems (e.g., batteries, generators, fuel cells).	Central Offices, nodes, critical equipment
Network Operators, Service Providers, and Property Managers should consider placing all power and network equipment in a location to increase reliability in case of disaster (e.g., floods, broken water mains, fuel spillage). In storm surge areas, consider placing all power related equipment above the highest predicted or recorded storm surge levels.	Central Offices, nodes, Cell sites, DLC RTs, critical equipment
Network Operators, Service Providers, Equipment Suppliers, Property Managers, and Public Safety should design standby systems (e.g., power) to withstand harsh environmental conditions.	Critical equipment
Network Operators, Service Providers, Public Safety, and Property Managers, when feasible, should provide multiple cable entry points at critical facilities (e.g., copper or fiber conduit) avoiding single points of failure (SPOF).	Distribution lines
Service Providers, Network Operators, Public Safety, and Property Managers should ensure availability of emergency/backup power (e.g., batteries, generators, fuel cells) to maintain critical communications services during times of commercial power failures, including natural and manmade occurrences (e.g., earthquakes, floods, fires, power brown/black outs, terrorism). Emergency/Backup power generators should be located onsite, when appropriate.	Critical equipment
Network Operators and Service Providers should minimize single points of failure (SPOF) in paths linking network elements deemed critical to the operations of a network (with this design, two or more simultaneous failures or errors need to occur at the same time to cause a service interruption).	Distribution
Back-Up Power Fuel Supply: Network Operators, Service Providers, and Property Managers should consider use of fixed alternate fuel generators (e.g., natural gas) connected to public utility supplies to reduce the strain on refueling.	Central Offices/nodes, cell sites, DLC RTs, critical equipment.
Network Operators and Public Safety should identify primary and alternate transportation (e.g., air, rail, highway, boat) for emergency mobile units and other equipment and personnel.	Cell sites, DLC RTs, critical equipment

8.5.1.1. Implied or Stated Performance Levels for Expected Hazard Levels

As discussed in Chapter 5, the performance level for an expected hazard event depends on the type of hazard and the design philosophy used for the hazard.

For wind, buildings and other structures are designed for serviceability. That is, in the expected wind event, such as a hurricane, the expectation is neither the building's structure nor envelope will fail. The ability of the building envelope to perform well (i.e., stay intact) is imperative for high wind events, because they are typically associated with heavy rainfall events (e.g., thunderstorms, hurricanes, tornadoes). Therefore, even if the building frame were to perform well, but the envelope failed, rain infiltration could damage the contents, critical equipment, and induce enough water related damage such that the building would have to be replaced anyway. The expectation is that a Central Office would not have any significant damage for the expected wind event, and would be fully operational within 24 hours. The 24 hours of downtime should only be required for a high wind event to allow for time to bring standby generators online if needed and ensure all switches and critical electrical equipment are not damaged.

Similarly, for an expected flood, a Central Office should not fail. There is likely to be some damage to the building and its contents at lower elevations, particularly the basement. However, if the critical electrical and switchgear equipment and standby power are located well above the inundation levels, the Central Office would be expected to be fully operational within 24 hours of the event.

For earthquakes, buildings are designed for life safety. Therefore, for Central Offices in highly seismic regions, some damage to the building is likely for the expected earthquake. As a result, it is likely that there will be some loss of functionality of a Central Office following the expected earthquake event. If the critical equipment and switchgear were designed and mounted, downtime would be expected to be limited (less than one week). However, if the critical equipment and switchgear were not mounted to resist ground accelerations, it could be weeks before the Central Office is fully functional again.

For cell towers, the primary hazard that is considered for design in ANSI/TIA-222 is wind. However, ice and earthquake are also considered. ANSI/TIA-222 provides three classes of tower structures (Wahba 2003):

- ***Category I Structures:*** Used for structures where a delay in recovering services would be acceptable. Ice and earthquake are not considered for these structures, and wind speeds for a 25-year return period using the ASCE 7-02/7-05 methodology are used.
- ***Category II Structures:*** This is the standard category that represents hazard to human life and property if failure occurs. The nominal 50-year return period wind, ice, and seismic loads are used.
- ***Category III Structures:*** Used for critical and emergency services. The nominal 100-year return period loads.

For the expected event, failures would only be anticipated for a small percentage of cell towers (e.g., less than five percent). It is noted that, as discussed in the previous section, the loading in ANSI/TIA-222-G is based on that of ASCE 7.

Communication distribution wires will likely experience some failures in the expected event, particularly for wind and ice storms. As discussed in the previous section, most distribution lines in the last-mile are below 60 feet above the ground and, hence, are not even designed to meet what Chapter 3 defines as the expected event if Rule 250B in NESC is followed for design. For lines that are designed to meet the NESC Rules 250C and 250D, it would be anticipated that only a small percentage of failure of the overhead wire would fail in an expected ice or wind event. However, as discussed earlier in this chapter and in Chapter 7, tree fall onto distribution lines causes many failures rather than the loading of the natural hazard itself. Therefore, service providers should work with the electric power utility to ensure their tree-trimming programs are adequately maintained.

8.5.1.2. Recovery Levels

As discussed in the previous section, Central Offices and cell towers should not have an extended recovery time for the expected event. Given that the earthquake design philosophy is life safety (rather than wind which is designed for serviceability), Central Offices may have some loss of functionality due to damage to the building envelope and critical equipment if it is not designed and mounted to resist adequate ground accelerations.

With respect to cell sites, wind, storm surge, and fire are the predominant hazards of concern for designers. Ice and earthquake are also considered, though not to the same extent in design. Given that the ANSI/TIA-222-G loads are based on ASCE 7 loading, it is anticipated that only a small percentage of cell tower structures would fail during an expected event. Cell towers are configured such that there is an overlap in service between towers so the signal can be handed off as the user moves from one area to another without a disruption in service. Therefore, if one tower fails, other towers will pick up most of the service since their service areas overlap.

For distribution lines, a key factor, more so than the standards, is location of the cables. For example, if the distribution lines are underground for a high wind or ice event, failures and recovery time should be limited. However, even if the distribution lines are underground it is possible for failure to occur due to uprooting of trees. For flooding, if the distribution lines are not properly protected or there has been degradation of the cable material, failures could occur. For earthquake, failures of underground distribution lines could also occur due to liquefaction. As discussed in Section 8.2.1, although underground lines may be less susceptible to damage, they are more difficult to access to repair and failures could result in recovery times of weeks rather than days. However, for an expected event, some damage to the distribution lines would be expected.

If the distribution lines are overhead, high wind and ice events will result in failures, largely due to tree fall or other debris impacts on the lines. The debris impacts on distribution lines is a factor that varies locally due to the surroundings and tree trimming programs that are intended to limit these disruptions. Although these lines are more likely to fail due to their direct exposure to high winds and ice, recovery/repair time of the lines for an expected event would be expected to range from a few days to a few weeks depending on the size of the area impacted, resources available, and accessibility to the distribution lines via transportation routes. Note that this only accounts for repair of the communications distribution lines itself. Another major consideration is the recovery of external power lines so the end user is able to use their communications devices. Chapter 7 addresses the standards and codes, and their implied performance levels for an expected event.

8.5.2. Existing Construction

Although the standards listed in Section 8.2 are used for new construction for communications infrastructure, older versions of these codes and standards were used in the design of structures for the existing infrastructure.

Central Offices designed and constructed within the past 20 years may have been designed to the criteria ASCE 7-88 through 05. Prior to that, ANSI standards were used. There have been many changes in the design loading criteria and methodology over the design life of existing Central Offices. For example, ASCE 7-95 was the first time a 3-second gust was used for the reference wind speed rather than the fastest mile for the wind loading criteria (Mehta 2010). Over the years, reference wind speeds (from the wind speed contour maps) have changed, pressure coefficients have been adjusted, earthquake design spectra, ground accelerations, and other requirements have changed. Overall, codes and standards have been added to/changed based on lessons learned from past disaster events and resulting research findings.

As discussed in Section 8.5.1, ANSI/TIA-222-G is the current version of the standard used for cell towers and antennas. However, prior to 2006, versions of the code include (TIA 2014):

- ANSI/TIA/EIA-222-F established in 1996
- ANSI/TIA/EIA-222-E established in 1991
- ANSI/TIA/EIA-222-D established in 1987
- ANSI/TIA/EIA-222-C established in 1976
- ANSI/TIA/EIA-222-B established in 1972
- ANSI/TIA/EIA-222-A established in 1966
- ANSI/EIA-RS-222 established as the first standard for antenna supporting structures in 1959.

The 1996 standard, ANSI/TIA/EIA-222-F, was used during the largest growth and construction of towers in the United States (TIA 2014). As noted in Section 8.5.1, earthquake was not considered in this version of the standard, allowable stress design was used rather than limit states design, and reference wind speeds used fastest mile rather than 3-second gust (Wahba 2003). Note that the use of fastest mile for the reference wind speed is consistent with ASCE 7 prior to the 1995 version (of ASCE).

Historically, communication distribution lines, like the new/future lines, have been designed to NESC standards. The following lists some of the most significant changes to NESC rule 250 that have occurred over the past couple of decades (IEEE 2015):

- Prior to 1997, NESC did not have what is now referred to as an “extreme” wind loading. Rule 250C adapted the ASCE 7 wind maps after the wind speed changed from fastest mile to 3-second gust as is used today.
- In 2002, Rule 250A4 was introduced to state that since electric and telecommunication wires and their supporting structures are flexible, earthquakes are not expected to govern design.
- In 2007, Rule 250D was introduced for design of “extreme” ice from freezing rain combined with wind.

These changes and their timeframe indicate older distribution lines, if not updated to the most recent code, may be more vulnerable to failures from wind and ice events than the current code. However, the NESC adopting these new standards should help lead to improvements of overhead distribution line performance in the future.

8.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels

Existing Central Offices designed to an older version of ASCE 7 or ANSI criteria should have similar performance to those of new construction for an expected event. However, it is possible that these structures may have varied performance depending on the design code’s loading criteria. Nonetheless, an existing Central Office should have similar performance to that of a newly constructed Central Office (see Section 8.5.1.1).

As discussed in the previous section, the ANSI/TIA/EIA-222-F 1996 standard was in effect when the largest growth and construction of cell towers took place (TIA 2014). For wind and ice, the towers would be expected to only have a small percentage of failures for the expected event as discussed in Section 8.5.1.1. However, earthquake loading was not included in any of the standards prior to ANSI/TIA-222-G (Wahba 2003). Although earthquakes do not typically govern the design of cell towers, highly seismic regions would be susceptible to failures if an expected earthquake occurred. For existing towers designed to standards other than ANSI/TIA-222-G in highly seismic regions, the design should be checked to see if earthquake loads govern and retrofits should be implemented if necessary. Existing towers that have electronics added to them are updated to meet requirements of the most up to date code (ANSI/TIA-222-G). Note that despite no earthquake loading criteria in ANSI/TIA/EIA-222-F, and older versions of this standard, designers in highly seismic regions may have considered earthquake loading using other standards, such as ASCE 7. However, this was not a requirement.

As discussed in Section 8.5.1.2, some communication distribution lines are anticipated to fail during an expected event. Given that "extreme" ice loading was not included in the NESC standard until 2007, distribution lines adhering to prior codes may be particularly vulnerable to ice storms.

8.5.2.2. Recovery Levels

As discussed in the previous section and Section 8.5.1.2, Central Offices and cell towers should not require a long time for full recovery after an expected event. However, given that older standards of ANSI/TIA/EIA-222 did not include earthquake loading criteria, a large number of failures and, hence, significant recovery time may be needed to repair or replace towers after an expected event in a highly seismic region. To replace a large number of towers would take weeks, months, or even years depending on the size of the impacted area. As discussed in Section 8.6.3, service providers have the ability to provide cell on light trucks (COLTs) so essential wireless communications can be brought online quickly after a hazard event in which the network experiences significant disruptions (AT&T 2014). However, the COLTs are only intended for emergency situations. They are not intended to provide a permanent solution. The best approach for cell tower owners in these earthquake prone regions is, therefore, to ensure the cell towers can resist the earthquake loading criteria in the new ANSI/TIA standard.

With respect to performance of distribution lines, performance and recovery time is largely dependent on the placement of the cables (i.e., overhead versus underground) as discussed in Section 8.5.1.2.

8.6. Strategies for Implementing Community Resilience Plans

Section 8.2 discusses critical components of communication and information infrastructure. The discussion includes examples from different types of hazards to encourage the reader to think about the different hazards that could impact the communication and information infrastructure in their community. The number, types, and magnitudes of hazards that need to be considered will vary from community to community.

Section 8.3 discusses the performance goals of the communication and information infrastructure strived for by the community. Section 8.3 does provide example performance goals for the routine, expected, and extreme event. However, the performance goals should be adjusted by the community based on its social needs, which will vary by community.

Sections 8.4 and 8.5 outline some regulatory levels and issues, and codes and standards the reader should keep in mind when planning to make upgrades/changes to existing structures as well as building new structures for their communications network. The objective of this section is use the information from Sections 8.2 through 8.5 to provide guidance on how a community or service provider should work through the process of assessing their communications infrastructure, defining strategies to make its infrastructure more resilient, and narrowing the resilience gaps.

8.6.1. Available Guidance

Recall that in the Section 8.3 discussion of setting performance goals of the communication and information infrastructure, there was also an "X" in each row corresponding to an example of what a community actually found its infrastructures' performance to be given a level of hazard. The question then becomes: How does the community/service provider determine where the "X" belongs for the various types of infrastructure in our community?

At this point, the community should have convened a collection (or panel) of stakeholders and decision makers to approach the problem and establish the performance goals for each type and magnitude of hazard. To assess the infrastructure, this panel should have the knowledge, or reach out to those in the community who have the knowledge to assess the state of the infrastructure. The panel of stakeholders and decision makers will have to assess the infrastructures' performance relative to the type and magnitude of event that the community may face because different types of hazards will result in different types of failure modes and, consequently, performance. In some communities, it may only be necessary to make assessments for one hazard (such as earthquake in some non-coastal communities in California or Oregon). In other communities, it may be appropriate to complete assessments of the performance for multiple types of hazards such as high winds and storm surge in coastal communities in the Gulf and east coast regions of the United States.

There are three levels at which the infrastructure can be assessed:

Tier 1. A high level assessment of the anticipated performance of the components of the communications infrastructure can be completed by those with knowledge and experience of how the components and system will behave in a hazard event. For Central Offices, this may include civil and electrical engineer/designers. For wires (both overhead and underground), and cell towers, this may include engineers, utility operators, service providers, technical staff, etc. As a minimum, each community should complete a high level (Tier 1) assessment of its infrastructure. The community can then decide whether additional investment is warranted in completing a more detailed assessment. The SPUR Framework (Poland 2009) took this high level approach in assessing their infrastructure for the City of San Francisco, and is highly regarded as a good example for the work completed to date.

Tier 2. A more detailed assessment can be used, based on an inventory of typical features within the communication infrastructure system, to develop generalized features for various components of the infrastructure. To do this, the community would have to use or develop a model for their community to assess the performance of common components of their infrastructure system for a specific type and magnitude of event (i.e., model a scenario event and its resulting impacts). Alternatively, the community could model a hazard event scenario to compute the loads (wind speeds/pressures, ground accelerations, flood elevations) to be experienced in the community and use expert judgment to understand what the performance of various components of the communications infrastructure would be as a result of the loading.

A Tier 2 communication and information infrastructure assessment would include the impact on typical components of the infrastructure system independent of the intra-dependencies. The Oregon Resilience Plan (OSSPAC 2013) provides a good example of modeling a hazard event to assess the resulting impacts of the current infrastructure. It used HAZUS-MH to model and determine the impacts of a Cascadia earthquake on the different types of infrastructure and used the losses output by the HAZUS tool to back-calculate the current state of the infrastructure.

Tier 3. For the most detailed level of analysis, a Tier 3 assessment would include all components in the communications infrastructure system, intra-dependencies within the system, and interdependencies with the other infrastructure systems. Fragilities could be developed for each component of the communications infrastructure system. A Tier 3 assessment would use models/tools to determine both the loading of infrastructure due to the hazard and the resulting performance, including intra- and interdependencies. Currently, there are no publicly available tools that can be used to model the intra- and interdependencies.

8.6.2. Strategies for New/Future Construction

For new and future construction, designers are encouraged to consider the performance goals and how to best achieve those goals rather than designing to minimum code levels, which are sometimes just for life safety (e.g., earthquake design). It is important to consider the communication and information infrastructure as a whole because it is a network and failure in one part of the system impacts the rest of the system (or at least the system connected directly to it). Therefore, if it is known that a critical component of the infrastructure system is going to be non-redundant (e.g., a lone Central Office, or a single point of entry for telephone wires into a critical facility), the component should be designed to achieve performance goals set for the extreme hazard.

Throughout this chapter, there are examples of success stories and failures of communications infrastructure due to different types of hazards (wind, flood, earthquake, ice storms). Designers, planners, and decisions makers should think about these examples, as well as other relevant examples, when planning for and constructing new communications and information infrastructure. There are several construction and non-construction strategies that can be used to successfully improve the resilience of communications infrastructure within a community.

Construction Strategies for New/Future Central Offices. With respect to Central Offices that are owned by service providers, the service provider should require the building to be designed such that it can withstand the appropriate type and magnitude of hazard events that may occur for the community. It is imperative that all hazards the community may face are addressed because hazards result in different failure modes. Designing for an extreme earthquake may not protect infrastructure from the expected flood, or vice versa. However, as was discussed during the workshops held to inform this framework, not all Central Offices or other nodes housing critical communications equipment are owned by service providers.

Sections of buildings are often leased by service providers to store their equipment for exchanges or nodes in the system. In this case, service providers typically have no influence over the design of the building. But, if a building is in the design phase and the service provider is committed to using the space of the building owner, the service provider could potentially work with the building owner and designers to ensure their section of the building is designed such that their critical equipment is able to withstand the appropriate loading. In a sense, the goal would be to “harden” the section of the building in the design phase rather than retrofitting the section of the structure after a disaster, as is often done. Adding the additional protection into the design of the building would likely cost more initially, and the building owner would likely want the service provider to help address the additional cost. However, the service provider would be able to compute a cost-to-benefit ratio of investment for paying for additional protection of their critical equipment versus losing their equipment and having to replace it.

Non-Construction Strategies for New/Future Central Offices. Although the design and construction of buildings that house critical equipment for Central Offices, exchanges, and other nodes in the communications network is an important consideration, non-construction strategies can also be extremely effective. For example, service providers who own buildings for their Central Offices should place their critical equipment such that it is not vulnerable to the hazards faced by the community. For example, Central Offices vulnerable to flooding should not have critical electrical equipment or standby generators in the basement. Rather, the critical electrical equipment and standby generators should be located well above the extreme flood levels. As shown by the success story of the Verizon Central Office after Hurricane Sandy described in Section 8.2.1, placing the critical equipment and standby generators above the extreme flood level can significantly reduce the recovery time needed. Similarly, for Central Offices in earthquake prone areas, service providers can mount their critical equipment to ensure it does not fail due to the shaking of earthquakes.

Service providers planning to lease space from another building owner should be aware of the hazards faced by the community and use that information in the decision making process. For instance, a service provider would not want to rent space in the basement of a 20-story building to store electrical and critical equipment for an exchange/node.

Construction Strategies for New/Future Cell Towers. New/Future Cell Towers should be designed to the latest TIA/EIT-222-G standard. As discussed in Section 8.2.3, the 2006 version of the TIA/EIT-222-G standard was updated to reflect the design criteria in ASCE 7 for wind, ice, and earthquake loading. For wind and ice, if the towers are designed and constructed in accordance with the appropriate standards, only a small percentage of cell towers would be anticipated to fail in an "expected" event. With respect to earthquake, where the design philosophy is life safety, towers should be designed beyond the code loading criteria. Since cell towers are becoming more numerous, they should be designed for the "expected" event.

Non-Construction Strategies for New/Future Cell Towers. Historically, the predominant cause of outages of cell towers has been the loss of electrical power. As discussed in Section 8.2.3, the FCC's attempt to mandate a minimum of eight hours of battery standby power to overcome this problem was removed by the courts. However, service providers should provide adequate standby power to maintain functionality following a hazard event.

As is the case for standby generators in Central Offices, standby generators for cell towers must be placed appropriately. Standby generators for cell towers in areas susceptible to flooding should be placed above the "expected" flood level. Similarly, in earthquake regions, standby generators should be mounted such that the ground accelerations do not cause failure on the standby generator.

Additional protection should be implemented for cell towers when appropriate and feasible. As discussed in Section 8.2.3, during Hurricane Katrina debris impacts from boats in flood areas resulted in failure of cell towers. Impacts from uprooted trees or branches during high wind events and tsunamis could also result in failure of these towers. Therefore, the topography and surroundings (e.g., relative distance from trees or harbors to cell towers) should be considered to ensure cell towers are protected from debris impact.

Strategies for New/Future Distribution Line to End User. As discussed in Section 8.2.1, there are several different types of wires (copper, coaxial, and fiber optic) that carry services to the end user. Each of the types of wires has advantages and disadvantages. More and more, service providers are installing fiber optic wires to carry services to the customer.

There is ongoing debate regarding whether underground or overhead wires are the best way to distribute services to the end user. For new/future distribution lines, several factors should be used to decide which method of distribution of services is best. The factors should include:

- Building cluster to which the services are being distributed
- Potential hazards to which the community is susceptible
- Topography and surroundings of distribution lines
- Redundancy or path diversity of distribution lines

The first three items can be considered together. The building cluster to which the services are being delivered (1st bullet) is a key consideration. As seen in Section 8.3, performance goals for transmission of communications services to critical facilities reflect a desire for less recovery time (i.e., better performance) than the clusters for emergency housing, housing/neighborhoods, and community recovery. The hazards the community faces (2nd bullet) can be used to determine how to best prevent interruption of service distribution to the building (i.e., end user). For example, in regions that are susceptible to high winds events (i.e., 2nd bullet), it may be appropriate to distribute communication services to critical services (and other clusters) using underground wires rather than overhead wires. The use of overhead wires would likely result in poorer performance in wind events because of failures due to wind loading or, more likely, debris (i.e., tree) impact (3rd bullet).

Redundancy or path diversity (4th bullet) of communications distribution lines to end users is an important consideration. As discussed in Section 8.2.1, building redundancy in the communications network is essential to ensuring continuation of services after a hazard event. For example, single points of failure in the last/first mile of distribution can be vulnerable to failure causing long term outages. Redundancy (i.e., path diversity) should be built into in the distribution network, especially the last/first mile, wherever possible.

8.6.3. Strategies for Existing Construction

Similar to new/future communication and information infrastructure, there are several construction and non-construction strategies that can be used to successfully improve the resilience of existing communications infrastructure within a community. However, unlike new/future components of the communications infrastructure system, existing components must be evaluated first to understand their vulnerabilities, if they exist. If it is determined that a component is vulnerable to natural loads, strategies should be used to improve its resilience.

Given that the communication and information infrastructure system is extremely large and much of the existing infrastructure is owned by service providers or third party owners (e.g., building owners) with competing needs for funding, it is not reasonable to expect that capital is available for service providers (or third parties) to upgrade all infrastructure immediately. However, prioritization can address the most critical issues early in the process and develop a strategy to address many concerns over a longer time period. Moreover, by evaluating the inventory of existing infrastructure and identifying weaknesses, service providers can use the data to implement strategies for new/future infrastructure construction so the same weaknesses are not repeated.

Construction Strategies for Existing Central Offices. Existing buildings owned by service providers and used as Central Offices should be assessed to determine if the building itself and sections of the building containing critical equipment and standby generators will be able to meet performance goals (see Section 8.3). As stated for the case of new/future construction, if the Central Office is a non-redundant node in the service provider's infrastructure network, the Central Office should be evaluated to ensure it can resist the "extreme" level of hazard. However, if the Central Office is a node in a redundant infrastructure system, and failure of the Central Office would not cause any long-term service interruptions, the Central Office should be assessed to ensure it can withstand the loads for the "expected" event.

If the service provider finds that its Central Office will not be able to withstand the loading for the appropriate level of hazard event, it should take steps to harden the building. Although this is likely to be expensive, if the Central Office is critical to the service provider's performance following a hazard event in both the short and long term, a large investment may be necessary and within a reasonable cost-benefit ratio.

For nodes, exchanges, or Central Offices located in leased (existing) buildings, the service provider does not have control over retrofitting or hardening the building. However, the service provider could attempt to work with the building owner to have the sections of the building housing critical equipment hardened. Alternatively, there are also several non-construction strategies that could be used to protect the critical equipment.

Non-Construction Strategies for Existing Central Offices. Critical equipment in Central Offices or in other nodes/exchanges in the communications infrastructure network should be assessed to determine whether it is likely to fail during hazard events faced by that community. Whether the building is owned by the service provider or leased from a third party, relatively easy and inexpensive changes can be made to protect the critical equipment.

As was demonstrated by the example of the Manhattan Verizon Central Office at 140 West Street discussed in Section 8.2.1, non-construction strategies can be used to successfully improve performance of critical equipment in hazard events. Recall that the 140 West Street Central Office was hardened after 9/11. What may have been the most successful change was elevating the standby generators and critical equipment to higher elevations such that they would not fail in the case of flooding (City of New York 2013). Compared to another Central Office located at 104 Broad Street in New York City that had critical equipment and standby generators stored in the basement, the Verizon Central Office performed much better. The 104 Broad Street had an outage of 11 days, whereas the Verizon Central Office was operational within 24 hours. The 104 Broad Street did not meet the performance goals for the expected event in Section 8.3. With the singular change of elevating critical equipment and standby generators, the Verizon Central Office met the performance goals presented in Section 8.3.

Construction Strategies for Existing Cell Towers. Existing cell towers should be evaluated to determine whether they can resist the loading from the "expected" event the community faces (wind speed/pressure, earthquake ground accelerations, ice storms). Versions older than the 2006 ANSI/TIA-222-G did not include earthquake design criteria. Therefore, design loads for existing cell towers, particularly in earthquake-prone regions, should be assessed to understand the loading that the towers can withstand. It is assumed that a designer in an earthquake-prone region would use loading based on other codes and standards, but it is possible that the loading used in the original design may not be adequate. If it is found after assessing the cell tower for earthquake loading that it was not designed to resist adequate loads, retrofits such as the addition of vertical bracing can be constructed to ensure the loading can be resisted. Similarly, since there have been changes in the wind and ice loading in ANSI/TIA-222-G to better match the loading criteria in ASCE, cell towers should be assessed to ensure they will resist the appropriate loads, and retrofitted if needed.

Non-Construction Strategies for Existing Cell Towers. Existing cell tower sites should be assessed to determine whether adequate standby power supply is available given the criticality of the site and whether the standby generator and switchgear are protected against loading from the appropriate magnitude (expected) of natural hazard. Although it may not be economically feasible to provide standby generators for all cell towers immediately, a program can be developed to accomplish this over time. The immediate surroundings of cell sites should be assessed to determine vulnerabilities to airborne and waterborne debris. If the cell site is located such that it is vulnerable to tree fall or other debris in a high wind or flood event, additional protection should be provided to protect the cell tower.

Strategies for Existing Distribution Line to End User. For existing distribution lines to the end user, an inventory of wires, including the type, age, and condition should be recorded. When wires are damaged or have deteriorated due to age, they should be retired and/or replaced.

As discussed for new/future distribution lines, overhead versus underground wires is an ongoing debate in the industry. Distribution lines, particularly to critical buildings, should be assessed to determine whether overhead or underground wires are best for the communications infrastructure system. If a service provider is considering switching from overhead wires to underground wires to avoid possible outages due to ice storms or high wind events, a cost-benefit ratio should be computed as part of the assessment and decision making process. If cost is much greater than projected benefits, the service provider may want to consider other priorities in making their infrastructure more resilient. In fact, rather than switching the distribution lines from overhead to underground wires, the service provider may find it more economical to add redundancy (i.e., path diversity) to that part of the infrastructure network. Thus, the service provider would not be reducing the risk to the existing overhead distribution wires, but reducing the risk of service interruptions because it is not solely reliant on overhead distribution lines.

Non-Construction Strategies for Critical Facilities/Users. As previously discussed, communications network congestion is often seen during and immediately after a hazard event. The following programs have been implemented to help critical users have priority when networks are congested due to a disaster event (DHS 2015):

- Government Emergency Telecommunications Service (GETS)
- Wireless Priority Service (WPS)
- Telecommunications Service Priority (TSP)

GETS works through a series of enhancements to the landline network. It is intended to be used in the immediate aftermath of disaster events to support national security and emergency preparedness/response. Cell phones can also use the GETS network but they will not receive priority treatment until the call reaches a landline. Rather, the WPS is used to prioritize cell phone calls of users who support national security and emergency preparedness/recovery when the wireless network is congested or partially damaged. WPS is supported by seven service providers: AT&T, C Spire, Cellcom, SouthernLINC, Sprint, T-Mobile, and Verizon Wireless (DHS 2015). The GETS and WPS programs are helpful in coordinating recovery efforts in the wake of a disaster event. However, note that the main goal of these programs is to provide priority service when there is congestion due to limited damage. If a significant amount of the infrastructure fails, these services may not be available.

TSP is an FCC program that enables service providers to give service priority to users enrolled in the program when they need additional lines or need service to be restored after a disruption (FCC 2015). Unlike the GETS and WPS programs, the TSP program is available at all times, not just after disaster events. For all of these programs, eligible entities include police departments, fire departments, 9-1-1 call centers, emergency responders, and essential healthcare providers (e.g., hospitals).

Short-Term Solutions for Restoring Service. Service providers and other stakeholders (e.g., third party building owners) responsible for infrastructure cannot make all infrastructure changes in the short term due to limited resources, a competitive environment driven by costs, and competing needs. Therefore, as part of their resilience assessment, service providers should prioritize their resilience needs. Service providers should budget for necessary short-term changes (0-5 years), which may include relatively inexpensive strategies such as placement and security of critical equipment and standby generators. For the long term (5+ years), service providers should address more expensive resilience gaps that include hardening of existing Central Offices and replacing overhead distribution lines with underground lines.

Although not all resilience gaps can be addressed in the short term through investment in infrastructure, service providers should use other strategies to address these gaps. Ensuring there is a recovery plan in place so service to customers is not lost for an extended period of time helps minimize downtime. AT&T's Network Disaster Recovery (NDR) team provides an excellent example of using temporary deployments to minimize service disruption. The AT&T NDR was established in 1992 to restore the functionality of a Central Office or AT&T network element that was destroyed or in which functionality was lost in a natural disaster (AT&T 2005).

The NDR team was deployed after several disaster events to minimize service disruption where the downtime would have been long term, including after 9/11, the Colorado and California wildfires in 2012 and 2013, the 2013 Moore, OK tornado, 2011 Joplin, MO tornado, 2011 Alabama tornadoes, Hurricane Ike in 2008, and 2007 ice storms in Oklahoma (AT&T 2014). The AT&T NDR team completes quarterly exercises in various regions of the United States and around the world to ensure personnel are adequately trained and prepared for the next hazard event (AT&T 2014). Training and field exercises for emergency recovery crews are essential to helping reduce communications network disruptions and, hence, the resilience gaps.

After the May 22, 2011 Joplin tornado, the NDR team deployed a Cell on Light Truck (COLT) on May 23, 2011 to provide cellular service near the St. John's Regional Medical Center within one day of the tornado (AT&T 2014). The cell site serving the area was damaged by the tornado. Satellite COLTs can be used to provide cellular communications in areas that have lost coverage due to damage to the communication infrastructure system (AT&T 2014).

Using satellite telephones can be an alternative for critical facilities or emergency responders in the immediate aftermath of a hazard event. Satellite phones are almost the only type of electronic communications system that will work when cell towers are damaged and Central Offices or exchanges/nodes have failed (Stephan 2007). Unfortunately, satellite phones are used infrequently, especially with the continuing growth of cellular phones. In 1999, the State of Louisiana used Federal funds to provide the state's parishes with a satellite phone to use in the event of an emergency, but the state stopped providing the funding to cover a monthly $65 access fee one year before Hurricane Katrina occurred (Stephan 2009). As a result, only a handful of churches kept the satellite phones. However, even for those parishes that did keep their satellite phones, they did little to alleviate the communications problem because nobody else had them when Hurricane Katrina occurred. In general, people do not own satellite telephones so this is not the best solution for an entire community. However, for critical facilities and communications between emergency responders, satellite telephones may be a viable option to ensure the ability to communicate is preserved.

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9. Water and Wastewater Systems

9.1. Introduction

Water and wastewater systems represent essential infrastructure for sustaining the economic and social viability of a community. Although these systems provide basic public health and safety to homes, businesses, and industry, they are often taken for granted because of the high level of service and reliability provided by water and wastewater utilities. The importance of these systems is not recognized until a water main break or other disruption in service occurs. This chapter addresses disaster resilience of public water and wastewater systems.

While some utilities are already taking steps to improve the resilience of their systems, capital improvement programs and many others often focus on performing emergency repairs, increasing system capacity to meet population growth, or making system improvements to satisfy public health and environmental regulations. Replacing buried pipelines is often delayed until water main breaks become frequent or wastewater pipeline groundwater infiltration rates create excessive demand on the treatment system. Communities have a perfect opportunity to couple resilience with future/planned retrofits or replacements of old infrastructure, to improve the resilience of water and wastewater infrastructure. This chapter focuses on the water and wastewater infrastructure itself. However, the water and wastewater industry faces challenges beyond just the infrastructure performance. Water quality and environmental impact are two of the biggest concerns. For example, if water of poor quality is delivered to customers, there is significant risk that the public may become ill from consumption. The wastewater industry operates within strict environmental constraints that have and will likely continue to become more stringent. These restrictions prevent excessive pollution that contribute to environmental damage and, ultimately, impact the health of the humans and animals. Although this chapter touches on such challenges, its main focus is how to build a more resilient infrastructure system that will deliver good quality water with fewer disruptions and limit damage to wastewater systems, making spills less frequent.

9.1.1. Social Needs and Systems Performance Goals

Water services are essential to our daily lives. Using USGS data, Aubuchon & Morley (2012) calculated the average consumption of water across all U.S. states to be 98 gallons per person per day. However, water consumption varies by community and by customer. Personal uses include water for drinking and cooking, personal hygiene, flushing toilets, laundry, landscape irrigation, and many others. Many businesses and industries also depend on a continual supply of potable water and wastewater collection services. Absent functioning drinking water and wastewater systems, the operation of restaurants, child care facilities, hotels, medical offices, food processing plants, paper mills, etc., significantly compromised, if not completely impossible. Additionally, water systems in urban and suburban areas provide water supply for fire suppression. Chapter 2 discusses this societal dependence on water and wastewater systems and other infrastructure systems in more detail.

In the United States, communities generally accommodate to short-term (on the order of a few days) disruptions in water and wastewater services resulting from man-made or natural hazard events. However, longer-term disruptions are less tolerable. The Oregon Resilience Plan (OSSPAC, 2013) indicated a business that cannot reoccupy facilities (including functioning water and wastewater systems) within one month would be forced to move or dissolve. This timeline likely varies depending on community needs and the severity of the event. Water and wastewater utility providers need to work with customers and regulatory agencies to establish realistic performance goals for post-disaster level of service, evaluate their systems' status in relation to those goals, and then develop strategies to close the identified resilience gaps. Flow, pressure, and water quality should be considered in those performance goals.

9.1.2. Interdependencies

As discussed in Chapter 4, water system operations are interdependent with other infrastructure systems, both for day-to-day operation and restoration following a hazard event. Electric power is one of the most important services necessary for maintaining pumping and treatment operations. Transportation is critical to allow access for inspection and repairs after the event, as well as maintaining the supply chain. Figure 9-1 presents some interdependencies of the water infrastructure system with other infrastructure systems.

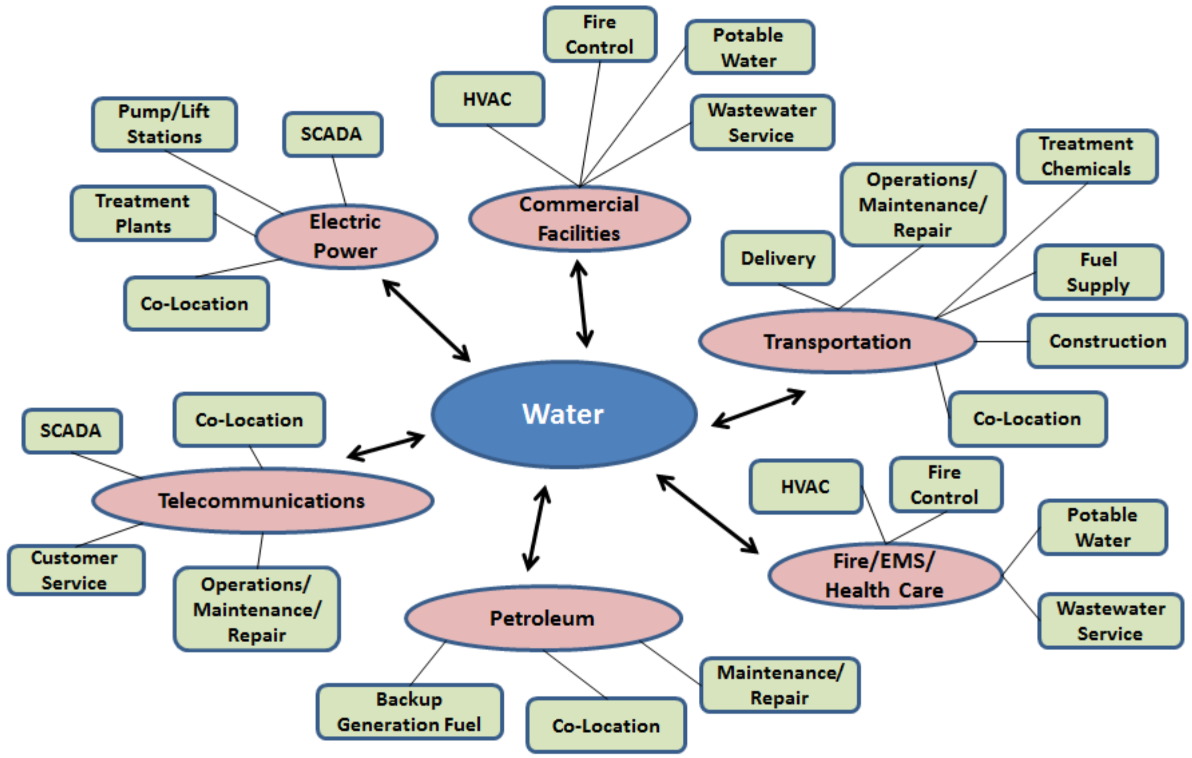

Figure 9-1. Water Interdependencies with Other Infrastructure Systems (Morley 2013)

Some of the most important dependencies for the water and wastewater infrastructure systems include:

1. ***Energy/Power (Electric and Fuel/Petroleum)*** **–** Water and wastewater utilities rely on commercial electricity to run pumps, treatment processes, and lab and office operations. Some of these functions may have standby power, but overall power demands make it impractical for most water and wastewater systems to run entirely on standby generators. However, short-term power loss events are often mitigated by standby generators supported to maintain water and wastewater operations. These emergency conditions are dependent on sustained fuel supply for standby generators to support utility vehicles and equipment. Disruption in fuel production, storage, or delivery may severely impact a water utility's ability to sustain operations on standby generator power and perform repairs.
2. ***Transportation (Staff, Supplies, Pipelines)*** **–** Staff at water and wastewater facilities depend on roadway and bridge transportation systems for access. Damage to transportation infrastructure potentially complicates and lengthens repair times or even prevents repairs until roadways and bridges are usable. Water and wastewater utilities generally keep a limited stock of pipe, fittings, and other repair materials to use in response and recovery operations. However, depending on the size of the event, this stock may be quickly depleted due to supply chain disruptions. Such disruptions may also impact the available support from relief equipment and personnel. Utilities also rely on a semi-regular delivery of treatment process chemicals essential for meeting water quality regulations.

Water and wastewater buried pipelines are often co-located with other buried infrastructure under or adjacent to roadways. Failure of pipelines may result in damage to the roadway (e.g., sinkhole from water main break or collapsed sewer pipeline) and impact to traffic during repairs. Therefore, the transportation system, particularly the roadway system, is dependent on the performance of the water and wastewater infrastructure systems.

3. ***Communications and Information* –** Water and wastewater utilities often rely on cellular networks to communicate to operations staff and contractors. If the cellular network is down for an extended period, complications and delays in repairs can occur. Additionally, supervisory control and data acquisition (SCADA) networks are used extensively within both water and wastewater systems to monitor and control widespread components and equipment.

   The communications system infrastructure also depends on water infrastructure. For example, air conditioning system cooling towers that support communications require water to keep sensitive electronic equipment in Central Offices at safe operating temperatures. Furthermore, technicians cannot enter Central Offices to maintain or repair functionality of the communications system if its water and wastewater systems are not functioning.

4. ***Buildings (Critical, Commercial, General Public)* –** Water and wastewater utilities rely on customers (e.g., critical facilities, commercial facilities, and households) to pay bills as a continued source of capital. Utilities will potentially experience significant capital expenditures in the aftermath of a disaster and customers may not have the ability to pay bills (i.e., loss of personal income from loss of wages or breakdown of electronic or posted payments), placing a large financial burden on the utilities. Water and wastewater utilities also operate administrative buildings. New Orleans Water & Sewer Board’s treatment, distribution, collection, and administrative operations were severely impacted following Hurricane Katrina. The administration’s disruptions included the loss of customer billing and other records due to significant flooding. During this same event, Children’s Hospital of New Orleans was forced to evacuate when the hospital lost water pressure and was unable to maintain the HVAC system needed by patients in critical care units.

   Commercial and other public buildings need water supply with adequate flow and pressure for fire suppression, as well as sanitation. Industrial facilities need functional water and wastewater systems for developing, processing, and manufacturing materials and products. The public relies on water and wastewater services for overall health of the community.

9.2. Water and Wastewater Infrastructure

This section describes basic components of water and wastewater systems. Performance observations from past disaster events characterize some key hazard vulnerabilities in water and wastewater systems. Water and wastewater infrastructure are vulnerable to a number of hazards: buried pipelines are vulnerable to breaks during earthquakes, water and wastewater treatment facilities are vulnerable to flood hazards. Facilities are often designed to be in or near flood hazard areas, given their functional dependency on natural water resources. To become more resilient, each individual community will have to consider its own hazards when implementing plans. Additionally, as discussed in the previous section, system interdependencies (e.g., loss of commercial electrical power in a high wind event) can have a significant impact on operability of water and wastewater systems (Elliott, T. and Tang, A., 2009).

9.2.1. Water Infrastructure

Water sources include groundwater and surface water, treated to satisfy public health standards and distributed to consumers by a network of pipelines. Some water utilities have their own supplies and treatment infrastructure, while others buy wholesale water from neighboring agencies.

Water systems are composed of six general infrastructure categories: 1) Supply, 2) Transmission, 3) Treatment, 4) Pumping, 5) Storage, and 6) Distribution. The basic function of each category and infrastructure system (electric power, transportation, communication) interdependent of the water system can be impacted by a variety of hazards, as shown in Table 9-1. Some examples of damage to water infrastructure seen in past events are discussed in the following subsections.

***Table 9-1. Hazard Impacts on Water Infrastructure System** (AWWA M19: Emergency Planning for Water Utilities)*

System Components – Likely damage, loss, or shortage due to hazards	Earthquakes	Hurricanes	Tornadoes	Floods	Forest or Brush Fires	Volcanic eruptions	Other Severe Weather	Waterborne Disease	Hazardous Material	Structure Fire	Construction Accidents	Transportation Accidents	Nuclear	Vandal, riots, Strikes
Administration/operations														
Personnel	♦	♦					♦	♦			♦	♦	♦	♦
Facilities/equipment	♦	♦	♦	♦	♦	♦				♦			♦	♦
Records	♦	♦	♦	♦	♦					♦				♦
Source Water														
Watersheds/surface		♦		♦	♦	♦		♦	♦				♦	♦
sources	♦	♦		♦				♦	♦				♦	♦
Reservoirs and dams				♦				♦	♦				♦	
Groundwater sources	♦	♦	♦	♦		♦	♦	♦	♦					♦
Wells and galleries														
Transmission														
Intake structures	♦		♦	♦		♦	♦					♦		♦
Aqueducts	♦										♦	♦		
Pump stations	♦		♦	♦	♦	♦	♦			♦	♦	♦		♦
Pipelines, valves	♦	♦					♦				♦			♦
Treatment														
Facility structures	♦	♦	♦	♦	♦	♦	♦			♦	♦	♦	♦	♦
Controls	♦	♦	♦	♦	♦	♦	♦			♦	♦	♦		♦
Equipment	♦	♦	♦	♦	♦					♦	♦	♦	♦	♦
Chemicals	♦	♦	♦	♦	♦					♦				♦
Storage														
Tanks	♦	♦	♦		♦	♦	♦	♦	♦	♦		♦	♦	♦
Valves	♦						♦					♦		♦
Piping	♦						♦							
Distribution														
Pipelines, valves	♦	♦					♦	♦	♦		♦			♦
Pump or PRV stations	♦	♦	♦	♦	♦	♦	♦			♦	♦	♦		♦
Materials	♦	♦		♦	♦					♦				♦
Electric power														
Substations	♦	♦	♦	♦	♦		♦			♦	♦	♦	♦	♦
Transmission lines	♦	♦	♦	♦	♦		♦			♦	♦	♦		♦
Transformers	♦	♦	♦	♦	♦	♦	♦			♦	♦	♦		♦
Standby generators				♦						♦				♦
Transportation														
Vehicles		♦	♦	♦	♦		♦				♦	♦		
Maintenance facilities	♦	♦	♦	♦	♦		♦			♦		♦		♦
Supplies		♦		♦	♦					♦				♦
Roadway infrastructure	♦			♦		♦	♦				♦	♦		♦
Communications														
Telephone	♦	♦	♦	♦	♦		♦			♦	♦	♦		♦
Two-way radio														♦
Telemetry	♦		♦	♦	♦	♦								♦

9.2.1.1. Supply

Water supply can come from groundwater or surface water, as described below.

Groundwater. Rainfall and snowmelt infiltrate into the ground to recharge groundwater aquifers. Groundwater wells tap into aquifers and supply water to individual households or municipal water providers. A well system consists of the groundwater aquifer, well casing and screen, pump and motor, power supply, electrical equipment and controls, connecting piping, and possibly a well house structure. Typically, wells are cased with a steel pipe. Screens in the well casing at the depth of the aquifer allow water to enter the casing. A submersible or surface-mounted pump conveys water to the transmission system.

Surface Water. Rainfall and snowmelt runoff that does not infiltrate into the ground collects in streams, rivers, and lakes, and is sometimes impounded by dams. Water intake structures in lakes or rivers and diversion dams then direct water to a pipeline inlet along the shoreline. All of these systems would generally include screens to keep large debris and fish from entering the treatment plant.

Just as with water and wastewater infrastructures, the water supply is particularly vulnerable flooding and earthquakes. The most significant hazard is contaminated water; flooding can cause contamination of surface and groundwater sources. Additionally, inundated well heads at the surface can introduce contaminants to well systems and groundwater. Floodwaters and generally carry contaminants like petroleum, nutrient/organic matter, bacteria, protozoa, and mold spores that pose significant health risks. Contamination can also result from tank or vehicle discharge in the watershed. In 2014, in West Virginia, 4-methylcyclohexanemethanol (MCHM) was released into the Elk River, contaminating water serving 300,000 people. It took months to restore full water service.

Although not often considered for their impact on water quality, wildfires can also lead to water contamination. Wildfires can burn watersheds, destabilizing the ground cover, which can cause landslides that contaminate the water when subsequent rains occur. Denver Water experienced wildfires in significant parts of their watershed in 1996 and 2002 that burned 150,000 acres of land, releasing one million cubic yards of sediment into one of their reservoirs.

Reservoirs behind dams often also serve as water supply features, but dam failure can present a secondary hazard in the wake of earthquakes, heavy rainfall, and flood events. Concentrated precipitation and flooding most commonly causes overtopping of the dam. While dams can reduce flooding, older and improperly designed and maintained dams are not equipped to contain large volumes of quickly accumulating water runoff. Landslides, caused by liquefaction from earthquakes can also lead to dam failure. These types of dam failures are rare, but present a significant risk to anyone's life downstream of a dam. Dams are critical infrastructure components that need to be designed to withstand extreme events.

9.2.1.2. Transmission

Large diameter transmission pipelines carry raw water from source to treatment plant, and treated water to storage facilities before branching out into smaller distribution pipelines. Depending on the system, these can range from one foot to several tens of feet in diameter. Transmission pipelines are constructed of welded steel, reinforced concrete, concrete cylinder, or ductile iron (historically cast iron).

Typically, these pipelines are buried, making them difficult to inspect and expensive and disruptive to repair. Burial reduces pipelines' vulnerability to hazards, such as high wind events; however, hazards that cause landslides, such as earthquakes, floods, long-term heavy rain, and wildfire, can damage transmission lines. Figure 9-2 shows a transmission pipeline bridge demolished in the Bull Run Canyon in a landslide event induced by heavy rains.

***Figure 9-2. Water Transmission Pipeline Bridge Damaged by Landslide** (Courtesy of Portland Water Bureau)*

9.2.1.3. Treatment

Water treatment plants process raw water from groundwater or surface water supplies to meet public health water quality standards and often to improve taste. The processes used depend on the raw water source, removing pathogens, organic or inorganic contaminants, chemicals, and turbidity. The treatment process commonly includes pretreatment, flocculation, sedimentation, filtration, and disinfection with variations of these processes in some modern plants. Water treatment plants typically consist of a number of process tanks, yard and plant piping, pumps, chemical storage and feed equipment, lab and office building space, and associated mechanical, electrical, and control equipment.

Water treatment plants are vulnerable to flooding, because they are often located near flooding sources (i.e., lakes, rivers). Electrical control systems are often damaged by flood inundation, leading to loss of functionality and service outages. In 1991, the Des Moines, Iowa Water Treatment Plant was submerged by riverine flooding, resulting in 19 days without potable water for the city of Des Moines.

Loss of power at water treatment plants from high wind events (hurricanes, tornadoes), severe storms, or other hazards can severely impact the system by preventing proper treatment prior to transmission and distribution. As a result, potable water may not be available and boil water notices necessary. While standby power systems are usually incorporated into a water treatment plant's design, they need to be well-maintained, tested regularly, and adequately connected, installed, supplied, and protected from hazard events to be reliable and function properly.

Earthquakes also cause damage to water treatment plants and their components. In 1989, the Loma Prieta earthquake in California heavily damaged the clarifiers due to sloshing water at the Rinconada Water Treatment Plant in San Jose, California, greatly curtailing its 40 MGD capacity (Figure 9-3). In the 2011 Tohoku earthquake in Japan, liquefaction resulted in differential settlement between pile-supported structures and direct-buried pipe at water treatment plants, as shown in Figure 9-4.

***Figure 9-3. Santa Clara Valley Water District, Rinconada Water Treatment Plant Clarifier Launders Damaged due to Sloshing, 1989 Loma Prieta Earthquake** (Courtesy of Don Ballantyne)*

***Figure 9-4. Liquefaction Caused Differential Settlement Between Pile-Supported Structures and Buried Pipe during the 2011 Tohoku Earthquake** (Courtesy of Don Ballantyne)*

9.2.1.4. Pumping

Pumping stations increase hydraulic head (i.e., raise water from one elevation to a higher elevation). A pump station typically consists of a simple building that houses pumps, motors that power the pumps, pipes, valves, and associated mechanical, electrical, and control equipment. Pump stations often have standby emergency generators to enable continued operation when commercial power supply is interrupted.

Similarly to water treatment plants, loss of commercial electrical power due to any type of hazard event prevents operation of pumps if there is no standby power supply. Furthermore, floodwater can inundate electrical equipment and controls at pump stations located wholly or partially below grade and/or in flood-prone areas. Figure 9-5 shows a pump station adjacent to the Missouri River damaged by flood inundation.

***Figure 9-5. Bismarck, ND Pump Station Damaged by Flood Inundation from Adjacent Missouri River** (Courtesy of FEMA)*

9.2.1.5. Storage

Water utilities use storage tanks and reservoirs to balance water demand with water production capacity. Stored potable water is drawn down during times of peak usage and recharged during off-peak hours. Typically, one to three days of daily water demand is stored to satisfy increased demand from fire suppression or other emergency needs. Reservoirs are often constructed by damning a valley with a concrete or earthen dam. If they are being used for treated water, they can be lined with asphalt or concrete and covered.

Modern steel storage tanks are either ground-supported, taller standpipes, or elevated tanks supported on a frame or pedestal. Reinforced concrete tanks are typically at grade or buried. Circular concrete tanks can be reinforced with wire wrapping or tendons.

Storage tasks are vulnerable to a number of hazards. Elevated storage tanks are more susceptible to hazards from high winds than structures located at grade and can be damaged to the point of structural failure, suddenly releasing their contents. In hurricanes, high winds present a higher hazard in coastal areas (than further inland) and are often accompanied by storm surge. Figure 9-6 shows a collapsed water tank in Buras, Louisiana near Hurricane Katrina's landfall that was likely caused by a combination of high winds and storm surge.

***Figure 9-6. Collapsed Water Tank in Buras, LA near Hurricane Katrina Landfall Location** (Courtesy of David Goldbloom- Helzner)*

At-grade or partially-underground storage tanks are more susceptible to flood damage (from hurricane storm surge, riverine flooding, or tsunamis), particularly if located in or near flood-prone areas. Tank damage or failure can be caused by both hydrostatic forces from standing or slow moving water, or hydrodynamic forces imposed by higher velocity flows or wave action. Buoyancy forces can cause uplift of empty subgrade tanks if the soil becomes saturated. Figure 9-7 shows two liquid fuel tanks in the foreground that were floated and toppled by tsunami wave inundation after the 2011 Tohoku, Japan tsunami. The tank in the background was on higher ground and does not appear to be damaged.

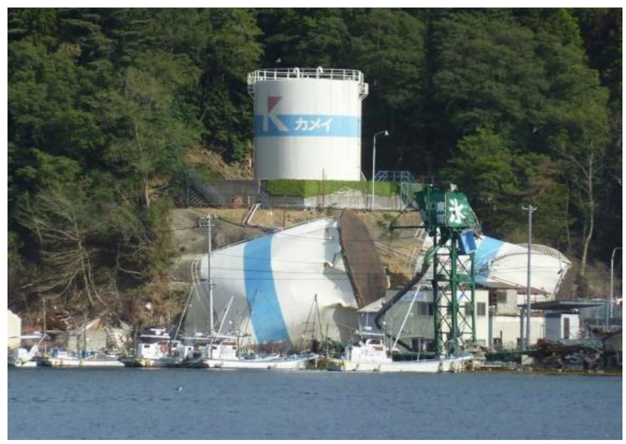

***Figure 9-7. Steel Tanks Damaged Due to Tohoku, Japan Tsunami in 2011** (Tang & Edwards 2014)*

Earthquakes can damage storage tanks due to lateral loads (shaking) and permanent ground deformation due to liquefaction and landslides. Water sloshes in storage and process tanks imparting extreme loads on tank walls and baffles. In the 1994 Northridge earthquake, a Los Angeles Department of Water and Power (LADWP) tank moved, severing piping, as shown in Figure 9-8. The utility just north of LADWP suffered elephant's foot buckling in a steel tank as shown in Figure 9-9.

Figure 9-8. Tank Moved, Severing Connecting Pipe in 1994 Northridge Earthquake (Courtesy of Los Angeles Department of Water and Power)

Figure 9-9. Steel Tank "Elephant's Foot" Buckling in 1994 Northridge Earthquake (Courtesy of Donald Ballantyne)

9.2.1.6. Distribution

Smaller diameter distribution pipelines carry treated water from transmission pipelines to neighborhoods commercial and industrial areas. Service connections with meters branch off distribution pipelines to supply individual customers. The portion of the service connection before the water meter is typically maintained by the water utility and the portion after the water meter is the responsibility of the individual customer. The system is controlled with manually operated valves distributed at most pipeline intersections. Distribution systems have fire hydrants located every 300 feet along the pipeline. Distribution pipelines are commonly made with ductile iron (historically cast iron), welded steel, PVC, or asbestos cement.

Leaks and breaks are two main concerns for distribution pipelines. A leak commonly refers to relatively minor damage to a pipe barrel or joint that causes minor to moderate water loss, but does not significantly impair the distribution system's function. However, breaks commonly refer to major damage to a pipe barrel or joint that causes major water and pressure loss in a zone or drains nearby tanks. When there are breaks in the water distribution system, it can lead to depressurization of the system. Depressurization can result in sediment accumulation within the pipelines affecting the potability of the water, contamination and loss of potability means boil water orders should be issued. Before water can be considered potable again, the distribution systems must be fixed and the water quality monitored and tested continuously to meet public health standards.

Breaks of distribution pipelines can result from a number of hazards. Floods cause erosion, exposing, possibly breaking pipelines (see Figure 9-10).

Figure 9-10. Exposed and Broken Distribution Lines Resulting from Flooding in Jamestown, CO (Courtesy of David Goldbloom-Helzner)

Earthquakes can cause liquefaction or permanent ground deformation, causing pipeline breaks. In the 1994 Northridge earthquake, the Los Angeles Department of Water and Power had approximately 1,000 pipeline breaks, primarily in cast iron pipe. While there was only limited liquefaction, ground motions were very strong. A year later, the Kobe earthquake caused approximately 1,200 pipeline failures due to extensive liquefaction. Most of the system was constructed of ductile iron pipe, which primarily failed by joint separation as seen in Figure 9-11.

Figure 9-11. Joint Separation in Ductile Iron Pipe due to Liquefaction during 1995 Kobe Earthquake (Courtesy of Kobe Water Department)

High wind events, such as hurricanes or tornadoes, can result in damage to distribution lines, though not directly cause by high winds, but by uprooted trees. For example, during Hurricane Andrew, there was extensive damage to the water distribution systems in Southern Florida primarily caused by tree roots that had grown and wrapped themselves around the water mains and service lines. When these trees were uprooted by hurricane force winds, (Hurricane Andrew was a Category 5 on the Saffir-Sampson scale when it made landfall in Dade County, Florida) they pulled the lines too. Similar damage to water transmission and distribution systems occurred during Hurricanes Katrina and Rita in Louisiana (Allouche, 2006). As stated above, no matter the cause of damage, pipeline breaks resulting in a depressurized system contaminate the pipelines, affecting the potability of the water and requiring additional recovery time.

9.2.2. Wastewater Systems

Wastewater systems collect domestic and industrial liquid waste products and convey them to treatment plants through collection and conveyance systems and pump stations. After separation of solids, biological processing and disinfection, treated wastewater is discharged as effluent into a receiving body of water or alternatively, may be reused for irrigation or other purposes. Some utilities have separate collection systems for wastewater and storm water; other utilities have collection systems combine collected wastewater and storm water in the same pipelines.

Pipeline system failure can discharge raw sewage into basements, on to city streets, and into receiving waters, resulting in public health issues and environmental contamination. Standard wastewater systems are composed of five general categories of infrastructure: 1) Collection, 2) Conveyance, 3) Pumping, 4) Treatment, and 5) Discharge. The basic function of each of these categories is briefly described in the following subsections. Apart from standard systems, pressure and vacuum systems are used on occasion. Pressure systems require a grinder pump at each house that pump the sewage through small diameter pipe to a larger pipe collector, and often times to a gravity sewer. Vacuum systems work in a similar manner, except a vacuum pump and tank pull sewage through shallow small diameter pipe to a central location.

9.2.2.1. Collection

The collection pipeline network for wastewater systems is similar to that for water systems, except instead of delivering water to individual customers the wastewater collection system conveys liquid and other waste products away from customers. This is usually accomplished using gravity sewers. In some instances pumps convey wastewater through pressurized force mains. The elevation and grade of the pipelines in the system need to be carefully controlled to maintain gravity flow in the system. Infiltration and inflow of groundwater into the collection system through cracks and breaks in the pipe can significantly increase the volume of wastewater that arrives at the treatment plant. A variety of pipe materials are commonly found in collection systems, including:

- Vitrified clay – smaller diameter collection
- PVC – smaller diameter collection
- Asbestos cement – historically smaller diameter collection
- Reinforced concrete – larger diameter interceptors
- Steel – force mains or siphons
- Polyethylene – force mains or siphons
- Ductile iron (or historically cast iron) – collection or force mains
- Brick – larger capacity interceptors
- Fiberglass or FRP
- ABS

Gravity systems have manholes at regular intervals allowing access for cleaning and maintenance. Manholes are usually constructed with concrete, although historically manholes were often constructed with brick.

Wastewater collection pipes have similar causes of damage to those of water distribution and transmission pipelines. Wastewater collection pipelines can be exposed and damaged because of landslides, erosion, or scour, which damages or breaks the pipelines. Furthermore, wastewater collection pipelines can be damaged in high wind events by uprooted trees with root systems grown around the pipelines.

In the collection and conveyance system, pipelines are damaged by earthquake shaking, but more extensively due to liquefaction and associated lateral spreading. Sewer pipes can be damaged by shaking, which can cause joints to crack, but most remain operable. These cracks will ultimately have to be repaired to control infiltration. Liquefaction can result in pulled joints and displaced pipe. Another cause of failure is pipe flotation, occurring when a partially-filled gravity sewer is surrounded by liquefied soil.

Flooding can also damage wastewater collection pipelines in a number of ways. Pipelines that are co-located on bridges experience damage caused by flood inundation and flood-borne debris impact. Hydrodynamic forces associated with coastal flooding or high velocity flows are more likely to damage structures and attached pipelines than inundation alone. In the New Orleans area after Hurricane Katrina, the most common damage to buried wastewater pipelines observed by clean-up crews was separation of pipe joints, leaks, and breaks. This damage was believed to be the result of floodwaters supersaturating soils then draining, leading to soil shrinkage and subsidence. Without support of the soils, the rigid pipelines broke and fractured (Chisolm, 2012). Increased flow and pressurization of the wastewater collection systems as the result of inflow and infiltration during flood events can also damage pipelines, particularly in cases where pipes are composed of materials such as vitrified clay. For example, during the 1997 Red River Flood in Grand Forks, North Dakota, pressurization caused breaking of vitrified clay pipe and hairline cracks increased the rate of overall pipe deterioration (Chisolm 2012).

9.2.2.2. Conveyance

The conveyance system for the wastewater network is similar to the transmission system in a water system. The conveyance pipelines are larger in diameter, and are often times deeper underground. In many instances, these conveyance systems were installed in the early to mid-1900s as the United States began to clean up its waterways. The conveyance systems are designed to collect sewage from the collection system and move it to the wastewater treatment plant. Like collection systems, it may include pump stations. Recently, the EPA is pushing wastewater utilities to minimize discharge of raw sewage to receive water runoff during heavy rain events. This often resulted in cities having sewers that carried both sewage and storm water. As a result, many conveyance systems now have a built-in large storage capacity, taking the form of a wide point in the line and, in some cases, simplified wastewater treatment facilities.

9.2.2.3. Pumping

Gravity feed systems use pump or lift stations to lift wastewater to a higher elevation. The pump may discharge at the higher elevation to another section of gravity feed pipeline or may remain a pressurized force main and discharge at a distant location, such as a treatment plant. A pump station typically consists of a simple building that houses pumps, motors that power the pumps, pipes, and associated mechanical, electrical, and control equipment. The pumps can be located in a building (typically wetwell-drywell layout) or a large manhole (submersible). Pump stations are required to have standby generators to enable continued operation when the commercial power supply is interrupted.

Pump stations are vulnerable to a number of hazards, most notably earthquakes and flooding. Unless designed to be submersible, floodwater inundating pumps can disable and damage the pumps and their motors. This was a common cause of pump station failure in New York City during flood inundation from Hurricane Sandy (NYCDEP, 2013). Damage is even worse if salt water flooding is involved, leading to corrosion. Loss of commercial electrical power prevents operation of pumps if adequate standby power is not provided or these generators are not refueled in a timely manner. Earthquakes can cause liquefaction, resulting in buried wastewater collection wells at pump stations to float and tilt. This movement likely damages connecting piping and renders the pump station inoperable. Manholes and pump stations can float as well, when founded in liquefied soils, which changes the grade, making the sewer unusable or difficult to maintain.

9.2.2.4. Treatment

Wastewater treatment plants process raw sewage from household and industrial sources so the resulting effluent discharge meets public health and environmental standards. The typical process is: 1) Pretreatment using screens and grit chambers, 2) Primary treatment in a sedimentation tank, 3) Secondary treatment using biological treatment and clarifiers, and 4) Disinfection using chlorine or other disinfectants. In some cases, the effluent is further treated at a higher level to be used for irrigation. Solids drawn off from the four processes are further treated in digesters and solidified using presses or centrifuges. These processes require an extensive mechanical and electrical equipment and piping.

Wastewater treatment plants are susceptible to damage from several natural hazards, particularly flooding. Wastewater treatment plants are often located in or near flood-prone areas because they return treated water to naturally occurring bodies of water via gravity. Therefore, they can be vulnerable to flood inundation or storm surge and wave action from coastal sources, causing damage and loss of functionality to buildings, equipment, and electrical and mechanical systems. The New York City Department of

Environmental Protection (NYC DEP) noted in a recent study that all 14 of the wastewater treatment plants (WWTP) it owns and operates are at risk of flood damage (NYCDEP, 2013).

WWTPs in non-coastal regions of the United States are often located adjacent to rivers. With the projected sea level rise continuing through the 21st century, the frequency of these facilities flooding will increase. Some recent examples of WWTP riverine flooding include: 1) Nine days of lost functionality due to flooding of Valdosta, Georgia WWTP in 2009; 2) Flooding of the Pawtuxet River in Warwick, Rhode Island in 2010; and 3) Shut down of the Palmyra, Indiana WWTP in 2011 due to rising water levels.

In areas where wastewater treatment facilities are elevated or protected by levees, flooding can still lead to access issues. While the treatment facility itself may not be inundated, flooding around the facility can limit both ingress and egress of vital staff. This was the case for several WWTPs located along the Missouri and Mississippi Rivers during the 1993 flood. Access to facilities was only possible by boat, while roads inundated by the flood were not considered stable enough for larger vehicles, such as those that carried supplies for the plants (Sanders, 1997).

Release of untreated sewage is relatively common during major flood events when inflow and infiltration can overtax wastewater collection systems or when there are combined sewer overflows. During Hurricane Sandy, over 560 million gallons of untreated and diluted sewage, mixed with storm water and seawater, was released into waterways. This instance of sewage release was caused by infiltration of floodwaters into the sewer system, flood inundation of plant facilities, and power outages (NYC DEP, 2013). After Hurricane Sandy, electronic controls were inundated and damaged in many wastewater treatment facilities, which significantly delayed the facilities' recovery times (FEMA 2013). Similarly, after Hurricane Rita in 2005, the City of Lake Charles had a citywide power loss that affected the wastewater treatment plant serving two-thirds of the city, releasing raw sewage into a nearby lake for over a week, until power was restored.

While discharge or raw sewage contaminates the receiving water, chemical contamination of sewage can impact the WWTP treatment process itself. For example, in the 1989 Loma Prieta earthquake in California, the East Bay Municipal Utility District (EBMUD) WWTP biological treatment process failed due to a spill in the collection system contaminating the treatment plant influent. Coupled with the spill, EBMUD lost power and were unable to pump oxygen into the treatment system, resulting in the secondary treatment system being inoperable for several weeks.

WWTPs are at a low point in the elevation of the system. Though flooding from different hazard events (hurricane storm surge, coastal and riverine flooding, and tsunamis) is a primary concern, earthquakes can damage facilities by shaking, permanent ground deformation, and liquefaction. Shaking is particularly problematic in process tanks and digesters where the hydraulic load from sloshing sewage impacts the tank walls. Liquefaction-induced permanent ground deformation often causes process tank joint separation, damage to pipelines, pipe racks, etc. Even if treatment structures are pile-supported, direct-buried piping can settle differentially and break. In the 2011 Christchurch earthquake in New Zealand, clarifiers settled differentially rendering them inoperable. In the 1995 Kobe Earthquake, the Higashinada WWTP site settled differentially as much a one meter, and moved laterally as much as two meters due to liquefaction heavily damaging non-pile-supported structures. The resulting damage is shown in Figure 9-12. Figure 9-13 shows the Higashinada influent channel that was offset one meter by liquefaction during the 1995 Kobe earthquake.

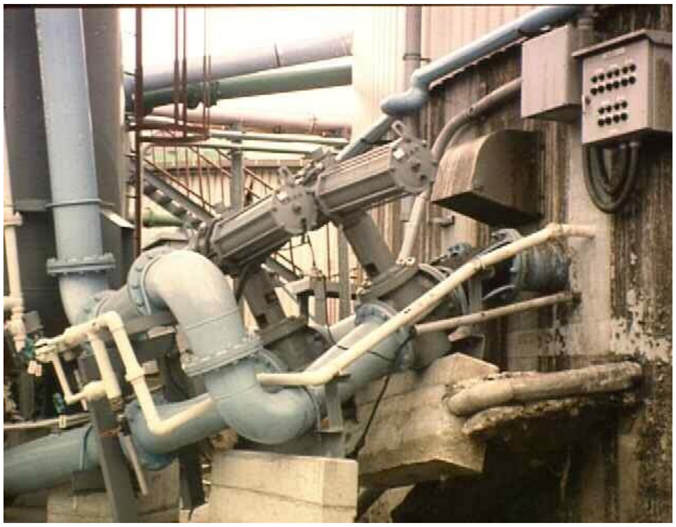

***Figure 9-12. Non-Pile Supported Structures Failed Due to Liquefaction in 1995 Kobe Earthquake** (Courtesy of Donald Ballantyne)*

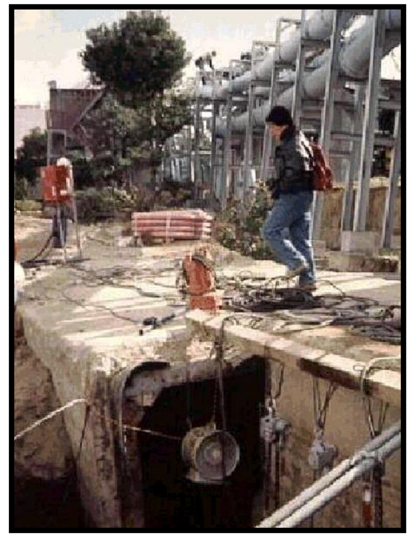

***Figure 9-13. Higashinda WWTP Channel Offset by Liquefaction in 1995 Kobe Earthquake** (Courtesy of Donald Ballantyne)*

Strong earthquakes can produce tsunamis that structurally damage treatment plant facilities due to lateral hydraulic loading and can inundate facilities, causing damage to electrical gear. The 2011 Tohoku earthquake in Japan caused heavy damage to the Sendai WWTP Effluent Pump Station's east wall, as shown in Figure 9-14. Much of the treatment plant's process tank equipment required replacement because of the large amount of damage, as shown in Figure 9-15.

***Figure 9-14. Sendai WWTP Effluent Pump Station Damaged by Tsunami in 2011 Tohoku Earthquake** (Courtesy of Donald Ballantyne)*

***Figure 9-15. Sendai WWTP Equipment and Piping Damage from 2011 Earthquake** (Courtesy of Donald Ballantyne)*

9.2.2.5. Discharge

Effluent from the treatment plant is discharged to a receiving body of water through an outfall. Outfalls are composed of a pipeline with a diffuser at the end discharging the water hundreds or thousands of feet away from the shoreline, at a depth that will minimize impact on the environment.

9.3. Performance Goals

The large and distributed nature of water and wastewater systems, combined with their interdependence on other infrastructure systems, limits the practicality of maintaining 100 percent operational capacity in the aftermath of a major natural disaster. This section provides an example of performance goals for water and wastewater systems in the fictional community of Centerville, USA.

Performance goals need to be discussed with individual utilities and communities before they are adopted. It is important to consider the uniqueness of the infrastructure of individual utilities and the specific needs of their customers when adopting system performance goals for a community. Water and wastewater stakeholder engagement is critical in establishing a community-specific level of service performance goals for each of the three different hazard levels (*routine*, *expected*, and *extreme*) defined in Chapter 3. Stakeholders should include representation from the following organizations as applicable:

- Residential customers
- Business owners
- Industry representatives
- Water wholesale customers
- Hospital representatives
- Fire department officials and crew
- Local government officials
- Local emergency management officials
- Drinking water regulators (Health Authority, etc.)
- Wastewater regulators (Dept. of Environmental Quality, Environmental Protection Agency, etc.)
- Water and wastewater utility operators and engineers
- Consulting engineers
- Interdependent infrastructure system operators (power, liquid fuel, transportation, etc.)

Establishing performance goals involves a discussion amongst the stakeholders about their expectations for the availability of water and wastewater systems following a hazard event in the short, intermediate, and long term phases for different hazard levels (e.g., *routine*, *expected*, and *extreme*). The assumed expectation of the public is that for *routine* hazard events there would be little, if any, interruption of service for water and wastewater lifelines. A dialogue is required between utilities and customers to determine the appropriate level of service performance goals for *expected* and *extreme* events. While examples are provided in Table 9-2 through Table 9-7 (pages 16 through 21), it is anticipated that actual goals will vary by community and are dependent on community priorities, as determined during the development of the goals and through outreach to and discussion among stakeholders.

There may be variability for an individual community's goals depending on the specific hazard being addressed. For example, if a community is subject to both seismic and wind hazards, they may determine that the damage to major collection lines within a wastewater system from an extreme seismic event is more likely and requires more restoration time, compared to damage from an extreme wind event.

There may be elements in a system that are so critical to public safety they need to be designed to remain operational after an *extreme* event. For example, failure of a water supply impoundment dam presents a significant life-safety hazard to downstream residents and should be designed for an *extreme* event.

Interdependencies of water and wastewater systems with other infrastructure also need to be considered when developing performance goals. For instance, availability of a reliable supply of liquid fuel impacts how long systems can run on standby generators and impacts repair crew's vehicles and equipment. In turn, delivery of liquid fuels depends on the status of the highway and bridge transportation network.

Performance goals are broken down into functional categories (i.e., water for fire suppression at key supply points, treatment plants operating to meet regulatory requirements, etc.) and further broken down into target timelines to restore the functional categories to 30 percent, 60 percent, and 90 percent operational status.

The infrastructure components in the example performance goals tables are not intended to be an exhaustive list. Some of the system components may not exist in all communities. For instance, in the water system performance goals, some communities may have the ability to distinguish between the general water supply and distribution and water supply for fire suppression. However, most systems are integrated and will not have a means to separate general supply and distribution from that needed for fire suppression. Additionally, some communities might have wholesale users – a system component listed in the performance goals – meaning their water system supplies all of the water used by other nearby, smaller communities. Wholesale users are treated as a critical part of the distribution system within the example, but are not a consideration for all communities. Each community will need to review these components to determine which ones to incorporate into their systems.

Similarly, communities may want to add certain system components to these goals that are not already captured here, to provide additional detail and allow for distinction between restoration timeframes. There may also be system components that are unique to a community that require special consideration. While the lists presented in the examples generally capture significant system components, it is recognized that communities may have additional infrastructure assets to consider.

The financial burden associated with upgrading all components of an entire system to be more disaster resilient would overwhelm the short-term capital improvement budgets of most utilities. Therefore, performance goals have been established around certain concepts.

- Prioritizing potential solutions to be implemented over many years to limit disruptions and recovery time rather than implementing them all at once
- Recognizing that there may be both short and long-term solutions capable of decreasing recovery times
- Balancing societal needs with realistic expectations of system performance

Focusing on major system components that form a backbone network capable of supplying key health and safety-related community needs shortly after a hazard event is one way to focus priorities. Recognizing that potentially less costly short-term solutions combined with longer term physical hardening of infrastructure allows for increased resilience would manage community's expectations and the cost of implementing solutions.

Table 9-2. Example Water Infrastructure Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Source		1									
Raw or source water and terminal reservoirs			90%		X						
Raw water conveyance (pump stations and piping to WTP)			90%		X						
Potable water at supply (WTP, wells, impoundment)			90%		X						
Water for fire suppression at key supply points (to promote redundancy)			90%		X						
Transmission (including Booster Stations)		1									
Backbone transmission facilities (pipelines, pump stations, and tanks)			90%		X						
Control Systems											
SCADA or other control systems			90%		X						
Distribution											
Critical Facilities		1									
Wholesale Users (other communities, rural water districts)			90%		X						
Hospitals, EOC, Police Station, Fire Stations			90%		X						
Emergency Housing		1									
Emergency Shelters			90%		X						
Housing/Neighborhoods		2									
Drink water available at community distribution centers				90%		X					
Water for fire suppression at fire hydrants				90%		X					
Community Recovery Infrastructure		3									
All other clusters					90%	X					

Footnotes:

1 Specify hazard being considered
Specify level -- Routine, Expected, Extreme
Specify the size of the area affected - localized, community, regional
Specify severity of disruption - minor, moderate, severe

2 30% | 60% | 90% Restoration times relate to number of elements of each cluster

3 X Estimated restoration time for current conditions based on design standards and current inventory
Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan
R Regional
S State
MS Multi-state
C Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

Table 9-3: Example Water Infrastructure Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Source		**1**									
Raw or source water and terminal reservoirs					90%						
Raw water conveyance (pump stations and piping to WTP)						90%				X	
Potable water at supply (WTP, wells, impoundment)			30%		60%	90%			X		
Water for fire suppression at key supply points (to promote redundancy)			90%			X					
Transmission (including Booster Stations)		**1**									
Backbone transmission facilities (pipelines, pump stations, and tanks)			90%					X			
Control Systems											
SCADA or other control systems			30%		60%	90%		X			
Distribution											
Critical Facilities		**1**									
Wholesale Users (other communities, rural water districts)				60%	90%						
Hospitals, EOC, Police Station, Fire Stations				60%	90%			X			
Emergency Housing		**1**									
Emergency Shelters				60%	90%			X			
Housing/Neighborhoods		**2**									
Drink water available at community distribution centers					60%	90%					
Water for fire suppression at fire hydrants						90%				X	
Community Recovery Infrastructure		**3**									
All other clusters					30%	90%				X	

Footnotes: See Table 9-2, page 16.

Table 9-4: Example Water Infrastructure Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 – Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Source		**1**									
Raw or source water and terminal reservoirs			30%		60%	90%			X		
Raw water conveyance (pump stations and piping to WTP)						60%	90%			X	
Potable water at supply (WTP, wells, impoundment)					30%	60%	90%			X	
Water for fire suppression at key supply points (to promote redundancy)					90%	X					
Transmission (including Booster Stations)		**1**									
Backbone transmission facilities (pipelines, pump stations, and tanks)			30%				60%		90%	X	
Control Systems											
SCADA or other control systems						30%	60%	90%			
Distribution											
Critical Facilities		**1**									
Wholesale Users (other communities, rural water districts)							60%		90%	X	
Hospitals, EOC, Police Station, Fire Stations						60%	90%		X		
Emergency Housing		**1**									
Emergency Shelters						60%	90%		X		
Housing/Neighborhoods		**2**									
Drink water available at community distribution centers					30%	60%	90%		X		
Water for fire suppression at fire hydrants						60%	90%			X	
Community Recovery Infrastructure		**3**									
All other clusters								60%	90%		X

Footnotes: See Table 9-2, page 16.

Table 9-5. Example Wastewater Infrastructure Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Treatment Plants											
Treatment plants operating with primary treatment and disinfection					90%	X					
Treatment plants operating to meet regulatory requirements					90%	X					
Trunk Lines											
Backbone collection facilities (major trunkline, lift stations, siphons, relief mains, aerial crossings)				60%	90%	X					
Flow equalization basins				60%	90%	X					
Control Systems											
SCADA and other control systems			90%		X						
Collection Lines											
Critical Facilities											
Hospitals, EOC, Police Station, Fire Stations				90%	X						
Emergency Housing											
Emergency Shelters				90%	X						
Housing/Neighborhoods											
Threats to public health and safety controlled by containing & routing raw sewage away from public				60%	90%	X					
Community Recovery Infrastructure											
All other clusters				60%	90%	X					

Footnotes: See Table 9-2, page 16.

Table 9-6: Example Wastewater Infrastructure Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Treatment Plants											
Treatment plants operating with primary treatment and disinfection					60%	90%					
Treatment plants operating to meet regulatory requirements						30%			60%	90%	X
Trunk Lines											
Backbone collection facilities (major trunkline, lift stations, siphons, relief mains, aerial crossings)					30%		60%	90%			X
Flow equalization basins					30%		60%	90%			X
Control Systems											
SCADA and other control systems						30%		60%	90%		X
Collection Lines											
Critical Facilities											
Hospitals, EOC, Police Station, Fire Stations					30%	90%				X	
Emergency Housing											
Emergency Shelters					30%	90%				X	
Housing/Neighborhoods											
Threats to public health and safety controlled by containing & routing raw sewage away from public				30%		60%	90%			X	
Community Recovery Infrastructure											
All other clusters						30%		60%		90%	X

Footnotes: See Table 9-2, page 16.

Table 9-7: Example Wastewater Infrastructure Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Treatment Plants											
Treatment plants operating with primary treatment and disinfection						30%	60%		90%	X	
Treatment plants operating to meet regulatory requirements										90%	X
Trunk Lines											
Backbone collection facilities (major trunkline, lift stations, siphons, relief mains, aerial crossings)							30%	60%		90%	X
Flow equalization basins							30%	60%		90%	X
Control Systems											
SCADA and other control systems								60%		90%	X
Collection Lines											
Critical Facilities											
Hospitals, EOC, Police Station, Fire Stations						30%	90%			X	
Emergency Housing											
Emergency Shelters						30%	90%			X	
Housing/Neighborhoods											
Threats to public health and safety controlled by containing & routing raw sewage away from public						30%	60%	90%		X	
Community Recovery Infrastructure											
All other clusters								60%		90%	X

Footnotes: See Table 9-2, page 16.

9.4. Regulatory Environment

9.4.1. Federal

The federal EPA has requirements for drinking water quality defined in the Safe Drinking Water Act and wastewater discharge water quality defined in the Clean Water Act. These acts are amended on an ongoing basis. In most cases, the EPA gives states primacy to enforce these requirements. There are certain prescriptive requirements associated with each.

SDWA Example Requirements

- Filtration of surface water supplies, except in some cases special treatment of particularly clean surface water supplies
- Disinfection of supplies (except a few groundwater supplies)
- Covering of treated water storage

Clean Water Act Example Requirements

- Secondary treatment of wastewater discharges
- Disinfection of wastewater discharges

In general, these regulations all focus on water quality and have limited interest in catastrophic hazard event impacts and planning.

9.4.2. State

State Drinking Water Programs. States typically regulate water quality and require treatment approaches for recycled water. States ensure water systems meet Safe Drinking Water Act standards by ensuring water systems test for contaminants, reviewing plans for water system improvements, conducting on-site inspections and sanitary surveys, providing training and technical assistance, and taking action against non-compliant water systems.

State Water Quality Programs. States also ensure water systems meet Clean Water Act water quality standards using state water quality programs. They develop and implement water quality standards, regulate sewage treatment systems and industrial dischargers, collect and evaluate water quality data, provide training and technical assistance, and take action against non-compliant wastewater systems.

Emergency Planning and Community Right-to-Know Act (EPCRA). Facilities that store, use, or release certain chemicals may be subject to reporting requirements to state and/or local agencies through EPCRA. Information in reports then becomes publically available. Treatment chemicals stored and used at water treatment plants often require this type of reporting.

Planning Requirements. Water and wastewater planning and design requirements are generally controlled by states and local governments. States typically require comprehensive plans for water and wastewater system are prepared on a regular basis to assess future system needs (e.g. capacity) and how those needs will be met. The elements of those comprehensive plans are defined by the state. Often times, these plans include requirements to identify hazards to which the system could be subjected, and how the utility will address those hazards. These are typically quite general in nature and do not include detailed design criteria.

9.4.3. Local

Individual municipalities or utility districts may elect to impose regulatory standards in excess of federal and state standards. In practice, this is seldom done due to the increased cost to customers associated with meeting higher-than-minimum regulatory standards.

9.5. Standards and Codes

The state and local government are responsible for adopting model building codes, such as the International Building Code (IBC). Model building codes rely heavily on standards, such ASCE-7, *Minimum Design Loads for Buildings and Other Structures.* In many cases, the state will adopt these model codes; in some cases, local jurisdictions modify them to suit their needs. The IBC and ASCE-7 focus on building structure life safety. State and local agencies will also have special requirements for high risk facilities, such as dams. The Federal Energy Regulatory Commission controls designs of hydroelectric generating dams.

The development of design codes is a long and arduous process. Theses codes are updated on a regular basis taking into account performance of facilities since the last code was issued and other developments in the building industry. Once they are finalized, they are voted on by the code committee and finally adopted by state and/or local jurisdictions. Once a code is well vetted, the state and local jurisdictions adopt it.

The following subsections discuss some of the codes, standards, and guidelines that are important to the disaster resilience of water and wastewater infrastructure, the anticipated performance of the infrastructure after an expected hazard event, and the long-term recovery levels of the infrastructure when damage does occur.

9.5.1. New Construction

Design Standards. Developed and adopted by various organizations, the two organizations that have standards most relevant to natural hazard impacts on the water and wastewater industry include:

- **American Concrete Institute –** standards addressing concrete process tanks (ACI 350)
- **American Water Works Association (AWWA) –**
  - Standards addressing design of water storage tanks (AWWA D100, D110, D115), addressing seismic design of water storage tanks
  - Standard AWWA-J100, Risk and Resilience Management of Water and Wastewater Systems, addressing performance of water and wastewater systems when subjected to natural and manmade hazards

AWWA has other standards addressing pipeline design and water quality. However, none of these other standards addresses seismic design for other natural hazards.

For the design of new underground pipelines, there is not a unifying code for water and wastewater systems. This is especially true for seismic design of buried water and wastewater pipelines or buried pipelines that may be impacted by landslides induced by flooding. Often the Chief Engineer of a particular utility is responsible for establishing its design practices. While these agency-specific design practices are generally based on industry recommendations, variability in standards used by utilities results in variability in the intended system reliability for natural and man-made hazards.

Some utilities develop their own standards to address significant local hazards specifically. For example, the San Francisco Public Utilities Commission (SFPUC) developed its own internal standard that outlines level of service performance goals following a major Bay Area earthquake and specific requirements for design and retrofit of aboveground and underground infrastructure. The SFPUC Engineering Standard *General Seismic Requirements for Design of New Facilities and Upgrade of Existing Facilities* (SFPUC, 2006) establishes design criteria that in many cases are more stringent than building codes and/or industry standards, yet ensures the SFPUC achieves its basic level of service performance goal to deliver winter day demand to their wholesale customers within 24 hours after a major earthquake.

Guidelines and Manuals of Practice. A number of organizations have developed guidelines intended for use by the industry to enhance design of the particular product being addressed. Table 9-8 lists some of the model codes, standards, and guidance documents applicable to water and wastewater infrastructure.

This table also shows a matrix of system component to document. This list is not intended to be exhaustive. However, the reader should be aware of these documents that pertain to disaster resilience.

Table 9-8. Codes, Standards, and Guidelines for Hazard Resistance of Water and Wastewater Facilities

Org	Category (1)	Name	General	Pipelines	Pumping	Storage	Treatment
IBC	C	2012 International Building Code or applicable jurisdictional building code	x				
ASCE	S	Minimum Design Loads for Buildings and Other Structures	x				
ACI	S	350 Code Requirements for Environmental Engineering Concrete Structures				x	x
ACI	S	371R-08 Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks				x	
ACI	S	372R-03 Design and Construction of Circular Wire- and Strand-Wrapped Prestressed Concrete Structures				x	x
AWWA	S	D100-11 Welded Carbon Steel Tanks for Water Storage				x	
AWWA	S	D110-13 Wire- and Strand-Wound, Circular, Prestressed Concrete Tanks				x	
AWWA	S	D115-06 Tendon-Prestressed Concrete Water Tanks				x	
AWWA	S	G430-14 Security Practices for Operation and Management	x				
AWWA	S	J100-10 Risk Analysis and Management for Critical Asset Protection Standard for Risk and Resilience Management of Water and Wastewater Systems	x				
AWWA	S	G440-11 Emergency Preparedness Practices	x				
ALA	G	Guidelines for Implementing Performance Assessments of Water Systems	x				
ALA	G	Guidelines for the Design of Buried Steel Pipe (2001)		x			
ALA	G	Seismic Design and Retrofit of Piping Systems (2002)			x		x
ALA	G	Seismic Fragility Formulations for Water Systems (2001)	x				
ALA	G	Seismic Guidelines for Water Pipelines (2005)		x			
ALA	G	Wastewater System Performance Assessment Guideline (2004)	x				
ASCE	G	Guidelines for Seismic Design of Oil and Gas Pipeline Systems (1984)		x			
AWWA	G	Emergency Power Source Planning for Water and Wastewater	x				
AWWA	G	M9 Concrete Pressure Pipe		x			
AWWA	G	M11 Steel Pipe: A Guide for Design and Installation		x			
AWWA	G	M19 Emergency Planning for Water Utilities	x				
AWWA	G	M60 Drought Preparedness and Response	x				
AWWA	G	Minimizing Earthquake Damage, A Guide for Water Utilities (1994)	x				
EPA/AWWA	G	Planning for an Emergency Drinking Water Supply	x				
MCEER	G	MCEER-08-0009 Fragility Analysis of Water Supply Systems (2008)	x				
MCEER	G	Monograph Series No. 3 Response of Buried Pipelines Subject to Earthquakes		x			
MCEER	G	Monograph Series No. 4 Seismic Design of Buried and Offshore Pipelines		x			
TCLEE	G	Monograph 15 Guidelines for the Seismic Evaluation and Upgrade of Water Transmission Facilities (1999)		x			
TCLEE	G	Monograph 22 Seismic Screening Checklists for Water and Wastewater Facilities (2002)	x				
WEF	G	Emergency Planning, Response, and Recovery	x				
WEF	G	Guide for Municipal Wet Weather Strategies	x				
WEF	G	MOP 28 Upgrading and Retrofitting Water and Wastewater Treatment Plants					x
WEF	G	MOP 8 Design of Municipal Wastewater Treatment Plants					x
WEF	G	MOP FD-17 Prevention and Control of Sewer System Overflows	x				

C – Code; S – Standard; G – Guideline or Manual of Practice (MOP)

9.5.1.1. Implied or Stated Performance Levels for Expected Hazard Levels

Design of new aboveground structures (i.e., treatment plant office and lab buildings, pump stations, process tanks, water storage tanks and reservoirs, etc.) is typically governed by local building codes or design standards that prescribe a similar wind, seismic, or other hazard as the local building code. Design loads are prescribed by a consensus-based standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). This standard uses the concept of Risk Category to increase the design force level for important structures. Typical buildings are assigned to Risk Category II. Water and wastewater treatment facilities are assigned to Risk Category III, because failure of these facilities can cause disruption to civilian life and potentially cause public health risks. Water storage facilities and pump stations required to maintain water pressure for fire suppression are assigned to the highest category, Risk Category IV.

The building code intends that structures designed as Risk Category III or IV should remain operational or require only minor repairs to be put back into operation following a design level (*expected*) wind, seismic, or other event. By designing for this performance target for the *expected* level event, water and wastewater systems should remain operational under a *routine* level event and may experience moderate to major damage during an *extreme* level event.

The performance level implied by codes and standards for new construction provides an indication of the recovery level (timeframe) expected for individual system components. The timeframe required for water or wastewater systems to return to normal operating status following a hazard event is highly dependent on the recovery time for individual system components and the system's specific characteristics (e.g., type and number of components, age of construction, system redundancy, etc.). Estimating system recovery times for a specific hazard requires in-depth engineering and operational knowledge of the system.

Table 9-9 summarizes water and wastewater system component performance and recovery levels for earthquake hazard levels as implied by current codes and standards for new construction. Predicted recovery times are based on individual system components.

Table 9-9. Water and Wastewater System Component Performance and Recovery Levels for Various Earthquake Hazard Levels as Implied by Current Codes and Standards for New Construction

System Component	Hazard Level	Performance Level	Recovery Level
Structures (pump stations, treatment plants, office/lab buildings, tanks, reservoirs, etc.)	Routine (50 year return period earthquake)	Safe and operational	Resume 100% service within days
	Expected (500 year return period earthquake)	Risk Category III (I=1.25) – Safe and usable during repair	Resume 100% service within months
		Risk Category IV (I=1.5) – Safe and operational	Resume 100% service within days
	Extreme (2500 year return period earthquake)	Risk Category III (I=1.25) – Safe and not usable	Resume 100% service within years
		Risk Category IV (I=1.5) – Safe and usable during repair or not usable	Resume 100% service within months to years
Nonstructural components (process, lab, mechanical, electrical, and plumbing equipment, etc.)	Routine (50 year return period earthquake)	Safe and operational	Resume 100% service within days
	Expected (500 year return period earthquake)	Risk Category III (I=1.25) – Safe and usable during repair	Resume 100% service within months
		Risk Category IV (I=1.5) – Safe and operational	Resume 100% service within days
	Extreme (2500 year return period earthquake)	Risk Category III (I=1.25) – Safe and not usable	Resume 100% service within years
		Risk Category IV (I=1.5) – Safe and usable during repair or not usable	Resume 100% service within months to years
Pipelines	Routine (50 year return period earthquake)	Operational	Resume 100% service within days
	Expected (500 year return period earthquake)	Operational to not usable	Resume 100% service within months
	Extreme (2500 year return period earthquake)	Not usable	Resume 100% service within years

9.5.2. Existing Construction

9.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels

The design seismic hazard level was refined over time as the engineering and seismology community's understanding of United States seismicity improved. A significant portion of water and wastewater system components in the high seismicity regions of the western and central United States were designed and constructed considering a significantly lower seismic hazard than the hazard used by current codes and standards.

Expected seismic performance of water and wastewater system components is dependent on the hazard level, codes and standards used in original design, and the type of structure. System components built prior to the mid-1970s are generally expected to perform poorly in earthquakes, because design codes and standards used at that time lacked the detailed requirements that reflect our current understanding of structures' behaviors during earthquakes. System components built after the early 2000s are generally expected to perform similar to new construction as described above. Performance of system components built between the mid-1970s and early 2000s is dependent on the code edition and seismic hazard used in design. Structures that satisfy the benchmark building criteria of ASCE 41-13 (ASCE, 2013) and are in areas that haven't experienced a significant increase in seismicity are generally expected to perform similar to new construction as described above. However, some types of structures are inherently rugged. For example, many older cast-in-place concrete structures, particularly single story buildings with few opening would be expected to perform well.

Anticipated performance of nonstructural components should be evaluated on a case-by-case basis, as engineers now pay closer attention to seismic design and construction of nonstructural components.

Anticipated performance of pipelines should be evaluated on a system-by-system basis because performance of pipelines is dependent on pipe type, joint type, and earthquake ground movement parameters. Even today, there is no code or standard for seismic design of pipelines.

9.5.2.2. Recovery Levels

In the past, infrastructure systems have not performed to the level that communities would desire with extended recovery times beyond the example performance goals in Section 9.3. There are a number of examples of disaster events that have rendered utilities non-functional for weeks following the event and illustrate importance of considering the interdependencies of water and wastewater systems with other systems of the built environment. A few notable events and their actual recover levels are discussed herein.

Great Flood of 1993. In the Great Flood of 1993, the Raccoon River overtopped its banks and submerged the Des Moines, Iowa WWTP. The water receded and the plant was able to restore non-potable water within 12 days and potable water within 19 days. The water outage disrupted restaurant and hotel operations. The Principal Insurance Company headquarters had to haul in water and pump it into the building to cool computers. AT&T's regional central office came within minutes of losing phone service because of computer cooling issues.

Northridge and Kobe Earthquakes. In the 1994 Northridge earthquake, the Los Angeles Department of Water and Power's distribution system suffered approximately 1,000 pipeline failures, primarily in the San Fernando Valley. With their own forces and mutual aid, they were able to fully restore potable water service to everyone within 12 days. A year later, the 1995 Kobe Japan earthquake suffered 1,200 pipeline failures resulting in lost service to all households for up to 60 days.

Christchurch, New Zealand and Tohoku, Japan Earthquakes. The recent 2011 Christchurch New Zealand, and Tohoku Japan earthquakes both resulted in outages lasting in excess of 40 days. Impacted Japanese cities were assisted by mutual aid from their colleagues from cities in western Japan.

9.6. Strategies for Implementing Community Resilience Plans

Section 9.2 discusses components of water and wastewater infrastructure system. The discussion includes examples from different types of hazards to encourage the reader to think about the different hazards that could impact the communication and information infrastructure in their community. The number, types, and magnitudes of hazards that need to be considered will vary from community to community.

Section 9.3 discusses example performance goals for the water and wastewater infrastructure system in fictional town Centerville, USA. These example performance goals are provided for the routine, expected and extreme event. However, the performance goals should be adjusted by the community based on its social needs.

Section 9.4 and 9.5 outline some of the regulatory levels and issues, and codes and standards that the reader should keep in mind when planning to make upgrades/changes to existing infrastructure as well as building new structures for their water and wastewater infrastructure system. The objective of this section is use the information from Sections 9.2 through 9.5 to provide guidance on how a community should work through the process of assessing their communications infrastructure, defining strategies to make its infrastructure more resilient, and narrowing the resilience gaps.

9.6.1. Available Guidance

The purpose of the assessment is to quantify the anticipated performance and recovery of the overall system to determine whether it meets the performance goals described in Section 9.3. If the system does not meet the objectives, the assessment should identify system facility and pipe deficiencies that should be improved to achieve those performance goals.

Section 9.2.1 describes the basic components of water and wastewater systems and observations of where these systems failed in past disasters. System performance is also highly dependent on the current condition of the system and standards used in its design. Information about past disaster performance of similar systems combined with knowledge of current condition and original design standards of the system help a utility estimate the expected level of service they could provide after a hazard event. There is likely a gap in the level of service a system would provide if a hazard event occurred today versus community-established performance goals. It is likely that the capital expenditure required to close this performance gap far exceeds the short-term capital improvement project budgets of the utility. However, the resilience of any system can be improved incrementally over time by appropriately considering design criteria to reduce the impact of natural and man-made hazards in designing new and upgrading existing infrastructure. To estimate the level of service a water or wastewater system would provide after a given scenario hazard event, an assessment of expected damage to the system and restoration times is required.

The level of detail of this assessment can take one of three basic forms.

- ***Tier 1* –** A high-level assessment of hazards and their performance conducted by persons knowledgeable about the system (chief engineer, operations manager, etc.). This can be accomplished in a workshop setting using system maps and schematics, along with hazard maps of the service area, such as liquefaction susceptibility or flood plain maps. Restoration times will be based on professional judgment of the workshop participants.
- ***Tier 2* –** A more refined assessment based on published scenario events and hazard zones, system inventory (i.e., facility type, age, condition, and location relative to hazards, and pipe type, length and soil type), site visits, and use of generalized component fragilities, such as those included in HAZUS-MH and ALA documents. Restoration times are based on the extent of damage (e.g., number of pipeline breaks), estimates of the time to repair each category of damage, and crews and equipment available for restoration.
- ***Tier 3* –** A detailed assessment of all components in a system, specific component fragilities, and the interdependencies of system components. Same as Tier 2, with the addition of detailed

analysis (e.g. geotechnical, structural or hydraulic) of facilities and pipelines determined to be vulnerable and critical, should they fail, significantly impacting the overall system operation.

To characterize the current disaster resilience of water and wastewater systems appropriately, each service provider should undergo a Tier 1 assessment. If potential resilience vulnerabilities are identified, they should undergo a more refined Tier 2 or 3 assessment. Several methodologies and tools are available to conduct these resilience assessments, a few of which are described below.

HAZUS-MH is a multi-hazard (flood, earthquake, and hurricane) loss estimation tool developed by the Federal Emergency Management Agency (FEMA) for use in pre-disaster mitigation, emergency preparedness, and response and recovery planning (FEMA, 2012). Communities can use this tool to characterize their hazard exposure, estimate losses to the water and wastewater systems, and estimate repair costs and duration. It assists in conducting a Tier 2 analysis and an AWWA J100 analysis as discussed below.

The ANSI/AWWA J100-10 *Standard for Risk and Resilience Management of Water and Wastewater Systems* (AWWA, 2010) provides a methodology for conducting multi-hazard system risk and resilience assessments. The J100 aligns the national homeland security objectives in HSPD-5, PPD-8, PPD-21 and EO 13636. The J100 standard consists of a seven-step process for analyzing and supporting management decisions that maximize risk reduction and/or enhance resilience at the utility and the community it serves.

1. Asset Characterization
2. Threat Characterization
3. Consequence Analysis
4. Vulnerability Analysis
5. Threat Analysis
6. Risk/Resilience Analysis
7. Risk/Resilience Management

Asset level resilience for specific threats is part of the J100 assessment methodology, which may support a community's process for determining current performance and target performance (Section 9.3). The J100 also includes the Utility Resilience Index (URI), which is a system-level assessment of operational and financial indicators that are essential to resilience and, therefore, an asset's ability to effectively serve a community. The URI serves as a benchmark to evaluate potential resilience improvement projects and as a measure to track a utility's progress over time towards achieving resilience performance goals.

Several tools were developed by the U.S. Environmental Protection Agency to support the water utility assessment of risks. The Vulnerability Self-Assessment Tool (VSAT) (EPA 2014) is designed to assist water and wastewater utilities' application of the J100 standard. VSAT is complemented by the Water Health and Economic Analysis Tool (WHEAT), which quantifies three aspects of consequence associated with an adverse event's 1) public health impact, 2) utility-level financial impact, and 3) direct and indirect regional economic impact (EPA, 2014). WHEAT is specifically aligned with step 3 (consequence analysis) of J100 standard.

The EPA's National Homeland Security Research Center (NHSRC) also supported efforts to enhance utility resilience. Collaboration with AWWA resulted in the development of *Planning for an Emergency Drinking Water Supply*, which directly supports a capability assessment based on worst reasonable threats in J100 to determine options for maintaining service.

An example Tier 2 resilience assessment procedure for water systems is outlined in the following.

9.6.1.1. Example Tier 2 Resilience Assessment for Earthquake:

1. Identify the appropriate earthquake scenario or scenarios. Develop or obtain ground motion information for each. The USGS has scenarios available for a suite of earthquakes in the U.S.

Obtain liquefaction and landslide hazard maps available from the state department of geology. Use GIS for all mapping.

For buried pipelines:

2. Compile an inventory of system pipelines including pipe material, joint type, and length.
3. In GIS, superimpose the pipeline distribution system onto maps of the scenario hazard (peak ground velocity, liquefaction potential, and landslide potential).
4. Use empirical relationships developed by the American Lifelines Alliance (ALA) to predict the number of breaks and leaks in the pipeline system.
5. Estimate the time required to repair the predicted number of breaks and leaks based on historical crew productivity data. Modify this repair time, as appropriate, based on discussions of the expected damage states of interdependent lifelines (transportation, liquid fuel, etc.).

For aboveground infrastructure:

6. Compile an inventory of system components (tanks, pump stations, treatment plants, etc.), including type of construction, date of original construction, and any subsequent retrofits.
7. Estimate the level of damage predicted for the aboveground water system components based on observations from past earthquakes, the seismic hazard prescribed by the building code at the time of original construction or retrofit, and the professional judgment of engineers knowledgeable in the seismic performance of water systems. Use fragility curves found in HAZUS-MH to determine the anticipated performance for a particular facility type for a given ground motion.
8. Estimate the time required to repair the predicted damage to aboveground infrastructure. Modify this repair time, as appropriate, based on discussions of the expected damage states of interdependent lifelines (transportation, liquid fuel, etc.)

For the system:

9. Determine the expected system performance based on the damage to pipelines and facilities in a workshop format.
10. Determine the expected repair time for the system based on the repair times for buried pipelines and aboveground infrastructure estimated in steps 5 and 8.
11. Compare this estimate of repair time for the system to the performance goals established by the community to determine the resilience gap.

These different resilience assessment approaches should be evaluated and refined into one consistent methodology prior to implementation of nationwide water and wastewater system resilience assessments. The tier level of the assessment increases by conducting detailed analyses of each facility and pipeline.

Note that recovery time for utilities that purchase water from wholesale suppliers is highly dependent on the recovery time of the supplying utility. Wholesale water suppliers should work with their customers to assess the expected damage and restorations times from the source to the final individual customers. In this case, water and wastewater system resilience assessments may require a regional approach to characterize the anticipated performance of the system of systems in a hazard event appropriately.

9.6.2. Strategies for New Construction

Water and wastewater providers should consider resilience performance goals in all new construction projects. Projects should be designed to satisfy or exceed code requirements, where code minimum standards are not anticipated to provide a final product that would be expected to meet the utility's resilience performance goals. If no codes exist for a particular category of structure or facility, the designer should investigate guidelines that address hazard-resistant design issues (see Table 9.4). The incremental cost of designing and constructing for improved disaster resilience may be a relatively small percentage of total project costs.

9.6.3. Strategies for Existing Construction

Water and wastewater providers should consider resilience improvements to existing infrastructure as part of the capital improvement planning process. The process of conducting system resilience assessments will likely identify key pipelines and facilities that significantly impact the overall resilience of a system. These components should be evaluated in detail. Providers should evaluate a number of potential strategies, including retrofit or replacement of existing components, or building redundant components in anticipation of failure of existing components. Retrofit of existing infrastructure or new redundant components should be designed such that the final product would be expected to meet the utility's resilience performance goals. In some cases, redundant systems can be justified based on increasing demand requirements. The "new" redundant system could provide on its own an adequate supply to meet an average day's demand until the damaged system was repaired. Whatever is done needs to be part of the day-to-day needs of the utility. That is, if special features added to a system to increase resilience are never used, there is a high likelihood they will not be functional when they are needed.

Once water and wastewater providers and the community establish resilience performance goals and complete baseline resilience assessments, there may be a number of goals not currently met due to the anticipated performance of system components, financial resources of the utility, interdependencies with other lifelines, etc. These performance gaps are likely to be addressed by a phased program (perhaps over as long as a 50-year period) of new construction, retrofit of existing system components to better withstand hazard events, modifications to emergency response plans, coordination with interdependent lifeline providers, and other strategies. It is expected that these resilience enhancements will be coupled with other system improvements to maximize the benefit of limited financial resources.

For instance, it can be difficult to justify replacing hundreds of miles of water pipelines based on earthquake resilience considerations alone, but coupled with replacement of aging and failing pipelines, the incremental cost of using more earthquake-resistant pipe materials and joints is relatively minor. Major resilience improvements that take place on a shorter timeline require a more extensive campaign of public outreach and education.

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10. Community Resilience Metrics

10.1. Background

Community resilience metrics or indicators come in a wide variety of types. They can be descriptive or quantitative; they can be based on interviews, expert opinion, engineering analysis, or pre-existing datasets. They can also be presented as an overall score or as a set of separately reported scores across a broad spectrum of physical, economic, and social dimensions. Regardless of the methodologies used to develop and summarize the results, effective community resilience metrics must address two questions (National Academies 2012a):

1. *How can community leaders know how resilient their community is?*
2. *And how can they know if their decisions and investments to improve resilience are making a significant difference?*[1]

In 2012, the National Academies Committee on Increasing National Resilience to Hazards and Disasters and the Committee on Science, Engineering, and Public Policy evaluated 17 approaches to measuring various aspects of resilience. The authors concluded that none of the 17 existing methodologies satisfactorily addressed the two basic questions posed above. As a result, one of the six main recommendations coming out of the report was the development of a "national resilience scorecard, from which communities can then develop their own, tailored scorecards" (National Academies 2012b). Similar recommendations can be found in other recent reviews of disaster risk reduction and disaster resilience (Government Office for Science 2012; UNISDR 2012). The need for a tailorable or locally relevant scorecard recognizes that a single prescriptive scorecard is unlikely to be appropriate for communities of all sizes and types (e.g., from small tourism- or agriculture-centric communities to large financial- or industrial-centric cities) and for all planning scenarios (e.g., from preliminary scoping studies to comprehensive planning with ongoing follow-up assessments).

10.2. Desirable Characteristics for Community Resilience Metrics

From the community perspective, effective community resilience metrics should be accurate, reliable, comprehensive, scalable, affordable, and actionable indicators of the community's capacity to respond to and recover from a specified disaster scenario. Cutter (2014) suggests that communities seek a resilience measurement tool that meets the following criteria:

- Open and transparent
- Aligns with the community's goals and vision
- Measurements…
  - are simple, well documented
  - can be replicated
  - address multiple hazards
  - represent community's areal extent, physical (manmade and environmental) characteristics, and composition/diversity of community members
  - are adaptable and scalable to different community sizes, compositions, changing circumstances

For purposes of this framework, we are specifically interested in community resilience metrics or tools that will reliably predict the physical, economic, and social implications (either positive or negative) of community decisions (either active or passive) made with respect to planning, siting, design, construction, operation, protection, maintenance, repair, and restoration of the built environment.

[1] As stated in (National Academies 2012b), "measuring resilience is challenging but essential if communities want to track their progress toward resilience and prioritize their actions accordingly."

10.3. Types of Metrics

As defined in PPD-21 (White House 2013) and emphasized throughout this framework, the concept of disaster resilience extends well beyond the magnitude of direct physical damage sustained by the various components of the built environment under a specified disaster scenario. The centrality of community impacts and community recovery to the concept of community resilience demands that community resilience be evaluated and measured in much broader terms than, for example, critical infrastructure vulnerability.

Looking beyond direct physical damage and direct repair costs for the built environment, at least three broad categories of metrics should be considered by communities: (1) recovery times, (2) economic vitality metrics, and (3) social well-being metrics. A community can use these end result metrics to measure improvements through proactive planning and implementation. Resilience planning and implementation of plans will produce a faster and more robust recovery that avoids or minimizes the expected negative economic and social impacts of hazard scenarios. However, predicting how these end result metrics will be impacted by specific community planning and implementation decisions is a challenging and ongoing area of research.

Many indicators of community resilience may have a direct and quantifiable cause-and-effect influence on resilience; whereas others may either have some postulated influence on resilience or simply be correlated with resilience. Examples of indicators that may influence or correlate with recovery times, economic vitality, and social well-being are provided below.

10.3.1. Recovery Times

Recovery times for the built environment are easy to grasp as resilience goals, but difficult to predict with precision or confidence. Predicting recovery times under different planning scenarios should consider:

- Designated performance level or restoration level for each building cluster and infrastructure system
- Original criteria used in the design of the various components of the built environment and their condition immediately prior to the specified disaster scenario
- Loading conditions applied to the built environment during and after the specified hazard scenario
- Spatial and logical distribution of physical damage to the built environment
- Availability of resources and leadership to strengthen (pre-event) or repair (post-event) the built environment
- Critical interdependencies among the built environment and social structures within a community (See Chapter 2)

Recovery times have a direct bearing on many economic and social functions in a community. As such, explicit estimates (or at least a general sense) of system recovery times become a prerequisite for most, if not all, other measures of community resilience. Due to the large volume of data required and the inherent complexity of "system-of-systems" modeling, recovery times are likely to be estimated based on some combination of simplified modeling, past experience, and/or expert opinion.

Examples of community-level recovery time goals by building cluster and infrastructure system are provided in Table 3-10 through Table 3-12 in Chapter 3. These community-level recovery times are built-up from the buildings and sector-level recovery time examples discussed in Chapters 5 through 9. Each community should define its own set of building clusters, infrastructure systems, and designated performance levels that reflect its makeup and priorities.

10.3.2. Economic Vitality

Economic health and development are major concerns for communities. Economic development concerns include attracting and retaining businesses and jobs, building the tax base, addressing poverty and inequality, enhancing local amenities, and economic sustainability. These factors are discussed below. Further background on economic modeling approaches and issues appears later in Section 10.5.

10.3.2.1. Attracting and Retaining Businesses and Jobs

Attracting and retaining businesses and jobs is a major concern of most communities. A community that cannot attract and retain businesses and jobs is in decline. Communities also prefer businesses that produce high-paying jobs. Metrics for this would include the employment rate, per capita income or, per capital Gross Domestic or Regional Product, and education attainment rate.

Metrics indicative of a community's ability to continue attracting and retaining businesses and jobs through and after a hazard event would include the resiliency of infrastructure systems.

10.3.2.2. Tax Base

For most cities, local revenue sources consist of property tax and/or sales tax. Sales tax revenue is increased by attracting commercial businesses and jobs, and property tax revenue is increased by increasing property values.

Tax base indicators include real-estate prices, rents, and amount of tourism (for hotel tax revenues). Metrics indicative of how a community's tax base would be affected by a hazard event include the extent of property insurance coverage across the community, percent of property in areas susceptible to hazards (like flood plains), adopted building codes, and the number of buildings that fail to meet current codes.

10.3.2.3. Poverty and Income Distribution

Poverty and income distribution are a major concern of local communities. Many projects communities pursue aim to decrease poverty in their neighborhoods, and a significant amount of external funding available to communities aim to alleviate poverty. This concern intersects with community resilience because the disadvantaged are often the most vulnerable to disasters. Metrics of poverty and income distribution include the poverty rate and the Gini coefficient, a measure of income dispersion.[2]

Metrics that indicate or influence how a hazard event might affect poverty and income distribution include the poverty rate itself because poor people tend to fare worse in disasters.

10.3.2.4. Local Services and Amenities

Local services and amenities include the infrastructure systems discussed in Chapters 6-9, but also include a variety of other characteristics and services associated with communities, such as public transportation, parks, museums, restaurants, theaters, etc. Local services and amenities improve the quality of life for local residents. In addition, there is an expectation that improving local amenities will indirectly help attract and retain businesses and jobs. Amenities are provided by multiple sources. Some are provided by local governments, some are privately provided, and some are environmental. Metrics for infrastructure systems are discussed in Chapters 6-9 and in Section 10.3.5 of this chapter. Metrics for amenities will depend on the community.

10.3.2.5. Sustainability

Local communities are interested in ensuring that their community is sustainable. Sustainability includes two distinct ideas: 1) protecting and improving the environment (i.e., being "green" and maintaining a small footprint); and 2) producing a vibrant and thriving economy. It is desirable that a community remain sustainable, even amid disasters. Metrics of economic sustainability include population growth rates and growth rates of Gross Domestic or Regional Product.

[2] http://data.worldbank.org/indicator/SI.POV.GINI

Factors that might affect a community's sustainability in the presence of hazard events include the degree to which the local economy depends on a single industry. Metrics could include percent of jobs in the service industry or percent of jobs in agriculture and mining.

10.3.2.6. Other Economic Indicators

There are a number of economic indicators that are associated with or affect non-economic aspects of community resilience. For example, debt ratios generally impact a community's ability to deal with disasters. Poverty impacts the probability that people will rebound from a disaster, as do ownership of a car or phone. Similarly, job continuity and economic sustainability will strongly influence the continuity of social networks.

10.3.3. Social Well-being

Reflecting the hierarchy of human needs presented in Section 2.3, social metrics should address:

- ***Survival –*** preservation of life and availability of water, food, clothing and shelter
- ***Safety and security –*** personal safety, financial (economic) security, and health/well-being
- ***Sense of belonging –*** belonging and acceptance among family, friends, neighborhoods, and organizations
- ***Growth and achievement –*** opportunities for recognition and fulfillment

The resilience of a community following a hazard event depends on how well these needs are met. Examples of indicators or metrics for each of these needs are provided below. An example of a resilience plan that includes several of these indicators is the Canterbury Wellbeing Index (CERA 2014).

10.3.3.1. Survival

Survival depends on the ability of a community's residents, employees and visitors to possess physical requirements, including water, food, shelter, and clothing. Access to these requirements depends on the functionality of the supporting physical infrastructure, availability of distribution systems, and personnel. These tasks may be performed by the governmental organizations, non-governmental aid organizations, or the private sector. Metrics for survivability could include housing availability and affordability, poverty rates, homeless rates, etc.

Metrics affecting a community member's chance of survival during or after a hazard event include:

- Building code adoption and enforcement history
- Existence and effectiveness of warning systems
- Existence of comprehensive emergency management plans (mutual aid pacts, emergency response resources (e.g., urban search and rescue teams), public shelters)
- Number of community service organizations that assist in distributing water, food, or clothing or providing shelter in the wake of a disaster
- Level of household disaster preparation
- Percentage of homes that are owner occupied (i.e., renters may be more vulnerable in disasters)
- Percentage of insured homes and businesses
- Availability of short- and medium-term accommodation
- Distance to family/friends unaffected by the disaster

10.3.3.2. Safety and Security

Safety and security includes all aspects of personal and financial (economic) security, and health and well-being. People require safety and security in their personal lives from situations of violence, physical or verbal abuse, war, etc., as well as knowing that the safety of their family and friend networks are secure. Individuals also require financial safety, which can include job security, a consistent income, savings accounts, insurance policies, and other safety nets. Finally, people require safety from negative health conditions, so that they can enjoy life and consistent well-being.

Examples of metrics for personal safety evaluated before and after a hazard event could include community statistics on assaults, property offenses, re-offending rates, and reports on child abuse or neglect.

Examples of metrics for financial (economic) security include employment rates (also covered in Section 10.3.2.1 under economic metrics). Additionally, metrics that would be indicative of how a community member's employment would be affected by a hazard event include occupation type (e.g., some occupations, more than others, can be severely affected by a hazard event)[3], education levels, percentage of residents that commute other communities for work, and gender (i.e., women may have a more difficult time than men due to employment type, lower wages, and/or family care responsibilities).

Examples of metrics for health and well-being of community members include acute medical admissions, immunization rates, cancer admissions, substance abuse rates, and blood donor rates. Additionally, metrics that would be indicative of how a community member's health/well-being would be affected by a hazard event include percentage of the population with health insurance, access to health services (e.g., health system demand and capacity indicators: emergency room, in-patient beds, out-patient clinics, community health centers, mental health services, etc.), and community demographics (e.g., age distribution, number of individuals with disabilities or access and functional needs, etc.).

10.3.3.3. Sense of Belonging

Social metrics can also address the belonging need, which can represent belonging and acceptance among various groups of people (e.g., family, friends, school groups, sports teams, work colleagues, religious congregation) or belonging to a place or location. Examples of metrics or indicators related to sense of belonging include:

Civic participation[4]:

- Voter registration or voter participation rates
- Involvement in local action groups
- Perception of being well-informed of local affairs

Social networks:

- Frequency of contact with friends, family, neighbors, etc.
- Number of close friends/family (geographically)

Social participation:

- Membership in (and frequency of involvement in) community-wide social, cultural, and leisure clubs/groups including sports clubs
- Membership in (and frequency of involvement in) religious organizations and other belief systems
- Volunteering

Trust

- Confidence in leadership (at various levels)
- Trust in others (similar or dissimilar to member)

[3]Reference to University of South Carolina – Social Vulnerability Index

[4]Foxton, F. and R. Jones. 2011. *Social Capital Indicators Review*. Office for National Statistics http://www.ons.gov.uk/ons/dcp171766_233738.pdf

10.3.3.4. Growth and Achievement

Humans need to feel a sense of achievement and respect in society, accompanied by the need for continual growth and exploration. Examples of metrics or indicators related to growth and achievement include:

- Education
  - System capacity (sufficient numbers of teachers, classrooms, books, etc.)
  - Graduation rates
  - Memberships to public libraries
  - Education levels
- Participation rates in arts and recreation

10.3.4. Hybrids

Some metrics combine several indicators into an overall score. Often, additional types of metrics, beyond the three broad categories discussed above, are included. These other types of metrics, such as system-specific or ecological/environmental metrics, are discussed below in Section 10.3.5.

Due to the sparsity of data, the unique aspects of each hazard event, and the lack of generally applicable community resilience models, the scaling and weighting schemes used to aggregate disparate metrics into an overall score of community resilience are largely based on reasoning and judgment. A related technique is to attempt to monetize all of the dimensions (e.g., the statistical value of lost lives, lost jobs, lost business revenue, increased healthcare costs, etc.), but this approach cannot adequately address the social dimensions of community resilience.

10.3.5. Other Metrics

Examples of system-specific metrics include indicators such as:

- Temporary shelter demand in the housing sector
- Water pressure level or water quality level in water supply systems
- Vehicles per hour or shipping tonnage capacities in transportation systems
- Percentage of dropped calls or undelivered messages in communications systems
- Percentage of customers without service in electrical power systems

In the context of this framework, these system-level indicators can be thought of as performance levels to gauge recovery time for the built environment.

Ecological or environmental metrics include indicators such as debris and hazardous waste volumes (by which landfill and waste management requirements can be assessed), indicators of water and soil quality (e.g., salinity), and many more. While very important due their impact to public health, wildlife management, etc., these metrics address impacts and planning issues that are, for the most part, outside the scope of this framework.

10.4. Examples of Existing Community Resilience Assessment Methodologies

As discussed in Section 10.1, a variety of community-wide resilience assessment methodologies was presented in the research literature. In this section, we present brief overviews of nine existing methodologies and evaluate their applicability as tools for assessing both current resilience and plans for improved resilience within the context of planning decisions regarding the built environment. Not all of these methodologies were developed to address community resilience, but they are considered as relevant and potentially applicable in whole or part. This list is not meant to be complete and is expected to evolve along with this framework, as additional research and pilot studies are completed.

10.4.1. SPUR Methodology

The SPUR methodology provides "a framework for improving San Francisco's resilience through seismic mitigation policies." The stated goals of the SPUR report (2009) are:

1. *Define the concept of "resilience" in the context of disaster planning,*
2. *Establish performance goals for the "expected" earthquake that supports our definition of resilience,*
3. *Define transparent performance measures that help us reach our performance goals; and*
4. *Suggest next steps for San Francisco's new buildings, existing buildings and lifelines.*

The SPUR methodology focuses on establishing performance goals for several clusters of buildings (i.e., groups of buildings that provide a community service, such as critical response facilities, emergency housing, or neighborhood services) and establishing target recovery times for a specified earthquake scenario in the San Francisco area. While economic and social metrics are not direct outputs of the SPUR methodology, the building clusters selected and recovery time goals provided are clearly intended to improve both the economic and social resilience of San Francisco. Similarly, although SPUR focuses on earthquakes as the primary hazard, the underlying methodology is applicable to other perils.

10.4.2. Oregon Resilience Plan

In 2011, the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) was directed by House Resolution 3 "to lead and coordinate preparation of an Oregon Resilience Plan that reviews policy options, summarizes relevant reports and studies by state agencies, and makes recommendations on policy direction to protect lives and keep commerce flowing during and after a Cascadia earthquake and tsunami." The OSSPAC assembled eight task groups (earthquake and tsunami scenario, business and work force continuity, coastal communities, critical buildings, transportation, energy, information and communications, water and wastewater) and assigned the following tasks to each group:

1. *Determine the **likely impacts** of a magnitude 9.0 Cascadia earthquake and tsunami on its assigned sector, and estimate the time required to restore functions in that sector if the earthquake were to strike under present conditions;*
2. *Define **acceptable timeframes** to restore functions after a future Cascadia earthquake to fulfill expected resilient performance; and*
3. *Recommend **changes in practice and policies** that, if implemented during the next 50 years, will allow Oregon to reach the desired resilience targets.*

The Oregon Resilience Plan (2013) builds on the SPUR methodology and the Resilient Washington State initiative to produce a statewide projection of the impacts of a single earthquake and tsunami scenario. Immediate impacts include lives lost, buildings destroyed or damaged, and households displaced. Moreover, a particular statewide vulnerability identified in the study is Oregon's liquid fuel supply and the resulting cascade of impacts induced by a long-term disruption of the liquid fuel supply. The study includes recommended actions to reduce the impacts of the selected hazard scenario and shorten the state's recovery time.

10.4.3. UNISDR Disaster Resilience Scorecard for Cities

The United Nations International Strategy for Disaster Risk Reduction (UNISDR) Disaster Resilience Scorecard for Cities "provides a set of assessments that will allow cities to understand how resilient they are to natural disasters." The Scorecard is "intended to enable cities to establish a baseline measurement of their current level of disaster resilience, to identify priorities for investment and action, and to track their progress in improving their disaster resilience over time." There are 85 disaster resilience evaluation criteria grouped into the following areas:

- ***Research***, including evidence-based compilation and communication of threats and needed responses

- ***Organization***, including policy, planning, coordination and financing
- ***Infrastructure***, including critical and social infrastructure and systems and appropriate development
- ***Response capability***, including information provision and enhancing capacity
- ***Environment***, including maintaining and enhancing ecosystem services
- ***Recovery***, including triage, support services and scenario planning.

Each evaluation criterion is broken down into the aspect of disaster resilience being measured, an indicative measurement, and the measurement scale (from 0 to 5, where 5 is best practice).

The formal checklist is organized around "10 Essentials for Making Cities Resilient," which were developed to align with the five priorities of the Hyogo Framework (UNISDR 2005). The overall score is the percentage of possible points from each of the 85 measures. It is suggested that cities plan on 2 to 3 people working for a minimum of 1 week to complete an assessment, ranging up to 2 months for a more detailed and comprehensive assessment.

10.4.4. CARRI Community Resilience System

The Community and Regional Resilience Institute's Community Resilience System (CARRI CRS 2013) "is an action-oriented, web-enabled process that helps communities to assess, measure, and improve their resilience to … threats and disruptions of all kinds, and ultimately be rewarded for their efforts. The CRS brings together people, process and technology to improve resilience in individual communities. The system includes not only a knowledge base to help inform communities on their resilience path but also a process guide that provides a systematic approach to moving from interest and analysis to visioning and action planning. It also provides a collaborative mechanism for other interested stakeholders to support community efforts."

The CRS is a DHS/FEMA funded initiative. It began in 2010, convening three working groups: researchers (the Subject Matter Group), community leaders (the Community Leaders Group), and government/private sector representatives (the Resilience Benefits Group). The findings of these working groups culminated in the development of the CRS web-based tool along with pilot implementations in eight communities commencing in the summer of 2011.

The CRS addresses 18 distinct Community Service Areas (CSAs) and is designed specifically for use by community leaders. The web process is a checklist driven approach, with questions tailored for each of the CSAs. The answer to a question may trigger additional questions. For many of the questions, comment fields are provided so that communities may answer the questions as specifically as possible. The CARRI team notes that a facilitated approach (i.e., an outside group coming in, such as CARRI), is most effective. "The CRS process works more productively as a "partially facilitated" model where some supportive expertise assists communities in applying aspects of resilience to and embedding them within their community circumstances and processes."

10.4.5. Communities Advancing Resilience Toolkit (CART)

The Communities Advancing Resilience Toolkit (CART 2012) was developed by the Terrorism and Disaster Center at the University of Oklahoma Health Sciences Center. It was funded by the Substance Abuse and Mental Health Services Administration, U.S. Department of Health and Human Services, and the National Consortium for the Study of Terrorism and Responses to Terrorism, U.S. Department of Homeland Security, and by the Centers for Disease Control and Prevention.

CART is designed to enhance community resilience through planning and action. It engages community organizations in collecting and using assessment data to develop and implement strategies for building community resilience for disaster prevention, preparedness, response, and recovery. The CART process uses a combination of qualitative and quantitative approaches, and it involves the following steps:

1. Generating a community profile (CART Team and Partners)

2. Refine the community profile (Community Work Groups)
3. Develop a strategic plan (Community Planning Groups)
4. Implement the plan (Community Leaders and Groups)

The CART approach is not hazard specific, and it is applicable across communities of varying size and type. It is innovative, providing a complete set of tools and guidelines for communities to assess their resilience across a number of domains. The toolkit includes the CART assessment survey, key informant interviews, data collection framework, community conversations, neighborhood infrastructure maps, community ecological maps, stakeholder analysis, SWOT analysis, and capacity and vulnerability assessment. The focus of the approach is to provide a process that engages communities in thinking about resilience and provide a foundation to move forward into sophisticated activities.

10.4.6. Baseline Resilience Indicators for Communities (BRIC)

The Baseline Resilience Indicators for Communities (BRIC, Cutter et al. 2014) process builds on prior work by Cutter et al., and is based on empirical research with solid conceptual and theoretical underpinnings. BRIC measures overall pre-existing community resilience. The approach provides an empirically based resilience metric for use in a policy context. Using data from 30 public and freely available sources, BRIC comprises 49 indicators associated with six domains:

- Social (10 indicators)
- Economic (8 indicators)
- Housing and infrastructure (9 indicators)
- Institutional (10 indicators)
- Community Capital (7 indicators)
- Environmental (5 indicators)

BRIC is not hazard specific, and it has been implemented at the county level. The 49 indicators were selected through conceptual, theoretical, and/or empirical justification as capturing qualities associated with community resilience. Indicators in the aforementioned domains determine areas that policy makers should invest for intervention strategies to improve resilience scores.

10.4.7. Rockefeller Foundation City Resilience Framework

The City Resilience Framework (CRF 2014) is a framework "for articulating city resilience" developed by Arup with support from the Rockefeller Foundation 100 Resilient Cities initiative. One merit of this framework is that it is based on a very extensive literature review involving cities with different characteristics and a substantial amount fieldwork to collect data and develop case studies. The framework organizes 12 so-called "key indicators" into 4 categories:

- Leadership and strategy
- Health and wellbeing
- Infrastructure and environment
- Economy and social

This organization integrates social and physical aspects, and it considers human-driven processes as inherent components of the system-of-systems, making the community fabric of a city. Economic/financial constraints are also considered in an integral way, providing a realistic setting for its application for planning purposes. In turn, the 12 key indicators span 7 qualities of what is considered a resilient city: being reflective, resourceful, robust, inclusive, redundant, integrated, and/or flexible.

The CRF will serve as the basis for developing a City Resilience Index in 2015. The CRF report states that the CRI will further refine the 4 categories and 12 indicators of the framework into 48 to 54 sub-indicators and 130 to 150 variables or metrics.

10.4.8. NOAA Coastal Resilience Index

The National Oceanic and Atmospheric Administration's Coastal Resilience Index (NOAA CRI 2010) was developed to provide a simple and inexpensive self-assessment tool to give community leaders a method of predicting if their community will reach and maintain an acceptable level of functioning after a disaster. The tool is completed by experienced local planners, engineers, floodplain managers and administrators in less than three hours using readily available, existing sources of information, in a yes/no question format.

The CRI is targeted primarily at coastal storms, particularly hurricanes and other surge or rain induced flooding events with immediate and short-term recovery. More specifically, it focuses on the restoration of basic services and how long a community will take to reach and maintain functioning systems after a disaster. The eight page assessment form addresses six broad areas:

1. Critical facilities and infrastructure
2. Transportation issues
3. Community plans and agreements
4. Mitigation measures
5. Business plans
6. Social systems

The resulting assessment is meant to identify problems (vulnerabilities) that should be addressed before the next disaster – areas in which a community should become more resilient and where resources should be allocated. It also estimates the adaptability of a community to a disaster, but is not meant to replace a detailed study. The authors note that "The Resilience Index and methodology does not replace a detailed study…. But, the Resilience Index resulting from this Community Self-Assessment may encourage your community to seek further consultation."

The authors also state that the tool should not be used to compare one community to another. Rather, they recommend using it as an approach to internal evaluation to identify areas in which a given community might increase its resilience. As part of its development process the NOAA Community Resilience Index (CRI) was pilot tested in 17 communities in five states (Alabama, Florida, Louisiana, Mississippi, and Texas). In addition to developing their community indices, these pilot tests were also used to further refine and improve the assessment methodology.

10.4.9. FEMA Hazus Methodology

The Federal Emergency Management Agency's Hazus tool (FEMA 2014) "is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, hurricane and floods. Users can visualize the spatial relationships between populations and other fixed geographic assets or resources for the specific hazard being modeled – a crucial function in the pre-disaster planning process."

The Hazus methodology and data sets cover the entire United States, and the study region (i.e., community) can be defined as any combination of US Census tracts. The specific hazard models included are earthquake (including fire following), flood (riverine or coastal) and hurricane (wind and storm surge). The focus of the model is on immediate physical, economic and (to a lesser degree) social impacts. But, the model does produce outputs on expected loss of use for buildings, loss of use for infrastructure (earthquake and flood only), shelter requirements, casualties (earthquake only), building contents and inventory losses, lost wages and income and indirect economic losses (earthquake and flood only). Estimated repair times are explicitly considered in economic loss estimates produced by the model, but the economic outputs are not tabulated or viewable as a function of time. While Hazus can be used to assess losses avoided through some mitigation measures, it does not estimate mitigation costs and therefore does not output estimates of return on investment.

There are gaps between the results produced by Hazus and the information required for a community-level resilience assessment methodology, particularly in the areas of interdependencies, social impacts and recovery times. However, many of the Hazus methodologies and the types of results they produce could become portions of a larger framework.

10.4.10. Comparison Matrix

A summary comparison of the nine example methodologies discussed in the preceding sections is provided in Figure 10-1. As noted earlier, not all of these methodologies address community resilience, but were evaluated to identify relevant and potentially applicable methods, indicators, or processes.

Each methodology was assessed on five broad dimensions: (1) comprehensiveness, (2) utility, (3) impacts assessed, (4) techniques used, and (5) overall merit with respect to the maturity, innovativeness, objectivity, and scientific merit of the methodology. Assessments were made in the context of community resilience planning and assessment, specifically as it pertains to the built environment.

Consistent with the findings of previously published assessments, none of the nine methods reviewed is strong in all five dimensions. However, it may be possible to combine the strongest features of existing and emerging methodologies to produce a new community resilience assessment methodology that addresses the needs identified in this chapter.

			Existing Assessment Methodologies								
Group	**Category**	**Sub-Category**	**SPUR**	**Oregon Res. Plan (ORP)**	**UNISDR Scorecard**	**CARRI CRS**	**CART**	**BRIC**	**Rockefeller CRF & CRI**	**NOAA CRI**	**FEMA Hazus**
1	Comprehensiveness	Community size	•	•	+	+	+	+	+	•	+
		Hazards	•	•	+	+	+	+	+	-	-
		Recovery time scales	+	+	?	?	?	?	+	•	-
		Systems	+	+	?	+	-	-	+	•	•
		Interdependencies	•	•	?	+?	-	-	+?	-	-
2	Utility	User friendliness	•	•	+	+	+	+	•	+	•
		Utility without hired or volunteer SMEs	-	-	+	•?	•?	•?	•	•?	•?
		Value of outputs for resilience planning	+	+	•	?	?	?	+?	•	•?
		Consistency with PPD-21	+	+	•	+	+	•	•	•	-
3	Impacts assessed	Physical impacts and recovery times	+	+	•	•	•	•	•	•	•
		Economic impacts and recovery times	•	+?	•	•	•	•	+?	-	•
		Social impacts and recovery times	•	•	•	•	•	•	+?	•	•
4	Techniques used	Checklists	-	-	+	+	+	-	+	+	•
		Interviews, Surveys	-	-	-	•	+	-	+	•	•
		Ratings	+	+	+	•	+	-	+	•	+
		Existing national data sets	-	-	-	-	-	+	-	-	+
		Physical inspections	•	•	•	•	-	-	-	•	•
		Engineering analysis or expert opinion	+	+	•	•	-	-	-	•	+
		Statistical inference	•	•	-	•	-	-	-	-	+
		Simulations	•	•	-	•	-	-	-	-	+
5	Critical Assessment	Maturity	+	+	•	+	-	+	•	?	+
		Unique/innovative	+	•	•	+	+	+	•	-	+
		Objective/repeatable	•	•	•	•	•	+	+?	-	+
		Scientific merit	+?	+?	-	?	?	?	+?	?	+

Group	**Symbol**	**Description**
1	+	Addresses a broad range
	•	Focused subset, but not inherently limited
	-	Limitation
	?	Additional information required
2	+	High
	•	Moderate
	-	Low
	?	Additional information required
3	+	Explicitly assessed
	•	Partially or indirectly assessed
	-	Not assessed
	?	Additional information required
4	+	Yes
	•	Optional
	-	No
	?	Additional information required
5	+	Strength
	•	Neither a strength nor a weakness
	-	Weakness
	?	Additional information required

Figure 10-1. Preliminary Summary Assessment of Nine Existing Community Resilience Methodologies

10.5. Economic Evaluation of Community Resilience Investment Portfolio

This section presents a brief overview of existing economic concepts related to the evaluation of investments to improve community resilience. The focus is on the development of a portfolio of investments that maximize the social net benefits to the community, recognizing constraints, uncertainty, and interdependencies that affect the mix of investments.

10.5.1. Portfolio Considerations

10.5.1.1. Economic Efficiency

Economic efficiency refers to obtaining the maximum benefit from the resources available. Equivalently, it means not wasting resources.

10.5.1.1.1. Maximization of Net Benefits

Improved community resilience will also increase the level of service economically. Several alternatives may maximize the net benefits to the citizens of the local community.

This assessment takes into account the fact that improved levels of service are typically more costly. This type of analysis will identify the level of service where the net benefits (that is, the increased value of the improved level of service minus the cost of obtaining that level of service) are maximized.

10.5.1.1.2. Minimization of Cost + Loss

From an economic perspective, this is an equivalent formulation to maximizing net benefits. Since the “Level of Service” is defined in terms of minimizing costs and losses, it may be a more convenient format for analysis. Expressing the results of this analysis in terms of net benefits is straightforward.

10.5.1.1.3. First-Cost vs. Life-Cycle Cost

Any effort to identify the alternatives that produce a maximization of net benefits depends on accurate estimates of benefits and costs. With regard to the costs of attaining a desired level of service, all costs, covering the entire life-cycle of any mitigation measures, need to be accounted for. It is not sufficient to include first costs only. Operation costs, maintenance costs, replacement costs and end-of-life costs (among others) need to be included.

10.5.1.2. Multiple Objectives

There are several complementary (and overlapping) objectives that are likely to be considered, accounting for the types of losses that a community wishes to avoid. In any analysis of avoided losses, care needs to be taken to ensure that savings are not double-counted.

10.5.1.2.1. Minimize Economic Losses

The simplest consideration is that of minimizing economic losses. Treated in isolation, that simply means making sure that the difference between economic gain (in terms of losses avoided) and costs of the desired level of service are maximized. It is simpler than the other considerations because costs and benefits are both in dollar terms.

10.5.1.2.2. Minimize Loss of Life

The remaining objectives all relate to economic losses of one sort or another. The most important consideration is avoiding loss of life and other casualties.

10.5.1.2.3. Minimize Other Losses

Other losses a jurisdiction might wish to avoid include disruption of key government services, disruption of social networks, and damage to the environment. Including non-economic factors such as these in the optimization is difficult, as benefits and costs are measured in different terms. If loss of life is included in the optimization, the benefits are measured in terms of lives saved (or deaths avoided), while the costs are typically measured in dollars. The normal economic way of handling this issue is by assigning a value to the benefits. For lives saved, Value of a Statistical Life is a standard approach. For other benefits, a number of techniques are available to determine the value a community places on those benefits.

However, there is a strong reluctance to put a price on a life (which is nominally what Value of a Statistical Life does) and other non-economic amenities. As an alternative, some form of Lexicographic Preferences could be used. Here each objective is strictly ranked, and then optimized in order. For example, an assessment could optimize for loss of life and then for economic losses. This ranking approach would ensure the selection of an alternative that minimizes loss of life (irrespective of costs). Next, the minimum cost alternative that maintained the minimum loss of life would be found.

Why not choose zero loss of life? As a practical matter, tradeoffs between safety and costs cannot be avoided.

10.5.1.3. Constraints

To the extent a local community has a limited budget, that budget must be factored into the optimization. Other constraints can also be factored in, largely by screening out potential plans that do not meet the constraints.

10.5.1.4. Economic Interdependencies

The economy in general is affected by the resilience of the built environment. The reverse also holds – the resilience of the community depends on the health and resilience of the economy.

10.5.2. Economic Decision-Making Involving Risk and Uncertainty

10.5.2.1. Expected Utility Theory

Economists often approach decision-making with expected utility theory. The basic idea is that people will choose the alternative that has the best ‘utility’ or value for them, as indicated by the highest probability-weighted average value. The value is adjusted to account for both time preference and risk preference.

10.5.2.1.1. Time Preference

Most people prefer consumption now over consumption later. The typical way to address that is to discount future consumption.

10.5.2.1.2. Risk Preferences

Most people would prefer to avoid risk – that is, they are risk averse. For people who are risk averse, a large potential loss weighs more heavily than a large number of small losses, which together, add up to the same value as the big event. Someone who is risk neutral would weigh the two equally.

Risk aversion is handled in economic theory by weighting the large losses more heavily (or equivalently, by weighting large gains less heavily). The simplest approach, and the one used most often in net benefit analyses, is to assume that the community is risk neutral. Then you simply compute the present expected value. However, when it comes to disasters it seems unlikely that communities will be risk neutral.

To account for risk preferences, it will be necessary to measure those risk preferences. A number of widely-accepted methods for measuring risk preferences exist.

10.5.2.2. Behavioral Economics and Cognitive Bias

People are not Expected Utility maximizers; there is a very large body of literature regarding departures from Expected Utility maximization. Expected utility maximization is a difficult problem, and typically, there are not enough resources available to solve it. There are several approaches to thinking about these departures from economic theory, but the most widely accepted is the Heuristics and Biases school. They argue that people use standard shortcuts—heuristics—that work well most of the time. However, there will be cases where they do not work well, and in those situations they will be biased. The biases are generally used to try and identify the heuristics used.

There are a number of identified biases, some of which are relevant here. These include Uncertainty v. risk, overconfidence, and small probability events, among others.

10.5.2.3. Uncertainties

Uncertainties regarding estimates of expected damages and recovery times from disasters fall into two categories. First, there are factors that cannot be known with certainty in advance, such as the timing and magnitude of future hazard events. Second, there are things that are in principal knowable, but are not currently known with certainty. For example, while in principal the cost of a particular project can be estimated, the level of uncertainty associated with the estimate can vary and will likely increase with the scope of the project.

Mitigation costs, recovery costs, and losses will have uncertainties in their estimates. As community resilience plans are developed and refined, the level of uncertainty may reduce.

A particularly high level of uncertainty exists regarding business interruption losses. In cases where they have been estimated, such losses are often as large or larger than direct economic losses. However, they are difficult to estimate, due to the lack of data from past events to support estimates.

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FEMA Hazus Methodology: <https://msc.fema.gov/portal/resources/hazus>

Glossary

List of Terms and Acronyms and their Definitions

Term/Acronym	Definition
Building Clusters	A set of buildings that serve a common function such as housing, healthcare, retail, etc.
Building Disaster Resilience	Ability of a single building to adapt, withstand and recover from a natural or technological disaster
Building Resilience	Ability of a single building to adapt, withstand and recover from a disruption
Buildings	Individual structures including the equipment and contents that house people and support social institutions
Built Capital	Any mechanism, building, or technology that helps the community function. The built environment is a subset.
Built Environment	All buildings and infrastructure systems. Also referred to as physical infrastructure
Business Continuity	Ability of a single business to maintain function
Business Disaster Resilience	Ability of a single business to adapt, withstand and recover from a natural or technological disaster
Business Resilience	Ability of a single business to adapt, withstand and recover from a disruption
Communication and information Systems	Equipment and systems that facilitate distant communication
Community	People who live, work, learn, and/or play together under the jurisdiction of a governance structure, such as a town, city, county, region, state, nation
Community Disaster Resilience	The ability of a community's social institutions to recover from a natural, technological or human caused disruption
Community Leaders	Elected officials, paid staff, non-government organizations, and volunteers
Community Resilience	The ability of a community's social institutions to recover from any disruption
Community Social Institutions	A complex, organized pattern of beliefs and behavior that meets basic individual and household needs
Critical facilities	Buildings that support functions that are needed during the short term phase after a hazard event. These are also referred to as essential buildings.
Critical Infrastructure	Assets, networks, systems and structures, whether physical or virtual, that support community social institutions so vitally that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety.
Disaster	Any hazard event that causes significant damage and/or loss of functionality
Disaster Resilience	The ability to adapt to, withstand, and recover from a natural, technological or human caused disruption

Term/Acronym	Definition
Disruption	The occurrence of a hazard event
Element Resilience	Ability of an individual element to adapt, withstand and recover from any disruption
Emergency Responders	Official and volunteer workers during the short term phase after the disaster
Energy Systems	Electric power, liquid fuel and natural gas generation and distribution
Financial Capital	Any economic resource measured in terms of money used by communities buy what they need to provide their services
Function	A specific action or activity performed to support a community's social institution.
Functionality	Able to continue to use the system or structure at possibly an impaired level. This is also referred to as serviceability.
Governance Structures	The organizational framework of the governing body of the community
Hazard	A situation that poses a level of threat to life, health, property, or environment due to nature, technology, or human caused
Hazard Event	The occurrence of a hazard
Hazard Intensity	The quantification of the impact of a hazard
Hazard Level	The quantification of the size of a hazard
Human Caused Disaster	A hazard event caused by a deliberate action including a terrorist activity
Infrastructure	Physical networks, systems and structures that support community social institutions including transportation, energy, communications, and water and wastewater.
Infrastructure Disaster Resilience	Ability of the infrastructure to adapt, withstand, and recover from natural or technological disaster
Infrastructure Resilience	Ability of the infrastructure to adapt, withstand, and recover from a disruption
Interdependencies	Intersection of systems at points of dependence to continue full service
Life Safety	Alive, able to exit without assistance or remain in a stable environment
Mitigation	Improving the infrastructure by reconstruction, repair, or retrofit
Natural Disaster	A disaster that is rooted in nature
Performance Goals	Metrics that define the safety and usability of systems and structures in terms of occupant protection, cost of restoration and time allotted for repairs and return to function.
Performance Levels	Metrics that define the safety and usability of systems and structures.
Recovery Strategies	Actionable steps taken before the disaster to improve disaster resilience; includes recovery planning, land use planning, physical construction, retrofit reconstruction and education.
Redirecting	Softening or eliminating a hazard when possible by changing its path

Term/Acronym	Definition
Redundancy	Multiple systems or buildings that perform the same function
Resilience	The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions
Resilience Construction Standards	Codes and standards that include transparent performance expectations
Retrofitting	Improve the expected performance of existing infrastructure through reconstruction. This is also referred to as hardening.
Robustness	Sufficient strength to withstand the hazard without loss of function
Shelter-in-place	Able to safely remain in a residence with possible damage and impaired utility services
Social Capital	The links, shared values and understandings in society that enable individuals and groups to trust each other and so work together.
Technological Disaster	A human caused disaster due to an accident
Transportation Systems	Buildings, structures, and networks that move people and goods
Vulnerable populations	People who require special assistance during recovery
Waste Water Systems	Collection, treatment, and discharge of waste water
Water Systems	Collection, storage, purification, and distribution of water
Workforce	People who provide labor to one or more of the social institutions