

# DISASTER RESILIENCE FRAMEWORK

50% Draft for Norman, OK Workshop

20 October 2014

# DISASTER RESILIENCE FRAMEWORK

50% Draft for Norman, OK Workshop

## **1. Introduction (To be included in 75% Draft)**

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1.1.2. Scope of Framework

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3.1.1. Community Disaster Resilience for the Built Environment

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### **6.6. Resilience Assessment Methodology**

*6.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)*

*6.6.2. Strategies for new/future Construction*

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*6.6.4. Addressing Gaps in Resilience Plans*

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#### 7.5.1. New Construction

##### 7.5.1.1. Implied or Stated Performance Levels for Expected Hazard Levels

##### 7.5.1.2. Recovery Levels

#### 7.5.2. Existing Construction

##### 7.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels

##### 7.5.2.2. Recovery Levels

### **7.6. Resilience Assessment Methodology**

*7.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)*

*7.6.2. Strategies for new/future Construction*

*7.6.3. Strategies for Existing Construction*

*7.6.4. Addressing Gaps in Resilience Plans*

### **7.7. Tools Needed for Resilience**

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### 8.5.1. New Construction

8.5.1.1. Implied or Stated Performance Levels for Expected Hazard Levels

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8.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels

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## **8.6. Resilience Assessment Methodology**

*8.6.1. Assessment Methodology*

*8.6.2. Strategies for New/Future Construction*

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9.5.1. New Construction

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9.5.1.2. Recovery Levels

9.5.2. Existing Construction

9.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels

9.5.2.2. Recovery Levels

### **9.6. Resilience Assessment Methodology**

*9.6.1 Assessment Methodology*

*9.6.1.1. Tier 1 Plus Resilience Assessment*

*9.6.2 Strategies for New/Future Construction*

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*9.6.3. Strategies for Existing Construction*

*9.6.4 Addressing Resilience Performance Gaps*

### **9.7. Tools Needed for Resilience**

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9.7.2. Practice and Research Needs

9.7.2.1. Current Research

9.7.2.2. Future Development Needs

### **9.8. Summary and Recommendations**

### **9.9. References**

## **10. Tools and Metrics for Evaluating Disaster Resilience (To be included in 75% Draft)**

*10.1. Resilience Tools and Metrics*

*10.2. Prioritization of Community Resilience Alternatives*

*10.3. Risk Management*

## **11. Recommendations and Next Steps (To be included in 75% Draft)**

*11.1. Priority Action Plans for Standard Development*

*11.2. Research Needs*

## 2. The Community

### 2.1. Introduction

This chapter outlines the social aspects of community resilience – i.e., defining a community’s social needs and systems, acknowledging that these needs will require time-sensitive prioritization after a disaster, and identifying the functions required of community social systems to meet these prioritized needs within disaster recovery timeframes. Pre-event planning for ways to meet the desired functions (referred to in this chapter as performance goals) will increase a community’s resilience to disaster events.

*[Note to reviewers: In a future draft, this section will tie into the rest of the Framework which will define performance goals for the built environment.]*

### 2.2. The Community Defined

For the purposes of this Framework, a community is defined as “a cluster of people who live, work, learn, and/or play together under the jurisdiction of a governance structure, such as a town, city or county.” We acknowledge, however, that the term “community” can also refer to groupings of people based on a number of other factors, including geography, demographics, values, common interests or goals, economics, etc.

*[Note to reviewers: In a future draft, this section will discuss other definitions of a community.]*

#### 2.2.1. Levels of a Community

Communities are made up of various levels (or units), consisting of the individual, groups (e.g., households or businesses), community systems, and society/culture. Figure 2-1, based upon Bronfenbrenner’s Ecological Systems Theory, provides an example of various levels within a community.

*[Note to reviewers: In a future draft, this section will expand upon the idea of micro-, meso-, and macro levels – and articulate the different possible units of analysis within these]*

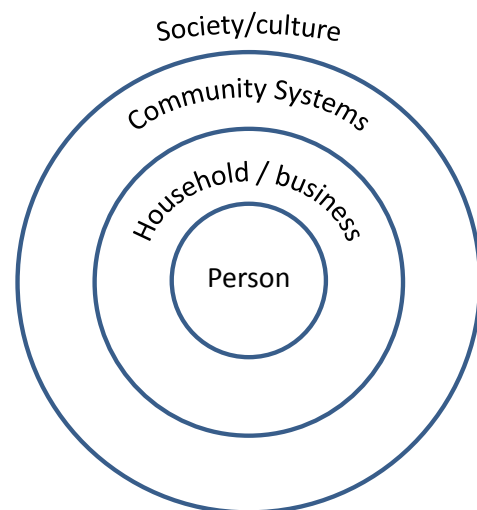


Figure 2-1: Levels of a community

##### 2.2.1.1. Society (or culture)

*This section is under development. Text to be included in a future draft.*

##### 2.2.1.2. Community Systems

Community systems are the social, economic, and physical/environmental infrastructure provided for individuals, households, and/or businesses within a community. A list of possible community services includes:

- Human or Social/Cultural services
  - Healthcare (physical and mental health)
  - Education
  - Local governance
  - Social services (e.g., welfare)
  - Public safety and security, including emergency management
  - Arts and recreation
  - Spiritual
- Economic or Business/Industry services
  - Financial

- Businesses
- Industry (including manufacturing and agriculture)
- Trade
- Physical/Environmental services
  - Transportation
  - Natural Environment
  - Water/wastewater
  - Energy
  - Communications
  - Housing
  - Air quality

*[Note to reviewers: In a future draft, this section will describe each system, linking to other Framework chapters. It will also discuss other services, systems, or other ways to categorize.]*

Communities can operate these systems in different ways based upon leadership, government policies/procedures (state-local levels), public vs. private, geography (e.g., different locations in the U.S. specialize in certain industries/business), social connectedness of the community (social capital), finances, budgeting, tradition, culture, wealth, religion, etc.

*[Note to reviewers: In a future draft, this section will describe these differences in more detail.]*

#### **2.2.1.3. Households or businesses**

*This section is under development. Text to be included in a future draft.*

#### **2.2.1.4. Individuals**

Individuals with certain traits, roles, and affiliations; for example; demographics (i.e., socio-economic status, educational background, age, gender, race/ethnicity, home ownership, special needs/disabilities, employment status), previous history/culture, individual relationships with family, etc.

*[Note to reviewers: In a future draft, this section will describe individuals in more detail].*

### **2.2.2. Interaction among Community Levels – Addressing Needs**

The purpose of community systems is to meet certain needs of the individuals, households, and groups in a community, shown in Figure 2-2, which then aid in meeting needs at the community level<sup>1</sup>. These individual/household needs are presented here in a hierarchical manner (Figure 2-2), showing the most fundamental need at the bottom (survival), followed by safety and security, belonging, and growth and achievement.<sup>2</sup>

*[Note to reviewers: In a future draft, this section will describe needs/hierarchy in more detail.]*

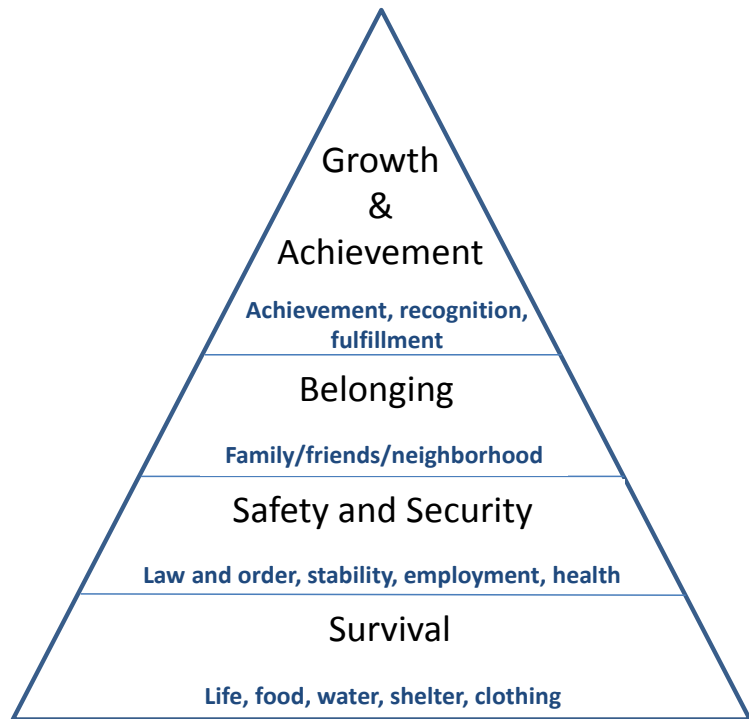
The first and most fundamental need in Figure 2-2 is that of survival. The survival need includes the physical requirements necessary for human survival, including air, water, food, shelter, and clothing. If these needs are not met, the human body cannot sustain life, since people can live no longer than 3 to 5 days without water and 6 weeks without food (assuming inadequate water supply)<sup>3</sup>. Also included in this is protection of life from the disaster itself.

*[Note to reviewers: In a future draft, this section will be expanded and discuss which community systems address survival needs.]*

The second need is that of safety and security. This need includes all aspects of safety and security, including personal, financial (economic), and health and well-being. People require safety in their personal lives from situations of violence, physical or verbal abuse, war, etc. Individuals also require financial safety, which can include job security, a consistent income, savings accounts, insurance policies, and other types of financial safety nets. Finally, people require safety from negative health conditions, so that they can enjoy life and consistent well-being in their communities.

*[Note to reviewers: In a future draft, this section will be expanded and discuss which community systems address safety and security needs.]*

The third need is one of belonging. In society, individuals need to feel a sense of belonging and acceptance among various groups of people; including family, friends, and other types of social groups (e.g., within neighborhoods, schools, work, religious community, sports teams, etc.). In sociological literature, the concept of social capital within a community is often discussed. Social capital includes the extensiveness of social networks within the community (i.e., the interconnectedness of social groups),



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

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<sup>1</sup> Note: Businesses and communities also have needs; e.g., a community needs economic activity, employment in manufacturing, etc. Authors will explore this in future drafts.

<sup>2</sup> Adapted from Maslow's Hierarchy of Needs – from a psychological perspective

<sup>3</sup> Scientific American. <http://www.scientificamerican.com/article/how-long-can-a-person-sur/>

civic engagement, and interpersonal, inter-organizational, and institutional trust<sup>4,5</sup>. The inclusion of all three of these aspects of social capital (networks, engagement, and trust) can increase the feeling of belonging among people in a 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. Additionally, it will discuss which community systems address belonging needs.]*

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

*[Note to reviewers: In a future draft, this section will be expanded and discuss which community systems address growth and achievement needs (other than education, arts/rec).]*

Based on societal norms, not all people use these systems and/or are provided access to community systems in the same ways. Therefore, interactions of individuals/households with community systems can introduce inequalities among certain subpopulations of a community. These inequalities can be carried over, and even exacerbated, in certain types of situations, such as disaster/disruption events.

*[Note to reviewers: In a future draft, this section will be significantly expanded, particularly with respect to social vulnerability. Case studies will be added.]*

*Notes for further discussion:*

*Pre-disaster vulnerability structures/norms exist and then have an impact (potentially negative impact) on the new “structure” or norms that are created post-disaster.]*

### **2.3. Social Performance Goals for Community Resilience**

Performance goals for the social systems of a community provide the foundation for accompanying performance goals for the built environment, in order to increase a community’s disaster resilience (see Chapter 3). In this chapter, a performance goal refers to a statement of the desired performance of a particular social system within a community, and the requirements of that system within a particular time frame (or time period) during the recovery process. These performance goals would be set, in advance, by communities to aid in recovery and resilience planning before disaster events.

In this Framework, three types of hazard levels are set for resilience planning: routine, expected, and extreme events (see Chapter 3 for more detail). Performance goals for any community should be set for all three hazard levels before an event occurs; however, the examples provided in this chapter reflect those necessary to prepare/plan for an “expected” event.

When a disaster occurs, it takes time, people, and resources to physically and socially rebuild (or foster the rebuilding of) a community. With that said, the hierarchy of social needs helps to prioritize those needs that are most important to address immediately after a disaster, and then those that can be addressed later in the recovery timeline. In this Framework, we consider three major time periods during the recovery process:

- Response phase: 0-3 days,

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<sup>4</sup> National Research Council of the National Academies. 2006. Facing Hazards and Disasters; Understanding human dimensions, National Academies Press, Washington, DC.

<sup>5</sup> Aldrich, D.P. and M.A. Meyer. 2014. “Social Capital and Community Resilience” American Behavioral Scientist, Published online 1 October 2014.



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- Workforce/Neighborhood Recovery 1 to 12 weeks
- Community Recovery: 4 to 36+ months

This chapter identifies example performance goals for social systems that should be set (pre-event) in order to meet individual/household needs that arise during each of the three recovery phases. Additionally, this chapter discusses the subpopulations that might become (or remain) more vulnerable in the process of meeting these performance goals.

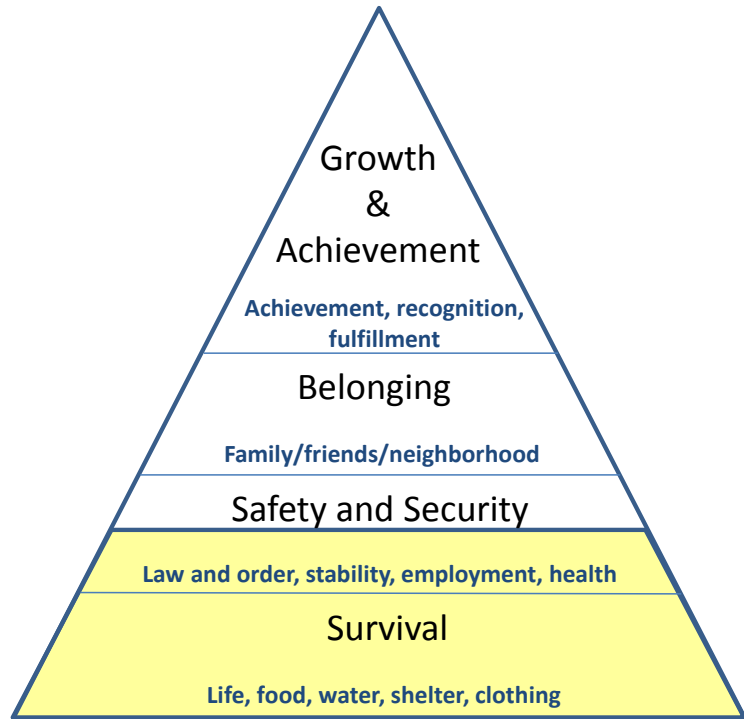
*[Note to reviewers: In a future draft, this section will describe performance goals in more detail. This section will also discuss the importance of, and the difficulties in, assigning time frames to performance goals.]*

### 2.3.1. Performance Goals for the Response Phase (0-3 days)

During the Response time period (i.e., 0-3 days after the event), a community should focus on addressing the most basic needs of individuals: Survival/Life Safety. Therefore, example performance goals are provided here for social systems of a community, so that the survival and (basic) safety and security needs of individuals are met by community systems during the Response Phase. Figure 2-3 highlights the most fundamental needs of individuals 0 to 3 days after an event occurs.

The most basic needs of individuals during the Response Phase are:

1. Life Safety
2. Food/water resources
3. Shelter
4. Health (critical health needs only)
5. Situational awareness (i.e., an understanding of the situation)



*Figure 2-3: The most important needs of individuals during the Response Phase (0-3 days)*

For each prioritized need, a social performance goal will be listed, an explanation of that goal, and then an identification of the subpopulations that may be more vulnerable (in meeting that need) than others during the Response Phase.

*[Note to reviewers: Listing the vulnerable populations may help decision-makers in taking these subpopulations into account when planning for disaster recovery for their community.]*

#### 2.3.1.1. Life Safety

**Performance Goal 1a:** Prior to an event occurring, develop emergency procedures that outline the ways/methods to protect all community residents and visitors before and during an event.

**Explanation:** Depending upon the type of event, a community should develop emergency plans to ensure life safety for its population (including visitors). Planning for life safety includes developing and testing emergency procedures/protective actions that individuals should take to protect themselves during

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different types of disasters, as well as procedures to create and deliver important emergency-related information to the public before and during an event.

Protective action procedures might include evacuation – i.e., the ways in which a community or part of a community should leave an affected area before (or after) a disaster; or shelter-in-place – i.e., the locations where a community (or portions of a community) should congregate to remain safe during a storm or other type of event. Communities should consider questions like – who needs to evacuate or shelter-in-place and who does not, based upon certain individual-based and/or event-based factors.

*[Note to reviewers: In a future draft, this section will be expanded.]*

Additionally, a community may wish to create pre-scripted emergency messages to disseminate to a community based upon the types of events likely to occur, as well as the types of technology that can be used to disseminate emergency information.

*[Note to reviewers: In a future draft, this section will be expanded with more explanation on message templates and constraints to providing emergency information via types of technologies. Additionally, guidance exists to help communities with emergency communication planning.*

*The future draft will also discuss the factors that can increase people's motivation to take protective action before/during a disaster, including appropriate, consistent, clear, specific information (from research).]*

#### **Potential vulnerable subpopulations:**

- **Emergency (action) procedures:** e.g., people without transportation, people with disabilities, people with severe health conditions, etc.
- **Emergency communication:** e.g., non-English speakers, etc.

**Performance Goal 1b:** Provide consistent emergency response capabilities, including search and rescue, safety from secondary effects, and/or property protection, to ensure life safety for the community after an event.

**Explanation:** Survival of the event itself does not ensure the need for life safety has been met. For example, individuals or household members could be buried under rubble during an earthquake or a tornado, and thus, in need of search and rescue operations. Additionally, protection from secondary effects of the event (e.g., fires or hazardous materials release) is crucial for community members or visitors who endured the disaster event.

*[Note to reviewers: Emergency response could come from within the community or from outside of the community (mutual aid), or from community residents/visitors; i.e., disaster research has shown that disaster survivors are often the first to provide emergency response support to other survivors. A future draft will discuss what this means for community decision-makers.*

*A future draft will also discuss the need for security of property and looting (and myths).]*

**Potential vulnerable subpopulations:** *This section is under development. Text to be included in a future draft.*

#### **2.3.1.2. Food and Water Resources**

**Performance Goal 2:** Determine how quickly resources can be mobilized to provide food and water to community residents (who did not evacuate from the area); for example, 72 hours, and then clearly educate community members and groups/networks to be prepared for that amount of time before additional help will arrive.

**Explanation:** Food and water resources could come from surrounding communities, federal or state agency assistance, local businesses, etc., and the community should plan for the ways in which to meet this need before a disaster occurs. Even with the best of plans, implementing these plans takes time; and

therefore, the community population should be prepared for self-sufficiency for some period of time until resources arrive.

*[Note to reviewers: In a future draft, this section will discuss who might be more self-sufficient in a disaster (i.e., people in rural communities). Case studies should be provided where this goal has been met with success.]*

**Potential vulnerable subpopulations:** *This section is under development. Text to be included in a future draft.*

### 2.3.1.3. Shelter

**Performance Goal 3:** Determine all options for sheltering community residents (who did not evacuate the area) and provide all viable options to residents within the first 24 hours after an event occurs.

**Explanation:** Shelter assistance can come from a variety of sources, including sheltering-in-place, family, friends, or others who live in surrounding areas; community-designated shelter locations (pre-event); or federally provided sheltering options (e.g., FEMA trailers). Evacuation of community residents is one way to help with after-event sheltering; however, this procedure could negatively impact community members' 'sense of place', and in turn, increase the community's recovery time (*note to reviewers, this needs further discussion of sense of place, belongingness, etc.*). Communities should plan for ways to meet this sheltering need, before an event occurs, weighing both the positives and the negatives of evacuation procedures on longer-term recovery of the community.

*[Note to reviewers: In a future draft, this section will discuss who might be more self-sufficient in a disaster; also what might influence people to find their own shelter (e.g., smaller, tight-knit community, family close by, etc.), strong ties with region.*

*This section will also have the addition of the SPUR example of 95% shelter in place (San Francisco) – plans to provide neighborhood centers that offer basic needs that cannot be met by homes, and people remain in their homes while the homes are being repaired. **May not work for every community.***

**Potential vulnerable subpopulations:** Renters, people without access to transportation, homeless populations, people with pets, people without insurance (finances/savings)

*[Note to reviewers: this section will be expanded in a future draft]*

### 2.3.1.4. Health

**Performance Goal 4:** Provide consistent emergency care for time-critical health needs, including mental health needs, and access to critical, lifesaving medication.

**Explanation:** The community should plan for the ways to meet time-dependent, critical health needs brought on by the event, as well as those pre-existing before the event occurred<sup>6</sup>. Healthcare workers, equipment, medical supplies, and medication could come from within the community or from outside (either from surrounding facilities or from federal/state agency assistance); however, these mutual agreements should be set in place before an event occurs.

*[Note to reviewers: In a future draft, this section will discuss the importance of providing mental health support to disaster survivors – because a lack of mental health support can lead to negative physical health conditions and slower recovery times for the community.<sup>7</sup> Mental health support can also be*

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<sup>6</sup> Chapter 5, which focuses on buildings, discusses the importance of increasing the resilience of healthcare facilities, so that critical health needs are met during the Response Phase. Other chapters in the Framework, e.g., Chapter 7 on power/energy and Chapter 9 on water and wastewater discuss the importance of increasing the resilience of the infrastructure that would support these healthcare facilities.

<sup>7</sup> Canterbury Earthquake Recovery Authority (CERA). 2014. "Canterbury Wellbeing Index", CERA, Christchurch, NZ.

*provided (and has been shown to be provided) by other affected members of the community (add case study).*

*This section will also discuss the importance of providing necessary medications to community members.]*

**Potential vulnerable subpopulations:** e.g., people without transportation, people with disabilities, people who are immobile, people with severe health conditions, people without health insurance, etc.

*[Note to reviewers: this section will be expanded in a future draft]*

#### **2.3.1.5. Situational Awareness**

**Performance Goal 5 (Situational awareness):** Provide consistent and accurate information on the status of the event and the people and places most affected.

**Explanation:** After an event, disaster survivors or family/friends are in need of information about subsequent protective actions to take, the methods and means to access critical systems (to meet food, water, shelter, and health needs), and status updates on people and things that mean the most to them. Additionally, disaster survivors attempt to “reach out” to their loved ones to connect and make sure that they are safe, secure, and healthy; making working communication systems crucial during this time. Using multiple forms of technology, including more traditional means and non-traditional or newer means, e.g., social media, to inform your population about what is going on and the condition of people and places within the community will encourage individuals to more closely follow important instructions and procedures set in place during the Response Phase of recovery; keeping them and others safer in the process.

*[Note to reviewers: In a future draft this section will discuss the sociological importance of milling before, during, and after an event – and the ways in which the community can support this. It will also discuss the use of social media – its pros and cons. The section will discuss the technology that is most used after a disaster occurs and the reasons for that (sociological research).*

*A future draft will also discuss the importance of bonds within a community/neighborhood and how these should be fostered during each stage of recovery. For example, add a discussion about where, in the community, are the strongest community bonds, social support systems, etc. Also discuss that these bonds can be strained in post-disaster settings.*

*Future drafts will also discuss the opportunities and challenges of various kinds of technology, including social media (e.g., a challenge could be the need to monitor and correct misinformation). Note that existing technology may exacerbate social inequalities/vulnerabilities if attention is not paid.*

*Include case studies on ways in which community bonds have been maintained after a disaster.]*

**Potential vulnerable subpopulations:**

*This section is under development. Text to be included in a future draft.*

#### **2.3.2. Response Phase Discussion**

It is important for community decision-makers to recognize that, especially in those communities with stronger social capital, community members, themselves, may provide some of these needs (e.g., food and water supplies, shelter, mental health support, search and rescue operations, and/or financial resources) during the Response Phase of a disaster event. Communities should identify, ahead of any disaster event, the ways in which community members organize, interact, and engage together in pre-disaster time periods, since these involvements can aid in decreasing disaster recovery time frames and increasing overall social well-being.

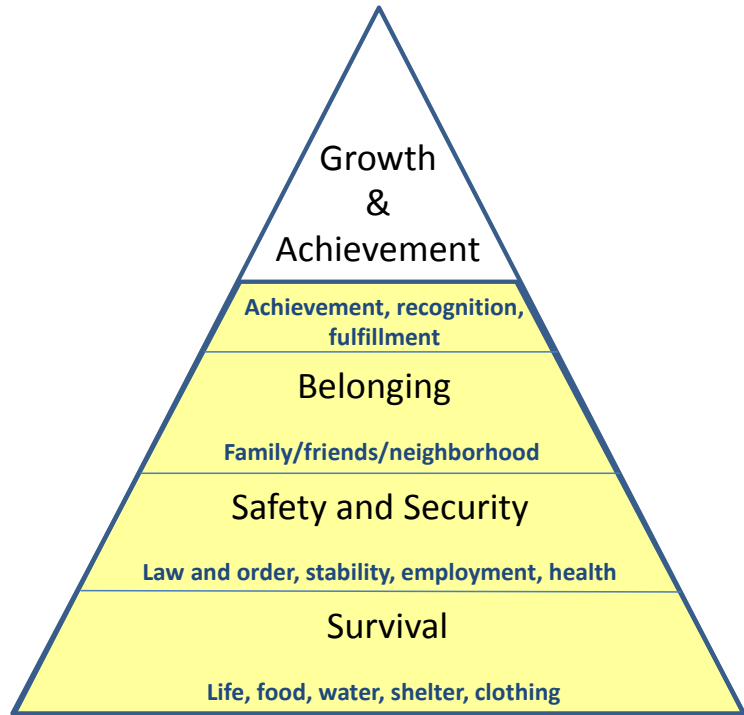
*Future drafts will discuss differences between bonding social capital, bridging social capital, and linking social capital<sup>8,9</sup>*

### 2.3.3. Performance Goals for Workforce/Neighborhood Recovery (1 to 12 weeks)

During the Workforce/Neighborhood Recovery time period (i.e., 1 to 12 weeks after the event), a community should focus on setting and meeting performance goals that address survival, safety and security, and belonging needs during this recovery timeframe.

*[Note to reviewers: A future draft of this section will identify the prioritized needs of individuals during this phase (including employment, stability – financial, belonging, and achievement – education), stressing the need to restore neighborhoods and foster/renew/rebuild the sense of belonging within members of the community.*

*A future draft of this section will also develop performance goal(s) for each need.]*



**Figure 2-4: The most important needs of individuals during the Workforce Phase (1–12 weeks)**

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<sup>8</sup> Aldrich, D.P. and M.A. Meyer. 2014. "Social Capital and Community Resilience" American Behavioral Scientist, Published online 1 October 2014.

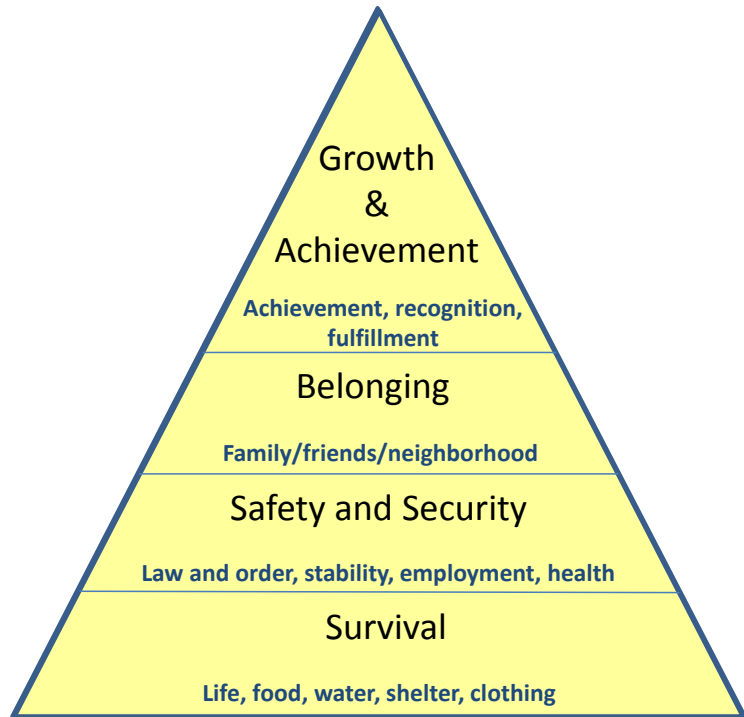
<sup>9</sup> Ritchie, L.A. and Gill, D.A. Forthcoming. "The Role of Social Capital in Community Disaster Resilience." Invited book chapter for *The Resiliency Challenge: Transforming Theory to Reality*. Virginia Tech Center for Community Security and Resilience.

#### 2.3.4. Performance Goals for Community Recovery (4-36+ months)

After 4 months, communities should focus on setting and meeting performance goals that address all needs in the hierarchy, as shown in Figure 2-5. The Community Recovery Phase allows for reconstruction in support of economic recovery of the community.

*[Note to reviewers: In a future draft, this section will identify the prioritized needs of individuals during this phase related to the restoration of communities' economic and social basis, stressing the need to foster the sense of belonging and achievement within members of the community.]*

*This section will also develop performance goal(s) for each need.]*



*Figure 2-5: The most important needs of individuals during the Community Phase (4-36+ months)*

#### 2.4. Community Engagement in Resilience

*This section is under development. Text to be included in a future draft.*

#### 2.5. Conclusion

*This section is under development. Text to be included in a future draft.*

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### 3. Community Disaster Resilience for the Built Environment

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#### 3.1. Community Level Disaster Resilience

Communities come in varying sizes and shapes and they all face a wide range of opportunities, challenges, and hazards. A community can be as small as a neighborhood and as large as a nation. 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.

Boosting community disaster resilience is best initiated at the neighborhood level, organized around a well-orchestrated community effort and supported, as needed, by state and national efforts and sufficient physical infrastructure (NRC 2012). As described in Chapter 2, community disaster resilience begins by recognizing the social needs during recovery that will provide the basis for establishing performance goals for recovering the physical infrastructure. Rebuilding infrastructure will encourage and allow the members of the community to stay and support the recovery.

Physical infrastructure provides the foundation for community disaster resilience. A strong foundation provides the tools and 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 what is needed in terms of the social infrastructure during the three phases of recovery: emergency response, restoration of the workforce, and community recovery.

To understand what is needed from the physical infrastructure for each of those phases, a disaster resilient physical infrastructure is defined by performance level and restoration time needed for clusters of like functions. Those definitions, which become the metrics for resilience, are used to compare to the existing conditions to define gaps that represent opportunities for improvement.

Every community is different and will approach the development of a community resilience plan from a different perspective, tolerance for risk, and planning process. The vitality and usability of the plan depends of its unique adaptation to its community. Implementation will require a broad base of support, which can only be derived from a similar broad base of planning 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 it relates to the physical infrastructure, resilience means the ability of a building or system cluster to return to full occupancy and function, as soon as it is needed, to support a well-planned and expedited recovery. After identifying the social needs and the building or infrastructure system cluster needs, the next priority is to identify how soon each is needed. The timing will depend on both the type and intensity of the disturbance, the age and composition of the community, and available assistance from neighboring communities, region and state.

Achieving and maintaining community resilience is an ongoing effort that involves planning and mitigation before the disturbance; emergency response and long-term reconstruction and recovery after the disturbance. This framework defines a process for developing a plan that will inform actions before, during, and after disasters occur.

Beginning in 2007, the San Francisco Planning and Research Association (SPUR) pioneered this style of resilience planning. Their work focused at the community level and specifically considered what San Francisco needed from policies and programs to become a Disaster Resilient City ([www.spur.org](http://www.spur.org)). SPUR's work produced multiple policy papers and recommendations covering the broad issues of disaster resilience. Their policy recommendations focused on what is needed before the disaster, for disaster response, and after the disaster, as shown in Table 3-1.

The Oregon Seismic Safety Policy Advisory Commission led a planning effort in 2012-13 that followed the SPUR concepts and defined actions by Oregon communities needed to survive and bounce back from

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a magnitude 9.0 Cascadia earthquake and tsunami (<http://www.oregon.gov/OMD/OEM/ossprac/docs>). The plan determined the impacts of the earthquake statewide, defined acceptable time frames to restore functions needed to accelerate state-wide recovery, and recommended changes in practices and policies, that if implemented over the next 50 years, will allow Oregon to reach desired resilience targets.

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

*[Note to reviewers: In a future draft, this section will include an example from a flood planning effort, perhaps Grand Forks, ND.]*

**Table 3-1: The SPUR Plan for San Francisco**

SPUR's Resilient City Initiative	
<b>Before the Disaster</b>	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 <i>Urbanist</i> .
<b>Disaster Response</b>	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.
<b>After the Disaster</b>	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. Diversity of Communities**

Just as the prevalent hazards are different across the country, so are the communities with respect to their age, composition, and capabilities. The initial process of developing a disaster resilience plan requires an estimation of how quickly a community needs to recover from each of the prevalent hazards in order to maintain its population, workforce, and economic viability. Hurricane Katrina demonstrated that New Orleans was not resilient because of the impact the flood damage had on the long-term housing of the workforce. Other cities may be sufficiently 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 1994 Northridge earthquake's impact 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, allowed the workforce to return quickly.

From among the many metrics that give communities their distinguishing characteristics, the following serve to illustrate the impact on each and how they may inform the development of a resilience plan. Each needs to be considered by the plan developers as they seek to adapt ideas and needs from the work of other communities for their own use.

- **Attitudes** – Communities that have experienced a natural disaster learn from the experience. If the resulting recovery effort is orderly and successful, they develop a sense of contentment with their status quo, even if the experience was based on a moderate event. If the resulting recovery was challenged, drawn out and less than successful in the short term, they 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 preparedness activities and making big changes to their



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planning processes and codes. Communities that have not experienced a severe hazard are unlikely to proactively develop disaster resilience plans.

- ***Age of the Community*** – Age brings mature and sophisticated social structures, efficient and informed governance, historically significant landmarks, deep rooted cultural values, and more. It also brings an aging physical infrastructure that contributes to the resilience gaps. With more and larger gaps comes the challenging task of determining the priorities for closing the gaps in an orderly manner.
- ***Architecture and construction*** – Not all buildings and systems are built alike. Vulnerability to damage depends on the construction materials, the structural, non-structural and architectural systems, the quality of construction, the size and shape of the building or system, and its age. There are hundreds of permutations of architecture and construction styles that vary by community and impact the communities’ resilience. For example, in San Francisco, the multi-family apartment buildings of the 20s and 30s 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 early resilience programs is a mandatory program to retrofit these buildings to a shelter-in-place level.
- ***Vulnerable, at-risk populations*** – At-risk persons will likely need the most assistance after a disaster. Due to a lack of resources, physical strength, capabilities, etc., they are least capable of taking care of themselves and generally live and work in the oldest, most hazardous buildings. At-risk persons include the elderly, disabled, chronically ill, poor, et al. The sizes and compositions of these at-risk populations vary greatly across communities, as does the need and/or desire to care for them. If not taken into consideration, the emergency response resources needed to care for them will be overextended, which may potentially reduce the ability to execute an orderly recovery.
- ***Economic drivers*** – The financial health of a community depends largely on the availability of good jobs and a strong set of economic drivers. The vulnerability of the economy to a disaster depends on the transportability of its industries: Knowledge-based industries can move quickly 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 faced with broad-ranging 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 support for the emergency responders, planners and building officials, who need the bandwidth and capacity to develop and implement disaster resilient plans. The speed of recovery depends on those plans and the ability to implement them under recovery conditions.
- ***Codes, standards, administration, and enforcement*** – Strong local building codes are a key tool for building the right kind of physical infrastructure and requiring retrofitting at opportune times. A community’s history with the adoption, administration and enforcement of codes will have a significant influence on 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.
- ***Priorities for emerging public policies*** – Communities face 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 moving toward becoming resilient with other competing opportunities and demands.
- ***Resources*** – Ongoing efforts to encourage development and achieve sustainability through energy efficiency and alternate energy generation have created a variety of new funding mechanisms.

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Community backed bonds, locally-crafted loan programs, and in California, Mello-Roos parcel taxes, are being used to finance buildings needing mitigation. Tax incentives can also be enacted as a means of using public funds to underwrite mitigation activities that are needed for community resilience. The lack of immediate funding, however, should not overly influence the content of the disaster resilience plan. The plan should point to the need for new funding solutions for the long term.

- ***Governance Structure*** – While resilience planning begins at the neighborhood level, the process and structure needed to build up to a community level 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/around their dependence on others in their region.

### **3.1.3. Acceptable Risks**

Today, acceptable risks in the built environment can be inferred from the national model building codes, standards, and guidelines. Because of their development process, they are the best mechanism for defining a minimum, uniform, consensus definition of acceptable risk as it applies to the built environment. Standard 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 acceptable level. The codes, standards, and guidelines provide the benchmark used as a starting point for selecting the hazards, hazard levels, and determining recovery times to be incorporated in the disaster resilience plan.

Each community's current construction standards are a measure of the risk they have accepted with regard to the built environment, though this decision is often based on other factors such as costs. For this reason, community construction practices and the degree of compliance with the latest national standards vary dramatically across the nation. The lack of experience with a damaging hazard and the lack of understanding about the level of damage expected when a significant hazard event occurs often lead to misconceptions of vulnerability. Communities should recognize their vulnerabilities based on the national experience, not just on their experiences with local disruptions, which is best done by adopting and enforcing the national model building codes.

The resilience planning process needs to consider the consequence of the performance expectations imbedded in current design codes, as an indicator of what should be expected for the existing construction. Since the need is focused at the community level, the plan does not insist that all buildings meet the required performance levels for its cluster; rather, the cluster as a whole should meet the needed performance. Are there enough newer buildings in a cluster, that compensate for the older buildings, to meet the goal? A community's level of acceptable risk will likely be based on those levels.

### **3.1.4. Implementing Community Resilience Planning**

A community resilience plan should be developed by a group of interested citizens, a Chamber of Commerce or similar business-related organization, in collaboration with the local governance structure. Because of the holistic nature of the plan and the need to be fully supported during implementation, developing a plan is best done as a public-private partnership between the Mayor's office, community departments, agencies, and organizations, business groups, the professional community, and related non-government organizations.

- ***The Mayor's Office*** 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

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communities within the region and the State using a “survivor-centric approach” that is focused on making the process as easy as possible.

- **City Council or Board of Supervisors** represents the diversity of community opinion, adopts the needed plans, and enacts legislation establishing the needed mandatory mitigation efforts.
- **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 social and economic metrics, their relationship and interconnection to the physical infrastructure, and the location of key vulnerabilities.
- **Department of Public Works** is responsible for the publicly owned buildings and roads, and identifies emergency response and recovery routes.
- **Public Utilities Commission** is responsible for the publicly owned systems and assists in developing recovery goals.
- **Planning Department** identifies post-event recovery opportunities that will improve the city’s layout and is accomplished through repair and reconstruction projects and future development.
- **Emergency Management Department** identifies what is needed from the physical infrastructure to streamline response and recovery including defining a set of standardized hashtags to facilitate community-wide information transfer
- **Chamber of Commerce, Community Business Districts, Building Owners, and Managers** provide the business perspective on 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 and should work together to understand the community needs and proprieties for recovery, and the interdependencies they share.
- **Architects and Engineers** bring the design and performance capabilities for the physical infrastructure and assist in the development of suitable standards and guidelines, as needed. They are the best resource for information on the existing built environment.

Implementing a resilience plan for the physical infrastructure is a long-term effort that requires constant attention, monitoring, and evolution. Because of the cost and the need to transform the governance, real estate, and construction cultures, it can easily take up to 50 years or more to fully implement. Fortunately, 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 have shown 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 the new goals has been shown to be generally cost prohibitive. However, the resilience plan allows the resilience gaps related to clusters of buildings or systems to be judged in terms of relative importance and mitigated as appropriate.

### 3.2. Pathway to Community Resilience

Figure 3-1 shows a flow chart of the Community Resilience Planning process. Among the first steps to becoming a disaster resilient community are defining: 1) the hazards to be planned for; 2) the size and intensity expected for each one, based on the social needs defined in Chapter 2; 3) the clusters of buildings and infrastructure systems that form the foundation of response and recovery and community plans; and 4) the desired performance of each cluster. When a hazard occurs, each building and system must perform in a manner that protects the occupants from serious injury or death. In addition to safety, communities need to determine how soon these clusters of buildings and systems will be used to support recovery. That decision will depend on the social needs, the size of the area affected and the level of disruption experienced.

Given a set of performance goals organized around hazards, building and infrastructure system clusters, and levels of disruption, communities need to develop and implement a resilience plan that begins with defining the existing conditions. These conditions are measured in terms of safety, usability, and repair times. Comparing the performance of the existing built environment to the performance goals identifies the opportunities for mitigation. Those opportunities involve both specific construction projects and a variety of non-construction related programs.

The outcome of planning is summarized in a *Summary Resilience Matrix*, as defined in Section 3.2.7.

#### 3.2.1. Hazard Events

Developing the physical infrastructure needed to support a disaster resilience community begins with the identification of the hazards to be considered. This framework recognizes that resilience planning is best done at three levels for events that are routine, expected, and extreme. The definition of each level depends on the traditional characterization of the hazard, the type of physical infrastructure under consideration, a community's tolerance for damage, and the need to mandate repairs in a timely manner.

Communities should select their prevailing hazards to be considered in their framework related to the physical built environment, such as:

- **Wind** – storms, hurricane, tornadoes
- **Earthquake** – ground shaking, faulting, landslides, liquefaction
- **Inundation** – riverine flooding, coastal flooding, tsunami
- **Fire** – building and wildfire
- **Snow or Rain** – freeze or thaw
- **Man-made** – blast, vehicular impact

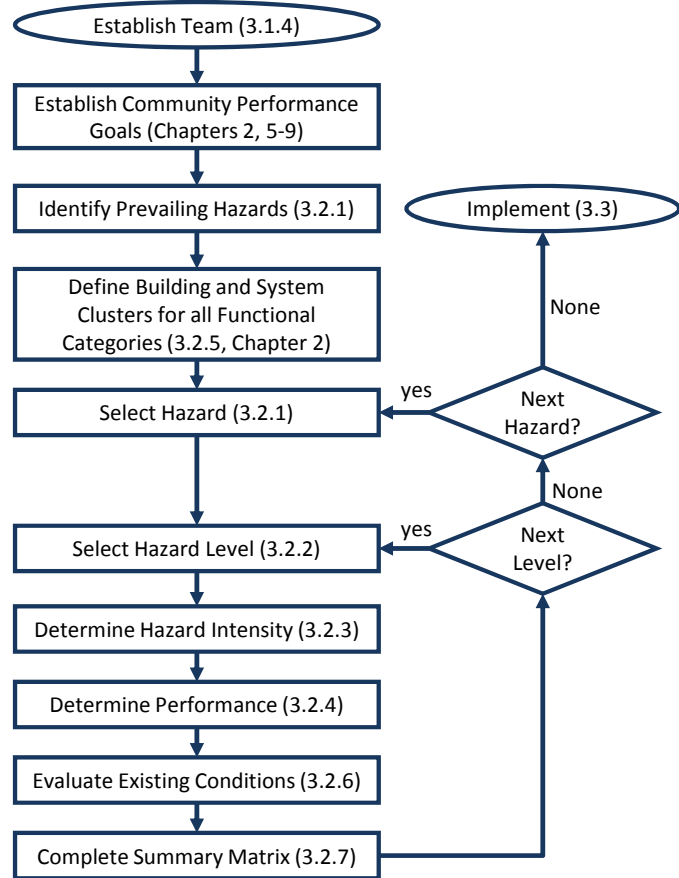


Figure 3-1: Flow Chart for Developing Resilience Plan

**3.2.2. Hazard Levels for Resilience Planning**

For each of the hazards selected, communities should determine the following 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 systems should remain fully useable and not experience any significant damage that would disrupt the flow of normal living.
- **Expected** – Design hazard level. 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** – Maximum considered occurrence based on the historic record and changes anticipated due to climate change. Critical facilities and infrastructure systems should remain functional. 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 extreme level.

Table 3-2 contains the definitions that SPUR used for the three levels of seismic hazard they recommended for San Francisco resilience planning.

*Table 3-2: Sample Hazard definition for earthquakes developed by SPUR for San Francisco*

<b>Routine</b>	<i>Earthquakes that are likely to occur routinely.</i> 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.
<b>Expected</b>	<i>An earthquake that can reasonably be expected to occur once during the useful life of a structure or system.</i> 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.
<b>Extreme (Maximum Considered Earthquake)</b>	<i>The extreme earthquake that can reasonably be expected to occur on a nearby fault.</i> 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 the hazard levels for use in design nationwide. Table 3-3 presents suggested design hazard levels for buildings and facilities based on ASCE 7-10. Note that the extreme level is currently defined for seismic loads, but not for other loads. A scientific basis for other extreme loads that is consistent with current design practice needs to be developed. Communities may define the size of a hazard they want to consider for each level, based on the table or based on other information available to them.

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

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

<sup>1</sup> 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.

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

<sup>3</sup> 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.

<sup>4</sup> Hazards to be determined in conjunction with design professionals based on deterministic scenarios.

<sup>5</sup> Hazards to be determined based on deterministic scenarios. Reference UFC 03-020-01 for examples of deterministic scenarios.

### **3.2.3. Hazard Intensity**

The impact of hazards depends on more than just size and frequency. Impact also depends on the size of the area affected, the extent of civilization in the affected area, and the community’s ability to respond. The size of the area depends on the particular hazard, as does the distribution of the intensity. The extent of the built environment in the affected area will determine the amount of disruption caused. A wild fire in the wilderness areas of the California Sierra Nevada Mountains, where there is little population, can burn multiple square miles of forest with little disruption. 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 area was small, but the population and built environment were extensive, and the disruption was severe.

For purposes of this framework, affected area and disruption are defined in terms of the Community seeking to develop a Resilience Plan.

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*Table 3-4: Affected Area and Disruption Level*

	Category	Definition
<b>Affected area</b>	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.
	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.
	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.
<b>Disruption Level</b>	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 is 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 is 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 is not functional for most needs.

**3.2.4. Performance Goals**

Performance goals are a combination of performance levels and restoration times. Standard definitions for performance levels that cover safety and usability are needed to 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, as well as prioritizing recovery based on the interdependencies of the buildings and systems. Recovery times are needed based on stages of recovery that address immediate needs, such as temporary facilities, and longer term needs, such as the sequence of infrastructure systems restoration which considers interdependencies between buildings and infrastructure systems

**3.2.4.1. Performance Levels for Buildings**

To assure that a community framework is compatible with others nationwide, and to inform the building standards development process, common definitions of performance are needed for facilities and infrastructure systems. Setting goals for both safety and usability as metrics are important for new construction and the retrofitting of existing facilities and infrastructure systems. For new construction, such goals can minimize the cost of mitigation by planning for repairs. For existing construction, it determines the clusters of facilities and infrastructure systems that need to be retrofitted to perform as expected. Table 3-5 provides standard definitions for the performance levels that should be used.

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*Table 3-5: 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 at near capacity without interruption. Essential facilities such as hospitals and emergency operations centers need to have this ability.
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” and will be safe to occupy. This level of performance is suitable for “shelter-in-place” residential buildings, neighborhood businesses and services and buildings needed for emergency operations.
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. They are suitable for facilities that support the community’s economy. Demand for business and market factors will determine when they will be repaired or replaced.
D. Unsafe – partial or complete collapse	These facilities are dangerous, given the occurrences of the prevalent hazard because of the extent of damage that will lead to casualties.

**3.2.4.2. Restoration Times for Clusters and Systems**

Restoration times will vary with the hazard under consideration. At this point, accuracy is not important and generalized time frames such as days, weeks, and months are sufficient. Disaster response and recovery traditionally is organized around the following three basis phases. The time frames shown are suggestions and may not be applicable for all plans.

*Table 3-6: Restoration Time Categories*

Phase	Name	Time Frame	Condition of the built environment
I	Response	0 to 3 days	Initial response and staging for reconstruction
II	Workforce	1 to 12 weeks	Workforce housing restored – ongoing social needs met
III	Community	4 to 36+ months	Reconstruction in support of economic recovery

**For Building Clusters.** While individual buildings are assigned performance levels as noted above, the performance of a cluster of buildings depends on how many of the buildings in the cluster are restored and usable. For purposes of planning, it is worthwhile to set goals for three levels of cluster recovery in terms of the percentage of buildings recovered.

*Table 3-7: Building Performance Standards*

Category	Performance Standard
30% Restored	Minimum number needed to initiate the activities assigned to the cluster
60% Restored	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 3-8: Infrastructure Performance Standards*

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

**3.2.5. Identify Building and Infrastructure Clusters for Each Phase**

For each of the three response and recovery periods, the clusters need to be defined in terms of buildings and the infrastructure systems. The basis for inclusion depends on the hazard, the community, and the



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intensity of the hazard level under consideration. Refer to Chapters 5 through 9 for specific guidance on how to define the clusters of facilities and support systems needed for each phase of each hazard with consideration given to at least the following clusters. Refer to Chapter 4 for guidance on considering the interdependencies of buildings, their dependency on the physical infrastructure and the interdependencies of the infrastructure systems.

*Table 3-9: Clusters by Recovery Phase*

Phase	Cluster
<b>1. Response</b>	<b>Critical Facilities</b>
	<ol style="list-style-type: none"> <li>1. Hospitals</li> <li>2. Police and Fire Stations</li> <li>3. Emergency Operations Centers</li> <li>4. Disaster Debris and Recycling Centers</li> <li>5. Related Infrastructure Systems</li> </ol>
	<b>Emergency Housing</b>
	<ol style="list-style-type: none"> <li>1. Public Shelters</li> <li>2. Residential Shelter-in-Place</li> <li>3. Food Distribution Centers</li> <li>4. Nursing Homes, Transitional Housing</li> <li>5. Animal Shelters</li> <li>6. Soup Kitchen (Community Food Banks)</li> <li>7. Emergency Shelter for Response and Recovery Workforce</li> <li>8. Related Infrastructure Systems, including Recharging Stations and Banking Facilities</li> </ol>
<b>2. Workforce</b>	<b>Housing/Neighborhoods</b>
	<ol style="list-style-type: none"> <li>1. Essential City Services Facilities</li> <li>2. Schools</li> <li>3. Medical Provider Offices</li> <li>4. Neighborhood Retail</li> <li>5. Daycare Centers</li> <li>6. Houses of Worship, Meditation, and Exercise</li> <li>7. Buildings or Space for Social Services (e.g., Child Services) and Prosecution Activities</li> <li>8. Temporary Spaces for Worship</li> <li>9. Temporary Space for Morgue</li> <li>10. Temporary Spaces for Bath Houses</li> <li>11. Temporary Spaces for Markets</li> <li>12. Temporary Spaces for Banks</li> <li>13. Temporary Spaces for Pharmacies</li> <li>14. Food Distribution from Local Grocery Stores (location known by community)</li> <li>15. Related Infrastructure Systems</li> </ol>
<b>3. Community</b>	<b>Community Recovery</b>
	<ol style="list-style-type: none"> <li>1. Residential Housing Restoration</li> <li>2. Commercial and Industrial Businesses</li> <li>3. Non-Emergency City Services</li> <li>4. Resilient Landscape Repair, Redesign, Reconstruction, and Repairs to Domestic Environment</li> <li>5. Water Pollution from Severe Flooding</li> <li>6. Cradle-to-Cradle for Temp Housing – no debris when new housing comes on line</li> <li>7. Related Infrastructure Systems</li> </ol>

**3.2.6. Estimating the Vulnerability of the Existing Buildings and Infrastructure Systems**

The majority of buildings and infrastructure systems in service today have been designed to serve their intended functions on a daily basis, given the normal environmental conditions in which they operate. The designs are provided by experienced architects and engineers following their communities standards of practice. The standards of practice for design are continually evolving due to failures that occur. Failures lead to improved design procedures that often start as guidelines and sometimes are formalized into consensus-based design standards.

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In the early 20<sup>th</sup> century, communities started requiring minimum qualifications for engineers through licensure and began adopting building codes to set minimum standards of performance in the interest of protecting public safety. Since the latter half of the 20<sup>th</sup> century, this interest has grown beyond public safety to include resilience. For example, the 1971 San Fernando, California earthquake led to the requirement that California's hospitals be designed to remain functional, in so far as practical, after a major earthquake.

Current design practices related to achieving resilience for the expected or extreme prevailing hazards are very uneven. The technologies needed to determine the expected performance of existing buildings and infrastructure systems are available and 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.

Architects and engineers deal with buildings and infrastructure systems one building or system at a time. The resilience levels achieved by 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 those goals, it is neither necessary nor practical. What is important is that a community has a critical mass of buildings and systems to support recovery in the short term, when taken as a whole. There is a need to evaluate and rate how long it will take for a cluster to return to service and compare that to the resilience goal.

As the last step in developing a disaster resilience plan, a community needs to evaluate each of its designated recovery clusters and estimate how long it will take to reach the designated goal for each level of the prevailing hazard. This information can be recorded on the summary matrix.

### **3.2.7. 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 Infrastructure System Resilience Matrix for each of the infrastructure components, including buildings and infrastructure systems. These are summarized into a single page Summary Resilience Matrix that gives an overview of the anticipated response and recovery demands placed on the built environment. One set of matrices is intended to be used for each hazard and hazard level. Table 3-10 is a Summary Resilience Matrix for a single example application and is offered as an illustration. The related individual matrices for each of the components are discussed in Chapters 5 through 9.

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*Table 3-10: Summary Matrix*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

Functional Category: Cluster	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+
<b>Critical Facilities</b>									
Buildings	90%								
Transportation		90%							
Energy						90%			
Water			90%						
Waste Water				90%					
Communication	90%								
<b>Emergency Housing</b>									
Buildings			90%						
Transportation			90%						
Energy							90%		
Water			90%						
Waste Water				90%					
Communication				90%					
<b>Housing/Neighborhoods</b>									
Buildings				90%					
Transportation					90%				
Energy							90%		
Water				90%					
Waste Water					90%				
Communication				90%					
<b>Community Recovery</b>									
Buildings								90%	
Transportation								90%	
Energy							90%		
Water				90%					
Waste Water								90%	
Communication				90%					

**Footnotes:**

- 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
- 30% 60% 90% Restoration times relate to number of elements restored within the cluster
- X Estimated 90% restoration time for current conditions based on design standards and current inventory

**3.3. Mitigation and Recovery Strategies**

The disaster resilience planning exercise described above and summarized in the matrices provides a comprehensive picture of the gaps between what is needed from the physical infrastructure to support response and recovery and what currently exists for all the prevalent hazards and hazard levels considered. Communities should consider and balance their opportunities for mitigation and for recovery processes. Mitigation before the event costs money, but reduces demands during recovery and can speed up the overall recovery process. Streamlining recovery processes can reduce the need for mitigation.

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

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Cost is always an issue with regard to funding mitigation activities. While the initial planning is complex and requires the interaction of a large number of people, it is the first and most cost effect step in the process. Once the plan is in place, there are a number of low-cost, non-construction activities that can be done at low cost and will have significant long-term benefit. There are also a series of construction related activities that can significantly improve community resilience.

### **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 can be extensions on 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. Adopting the latest national model building codes and standards for the physical infrastructure.
4. Insist on the development of codes and standards that are compatible with resilience planning and set transparent performance goals.
5. 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.
6. Develop processes and guidelines to be deployed for post-event assessments and repairs.
7. Collaborate with adjacent communities to promote common understanding and opportunities for mutual aid during response and recovery.
8. Elevate the level of inter-system communication between the infrastructure community's providers and incorporating the interdependencies in their response and recovery plans.

### **3.3.2. Construction-Related Strategies**

1. Prioritize gaps identified between the desired and expected performance of infrastructure clusters, as summarized in the Resilience Matrix for the prevailing hazards.
2. For each gap, identify the guidelines and standards used to assess deficiencies in individual public and private buildings and systems and processes. Define the gap in a transparent and publicly available method and announce the result.
3. Include retrofitting of public buildings to achieve the resilience goals in the capital planning process and make it a part of the prioritization process.
4. Develop incentives to encourage new construction be built to the resilient standards and for deficient existing construction to be retrofitted.
5. Support national efforts to improve code-based design standards that match the resilience metrics defined in this framework.
6. 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. Interdependencies and Cascading Effects**

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The development of a specific Community Disaster Resilience Plan requires an understanding of the building and system interdependencies and the potential cascading effects that can occur. Chapter 1 provided an overview of the framework development goals and process. This framework is intended to allow communities to understand their social and economic structures and develop recovery strategies that will allow them to be resilient to natural and manmade hazards as well as other unanticipated disruptions. Chapter 2 provided guidance for defining a community's social and economic structures and their dependence on the built environment. Following Maslow's hierarchy of needs – survival, safety and security, belonging, growth and achievement - provides a means of defining community resilience. Chapter 3 defined a vocabulary and structure for the Community Disaster Resilience Plan in terms of the hazards to be addressed, defined performance levels related to the degree of damage and recovery time, for defined clusters, that is permissible for each of the built environment sectors. Recovery times are defined for the clusters and organized around four categories within the built environment and three phases of recovery. Chapters 4 through 9 provide detailed guidance for developing the plan. This chapter deals with the need to consider the interconnectedness of the various buildings and infrastructure systems when setting performance goals for community recovery.

### **4.1. Introduction**

The goal of the community disaster resilience plan is to determine “the performance needed for the various clusters (groupings of buildings or systems of common function) of the built environment to protect a community from significant and non-reversible deterioration.” This is done by defining an orderly and rapid process for managing recovery that includes the just-in-time availability of a sufficient number of buildings in each of the designated clusters and infrastructure systems that support them. To achieve the goals, each cluster's performance depends not only on its primary function but also on the interdependencies between clusters and the interdependencies between infrastructure systems that support them. These interdependencies need to be addressed during the process of setting the performance goals in order to avoid cascading failures of multiple systems.

Cascading failures occur when the failure of one part triggers failure of successive parts downstream. It can occur within one system, such as a failure that cascades through the power grid when one component fails causing an overload and subsequent failure of other components in a sequential manner. It can also occur between systems when the failure of one system causes the failure of other systems. A multiple hour loss of power in a community can cause failure in the cell phone systems if there is not back up power to maintain the cell tower batteries. Intra-system cascading failures can affect power transmission, computer networking, mechanical and structural systems, and communication systems. Inter-system cascading failures can affect all buildings and systems.

Identifying the interdependencies and potential cascading failures is the first step. Mitigating their possibility and consequence and setting balanced goals can be done by adding redundancy, over capacity, and in some cases weak links that cause constructive isolation of systems that do not need to be interconnected. Governance processes and public policies also play a key role in orchestrating mitigation programs and in recovery management.

### **4.2. Interdependencies of Building Clusters**

The resilience framework defined in Chapter 3 organizes the Community Resilience Plan around the three phases of response and recovery using four categories of building clusters. The first phase, focused on immediate response, is expected to last for days, and requires building clusters that serve as critical facilities and those that provide emergency housing to return to full functionality. The second phase, focused on restoring the workforce, is expected to last for weeks, and requires building clusters that provide housing and all the neighborhood level services needed including the schools. The third phase

focuses on activities and building clusters that are needed for the economic and social base of the community to fully recover. Each category has a unique set of interdependencies as is introduced below.

#### **4.2.1. Critical Facilities**

Critical facilities, as defined in Chapter 3, are a small number of building clusters that need to be usable immediately after an event to organize and direct the emergency response, secure the disaster area, and provide a safe environment for emergency responders. With the exception of access and housing for responders, the degree of interdependence on other clusters depends on their ability to operate in isolation using emergency power, an independent communication network, and possibly on site housing and subsistence for the staff. Access routes need to be established immediately for use by staff, users, and supply vehicles that are needed to replenish on site supplies including fuel, water, food, medical supplies, etc. Performance goals need to represent an appropriate balance between having the needed supplies on hand to operate independently and defining restoration times that are achievable.

#### **4.2.2. Emergency Housing**

The need for Emergency Housing for emergency responders, and displaced individuals and animals occurs immediately and is often met by using schools, shelters, hotels, conference centers, residences that are safe to “camp in” (shelter-in-place), etc. Food, water, security and sanitation needed to protect public health are usually provided at centralized locations. During the response period, there is a limited need for transportation, power, and communication. Current thinking says that it is best for residents to shelter in their homes, neighborhoods, or within their community. Recovery performance goals should address that possibility.

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

#### **4.2.3. Workforce/Neighborhoods**

Restoring fully functioning neighborhoods is key to providing the workforce needed to restore the economic vitality of the community after an event. Personal residences and the schools and businesses that support them need to recover fast enough to give the population confidence to stay and help with the restoration (tip-in) and to keep the small neighborhood businesses viable. There is a strong interdependence between where people live and where they shop, their kids go to school, they receive professional services, they worship, and they gather together. All of these activities need to recover in the same time frame. During this period, special attention must be paid to the needs of the disadvantaged and at-risk populations who will require a higher level of assistance.

If people are unable to shelter in their neighborhoods, the small neighborhood businesses they depend on will lose their client base and close. Once they close, they rarely can reopen when the people return. This in turn cascades into delays in the availability of the stable workforce needed to restart and restore the community economy.

The condition of the built environment that supports residences and neighborhoods is one of the keys to preventing the cascading failure to replenish the workforce. While the emergency response period will be over within days, the workforce needs to be re-established in weeks if the community is to restore its vitality to the pre-event levels. Significant structural damage to buildings and lifeline systems cannot be repaired within a few weeks. It takes months. Buildings need to be usable while being repaired or temporary facilities must be created in which they operate. The transportation, energy, water, waste water, and communication systems that support these clusters need to be restored within a few weeks. The need

for schools to be able to reopen is a key contributor to creating a stable and productive living environment.

#### **4.2.4. Community Recovery**

Restoring a community from a major event will provide a significant, short term stimulus to the economy due to the accelerated construction activity that is financed with the new money that flows in from government, insurance companies, large businesses, private savings and developers. In order for this natural occurrence to successfully jump start the local economy, there has to be a governance structure in place that approves reconstruction rapidly while protecting the community's interests and that can seize the opportunity to build back better. The key interdependency at this point is between reconstruction and governance. Any stall or stalemate in the decision making process quickly cascades into a stalled recovery and lost opportunity to use the construction activities to restart the economy.

It is a fundamental right of building and lifeline owners to maintain their properties under the codes they were originally constructed. Many believe that when a disaster causes damage, they can be rebuilt to the same standard. Building standards as they relate to disaster resilience have been maturing rapidly for the past 100 years and the recent interest in sustainability and building to limit damage is accelerating the change. Unfortunately, this only affects the construction of new buildings and systems. A natural disaster provides an opportunity to require repairs and restoration work to meet higher resilience standards set by communities. To be effective and enforceable, that requirement must be institutionalized well before the disaster occurs.

Community health and sustainability depends in part on sound urban planning that continues to adapt to changing conditions. Major changes in land use and zoning are often needed in communities, but they are not possible because of the cost and inertia surrounding the existing conditions. A significant disaster provides an opportunity and the needed funding to make major changes, but these are not generally possible if introduced during the aftermath of the disaster. They must be developed, properly vetted and included in the Community's General Plan so that their implementation can be accelerated in the post event recovery and reconstruction period.

### **4.3. Interdependencies among Infrastructure**

All infrastructure systems – transportation, energy, water, wastewater, and communication – are interdependent because of the services they provide each other, but also because of the cascading impact of the failures that occur. For example, everyone needs electricity, even generation facilities need electricity to restart. Electricity needs streets and highways to move repair crews and materials, water for cooling, fuel for generation, communication and a stable and safe environment to work in. A broken water line collocated with an electrical vault can flood the vault and shut down a distribution network.

A well-functioning resilient community understands these interdependencies and works to break down the traditional silos of silence between providers, facilitates development of recovery plans that restore services in an ordered manner, orchestrates publicly funded mitigation programs that resolve choke points and barriers, and has plans for recovery that minimize impact on the community.

#### **4.3.1. Identifying Interdependencies**

Understanding the interdependencies between infrastructure systems is a new and developing area of planning related to resilience and recovery from significant disruptions. It has benefited from focused research since the mid-90s that has taken two tracks – one related to specific modeling and analytical studies using engineering metrics, the other based on empirical evidence gathered from both providers and users. The analytical methods provide more numerical precision but suffer from complexity and a lack of data on the systems and the fragility of their components. The empirical methods are based in reality and the perceptions of their operators but suffer from inconsistency amongst system reporting.

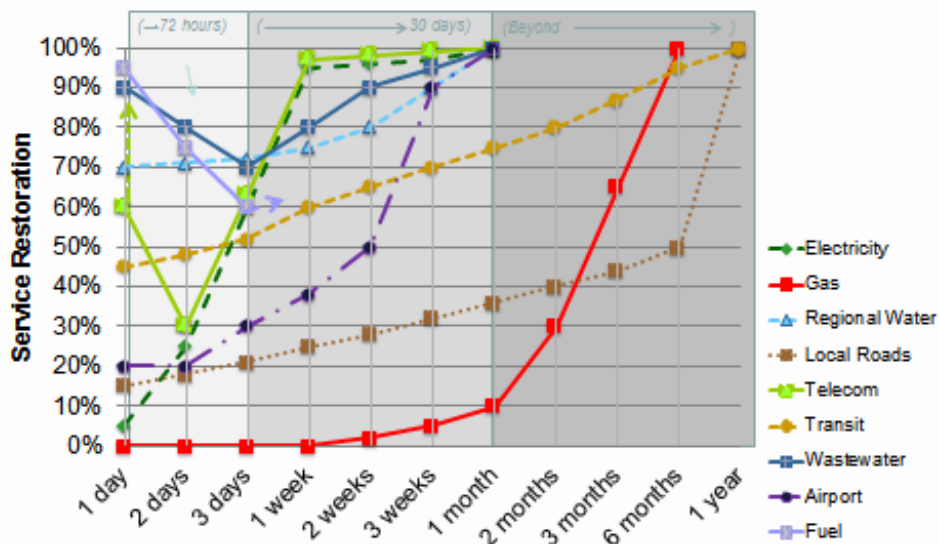
**Interdependencies and Cascading Effects, Interdependencies among Infrastructure**

There is ongoing research in both methods that will develop new tools to assist in community based studies.

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 for communities 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 lifelines council of private and public infrastructure owners and provide a quarterly forum for them to meet, share planning activities to date, 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 that can be related to infrastructure system performance from the view of the infrastructure provider. Figure 4-1 illustrates the restoration times estimated by the providers in the San Francisco study.
3. For each infrastructure sector, 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 collocation, overlaps and hindrances related to restoration and recovery plans. Table 4-1 illustrates the interdependences 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.

Chapters 5 through 9 provide detailed discussion about the building clusters and each of the primary infrastructure systems. Each chapter includes the related Resilience Matrix and suggestions related to target performance goals in terms of usability and restoration time. The Summary Resilience Matrix presented in Chapter 3 combines all the information into a single page and serves as a clear statement of the interdependencies between buildings clusters and infrastructure systems. It should be apparent that the process of developing performance goals for building clusters and the infrastructure sectors that serve them is an iterative process that balances the needs with the capability of the existing systems and the availability and practicality of providing temporary services to meet the needs of the building clusters.



*Figure 4-1. Potential Service Restoration Timeframes following a Scenario M 7.9 Earthquake on the San Andreas Fault. (CCSF Lifelines Council 2014)*



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

**Legend:**

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

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

	Regional Roads	City Streets	Electric Power	Natural Gas	Telecom	Water	Auxiliary Water	Waste-Water	Transit	Port	Airport	Fuel
<b>Regional Roads</b>	General	Restoration Substitute	Restoration	Restoration	Restoration	Restoration		Restoration	Substitute		Restoration	Restoration
<b>City Streets</b>	Substitute Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Restoration
<b>Electric Power</b>	Restoration	Collocation, Restoration	General		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
<b>Natural Gas</b>	Restoration	Functional, Collocation, Restoration	Substitute	General	Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
<b>Telecom</b>	Restoration	Collocation, Restoration	Functional, Restoration	Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration			Restoration	Restoration
<b>Water</b>	Restoration	Restoration	Restoration		Restoration	General				Collocation		Restoration
<b>Auxiliary Water</b>	Restoration	Functional, Restoration	Restoration		Restoration	Functional, Restoration	General			Collocation, Restoration		Restoration
<b>Waste-Water</b>	Restoration	Collocation, Restoration	Functional, Restoration		Restoration	Functional, Restoration		General		Collocation, Restoration		Restoration
<b>Transit</b>	Substitute, Restoration	Functional, Substitute, Collocation, Restoration	Functional, Restoration		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, General	Collocation, Restoration		Functional, Restoration
<b>Port</b>	Restoration	Collocation, Restoration	Collocation, Restoration		Collocation, Restoration	Collocation, Restoration	Collocation	Collocation	Collocation	General		Restoration
<b>Airport</b>	Restoration		Restoration		Restoration	Restoration		Restoration	Collocation, Restoration		General	Functional, Restoration
<b>Fuel</b>	Restoration	Restoration	Functional, Restoration		Restoration	Restoration				Restoration	Restoration	General

Operator's dependency on other Infrastructure systems (read across each row)

Key to terms used in the matrix of interdependencies

- *Functional* disaster propagation and cascading interactions from one system to another due to interdependence
- *Collocation* interaction, physical disaster propagation among lifeline 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 are more crucial issues for the system's potential disruption and restoration.)

#### **4.4. References**

*Lifelines Interdependency Study/Report*, City and County of San Francisco Lifelines Council, San Francisco, CA, 2014, <http://www.sfgsa.org/modules/showdocument.aspx?documentid=12025>

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## **5. Building Sector**

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### **5.1. Introduction**

This chapter focuses on establishing a basis for setting performance goals for buildings within a community to support a resilient community. Building stock within a community is widely varied, in terms of use, occupancy, ownership, age, and condition. The variability in occupancy and use leads to different performance goals. The variability in age and condition leads to different performance, even within the same class of building. The variability in ownership, between public and private, can lead to challenges in implementing minimum performance goals, particularly with existing construction. This chapter discusses the various classes and uses of buildings, their ideal performance goals to support community resilience, what past and current codes and standards provide, and what gaps are present and improvements needed to support community resilience.

#### **5.1.1. Social Needs and Systems Performance Goals**

Buildings fulfill a multitude of social needs, from the most basic – providing shelter – to housing necessary services, like medical care and food. There are also many types of buildings that house goods or businesses that can be forgone for a while following a major disaster. Therefore the performance goals for buildings depend specifically on what they house or the function they serve. Some buildings must be fully functional immediately or very soon after the disaster, while others need only provide basic stability so they do not collapse and kill their occupants. Because of the wide variety of social needs various buildings fulfill and the fact that the post disaster performance needs are tied to the building’s occupancy and use, there are many different potential performance goals. Section 5.2 discusses different classes of buildings and some recommended performance goals based on the overarching framework set forth in Chapter 3.

#### **5.1.2. Reliability v. Resilience**

Many provisions within building codes and standards deal with resilience, rather than just pure safety. The scope of the *International Building Code*, a commonly adopted model building code, is to “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.” There are many requirements for protection of routes out of the building and into the building for emergency responders. The fire suppression requirements are not simply based on allowing egress, but to quickly extinguish a fire to limit damage and allow for quick return to function.

However, the engineering standards currently used throughout the country for building design are focused primarily on preserving occupant safety in major natural hazard events. For some hazards, such as wind, snow and rain, the intention is that the building sustain little or no damage under the design event by requiring that each element have a specific safety reliability index. For other hazard events, such as earthquakes, the design intention is for typical buildings to provide life safety, which allows structural damage but not collapse. For these hazards the reliability is based on a target probability of collapse as opposed to element-specific safety reliability. Thus, while a building will protect its occupants, it may not function and will need to be demolished after a seismic event.

While safety reliability is important, it is not synonymous with resilience. If a building has sustained damage such that following the disaster it cannot perform its pre-disaster function even if there was no collapse, it may negatively affect a community’s resilience. An example of this is a fire station where the doors cannot open and the fire trucks cannot exit to fight fires. Furthermore, some buildings may need to be brought back online sooner than others. Providing a uniform level of safety does not necessarily allow this to happen, which is why additional requirements exist throughout building codes for resilience.

### **5.1.3. Interdependencies**

Community resilience depends on the performance of various different buildings. The performance of most buildings is directly linked to the utilities that feed power and water to them, their wastewater systems, and the local transportation infrastructure. Additionally, some buildings directly affect power infrastructure, water and wastewater systems, and other utilities. The effect of any specific building on an infrastructure distribution system should require that the building be as resilient as or more resilient than the infrastructure system of which it is a part. Refer to other chapters of this framework for the various infrastructure system resilience recommendations.

## **5.2. Buildings Classes and Uses**

### **5.2.1. Government**

In most communities, the primary emergency operations center, airports, penitentiaries, and first responder facilities are government-owned buildings. These buildings support and shelter the people and equipment that provide essential services and must remain operational during and after a major disaster event. Communities expect and plan for these facilities to be operational during and after hazard events. Therefore buildings for emergency operation centers, police and fire stations, penitentiaries and other correctional institutions, water and wastewater treatment facilities, and emergency shelters need to remain operational – Category A as defined in Chapter 3.

Currently, most of these essential buildings would fall under Risk Category IV in the *International Building Code*, which requires the highest design forces and has provisions for nonstructural systems remaining operable post-disaster. Some are classified as Risk Category III, which requires higher design forces than a typical building, but fewer specific nonstructural system requirements than a Risk Category IV building. However, as will be discussed in Section 5.5, gaps exist between the current model building codes and standards' requirements and providing truly functional buildings following a major disaster.

Other government buildings may not be immediately needed following a disaster, yet a community may determine they are critical to recovery, such as a City Hall or county administrative building, schools, mass transit stations and garages, courts, and community centers. A possible goal for these buildings would be to have them functional in about a month, depending on their role in the community, following the disaster. In some cases these buildings are designed as Risk Category III, while others are designed as Risk Category II (typical buildings). Neither Risk Category II or III have specific provisions which would provide a high level of confidence that the building could be returned to operation within a month. In the Chapter 3 performance vernacular, a performance level for these types of buildings might be Category B – Safe and usable during repair. This may be the performance Risk Category III delivers, but not what Risk Category II intends.

### **5.2.2. Healthcare**

Emergency medical facilities are critical to response and recovery efforts following a major disaster. Therefore hospitals, other such healthcare facilities, and their supporting infrastructure must be operational (Category A) following the disaster. Currently, hospitals are designed to Risk Category IV requirements, with some local communities or federal agencies placing additional requirements on them. For example, the state of California requires that all hospitals, regardless of location or ownership (municipal or private), have their designs reviewed and construction overseen by a state agency.

Nursing homes and residential treatment facilities that house patients who cannot care for themselves independently may also need to be immediately functional after the disaster and are designed the same as acute care hospitals.

Other healthcare facilities, like doctors' offices and outpatient clinics, need not be immediately available, but a community may determine they are needed shortly after the initial shock of the disaster. Therefore medical office buildings may be designed to be safe and usable during repair (Category B). In most cases

they are currently designed as Risk Category II buildings, meaning they have no major structural requirements beyond preservation of safety without consideration for post-disaster function.

### **5.2.3. Schools and Daycare Centers**

Many communities have concluded that K-12 Schools should be designed to a higher performance than typical buildings because they have large assemblies of children. This belief is reflected in the IBC designated schools Risk Category III. In many localities, school gymnasiums or entire school buildings are also designated to serve as emergency staging areas or emergency shelters. Additionally, the research that went into the SPUR Resilience City Initiative found there is a perception that if children can return to school, then things are getting back to normal and their parents can return to work. Thus, expeditious resumption of function is important for schools across a community.

There is a dichotomy of performance requirements for a school. On the one hand providing enhanced safety and returning to operation quickly would place a school in Category B – safe and usable during repair. However, the expectation that it could be used as an emergency shelter, would in turn place it in Category A – operational. The current Risk Category III provisions, to which most K-12 schools are designed, may provide Category B, but definitely will not provide Category A performance. Therefore, it is recommended that any school that will be designated as an emergency shelter be designed for Category A requirements, which would mean being designed or upgraded to a higher level than is commonly used today, possibly Risk Category IV requirements per the IBC or greater.

Higher education facilities are generally regulated as business or assembly occupancies with some exceptions for specific uses, such as laboratories and other research uses. Research universities often have the added concern of protecting their research facilities and long-term experiments.

### **5.2.4. Religious and Spiritual Centers**

Religious and spiritual centers have special role in many communities. They are places that can offer a safe haven for people following the emotional distress a major natural disaster can inflict. Logistically, they often become critical nodes on the post-disaster recovery network. Many religious organizations have charity networks that provide supplies to people following a disaster. In past disasters, a number of religious institutions have opened their doors to serve as shelters. In most cases, however, these buildings are designed to the same standard as any other building, meaning they have no explicit design for function preservation. Compounding the issue, these buildings are often some of the oldest in a community and built out of archaic materials that perform poorly in major disasters.

Because these facilities can have such an important role following a major disaster, a desired performance level would be Category B – Safe and usable during repair per Chapter 3. However, a number of factors could influence a community to accept a lesser performance goal. First, many of these institutions are nonprofit entities, with little funding for infrastructure improvement. Second, many of the historic buildings would have to be modified in such a manner that their historic fabric would be unacceptably disrupted to meet this higher performance category. Therefore, a community should understand the resilience of its various churches and spiritual centers and factor that into its recovery plan.

### **5.2.5. Residential including neighborhood commercial districts**

Current thinking suggests that residential buildings and neighborhoods should be designed to provide shelter for a significant portion of the population following a disaster. Houses, apartment buildings, and condominiums need not be fully functional, like a hospital or emergency operation center, but they do need to safely house their occupants to accelerate the ability of the workforce to return to work. By not being fully functional, we mean that a house or apartment may be without power or water, yet can still provide sufficient shelter for its inhabitants. The significant loss of housing stock led to the migration of a majority of the work force following Hurricane Katrina's impact on New Orleans. Such a "shelter in

place” performance level is a key component of the SPUR Resilient City initiative and prompted the City of San Francisco to mandate a retrofit ordinance for vulnerable multi-family housing.

In addition, an effective response to most disasters requires supplemental first responders and other personnel for a period of time. If the majority of the residential buildings are not functional, then the demand for emergency shelter competes with the demand for housing temporary responder and recovery workers.

Currently multi-unit residential structures are designed to Risk Category II provisions, except in certain cases where the number of occupants is quite large, over 5,000 people, then they are designed to Risk Category III. Risk Category II may not provide the requisite level of performance in a major disaster.

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 some 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 in some instances better than, engineered buildings. Whether there is a discrepancy in performance between the IBC and the IRC should be investigated further, because of the importance of residential housing.

#### **5.2.6. Business and Services**

While it would be ideal to have all community businesses open shortly after the disaster, it may not be economically practicable. Most buildings that house offices, retail, and manufacturing are currently designed to Risk Category II. As we will discuss further in this chapter, the performance of Risk Category II buildings is really based on safety, but not function preservation or resumption. That is not to say, all commercial buildings are designed to the code minimum, because many are designed for higher performance, but for the purpose of this framework it is assumed that most are.

Certain types of commercial buildings are likely critical to the post-disaster recovery effort. The community needs to designate which buildings perform to a higher performance level so they can be available in an appropriate period of time following the disaster. Each community should select design and recovery performance goals for its businesses and services, depending on their role in the community during the recovery period. Some businesses and services that commonly are essential to recovery include:

- ***Grocery stores*** – It is important that people be able to get food and water following a major disaster. Additionally, major grocery stores typically have robust distribution networks outside of the affected area that can be tapped to bring supplies into the area. While 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 is great in major natural disasters. For example, the Oregon Resilience Plan recommends two weeks of food and water.
- ***Banks or financial institutions*** – Banks or at least structures housing automated teller machines are important because they provide people with access to money.
- ***Hardware / Home improvement stores*** – These stores are critical to the post-disaster recovery effort in their ability to provide building materials to aid in the reconstruction, and even emergency shoring of damaged buildings.
- ***Gas Stations and Petroleum Refineries*** – Many communities have been planned in a manner which necessitates that residents have automobiles to carryout basic functions, like shopping and commuting to work.
- ***Buildings that house industrial and hazardous materials or processes.***

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**5.3. Performance Goals**

The resilience goal matrices in Chapter 3 are based on specific clusters of building and infrastructure being brought back on-line at specific intervals following the disaster. Chapter 3 contains a specific example of how a San Francisco public policy think tank, SPUR, adapted a resilience matrix for a major earthquake affecting San Francisco. The concepts used in that example and in Chapter 3 provide a basis for other communities to determine their needs post-disaster. The previous section discussed specific performance goals for various types of buildings using the Chapter 3 terminology, which are summarized in Table 5-1.

*Table 5-1: Building Section Resilience Matrix*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

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+
<b>Critical Facilities</b>		<b>A</b>									
Emergency Operation Centers			90%								
First Responder Facilities			90%								
Acute Care Hospitals			90%								
<b>Emergency Housing</b>		<b>B</b>									
Temporary Emergency Shelters				90%							
Single and Multi-family Housing				90%							
<b>Housing/Neighborhoods</b>		<b>B</b>									
Critical Retail					30%	60%	90%				
Churches and Spiritual Centers					30%	60%	90%				
Schools						30%	60%	90%			
<b>Community Recovery</b>		<b>C</b>									
Businesses							30%		60%		90%

**Footnotes:**

- 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
- 30% 60% 90% Restoration times relate to number of elements of each cluster
- 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
- Indicate levels of support anticipated by plan  
R Regional  
S State  
MS Multi-state  
C Civil Corporate Citizenship
- Indicate minimum performance category for all new construction.  
See Section 3.2.6

**5.4. Regulatory Environment**

No explicit building code is mandated by the federal government for use throughout the country. Building codes are left under the purview of the state or local jurisdiction. Federal buildings and certain buildings that receive federal funding to be built or operate are an exception to this rule. In the United States, two organizations publish model building codes that can be adopted by federal agencies or state and local governments. One building code is published by the International Code Council, which was formed as a merger of three organizations that published regional model building codes. The other building code is

published by the National Fire Protection Association. The ICC's *International Building Code* is the most widely adopted model building code in the United States. Most federal agencies also use that code as the basis for their building standards. These model codes contain many reference standards that are typically published by non-for-profit standards development organizations, professional societies, and industry groups. The model building codes and the standards referenced are typically modified by federal, state, and local agencies for their specific purposes.

While the model building codes specify minimum requirements that are meant to be applicable throughout the country, states and local municipalities draft their own building codes based on modifications to the model 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.

In general, most states and municipalities adopt building codes as stringent or more stringent than the model building codes. However, there are locations where no building code may be adopted or portions of the model code may be excluded.

Enforcing standards is as important, if not more important, than having a building code and building standards. Typically enforcement is the purview of the local jurisdiction. The level of enforcement can have a very significant impact on 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 expected performance of each building depends upon the codes and standards in-force at the time of construction, as well as the level of maintenance. Building codes and standards are dynamic and ever-changing. Many changes have come in response to disasters, while others have come from a perceived weakness to natural disasters brought about by research on the subject. That means that codes from a generation ago, or even a decade ago, may not have produced a building stock with the resilience needed for a community.

Building codes and standards are primarily aimed at regulating new construction and are based on the best understanding of hazards at the time they are published. The challenge is that with every major hazard, there are commonly portions of the building code that are found insufficient and are enhanced. Some provisions, when changed, become retroactive or are enforced during renovations. Examples of these are egress protection, access for disabled people, and fire suppression system requirements. However, the most significant changes to the code, most commonly in structural provisions, would require such major modification to existing buildings that retroactive compliance is deemed impractical to mandate. This is a major issue in resilience planning because an egress or fire system can meet the state of the art, but the stability of the entire building due to a hazard event could be questionable. Communities primarily consist of existing buildings, most of which were not designed to conform to current code standards. Therefore, most buildings do not fully comply with the state-of-the-art standards for resilience. The mix of building types, construction, and age can create significant challenges when developing plans for a resilient community, because the structural stability of buildings may not be sufficient for the expected hazard.

#### **5.5.1. New Construction**

Current design criteria for new construction are critical, as they form the basis for future resilience planning. It is important to draft standards for new construction that provide for the resilience goals a community desires. This is the easier place to make changes, because the consequences in increased



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requirements for new design are orders of magnitude less costly than trying to require retrofit of existing construction to meet those standards.

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 some hazards induced large forces that were difficult to resist without any structural damage. This led to a philosophy of designing buildings for major hazards, such as earthquakes, that remain stable with some structural damage but do not collapse.

As scientific understandings of natural hazards evolved, return periods for the given hazards were selected to define the loadings, as opposed to determining specific loadings based on judgment and experience. The design intention, however, was still that the individual structural elements have a margin of safety against failure when subjected to that specific load. Code provisions were developed with the intent of most buildings having the same level of structural safety. However, in actuality, this level of safety was greatly influenced by the selected construction material and local building regulations and practices.

As codes evolved, two things became apparent – certain buildings need to perform to a higher level of safety and other buildings, because of their use, should retain their pre-event function. For example, model building codes specified that schools and buildings with very large occupancies be designed for higher forces, in an attempt to provide a greater level of safety than typical buildings. Additionally buildings, such as unoccupied agricultural storage facilities, could be designed for lower forces, permitting them to have a lesser level of safety for natural hazards than a typical building. Hospitals, first responder facilities, and emergency operations centers are classified as buildings that should have some ability to return to their pre-disaster function following the design hazard level. This delineation of buildings into different categories has evolved into the four Risk Categories found in current national model building codes specifically the International Building Code.

Following the 1994 Northridge Earthquake, where there was little loss of life but extreme economic losses, there was a move toward performance-based design and evaluation of buildings. It was felt that engineers should be provided tools to allow for designing buildings beyond the prescriptive provisions in the building codes, and instead target an intended performance to a specified hazard. That approach led to definition of discrete building performance states of Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. With this came the recognition that the nonstructural systems in a building, such as the architectural element and the mechanical, electrical and plumbing systems, contribute significantly to building performance, especially in critical facilities that communities expect to be functional.

One major design criterion missing from the *International Building Codes* is explicit performance goals for post-disaster recovery. Many municipalities' emergency plans are based on certain buildings being available within a set period of time from the onset of the disaster. While this goal is not at odds with the current Risk Category or performance-based design approach, it does present challenges because some buildings' current design parameters may not align with community needs. The major difference between this need and typical performance-based design approaches is the use of downtime as the key performance metric.

**Wind hazards.** Today, for wind load designs, ASCE 7-10 prescribes design wind speeds based on different return periods. The return periods are tied to the Risk Category of the facility. For Risk Category I a facility, typically unoccupied agricultural buildings, the return period is 300 years. For Risk Category II facilities, typical buildings and other structures, the return period is 700 years. For Risk Category III facilities, schools and high occupancy structures, and Risk Category IV facilities, hospitals and emergency responder 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 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 structures 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 structures out of the flood zone, or to elevate the structure above the design flood elevation. For structures subject to flood forces, the current provisions provide methods to resist flood forces, but may not necessarily preserve functionality of the building.

***Seismic hazards.*** The performance of buildings during earthquake events is most developed of the hazards in the building codes and standards. Since the beginning of earthquake design, it has been recognized that designing for the hazard elastically, as is done with other hazards, would not be practical or economical. Therefore the approach adopted prescribed forces and design requirements that would allow the building to be damaged, but not collapse. Following the 1971 San Fernando earthquake it was recognized that essential facilities like hospitals needed to be designed to a higher standard, to significantly improve their likelihood of remaining functional following the design earthquake. A design earthquake with approximately a 500-year return period was chosen and used until the early 2000s, when it was decided that a longer earthquake return period was needed to capture the seismic hazard in other parts of the country. Since then the maximum considered earthquake shaking hazard has been around a 2,500 year return period.

Recently, there was a shift from a uniform 2,500 year hazard to a risk targeted hazard level. By setting a uniform risk of 1% probability of collapse (or a 99% probability of not collapsing) in 50 years, the return period required to achieve that goal varies based on the seismicity at a specific location. For most parts of the country the return period is not significantly different than 2,500 years.

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.*** Fire hazards typically are addressed prescriptively through fire protection requirements for structural members or other construction standards that are typically under the purview of the building

architect, not the structural engineer. Performance-based provisions for providing fire protection are becoming more common, but are mostly for large or high profile buildings.

**Man-made hazards.** Currently codes and standards do not have explicit structural design requirements and design standards for man-made hazards such as explosions or impact events, although some nominal provisions attempt to provide robustness to arrest the spread of damage so a disproportionate collapse does not occur. There are many requirements in the IBC that require facility layout and hazard mitigation measures that attempt to prevent explosions of building contents.

### **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 and, while construction costs may increase, the new buildings would therefore 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. That 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 to be retrofit.

When existing buildings are evaluated for their expected performance relative to resilience goals and required retrofit actions, the standards for new construction are typically applied for the structural design, which often leads to very conservative results. However, the 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 too conservative can lead to significant retrofit requirements. Those requirements can make the retrofit economically unappealing to building owners. Therefore, a major impediment to mitigating existing building natural disaster hazards that needs to be addressed, is refining engineering standards to allow simple, focused identification and retrofit of the most dangerous or most significant existing building hazards.

## **5.6. Resilience Assessment Methodology**

### **5.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)**

Current engineering standards provide tools to assess 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. Similar standards do not exist for other hazards. Building codes provide provisions that can be used to understand whether a building has sufficient fire resistance, egress, and other occupant safety related issues. These methodologies are useful for individual buildings safety, but fall short of being able to understand the amount of damage versus time to return to function.

The FEMA-created HAZUS project provides a platform for communities to assess their vulnerabilities to earthquakes, hurricanes, and other hazards. HAZUS is a useful tool for assessing the effects of a disaster on a community. HAZUS is useful only if the existing building stock is adequately reflected in the model, which can require significant data gathering to accomplish.

### **5.6.2. Strategies for new/future Construction**

New construction standards are a good vehicle to begin making changes to better enable community resilience. One major place where change can be made is to align new risk categories with the resilience goals set forth in Chapter 3. By clearly defining the performance of buildings following a major disaster in terms of function preservation and return to function, communities could better tailor their building codes and standards to their specific resilience goals.

There needs to be better alignment between various engineering and architectural requirements within the building codes and standards to promote resilience. There are instances currently where architectural requirements for existing and life safety are more stringent than the nonstructural anchorage requirements that keep objects from falling and obstructing egress points.

### **5.6.3. Strategies for Existing Construction**

In addition to the issues raised with new construction, there is the major issue of the varied quality and resilience of existing buildings. Building codes and standards have evolved, but very little retroactive compliance is required, meaning that when a code or standard changes a building does not have to be retrofit to conform to the latest edition's requirements. This is a major issue because the cost of retrofit exceeds, by orders of magnitude, the cost to add resilience to a new building that is under design. The presence of a strong willingness to neglect building retrofit because of the cost, inconvenience to the building occupants, and disruption of operations creates a significant challenge for resilience planning. As discussed in Section 5.2, many types of buildings have been designed to codes that did not provide for the performance that the Chapter 3 framework would recommend. Most of these buildings are not public buildings, so any attempt to mandate retrofit for resilience planning would mean placing a financial burden on a private property owner. This is one major issue that the SPUR Resilient City initiative identified for San Francisco.

A strategy that has been shown to work is to identify the most significant hazards posed by various types of buildings and to mandate retrofit or demolition of those buildings. There have also been programs specifically aimed at critical facilities like hospitals and fire stations, where those buildings must be retrofit or replaced.

Another strategy that is gaining momentum in Los Angeles is requiring that all building owners have their building's safety rated. The belief is that such a rating system could create a market-based mechanism where more resilient buildings become more desirable and people are willing to pay a premium to be in those buildings. This approach is modeled after the very successful LEED rating systems created by the US Green Building Council, which created and continues to inspire advances in designing and building environmentally sustainable buildings.

### **5.6.4. Addressing Gaps in Resilience Plans**

*This section is under development. Text to be provided in a future draft.*

## **5.7. Tools Needed for Resilience**

As discussed previously there are a number of resilience gaps in the current inventory of buildings that involve both the standards used for the design of new buildings as well as the need to retrofit some buildings. As part of the process, communities should prioritize the mitigation of the gaps that exist and develop programs that address closing those gaps.

### **5.7.1. Standards and Codes Gaps**

Performance goals needed for post-disaster recovery are one major design criterion missing from model building codes. Many municipalities' emergency plans are based on certain buildings being available within a set period of time from the onset of the disaster. While this is not at odds with the current Risk Category or performance-based design approach, it presents challenges because some buildings' current

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design parameters may not align with community needs. The major difference between this need and typical performance-based design approaches is the use of downtime as the key performance metric.

Existing codes and standards provide minimum requirements and some options for higher performance levels. Until recovery and other resilience concepts are incorporated into the codes and standards, communities must make decisions to go beyond the model building code that will provide a built environment that can meet their resilience goals.

The most significant challenge for disaster resilience standards development is aligning the design philosophy of all the environmental hazards with intended performance goals. As discussed earlier, wind, ice, rain and snow are based on an element-specific reliability at different hazards level, while seismic is calibrated based on system reliability for another hazard level. The hazards designed with element-specific reliability may have greater system reliability than those hazards where system reliability is the only design goal. The inability to accurately predict what is safe enough versus what is truly dangerous has led to impediment to addressing the hazards posed by the most dangerous existing building.

In addition, few provisions exist for facility function preservation for most hazards. Seismic has the most significant requirements, in part because it has established nonstructural requirements. For other hazards structural and nonstructural requirements to preserve function in essential facilities are needed. This is a significant issue that must be addressed because, although a facility's structure may be undamaged, if critical systems not functioning prevents it from performing its intended function, the recovery is hindered.

Along with the lack of function preservation provisions, the lack of tools that engineers can use to estimate a building's reliability of being returned to function in a given time period is a factor. Disaster plans and the Chapter 3 resilience goals assume that specific buildings are brought back online with a set period of time for each hazard. Without the ability to assess this, engineers are typically left with the binary distinction of whether or not a building meets Risk Category IV or Immediate Occupancy criteria (similar to Category A), which are typically too conservative for Category B facilities.

Another overarching issue related to existing engineering standards is how to bridge the gap between deterministic performance-based goals, like those enumerated in Chapter 3, and the probabilistic basis of the hazards. In many cases this has led to overly conservative provisions because of the goal of having significant certainty in the hazard outcome. Conversely, determining an acceptable level of reliability is difficult to quantify. For a dense, urban area, there may be several hospitals within an affected area of a disaster. Therefore the reliability of each hospital need not be 100%, because the loss of one hospital may not significantly hinder community resilience. On the other hand, a rural community may have one hospital for the entire county and that hospital must have significantly higher reliability. Designing for a very high reliability of safety and return to function for all new buildings has not been a significant issue, but allowing lesser reliability of return to function for redundant facilities may alleviate some of the burden of evaluation and retrofit costs for existing buildings needed to achieve the resilience goals.

For specific hazards, there are some disparities in the magnitude of hazard events that is currently being designed for. Flood and storm surge loads are currently the most significantly out of harmony with other hazards. The fact that an essential facility is designed for a 1,700 to 3,000-year return period hurricane, but need only be designed for a 100-year storm surge or flood, is disproportionately unbalanced. Flood design hazards for essential facilities need to be increased, possibly significantly.

Currently tornadoes are not explicitly addressed in building codes for a number of reasons. There are beliefs that the probability of a tornado striking a specific building is so low that it need not be explicitly considered or that nothing can be done to resist tornadic events. The commentary to the wind design provisions in ASCE 7 discusses this issue in more detail. However, a significant number of communities are affected by tornadoes every year, and design guidance to improve performance and recovery of the built environment is required.

**5.7.2. Practice and Research Needs**

*This section is under development. Text to be provided in a future draft.*

**5.8. Summary and Recommendations**

*This section is under development. Text to be provided in a future draft.*

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## **6. Transportation Sector**

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### **6.1. Introduction**

The transportation sector is critical to our daily lives. People use various methods of transportation on a daily basis to travel to and from work/school, visit family and friends, attend business meetings, and provide assistance in a medical emergency. However, the transportation network is used for much more than just personal needs. Businesses use trucks, ships, trains, and airplanes to transport goods from the source/manufacturer to communities. For example, food is often transported from the source (e.g., a farm) to a processing and packing plant, then a regional or national distribution center, which in turn sends the food to the local stores where it can be purchased by consumers. All of these steps, to get food from the source to the consumer's home/business, rely heavily on the transportation sector.

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

- Airplanes to transport people and goods long distances in a short period of time
- Passenger and freight rail to transport people and goods regionally/nationally
- Subways or light rail in large urban centers (e.g., New York, DC, Chicago, Los Angeles) to transport people to/from work and entertainment/leisure activities
- Ships to import/export goods to the international community
- Ferries to transport the workforce to/from work (e.g., San Francisco)

Although these other methods of transportation provide additional ways to move people and goods efficiently, they cannot be used alone. Many people rely on multiple methods of transportation (i.e., intermodal transportation) every day to travel to business meetings, and visit loved ones. Businesses use multiple methods of transportation to move goods efficiently and cost effectively. For example, businessmen and woman often travel long distances for meetings using air transportation, but also use a vehicle to get from their home or place of business to the airport, and then from the airport to their meeting location. Similarly, goods may be imported using ships. However, to get the goods from the ship to the next step in the supply chain requires using either trucks or rail. More discussion on intermodal transportation is in Section 6.1.2.

Transportation systems are a large part of our daily lives in the United States and are often taken for granted. The transportation sector is even more important in the aftermath of a natural disaster to permit:

1. Emergency repair crews for other sectors (energy, communications, and water/wastewater) to access areas where there are failures so they can be repaired and their services can be brought back online
2. Emergency response crews (firefighters, paramedics, police) to reach people in need
3. Parents to convey their children from school or daycare
4. People to attend to the needs of vulnerable family members (e.g., the elderly/ill) and friends

However, when addressing resilience, communities must also consider the longer term and improving transportation network performance in the next disaster event. The intermediate and longer term needs of communities, in terms of the transportation infrastructure, include:

1. Ability for citizens to get to work, school, and sports/entertainment facilities
2. Re-establish access to businesses (both small and large), banks, retail, etc. so they can serve their clients
3. Re-establish access to key transportation facilities (airports, ports/harbors, railway stations) so goods can be transported and supply chain disruption is limited
4. Restoration, retrofits, and improvements for damaged infrastructure so it will not fail in the same way in a future event

5. Re-establish airports, subways, and light rail so mass transportation can be used to relieve stress on other components of the transportation network, such as roads and bridges.

This chapter addresses disaster resilience of the transportation sector. 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 identifies and discusses recommended performance goals for components of the transportation network through the use of a performance goals table. Communities can also use the performance goals table to identify the expected performance of existing infrastructure and identify their largest resilience gaps/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 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 performance goals in terms of the time it takes for its critical infrastructure to be restored following a disaster event for three levels of hazard: 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. Currently, communities think about recovery in terms of emergency response and management goals. For transportation these include:

1. Access to facilities for shelter, medical care, banks/commerce, and food
2. Access to areas where failures in other sectors (energy, communications, water/wastewater) require repair
3. Egress/evacuation from a community before or immediately after a disaster event, if needed
4. Ingress of goods and supplies immediately after event to provide aid

However, as discussed in the introductory section, communities must think about the longer term when addressing resilience. The intermediate goal of a community is to get back to normal in terms of their daily routine, including traveling to work and school, visiting local retailers and banks, and re-establishing their typical method transportation whether by car, bus, subway, light rail, or some combination of these methods.

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 of people on the already congested road network, or worse, at home).

### **6.1.2. Interdependencies**

Chapter 4 details the interdependencies of all critical infrastructure sectors 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 infrastructure systems of other sectors. Hospitals, fire stations, police, and other emergency response systems depend on transportation before, during, and after a disaster. 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.



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Specific interdependencies of the transportation sector with the other sectors 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 cannot operate and, therefore, hinder 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 and ports rely on electric energy for lighting, functionality of mechanical components (e.g., loading equipment at a port), and for functionality of the buildings themselves (see Chapter 5). Subways and light rail rely on electric energy to function as well as for lights inside the tunnels. However, the energy industry also relies on the transportation sector so repair crews can reach areas where failures have occurred and bring services online quickly.
2. **Communication** – The communications sector relies on roads and bridges so repair crews can get into areas where there have been failures so that services can be repaired. Conversely, transportation systems depend on communications to relay information. Airports use communications 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.
3. **Building/Facilities** – Buildings are rendered useless if people cannot reach them. The transportation system allows people to travel to critical facilities, businesses, and to other homes/facilities to check on the safety of friends, family and vulnerable populations.
4. **Water and Wastewater Sector** – Water and wastewater often passes underneath 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 sector (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 (i.e., barge), 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 frame. 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 may be no need for the rail system to transfer those goods 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 of loved ones, banks, etc. People who live and work in large cities often rely on mass rapid transit, such as light rail or subways, for most of their commutes. However, to get to their individual final destinations, they may rely on the roadway system, including buses, taxis, or walking.

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

## 6.2. Transportation Infrastructure

The transportation sector in the United States is 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 and Subway Systems
- 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 that have been used in the past to successfully mitigate failures. The first four sections deal with systems of the larger transportation network that are used to move both people and goods. The fifth section, Pipelines, discusses a system used to move resources alone (e.g., 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 3 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 on a daily basis. 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.

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 the initial and possible secondary hazards (e.g., a tree or other debris falling on an exposed gas or water pipe). For example, flooding can result in undercutting roads. In Figure 6-1, a pipe (an example of an interdependency) that lies directly underneath the road was also vulnerable to damage as a result of road failure.



**Figure 6-1: Road undercutting in the aftermath of Hurricane Irene.**

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 of transportation infrastructure (tunnels, bridges, railways, etc.), but 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 (i.e., alternate routes can be used). 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. 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 locations where their assistance is needed.



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

Ice storms, as previously discussed, can also cause tree fall and thus, road blocks, 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. Bridges make the road network more efficient by shortening routes and travel time for drivers. 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 environmental conditions of the community (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 disaster 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).

Bridges are designed to meet the criteria in AASHTO and/or local DOT requirements that supersede AASHTO. The primary design consideration for bridges is traffic. AASHTO specifies application of a three axle truck (i.e., the HS20 truck), which has a gross mass of 72,000 lbs, for design (Tonias and Zhao 2007).<sup>1</sup> Therefore, although loads from natural disasters such as earthquakes, wind, and flood, are considered in the design process, traffic loading often governs design. As a result, in the expected event, there should be few, if any, bridge failures. However, as seen in past disaster events, bridges do fail during natural disasters. During Hurricane Katrina, wave-induced forces pushed multiple spans of the I-

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<sup>1</sup> The HS20 truck is not representative of a real truck used to transport good. It is used to simulate the maximum loading (shear and bending) that a bridge must withstand (Tonias and Zhao 2007).

10 twin bridges over Lake Pontchartrain off their bearings (Figure 6-3) (FHWA 2010). 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, but can also be caused by earthquakes. Earthquakes in San Fernando Valley, Loma Prieta, and Northridge, CA have also shown that bridges can collapse due to failure of piers and decks (FHWA 2010).

Longer bridges tend to have relatively lightweight superstructures (decks and girders) so they can span long distances. Historically, their relatively low natural frequencies have 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 (FWHA 2011). Moreover, some older long span bridges have been tested and retrofitted to ensure that they are not vulnerable to wind failures.



*Figure 6-3: Bridge sections slid off their moorings during Hurricane Katrina due to wave action.*

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, it is recommended that they 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 road, an area of the community that has many businesses and critical facilities, it is recommended that the bridge be designed for the "extreme" event, as defined in Chapter 3. However, given that bridge failures are not common even in disaster 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 disasters 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 (Meyer et al. 2014). During long-term inundation inside a tunnel, corrosion is a major mode of damage, especially to any electrical or piping infrastructure that runs through. That said, there is value in letting some tunnels flood in urban environments to reduce infrastructure damage elsewhere. This concept is used in the design of the Malaysian SMART tunnel, which has lower and higher roadways and the capacity to flood its bottom half while allowing traffic flow to continue in the higher portion (ITS 2012). 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 (US DHS 2013).

### 6.2.2. Rail and Subway Systems

**Rail Systems.** 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. 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 have 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 disaster (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 US about \$200 billion annually, 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 and, thus, redundancy into the system.



*Figure 6-4: A railroad bridge in New Orleans is washed out by flooding.*

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 is 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 or artificial hazards. Relocating transit lines to newer tracks that are placed with more consideration of natural hazards and disaster 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).

A focus on early warning systems prior to a disaster event, whether that system is implemented by the weather service or by the rail companies themselves, is essential if trains are to be moved to safer locations. As with other forms of transportation, adding forms of damage assessment will enable better prioritization of resources and, thus, 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. 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 subway 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 combined to 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 that representatives of the energy sector be involved in decision making because of subways' strong dependence on the power supply.

**RESILIENCE EXAMPLE:** The New York City metro 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 leadership being empowered throughout the system, critical decision making was fast and unhindered by a chain of command. Trains were rerouted around the disaster, 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).

### 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.

Unfortunately, airports are more sensitive to disruptions than other forms of transportation infrastructure. Seventy percent of airport delays are due to extreme 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, we can learn valuable lessons from previous disasters.

Flooding, debris, snow, 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 losses. Their equipment could only clear a runway one hour after deicer 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. 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). Even outside of storm events, heat waves can cause the tarmac to buckle under the heavy loading caused by takeoff and landing.

The airport terminals are vulnerable to the same hazards as other buildings, as discussed in Chapter 5.

As previously discussed, airports play an integral role in moving people and supplies before and after a disaster. Any major disaster will include increased load from evacuation. Additionally, if some 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 necessary when they are most vulnerable, directly before and after a disaster. Increasing disaster resilience in airports is, therefore, essential to increasing overall community resilience.



*Figure 6-5: Flooding closed the Chester County Airport and moved planes.*

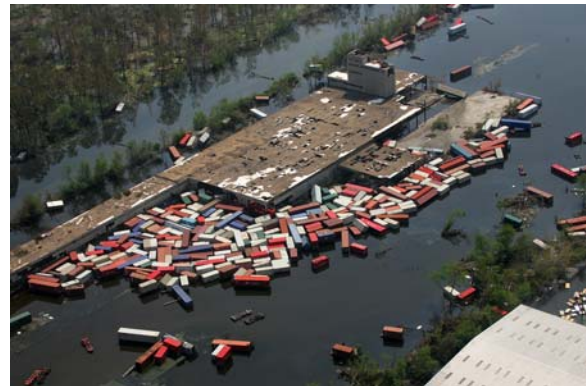
#### **6.2.4. Ports, Harbors, and Waterways**

Ports, harbors, and waterways are used largely for import/export of goods and materials. The US 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 US 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).

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 storm surge damage. Also, strengthening the structures themselves and strengthening the ground adjacent to the water, where soil may be weak, can be beneficial. Additionally, focusing on early warning systems for ship owners and port authorities gives facilities and watercraft time to prepare or evacuate (The World Bank 2012).

Hurricanes, storms, and other heavy precipitation events can lead to extreme flooding and overtopping via precipitation and storm surge. This damages structures, dislodges containers (see Figure 6-6), undermines foundations, and destroys buildings outright. When hazardous chemicals are transported, there is a risk of hazardous spills in addition to the risk of oil spills. Flooded drainage systems cause flooding in areas that would otherwise be unaffected by a storm – not all areas and buildings are inundated by rainfall and wave action – representing a vulnerability caused by existing infrastructure. Finally, high winds associated with these types of events can damage critical equipment, such as cranes, and structures (URS 2012).

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, both forces that far exceeded 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 in a disaster situation. 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).



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

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).

### **6.2.5. Pipelines**

Pipelines are a key lifeline of the US transportation and energy supply infrastructure. Roughly two million miles of natural gas pipeline and more than 200,000 miles of pipeline carry crude oil and petroleum products throughout all 50 states (EIA 2007; FERC 2004). These pipelines transport more than 38 million barrels of crude oil and petroleum products a day; and the natural gas national network transports more than 40 trillion cubic feet of gas each year (EIA 2007; FERC 2004). The majority of hazardous liquid and gas pipelines are located underground on land or offshore; however portions of the hazardous liquid pipeline network are located above ground, for example along the Trans-Alaska Pipeline System, which transports crude oil (DOT 2014). Pipelines connect to compression stations, processing facilities, production platforms, wells, and storage facilities. Short term disruptions of the pipeline system by natural disasters complicate, hinder, and prolong disaster response and recovery. Long term disruptions have a negative impact on the national economy, national security, and ecology.

Pipelines and their equipment and 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 to the transportation sector 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 natural gas facilities and 72 spills from damaged or leaking offshore pipelines (DNV 2007, 29). Damages to fuel and natural gas processing and refining facilities caused by Hurricanes Katrina and Rita resulted in a loss of about 8% of the nation’s capability to refine/process fuels, which significantly reduced the domestic supply of refined fuels (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 to the East Coast, and New Jersey and New York, and created a supply chain problem in New Jersey and New York, but 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) that caused additional property damage (Ballantyne 2008, 1). Figure 6-8 shows an example of property damage caused by fire from broken gas lines.

The DOT’s Pipeline and Hazardous Materials Safety Administration have 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 key first step toward resiliency. Knowing where pipelines are located and making that information available is important to comprehensive planning, hazard mitigation planning, and preparedness, response, and recovery activities. Redesign or realignment of pipes to avoid liquefaction zones, faults, areas of subsidence and floodplains is only possible if a 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 increase the right-of-way to provide an extra



*Figure 6-7: Natural gas crew shuts off gas after Hurricane Sandy (Photographer: Liz Roll, 2012)*



*Figure 6-8: Fire damage from broken gas lines (Photographer: Christopher Mardorf, 2014)*

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 can be used to help mitigate damages to pipes due to earthquakes. These include: replacing older pipe 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).

### **6.3. Performance Goals**

Performance goals in this framework are defined in terms of how quickly the functionality of the infrastructure systems can be recovered after a disaster event. Minimizing downtime can be achieved during design or by developing and implementing a well prepared recovery plan – ideally both.

Performance goals for the transportation sector 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 sectors (e.g., power and water/wastewater). For the transportation sector, in particular, it is imperative that other sectors are involved in making recommendations and establishing the performance goals because several sectors have strong interdependencies with the transportation sector as discussed in Section 6.1.2. For example, both overhead and underground distribution lines for the power and communication sectors are often within the right-of-way of roads and bridges, and thus are subject to DOT requirements. In the case of light rail, the method of transportation is heavily reliant on the energy sector. Once a panel of stakeholders is established, they can work to establish the performance goals for the transportation sector of their community.

Table 6-1 presents recommendations of performance goals for the “expected” event, whether it be a hurricane, earthquake, flood, etc. Although the loading on the infrastructure and failure modes will differ depending on the type of disaster event, the social needs that drive the establishment of performance goals remain the same.

The matrix provides 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 disaster. 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.

Recovery times are broken down into three main phases: Phase 1) Response, Phase 2) Workforce, and Phase 3) Community. Phase 1 (0-3 days) includes the needs/goals to support immediate recovery of the community in the wake of a disaster event. Phase 2 (1-12 weeks) includes the needs/goals to support to support citizens and businesses returning to their daily functionality. Phase 3 (4-36+ months) performance goals support the need to rebuild, retrofit, and strengthen the transportation network to become more resilient for future disaster events.

Table 6-1 is intended as a guide that communities/owners can use to evaluate the vulnerabilities of their transportation infrastructure. The table should be used by communities/owners to establish performance goals based on local social needs. Tables similar to Table 6-1 can be developed for any community (rural or urban), any type of disaster event, and for the various hazard levels (routine, expected, and extreme) defined in Chapter 3.

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The performance goals in Table 6-1 show 3 levels of desired restoration after an “expected” disaster event:

- Light orange boxes indicate the desired time to have 30% functionality
- Light yellow boxes indicate the desired time to have 60% recovery
- Light green boxes indicate the desired time to have 90% recovery

The performance goals in Table 6-1 were established based on the performance seen in previous disaster events, such as Hurricanes Sandy and Katrina.

The affected area of a given disaster 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 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 in the performance goals table is based on the current state of the transportation infrastructure system as a whole, and should be specified as usual, moderate, or severe.

In the individual rows of Table 6-1, an “X” is shown in some of the rows as an example of how a community can indicate the expected performance and recovery of the infrastructure in their evaluation. As seen in Table 6-1, there are some significant gaps between the desired level of performance and what is being seen in reality. This difference is a resilience gap. Once a community completes this table based on their local social needs and current expected performance, they can prioritize which gaps to address first.

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*Table 6-1: Transportation Performance Goals for Expected Event to be Developed by Community*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

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+		
<b>Ingress (goods, services, disaster relief)</b>		<b>A</b>											
Regional Airport						90%			X				
National/International Airport					90%	X							
Marine Port						90%							
Ferry Terminal					90%	X							
Subway Station					90%		X						
Rail Station, Local					90%	X							
Rail Station, Regional						90%	X						
Rail Station, National						90%	X						
<b>Egress (emergency egress, evacuation, etc)</b>		<b>1</b>											
Bridge				90%	X								
Tunnel					90%	X							
local freeway			90%										
state freeway			90%										
National freeway				90%									
subway				30%		X							
Ferry				90%	X								
Regional Airport				30%					X				
National/Int'l Airport				30%			X						
Rail Local				30%			X						
Rail Regional						30%	X						
Bus			90%	X									
<b>Community resilience</b>													
<b>Critical Facilities</b>		<b>A</b>											
Hospitals			60%	90%									
Police and Fire Stations			60%	90%									
Emergency Operational Centers			60%	90%									
<b>Emergency Housing</b>		<b>B</b>											
Residences				60%	90%								
Emergency Responder Housing					90%								
Public Shelters			90%										
<b>Housing/Neighborhoods</b>		<b>B</b>											
Essential City Service Facilities								90%					
Schools					60%	90%							
Medical Provider Offices								90%					
Retail							90%						
<b>Community Recovery</b>		<b>C</b>											
Residences							30%		60%	90%			
Neighborhood retail						30%	60%		90%				
Offices and work places							90%	X					
Non-emergency City Services						30%	60%			90%			
All businesses							30%		60%		90%		

**Footnotes:**

- 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
- 30% 60%
- 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

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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

## **6.4. Regulatory Environment**

### **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 oversee the safety and security of infrastructure and operations. As the transportation industry features a diverse range of methods and operating environments and is overseen by a myriad of regulatory agencies and funding streams that are subject to variability in direction of different political administrations, efforts to assess and address resilience across the transportation industry vary in scope. Some of the key regulatory agencies are discussed in the following sections:

#### **6.4.1.1. Federal Highway Administration**

The Federal Highway Administration (FHWA) is an agency within the US 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 has 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 is to improve the transfer area of the Fairbanks, AK Freight Yard so trucks can make pick-ups/drop-offs in a shorter period of time (FHWA 2009). The current pick-up/drop-off location does not provide not enough room in the pick-up/drop-off area for the trucks to get to the trains, thus creating bottlenecks even before a disaster event occurs.

The FHWA has 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). The intent of these programs is to 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 can be especially helpful after a disaster event.

Climate change is another challenge to which the transportation network will be vulnerable. The FHWA has initiated 19 pilot programs around the country to evaluate the risk of the existing and planned transportation network to effects of climate change (FHWA 2014).

#### **6.4.1.2. Federal Transit Administration**

The Federal Transit Administration (FTA) is a federal agency within the US Department of Transportation that provides financial and technical support to local public transit systems (i.e., buses, subways, light rail, commuter rail, monorail, passenger ferry boats, trolleys, inclined railways, and people movers). Through financial support from the federal government, the FTA assists in developing new

transit systems and maintains existing systems. In addition, they oversee grants that fund research, management and support of local 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 promulgated 49 CFR Part 633 to cover system safety issues in design and construction of major capital projects. Later, after 9/11, it developed requirements to cover security issues. However, these regulations did not cover the preponderance of transit systems out there that offered rubber tire 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. While these programs do potentially cover climate change issues, as transit systems are required to perform design and operational risk assessments (the latter is not a mandate and necessarily enforced by a standardized framework but the former is more so) at this time, the FTA does not have a systematic regulatory program to address climate change or resilience, but has developed guidance and a pilot program for agencies to investigate the issues.

#### **6.4.1.3. Federal Railroad Administration (FRA)**

The FRA covers heavy rail freight systems, commuter and inter-city passenger rail systems. Forty-nine CFR Parts cover various safety and security engineering, design and operational requirements of these agencies. The TSA also has an active role in the security of rail freight and inter-city passenger service.

#### **6.4.1.4. Federal Aviation Administration (FAA)**

The Federal Aviation Administration (FAA) is an agency of the US Department of Transportation that oversees all civil aviation in the country. The major roles of the FAA include regulating US commercial airspace, regulating flight inspection standards, and promoting air safety.

The FAA is currently assessing airport sustainability planning. They developed a Sustainable Master Plan Pilot Program that will be piloted at ten airports across the country. In addition, 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.

#### **6.4.1.5. US 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).

### **6.4.2. Regional**

Metropolitan Planning Organizations have been encouraged to review the safety and security of the regional transportation network since the enactment of SAFETEA-LU in 2005. FHWA has funded and encouraged MPOs across the US to look into ways MPO can foster considerations of safety and security planning – including resilience efforts – in the long-term capital plans which MPO develop and fund.

*[Note to reviewers: This section is under development. In a future draft, examples from Port Authorities will be included]*

### **6.4.3. State**

*This section is under development. Text to be provided in a future draft.*

#### **6.4.4. Local**

*This section is under development. Text to be provided in a future draft.*

#### **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.

The failure modes discussed in this chapter may represent key vulnerabilities in the codes that are exposed during disaster events. Table 6-2 presents a summary of the methods of transportation used, whether they are used for public or private transportation, and which oversight authorities are involved in their regulation.

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*Table 6-2. Transportation Sector Code and Standards Governing Agencies*

Industry	Sector	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	
	Rubber Tire	Passenger	Inter-City Motorcoach	X	X	X	X	X	X			X	X	X				X
			Intra-City Bus/Motorcoach	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. New Construction**

*This section is under development. Text to be provided in a future draft.*

**6.5.1.1. Implied or stated Performance Levels for expected hazard levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.1.2. Recovery Levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.2. Existing Construction**

*This section is under development. Text to be provided in a future draft.*

**6.5.2.1. Implied or stated Performance Levels for expected hazard levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.2.2. Recovery Levels**

*This section is under development. Text to be provided in a future draft.*

**6.6. Resilience Assessment and Mitigation Methodology**

*This section is under development. Text to be provided in a future draft.*



### 6.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)

*This section is under development. Text to be provided in a future draft.*

### 6.6.2. Strategies for new/future Construction

Several federal entities have begun recommending design practices that may increase resilience of the transportation system. FHWA recently published the “Framework for Improving Resilience of Bridge Design” with a fault tree methodology framework, where lessons from past bridge failures are used extensively to identify events that could lead to a bridge failure (FHWA 2011). An engineer can use the methodology in this document to design a bridge that is sufficiently devoid of the sort of weaknesses that might lead to bridge failure after a natural hazard event.

*[Note to reviewers: This section to be expanded in a future draft.]*

### 6.6.3. Strategies for Existing Construction

*This section is under development. Text to be provided in a future draft.*

### 6.6.4. Addressing Gaps in Resilience Plans

Several gaps exist in creating a truly resilient infrastructure transportation system, as noted by the DOT Climate Adaptation Plan (USDOT 2012):

- **Existing Infrastructure resilience:** The existing US infrastructure is owned and operated by different entities, including state, local, public, and private groups. This infrastructure varies in age and sophistication and has not been built to a consistent design standard. Currently, different owners choose whether to consider climate or natural hazard risk when making decisions regarding replacement or service life.
- **New Infrastructure Resilience:** New infrastructure is built to the best available codes and standards; however, many codes and standards do not currently consider climate change or natural hazard risk.
- **System Resilience:** Interdependencies of systems play a key role in transportation resilience. System resilience is best viewed across transportation modes and the many system owners. Many of these modes may be obvious, other dependencies may be less so. Thus, interdependencies may be hidden among the many variables.

There are multiple methods of transportation that have different operational, infrastructural, funding, policy and maintenance goals/needs, including:

- Methods of transportation that run on land, sea and in the air have distinct operational issues and risks.
  - Operational areas – rural, city, mountainous, elderly, millennial, earthquake prone vs. storm surge prone, etc., all require different kinds of needs for basic operations let alone to prepare for a specific type of incident/problem
- Rubber tire and ferries are generally, from an emergency management standpoint, much more resilient systems than rail and air systems (the latter because of the infrastructural and guidance system needs). All require fuel and communications, though rubber tire and ferries can withstand an initial impact better overall.
- Highway and road agencies provide the infrastructure for road operations – thus a completely different mandate and business model from providing passenger or freight carriage.
- Private and public sector foundations
- Transit bus operations, which make up the preponderance of transit in the country, can be large and small and serve completely different markets and clientele.
- Shippers work with the USCG, ports and terminal operations, rail carriers, storage and trucking companies, etc. to execute their operations.

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- Regulatory ownership sparks different issues that impact resilience planning. For example, within the transit industry alone:
  - The FRA covers passenger systems that operate on the national railroad system like Amtrak and commuter railroads, and freight operations.
  - Transit buses operate on roads, bridges, tunnels, and in terminals/stations built and operated by other agencies.

Many transportation systems rely on contracts or MOU for fuel, communications, parts, facilities, vehicles, operators, etc. These contractors can be weak links in recovery and provide difficulty when determining internal contingencies, especially if many other regions/industries are similarly impacted by a catastrophe, competing for assets, or unable to get assets in due to debris clearance/restoration operations of other agencies.

### **6.7. Tools Needed for Resilience**

A number of tools are needed to adequately define and quantify resilience of our transportation system. Based on the method of transportation and purpose of the transportation (ingress, egress, etc.), tools needed to adequately represent resilience vary.

Tools requested by transportation stakeholders include models that quantify the egress capacity of transit systems, roadways and other modes of transportation with the capability of adjusting in real time if a transportation system or mode goes down in a disaster event.

*[Note to reviewers: This section will be expanded in a future draft based on conversations with stakeholders.]*

The standards and codes for transportation systems can be expanded to account for performance-based design and the current inventory of transportation systems. A methodology to ensure that resilient design is incorporated into existing transportation infrastructure should be included.

#### **6.7.1. Standards and Codes**

*This section is under development. Text to be provided in a future draft.*

#### **6.7.2. Practice and Research Needs**

*This section is under development. Text to be provided in a future draft.*

### **6.8. Summary and Recommendations**

*This section is under development. Text to be provided in a future draft.*

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## **7. Energy Sector**

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### **7.1. Introduction**

The aging United States infrastructure is a major issue for all communities nationwide. Although we have made progress in upgrading the existing electric infrastructure to a smart grid, grid modernization improvement is projected to continue for the next 25 years. The demand for electricity has increased by over 25% since 1990, intensifying our need to upgrade all elements of the energy infrastructure system and build for resiliency. In addition, the role and responsibility of utilities is evolving, with far more energy efficiency, Demand Side Management, MicroGrid, and Smart Grid technologies vastly influencing a change from a function that is purely energy distribution to a more complex and interdependent energy transfer and tracking role. In an effort to build a resilient and flexible energy infrastructure there needs to be an understanding of the desired level of resilience, the potential changes resilience may bring, and the anticipated cost to accomplish this effort.

#### **7.1.1. Social Needs and System Performance Goals**

As communities address issues related to their expectations of energy sector performance, improving grid resilience, and the costs associated with those improvements with the utilities, there will be a focus across the nation to understand the needs of the consumer (public safety, hospitals, businesses, and residences). Systems need to have the ability to adapt to the ever-changing environment and be built to either minimize damage and impacts to the system or rapidly rebuild the system after significant events and disasters occur. There needs to be an encompassing effort to enable the various utilities, municipalities and co-operatives across the country to maintain the system while controlling costs. Because some utilities are operating in a competitive environment, they must find the lowest cost alternative while not impacting the overall network resiliency.

There is also a need for consumer education to discuss costs and benefits of facility and infrastructure hardening along with reasonable expectations of performance. Generation facilities and substations may need to be relocated into the communities they serve to ensure these facilities are sited and constructed to be resistant to coming hazards (e.g., flooding, storm surge, wildfire, etc.). Important conversations must take place to identify intended vs. expected performance and understand the costs and impacts of providing a reliable and resilient Energy Sector to minimize the impact to communities after all types of events.

If major changes are required to address the consumer expectation of readily available energy, fuels, and power after events (minor, major, and even catastrophic events) new community partners must be brought to the table.

#### **7.1.2. Reliability vs. Resilience**

Reliability and resilience are related, but distinct, concepts with different performance goals or metrics. In many cases, the projects and investments being made 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.”*

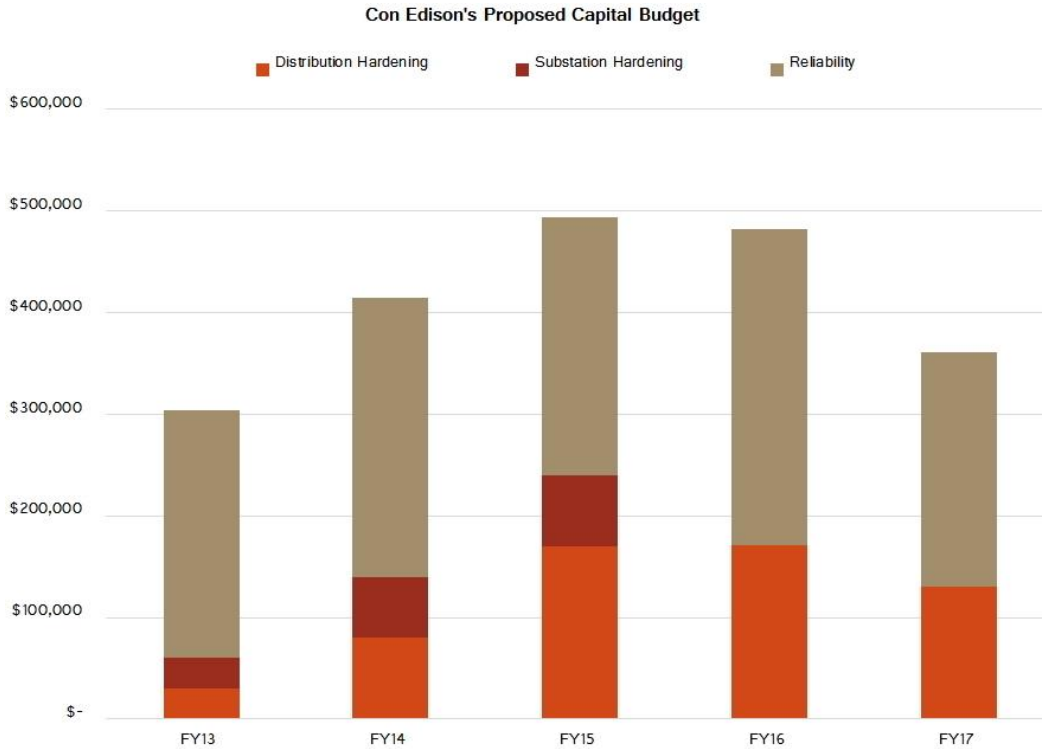
To explore some of the differences between reliability and resilience, we can look at recent events. In the wake of Hurricane Sandy, widespread power outages had cascading and disastrous consequences across the New York and New Jersey region, but specifically in lower Manhattan in New York City. “[It 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 tidal surge triggered

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flooding at a substation in lower Manhattan that knocked out power for customers below 39<sup>th</sup> Street for nearly five days.

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, by comparison, the funding investment for resilience hardening to the funding investment by Consolidated Edison for reliability over the same period of time (taken from Pentland 2013) shows that reliability is programmed and funded at a higher levels at this utility.



**Figure 7-1. Con Edison's Proposed Capital Budget**

*[Note to reviewers: This table from Pentland does not seem accurate on the \$\$ side. One would think this spending is in 100s of Millions, not hundreds of thousands. This will be verified further for the next draft.]*

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 sector as a whole? The answer to both questions is “no,” but the spending plan is a recent example to help our understanding of these two initiatives. Reliability can be stated to be a “core goal” of electric service and 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 to delineate: for example reliability expenditures, particularly in automation of operations, positively benefit resiliency so where should these expenditures be tracked?

Other utilities in the sector are also considering the challenge of resilience. 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.”

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PSEG is also looking at resilience and, 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 Chapter.

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 that the Electricity Sector has put into resilience, but the sector has 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. NERC defines adequacy in this context as “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.” It defines security as 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 it is not applicable to the distribution system, nor does it address infrastructures of other sectors such as 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 best make the infrastructure of the grid less susceptible to damage and outages during all types of events. Rather, the purpose is to look at the infrastructure elements of the Energy Sector (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 sectors will make it easier to define performance metrics for resilience in this and the other sectors and allow us to identify and understand interdependencies between the different sectors. Sections 7.7 and 7.8 have additional information regarding the relationship of reliability and resilience and what tools could be developed to aid in understanding and measurement of resilience in the Energy Sector.

### **7.1.3. Interdependencies**

The infrastructure in each of the critical infrastructure sectors in this framework can be considered both independent from the other sectors and dependent on those sectors. Most, if not all other sectors presented in this framework depend upon the Energy Sector for the required power to provide a functioning level of resilience within their sector. For example, although a hospital or emergency operations center may not be physically damaged by a hurricane, flood, or earthquake (a resilience success in that sector), 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).

For the Energy Sector, the infrastructure that comprises the generation facilities, substations, transmission and distribution elements of the electrical subsector; the drilling/processing, transmission, distribution, and dispensing stations of the natural gas subsector; and the drilling/refining, transmission, storage, transportation/distribution, and dispensing stations of the liquid gas subsector all have elements that can be designed and constructed to perform independent of other sectors (with only a few exceptions). However, there are dependencies. If another sector’s assets are damaged, the Energy Sector will be impacted and the measure or effectiveness of the sector’s resilience may be reduced. Some examples are:

1. If the transportation of liquid and natural gas over land (via truck and rail) is not possible, then the supply chain can be effectively stopped (depending on the severity of damage to the transportation sector from a specific event), which affects the resilience of the Energy Sector.
2. The resilience of the Electrical Subsector is based not only on whether the physical elements of the sector can resist the effects of a flood, wind, seismic or other events, but also on whether response teams, who are integral to the recovery (and resilience) of the Electrical Subsector, can mobilize and reach impacted areas. If they cannot perform response and recovery activities, the Energy Sector will be less resilient because damaged system elements cannot be reached or repaired.
3. Also, operations and control centers of utilities must be able to communicate with and send operational direction 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.

Where possible, interdependencies including but not limited to those presented here, have been considered in preparing the performance goals presented in Section 7.3.

## **7.2. Energy Infrastructure**

Our national infrastructure systems are designed for reliable service with some intention to building a stronger system due to potential disasters. 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 [Note for reviewers: example of the vulnerabilities and risk that were identified will be included for the next draft.]. However, these improvements in technology may have also inadvertently introduced new vulnerabilities or risks. Recent post-disaster studies and reports on climate change have shed light on why we see the damage and impacts to these systems from the natural hazard events of the past several years.

Our task now is to address what we consider to be the basis for design and performance of the critical components of the energy infrastructure. We need to address:

1. Why did failures occur?
2. Were the design criteria not correct to account for these storms?
3. Can and should higher criteria be used? Or were these recent storms 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)?

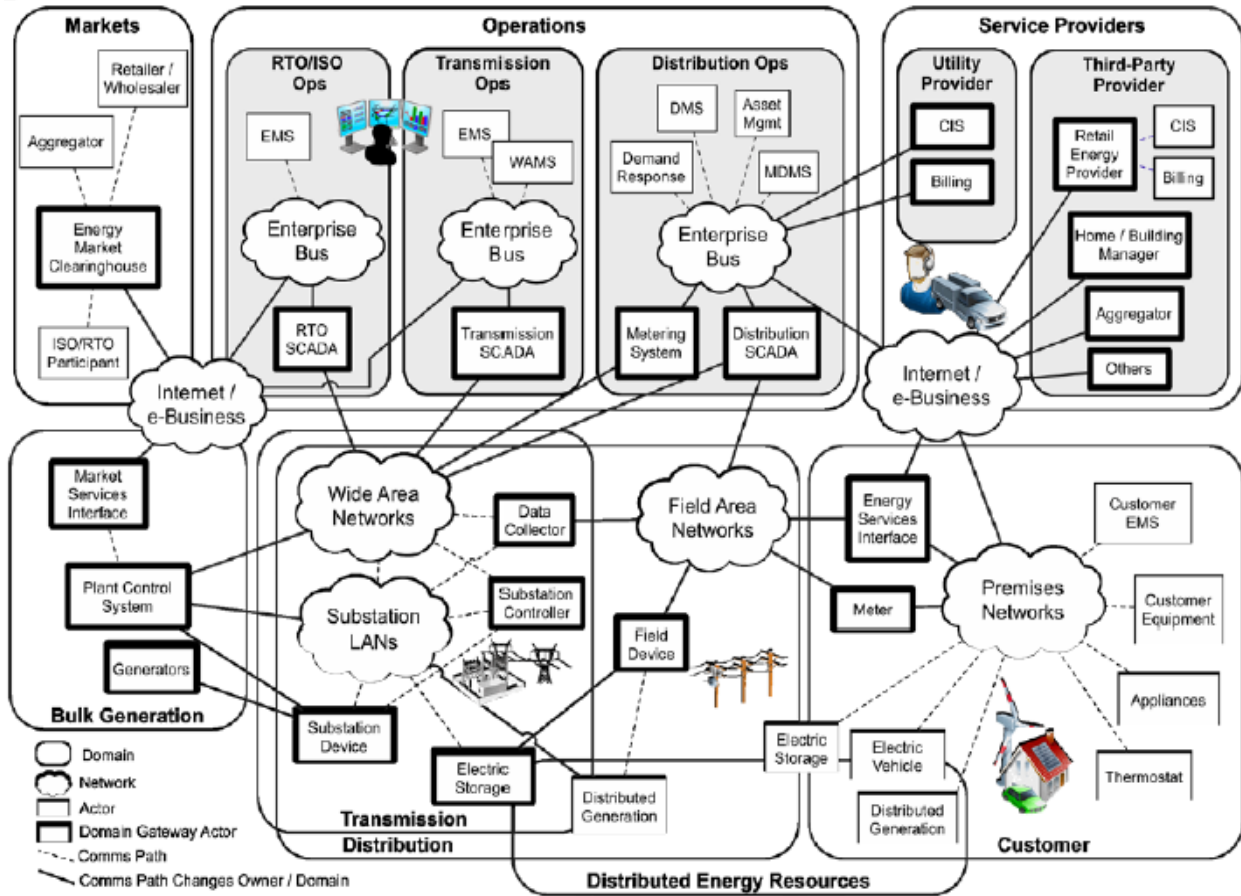
These important questions need to be discussed and answered to create a framework that provides design and construction guidance in the Energy Sector so generators, distributors, and users of the bulk power system can set and achieve performance goals. The performance metrics discussed in this guidance must be discussed in a common vocabulary by both providers and consumers within this sector 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 subsector 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* and is shown below.



*Figure 7-2. Conceptual Diagram of Smart Grid Information Networks (NIST 2012)*

Many households and businesses need access to electricity. Demand for electricity is derived from the requirement for electricity to operate all aspects of our lives including providing for our health and welfare, hospitals, critical facilities, industry, as well as commercial and residential use.

**7.2.1.1. Generation**

Similar to the changing landscape for utilities in general, 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 conveyed to the public. In that regulated public utility role the utilities forecast and managed both the generation and distribution of electric power. With the advent of deregulation, many states separated the governance role that the utility had over both 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, though even the IPP developers must still negotiate contracts to sell the power to the utilities who maintain their responsibility to manage and convey the electricity via the transmission grid. States that deregulated in this way also required the utilities to divest the generation assets they had previously controlled. A few states flip-flopped that role and maintained authority over generation assets and divested the transmission assets instead. Those states allowed competitive transmission providers to distribute electricity to the public and the utilities to manage the generation (power plants). The US today is a patchwork of regulated and deregulated states so, depending on the state, the utility could control both

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generation and transmission, only transmission, or only generation. To complicate matters further, the number of deregulated states has increased over time. Also, this patchwork of regulation and deregulation at the state level also applies to the distribution of natural gas by utilities.

Now, overlain on that already changing landscape, the US is seeing increasing development of renewable power projects, distributed generation by commercial entities, and an increasing push for demand-side management (such as demand response and energy efficiency and energy storage). Today the term “generation” increasingly includes “virtual generation,” resulting from the use of load-reduction to offset power demand or the use of storage during off-peak times rather than developing new generation (power plants). Additionally, more of this activity is evolving to be 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 that serves 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). These programs can be high-level state-wide improvements to public buildings (efficient light bulbs, improved insulation, etc.) or can entail the 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 for the rights to require them 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 the need to develop new generation. The DSM firm makes money by selling the load reduction or a form of virtual generation to the utility at times when electricity pricing is at a premium.

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 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 we ensure reliable and efficient power to the US population. To best inspire, protect, and ensure reliability one must first understand the implemented regulations by which this complex network is balanced. That understanding begins with the utilities and the state public service commissions that regulate them. The utilities themselves (even in deregulated states) are heavily regulated at the state level, and beyond. As noted previously, the term “deregulated state” has more to do with consumer choice or establishing a competitive market for power or transmission.

#### **7.2.1.2. Transmission**

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 once 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.

Although the electrical industry started with rapid innovation and expansion, it has become an industry that typically resists change and has changed very little over the last 75 years. However, transmission planning has evolved from relatively few new transmission lines being built nationwide to many new transmission lines being planned by most major utilities over the last 10 years. The cost and time to build new transmission lines have also increased significantly over the years due to public routing, regulatory and environmental restrictions.

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 natural disaster, such as hurricanes and flooding. As the intensity of storms are predicted to increase, so does the structural requirements of the transmission assets.

As new systems are engineered and constructed there is also a need to evaluate ongoing maintenance. As with any engineered infrastructure, every transmission line has a design life span, and the number of older lines that need regular assessment to maximize the use of each asset constantly increases. There has also been an alert issued by NERC in 2011 to validate the electrical clearances of the existing infrastructure in the in-situ conditions.

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 in an effort 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

#### **7.2.1.3. Distribution**

Given the aging infrastructure, some real vulnerabilities exist in the energy sector 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.

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. Many land owners will 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 clear 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.

As was discussed for transmission, many cyber-based monitoring systems are being developed annually to reduce the impact of any potential natural disaster 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 all 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 that no hot metal will hit the ground and potentially cause any fires. Dependent on the location nationally, there has also been a movement away from wood poles. Where the wooden poles are still being used, they are increasing the size and class to accommodate the overall design constraints.

#### **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 of the technologies, considered "plug and play," have been working together nicely with the right infrastructure. Many utilities are currently 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 across the country have implemented some form of distribution automation with very good results. These results have led to further technological advancements, which are 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 up additional opportunities for predictability and better understanding of communities' usage.

#### **7.2.2. Liquid Fuel**

The most common liquid fuels are gasoline, diesel, and kerosene-based products such as jet fuels, which are each 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 now 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).

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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 are the main focus of 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

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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 sector 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	
<b>Natural Hazards</b>											
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	
<b>Human Threats</b>											
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.

### **7.2.3. Natural Gas**

Natural gas pipelines, port terminals, 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). Imports of Liquid Natural Gas are expected to rise by 700% by 2030 to meet increasing demand (ASCE 2013). There are nominally over 1,500,000 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 to plastic or even steel. Extensive work has been done to develop models that predict the impact of disasters on NG systems, which can help leaders determine the risk to their local facilities.

Generation, in addition to piping, needs to be resilient in the event of a disaster. 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 disaster 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).

Port terminals, storage facilities, and generation plants are the most vulnerable parts of the natural gas system. Pipes are inherently protected from many disasters by being underground, but these buildings are subject to all the same risks as other commercial structures. 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. For example, a plant that has no roads for fuel trucks to import hydrogen is severely impaired (Fuel Cell and Hydrogen Energy Association 2014). These special vulnerabilities should be recognized and accounted for in addition to the steps taken to mitigate inherent risks of above-ground 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.”

A standby power system is defined by IEEE (1995) as “an independent reserve source of electric energy that, upon failure or outage of the normal source, provides electric power of acceptable quality so that the user’s facilities may continue in satisfactory operation.”

The NEC (NFPA 2005) divides standby power systems into two categories, as follows:

- **“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 for 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
- 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

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). NFPA 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



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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)

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 be

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).

### **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 Sector. Previous work to develop and establish performance goals or levels of performance is found in the efforts undertaken by SPUR (San Francisco) 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 represents sample performance goals for the Electrical Subsector for the **Expected** event (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.). 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 in the Energy Sector 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, we recognize that the 90% desired performance level is already at the existing or current performance level for most electric utilities in the sample matrix. However, the target performance levels proposed may not currently be what is being achieved by all utilities and providers. These performance goals are based on anticipated performance to support the communities in a manner that is considered resilient, based on recent actual events and response times after storm and hazard events the past several years, and anecdotal reporting of response times. Further, much of the current infrastructure and response efforts managed by larger utilities currently meet the 90% restored metric we have identified therefore we made that box blue as the “X” and 90% are “overlapping.” A notable caveat to this is that Municipals and Cooperatives (Muni’s and Co-Ops) are not performing at this level and across the board they would likely be at least one box to the right of the current condition (“X”) we mapped. That said, we do not feel they represent enough of the generation or transmission industry to push the box to the right so we did not move the X to the right at this time.

It is also important to note that, for this sector, there is a slight difference in the presentation of information related to percent of the Sector restored. The reality is that the percentage of the infrastructure the utilities look to get back on line immediately is not 30% of the infrastructure, but closer to 10% +/- for each sub element (such as Generation, Transmission, and Distribution). Therefore, the most critical clusters (or sub clusters) have a 10% restored metric included for discussion. 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 (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 have the ability 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.

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*Table 7-3. Sample Performance Goals for Power Systems within the Energy Sector*

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

Restoration times		
(2)	10%	Restored
	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current
	90%	At Goal

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+
<b>Power - Electric Utilities</b>											
<b>Generation</b>											
		1									
Critical Facilities and Infrastructure Systems	R/C		10%	30%	60%	90%					
Emergency Housing and Support Systems	R/C		10%	30%	60%	90%					
Housing and Neighborhood infrastructure	R/C					30%	60%	90%			
Community Recovery Infrastructure	R/C					30%	60%	90%			
<b>Transmission (including Substations)</b>											
<b>Critical Response Facilities and Support Systems</b>											
		1									
Hospitals, Police and Fire Stations			10%	30%	60%	90%					
Emergency Operations Centers			10%	30%	60%	90%					
Disaster debris/recycling centers			10%	30%	60%	90%					
Related lifeline systems			10%	30%	60%	90%					
<b>Emergency Housing and Support Systems</b>											
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 including recharging stations/banking facilities				30%	60%	90%					
<b>Housing and Neighborhood infrastructure</b>											
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		
<b>Community Recovery Infrastructure</b>											
Residential housing restoration							30%	60%	90%		
Commercial and industrial businesses							30%	60%	90%		
Non-emergency city services							30%	60%	90%		
<b>Distribution</b>											
<b>Critical Response Facilities and Support Systems</b>											
		1									
Hospitals, Police and Fire Stations			10%			30%	60%	90%			
Emergency Operations Centers			10%			30%	60%	90%			
Disaster debris/recycling centers			10%			30%	60%	90%			
Related lifeline systems			10%			30%	60%	90%			
<b>Emergency Housing and Support Systems</b>											
Public Shelters (General Population, Animal, etc.)							30%	60%	90%		
Residential Shelter-in-place							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 including recharging stations and banking facilities							30%	60%	90%		
<b>Housing and Neighborhood infrastructure</b>											
Essential city services facilities							30%	60%	90%		

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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+
Schools							30%	60%	90%		
Medical provider offices							30%	60%	90%		
Houses of worship/meditation/ exercise							30%	60%	90%		
Buildings/space for social services (e.g., child services) and prosecution activities							30%	60%	90%		
Food distribution from local grocery stores (location known by community)						30%	60%	90%	X		
<b>Community Recovery Infrastructure</b>											
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:**

- 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

**7.4. Regulatory Environment**

The Western Energy Crisis, the Enron scandal, and a historic East Coast blackout, led Congress to granted broad new authority to the Federal Energy Regulatory Commission (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 - (EPA 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.

**7.4.1. Federal Codes and Regulations**

At the federal level there is regulation by FERC who in short defines its role as “an independent agency that regulates the interstate transmission of electricity, natural gas, and oil. FERC also reviews proposals to build liquefied natural gas (LNG) terminals and interstate natural gas pipelines as well as licensing hydropower projects.”

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.”

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 Codes and Regulations**

The utilities are constantly in a complex regulatory dance with the state public service commissions regarding the rapidly changing rules governing their role 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; but the concern from utilities is that they remain responsible for the 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 too 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 the 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 Codes and Regulations**

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.

The electric codes that are 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). While this is truly a safety code, it is applied for use 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. And while most all 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 stringent wind and ice loading conditions from these codes.

### **7.5.1. New Construction**

*[Note to reviewers: This section is still under development and will be refined for a future draft.]*

For some elements of the Energy Sector, the design criteria for hazards have been aligned with Building Sector 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 “major,” “rare,” “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.

#### **7.5.1.1. Implied or stated Performance Levels for expected hazard levels**

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 want 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 sector itself.

#### **7.5.1.2. Recovery levels**

*This section is under development. Text to be included in a future draft.*

#### **7.5.2. Existing Conditions**

*This section is under development. Text to be included in a future draft.*

##### **7.5.2.1. Implied or stated Performance Levels for expected hazard levels**

*This section is under development. Text to be included in a future draft.*

##### **7.5.2.2. Recovery levels**

*This section is under development. Text to be included in a future draft.*

### **7.6. Resilience Assessment Methodology**

Because resilience is new, there is a huge need for tools to help both the community and the sector assess resilience. There are tools and methods to measure reliability, but again, these calculated values typically look at systems during “blue sky” events and not during severe or extreme events.

Thinking about resilience as an aspect of reliability might be the quickest means to develop assessment methodologies to assess and score resilience. 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 sector 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.

#### **7.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)**

The length of time needed 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 metric 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 act of vandalism, crime, and terrorism).

#### **7.6.2. Strategies for new/future Construction**

*This section is under development. Text to be included in a future draft.*

#### **7.6.3. Strategies for Existing Construction**

*This section is under development. Text to be included in a future draft.*

#### **7.6.4. Addressing Gaps in Resilience Plans**

*This section is under development. Text to be included in a future draft.*

### **7.7. Tools Needed for Resilience**

*This section is under development. Text to be included in a future draft.*

#### **7.7.1. Standards and Codes**

*This section is under development. Text to be included in a future draft.*

#### **7.7.2. Practice and Research Needs**

*This section is under development. Text to be included in a future draft.*

### **7.8. Summary and Recommendations**

Many electric systems across the nation are currently being upgraded to accommodate the rapid load growth and aging infrastructure. With the upgrade there is a major focus on building resiliency in the system; however, the criteria detailing that resiliency and its consistency across all system owners is not present. As the various utilities across the nation balance the required investment with design criteria and the overall impact to customers there will be a more resilient system than what exists today. Technology is rapidly expanding, which allows a quicker response time to any potential disaster. In some cases utilities are reaching the point where they can predict an impact to the system and begin to minimize the impact prior to the event.

More can be done. In addition to reliability initiatives, improved planning, and response efforts to natural hazard and human-caused (criminal or terrorist) events, a planned and coordinated evaluation of the approaches to harden the infrastructure itself is necessary.

- Regulatory bodies for design and construction from the building sector and the energy sector need to discuss the magnitude and criteria of the hazards the buildings and infrastructure are designed to resist. If the general building stock is designed to resist higher level events with minimal damage,



there will be greater pressure on the energy infrastructure to be on-line immediately after disasters and events occur.

- The baseline design criteria in the NESC and RUS should be increased to provide consistent and unified guidance to all entities designing above these minimums. This increase will ensure all hazards are addressed for the same return period of event.
- Study and determine what design strategies (i.e. using more switching within the Distribution Networks) can have a major impact on isolating damaged or impacted segments of the grid and provide opportunities to return to full service more quickly and easily.
- Study system criticality data that is documented in the NERC Brightline Assessments to highlight and prioritize the critical assets of the systems that should be mitigated first to improve resiliency.
- Identify and provide incentives for the energy sector entities to invest in their aging infrastructure prior to storm events.

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## **8. Communication and Information Sector**

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### **8.1. Introduction**

Communication and information systems have become 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 between and within companies. When the 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 (i.e., cell phones) and internet (Voice over Internet Protocol, VoIP) for voice communication, text messages and email. 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 email and access information via the internet to a society where smaller mobile devices, such as laptops and cell phones, are used, constantly, for the same purpose
- More and more people now use their laptops, smart phones and tablets to read news on the internet, 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:

1. Relaying emergency and safety information to the public
2. Coordinating recovery plans among first responders and community leaders
3. Communication between family members and loved ones to check on each other's safety
4. Communication between civilians and emergency responders
5. Communication between emergency responders in the field

When addressing resilience, communities must also think about the longer term and improving performance of the built environment in the next disaster event. The intermediate and long term needs of communities, in terms of communications and information infrastructure, include:

1. Ability to communicate with employers, schools and other aspects of individuals' daily lives
2. Re-establishing operations of small businesses, banks, etc., via internet and telecommunications so they can serve their clients.
3. Restoration, retrofits, and improvements to components of the infrastructure so it will not fail in the same way in future events (i.e., implement changes to make infrastructure more resilient)

This chapter addresses disaster resilience of communication and information systems. The first steps for a community to address resilience of their infrastructure are to identify the regulatory bodies, parties responsible for condition and maintenance of the infrastructure, work with the stakeholders to determine the performance goals of the infrastructure, evaluate the state of the existing communication and information infrastructure systems, identify the weak links in the infrastructure network and prioritize upgrades to improve resilience of the network. This chapter discusses a performance goals table specific to the communications infrastructure system, and illustrates how a performance goals table can be used by

communities to set their performance goals for various hazards. This chapter also lists stakeholders/owners of the various components of communications infrastructure, discusses critical infrastructure of various communication and information systems, and recommends improvements that can be made to enhance the resilience of the system.

### **8.1.1. Social Needs and System Performance Goals**

As discussed in Chapter 3, the social needs of the community drive the performance goals that are to be defined by each community and its stakeholders. The 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 disaster event for three levels of event: routine, expected, and extreme, as defined in Chapter 3.

The community has short (1-3 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 includes communication between:

1. Citizens and emergency responders
2. Family members and loved ones to check on each other's safety
3. Government and the public (e.g., providing emergency and safety information to the public)
4. First responders
5. Government agencies

However, as discussed in the introductory section, communities must think about their long term social needs when addressing resilience. The intermediate goals of the community are to recover so that 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. Reliability v. Resilience**

The communications industry typically thinks about service to customers in terms of reliability. Reliability is the ability to provide a consistent level of service to end users (i.e., reliable networks have infrequent outages). 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 service(s) they provide to the end user rather than the infrastructure (i.e., built environment) that supports the service.

Resilience is similar to reliability, though they are not exactly the same. Like reliability, resilience includes the ability to withstand disruptions. However, resilience also involves preparing for and adapting to changing conditions to mitigate the impacts of future events so that 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, the reliability of the communications network can be improved.

**Capacity.** The resilience and resulting reliability of communications infrastructure are dependent on the capacity of the network. 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 (such as the ill or elderly), communication between civilians and first responders, as well as communication between customers and service providers when outages occur. Unfortunately, the capacity of systems is not increased for disasters and so cellular phones, for example, may not function properly due to high volume use. This is especially true in densely populated areas, which may be located in large urban 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 is an exceptionally large facility used for sporting and entertainment events, and may have above average capacity, these facilities can be overwhelmed prior to, during and after disaster events because of the large influx of civilians seeking shelter, which results in a large 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.

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. For example, if the landline demand is 1,000,000 users, the cellular network demand is 500,000 users, and the landline network experiences a disruption in a disaster event, some of the landline demand will transfer to the cellular network (Jrad et al. 2005). The increased demand would then put stress on the wireless network and likely result in service disruptions due to overloading of the network.

### **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:

1. **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 used. Furthermore, distribution of communications and power service is often co-located (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 standby power to ensure continued functionality. Conversely, emergency repair crews for power utilities need to be able to communicate so they can get prioritize and repair their network efficiently.

The power provider controls the rights of the utility poles, and thus the design, construction, routing and maintenance of telecommunication lines are dependent on the requirements of the power utility provider requirements and regulations.

2. **Transportation** – As will be discussed in this chapter, one problem commonly seen after disaster events is that roadways and other parts of the transportation system needed in recovery of lifelines 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 they need to repair damaged communications infrastructure. On the other hand, transportation repair crews, including those for traffic signals, need to be able to communicate to ensure their system is fixed.

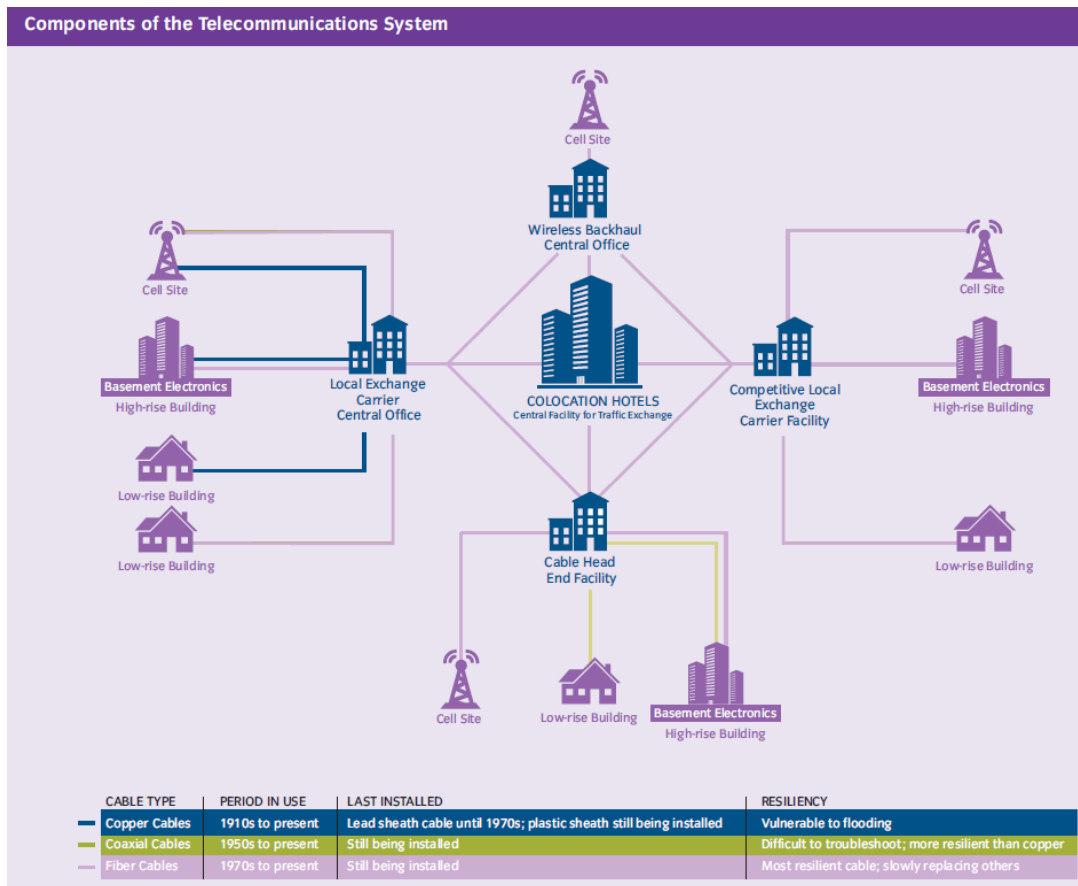
3. ***Building/Facilities*** – Buildings and facilities need their communications and information systems to function properly. Buildings used for business and industry communicate with clients, suppliers, and each other via telephone and email. Residential buildings need these services to communicate 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.

4. ***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 to no coordination in the efforts.
5. ***Security*** – Although security is not addressed as a sector in this framework, it 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. Therefore, 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**

There are a number of critical components in the communication and information system infrastructure. This section discusses some of these infrastructure components, 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 of the 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, and 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. Hence, landline telephones are generally a more resilient option for telephone communication. 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 the wires can result in lines for power, cable and telecommunications being cut, resulting in the 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, would be expected to be fully functional after an expected event.

The primary resiliency concerns for Central Offices are:

1. Performance of the structure

2. Redundancy of Central Offices/Nodes within Network
3. Placement/security of critical equipment
4. Threat to/from interdependent services

**Performance of the Structure.** The design of Central Offices is extremely important for continued service of the telecommunications system. Depending on the location of the community, the design considers different types and magnitudes of disasters. 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.

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 (see discussion in next section), these structures should be designed to resist more extreme environmental loads. In cases where Central Offices are located in older buildings, 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 was built into the network of Central Offices as will be discussed in the following section.

Since communities are ultimately responsible for the 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, it is recommended that these buildings are evaluated and hardened as needed to ensure that 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<sup>th</sup>, 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



**Figure 8-2. Damage to Verizon Building on September 11, 2001 (FEMA 2002)**

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 carriers/service providers that leased Verizon's space lost service as well since they did not provide redundancy either. 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. 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/Security of Critical Equipment.** Although construction of the building is important; placement and security 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, but should also be located such that it is not susceptible to other environmental loads such as wind. The 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).

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 the power was restored or the 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 at a data center in Manhattan, NY after Hurricane Sandy (FEMA 2013).



**Figure 8-3. Large Standby Portable Power Unit used when Basement Generators Failed (FEMA 2013)**

After 9-11, the Verizon Central Office at 141 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). After 9-11, and prior to Sandy, the 141 West Street Central Office:

- Raised their emergency 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 one at 104 Broad Street (also affected by Sandy), which had not been hardened. The 104 Broad Street Central Office positioned its emergency 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 141 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 141 West Street Central Office during and after Sandy illustrates that making relatively simple changes in location of equipment can significantly improve the performance of infrastructure/equipment following a disaster event. This example shows that

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.

Placement and security of critical equipment should be considered for all types of natural disasters a community may experience. As illustrated by the Sandy example, different hazard types warrant different considerations. For earthquake, equipment stability must be considered. Figure 8-4 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 the shaking will not lead to equipment failure.



*Figure 8-4. Light Fixture and Equipment Failure inside Central Office in Mexico City 1985 Earthquake (OSSPAC 2013)*

As indicated in Chapter 3 and presented in Table 8-1 (see Section 8.3), the desired performance of the communications system in the expected 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.

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 the expected 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 their critical equipment and electrical switchgear. The transportation system is needed for workers to maintain and monitor the functionality of equipment. Water is needed to ensure the fire protection systems of fire-fighting efforts can be used in the case of fire, which can occur as a secondary event after the primary natural disaster event.

Intra-dependencies with the rest of the communications infrastructure network must be also considered. A Central Office serves as a switching node in the network and if its functionality is lost, then 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.*** 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 that 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 was 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 the 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 because path diversity is built into the infrastructure system often using nodes that connect to the internet backbone. However, as was learned during workshops used to inform this framework, part of the last mile typically does not connect to the internet 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., the first/last mile) then the first/last mile customers will be of service.

In rural communities, there is likely to be less redundancy in the telecommunication and information network cable systems. 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: 1) In the past, the technology to send large amounts of data over a long distance had not been available; and 2) 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. However, 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. Furthermore, in the case where the reason for loss of telecommunication services is the loss of external power rather than failure of the communications system itself, restoration of services may be quicker for rural communities. As was learned in the 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 disaster event resulting in loss of external power, communication may, but is not guaranteed to, still be possible through the use of analog landlines.

Although copper wires perform well in many cases, they are being replaced more and more 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 norm in the 21<sup>st</sup> 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 has reported that its operating expenses have been reduced by approximately 70% 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 that the copper wire is encased in a plastic or another non-saltwater sensitive material. Furthermore, copper wires are older and generally, are 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 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 more and more by fiber optic cable since fiber optic cables 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 to 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 company instead of the communications provider itself for the end user. Consequently, during and after a natural disaster event where power is frequently interrupted, landline communications using fiber optic cables are lost (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.** Transmission 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 disaster. 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 the poles and cables or trees falling onto the cables. Figure 8-5 shows an example of a failure a (Cable Television) CATV line due to the direct action of wind during Hurricane Katrina.



**Figure 8-5. Failure of CATV cable due to the direct action of wind.**

Widespread failure of the above-ground system in high winds and ice storms is common and often associated with the effects of tree blow-down and falling branches, and it is difficult to mitigate without removing trees. Some improvement in performance can be achieved with continued trimming of branches, both to reduce the likelihood of branches falling on lines and to reduce the wind-induced forces acting upon the trees, which reduces the blow-down probability. Tree trimming is performed by the electric utility which owns the poles. The challenges associated with tree removal and trimming is discussed in Chapter 7.

Ice storms can also result in failure of above ground communication infrastructure. For example, in January 2009, Kentucky experienced an ice storm in which long-distance telephone lines failed due to icing on poles, lines and towers, and loss of power (Kentucky Public Service Commission 2009). Similar to wind hazards, the accumulation of ice seen in Kentucky, paired with snow and high winds led to tree fall 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 were 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 from workshops held to inform this framework, long distance communications do have standby power capability.

Emergency response and restoration of the telecommunications infrastructure after a disaster event is an important consideration for which the challenges vary by hazard. In the case of both high wind and ice/snow events, tree fall on roads (Figure 8-6) 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 difficulties of working for long periods of time in very cold and windy conditions which can be associated with these events. Therefore, communities must consider the conditions under which emergency restoration crews must work in establishing realistic performance goals of telecommunications infrastructure.



*Figure 8-6. 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.

In parts of the United States, communities 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:

1. Shorter design life of the underground system
2. Lack of maintenance and repair accessibility of the underground facilities
3. Above ground hardware issues
4. Converting all customers' wiring to accommodate underground in place of above ground 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 Sector), electric utility companies have tree trimming programs, and hence established budgets, to reduce the risk of tree branches falling on and damaging their distribution lines. 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 the underground utilities (City of Urbana Public Works Department 2001).

### **8.2.2. Internet Systems**

The internet has become the most used source of one and two-way communication over the past couple of decades. It is continually used for email, 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, email, 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. As healthcare moves towards electronic medical records, connectivity becomes more important in the healthcare system.

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 disaster 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 also 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). Similarly 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 of these buildings will be or have been built 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).
- Rooms housing critical equipment should be designed to resist the 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 disaster events.
- Where possible, redundancy and standby power for critical equipment should be provided.

All too often, communities have seen the same problems and damage in the wake of a natural disaster 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, an example was the comparison of two telecommunications Central Offices in New York City after Hurricane Sandy. Careful placement and protection of critical equipment can help to achieve the 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 synonym of redundancy). The more diversity that exists, the more reliable the system will be.

#### **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 wireless backhaul Central Offices. Figure 8-1 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 one or more of the following.

**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 that are designed to provide 4 to 8 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 8 hours of battery standby power, but the requirement was removed by the courts. It is recommended, however, that the former FCC mandate be followed by service providers. Figure 8-7 shows an example of a cell tower with standby power and switchgear at the base. 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).



**Figure 8-7. Base of Cell Tower Showing Standby Power and Switch Gear**

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 2) event. Consequently, adequate standby power is critical to ensure functionality. Recent experience with hurricanes and other disaster events suggest that 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 disasters, 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.

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 disaster 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 disaster 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 (large boats, etc.), whose momentum was likely well beyond a typical design flood impact. Figure 8-8 shows an example of a cell phone tower that failed due to high winds in Hurricane Katrina. 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 the 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 than 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.



*Figure 8-8. Tower Failed Due to Wind During Hurricane Katrina.*

#### **8.2.3.2. 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% functionality is not always feasible in the wake of a disaster 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 time has been shortened or even eliminated after a disaster event.

This section provides an example of performance goals that communication infrastructure stakeholders and communities can use to assess their infrastructure and take steps in improving their resilience to disaster 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 the performance goals.

Before we can establish the performance goals, it is imperative to understand who the owners, regulatory bodies, and stakeholders of the communications infrastructure are and how they operate because they should all be involved in establishing the performance goals and working together to narrow the 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 is no requirement for compliance with the standards. 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 disaster event. Moreover, improvements made to achieve the performance goals may result in better performance on a day-to-day basis as well. A service provider may benefit from excellent performance following a disaster event because customers frustrated with their own service may look for other options that are more reliable. 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 the 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 the components of the system. For resilience of the transmission and 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 the performance goals and improve the resilience of the transfer of the communications system from the provider to the building owner. Specifically, transfer of telecommunications and internet to a

building is often through a single-point of failure. Hence, 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 functionality of the infrastructure can be recovered after a disaster event. Minimizing downtime can be achieved during the design process. A generic table of performance goals for communications infrastructure, similar to the format presented in the Oregon Resilience Plan (OSSPAC 2013), is presented in Table 8-1. The Table 8-1 performance goals are recommendations for a generic “expected” event. However, it is noted that these performance goals were developed based on an expected wind event using current ASCE (ASCE 7-10) design criteria and performance seen in past high wind events. 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.

Table 8-1 is intended as a guide that communities/owners can use to evaluate their strengths and weaknesses in terms of the resilience of their communications systems infrastructure. It is recommended that communities and stakeholders 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 can be developed for any community (urban or rural), any type of disaster event, and for the various levels of hazards (routine, expected and extreme) defined in Chapter 3 of the framework.

Table 8-1 presents an example of suggested performance goals for different components of the communications infrastructure when subjected to an expected event. The orange shaded boxes indicate the desired time to have 30% functionality of the component. Yellow indicates the time frame in which 60% operability is desired and green indicates greater than 90% operability. We do not set a goal specifically for 100% 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 that this is frequently not the case.

In terms of granularity of the performance goals table, the communications infrastructure system is broken down into three categories (see Table 8-1): 1) Nodes/Exchanges/Switching Points, 2) Towers, and 3) Distribution to end users. Although the different components of the system (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.

The affected area of a given disaster 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.

**DISASTER RESILIENCE FRAMEWORK**

**50% Draft for Norman, OK Workshop**

**20 October 2014**

**Communication and Information Sector, Performance Goals**

*Table 8-1. Performance Goals for Expected Event to be Developed by Community and/or Stakeholders*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current or At Goal

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+		
<b>Nodes/Exchange/Switching Points</b>		A											
Central Offices			90%			X							
Buildings Containing Exchanges			90%			X							
Internet Exchange Point (IXP)			90%			X							
<b>Towers</b>		A											
Free Standing Cell Phone Towers			90%			X							
Towers Mounted on Buildings			90%			X							
<b>Distribution lines to ...</b>													
<b>Critical Facilities</b>		1											
Hospitals			90%			X							
Police and fire stations			90%			X							
Emergency Operation Center			90%			X							
<b>Emergency Housing</b>		1											
Residences					60%	90%		X					
Emergency responder housing					60%	90%		X					
Public Shelters					60%	90%		X					
<b>Housing/Neighborhoods</b>		2											
Essential City Service Facilities					30%	90%		X					
Schools					30%	90%		X					
Medical Provider Offices					30%	90%		X					
Retail					30%	90%			X				
<b>Community Recovery Infrastructure</b>		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				

**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:**

- 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
- 30% 60% 90% Restoration times relate to number of elements of each cluster
- 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
- Indicate levels of support anticipated by plan  
R Regional  
S State  
MS Multi-state  
C Civil Corporate Citizenship
- Indicate minimum performance category for all new construction.  
See Section 3.2.6

The disruption level based on the current state of the communications infrastructure system as a whole should be specified as usual, moderate or severe. We have put an "X" in the each row of Table 8-1 as an

example of how a community can indicate the expected performance and recovery of the infrastructure in their evaluation. As seen in Table 8-1, the “X” indicates that 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, for example, 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 to narrow the gap in resilience, including hardening the building to resist extreme loads and protecting equipment 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, Hurricane Sandy, Hurricane Katrina, and others.

As previously discussed, the performance goals may vary from community-to-community based upon its social needs. It is recommended that representatives of the stakeholders in a given community participate in establishing the performance goals and evaluating the current state of the systems. As discussed throughout the framework, contributions to community resilience include those from design professionals (e.g., engineers and architects), planners, utility operators, regulatory agencies, emergency management planners and first responders, business and political leaders, communications providers, financial analysts, building owners, etc. The City of San Francisco provides an excellent example of what bringing together stakeholders can accomplish. San Francisco has developed a lifelines council ([The Lifelines Council of the City and County of San Francisco 2014](#)), which brings together 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 system in the Bay Area.

#### **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. Furthermore, 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. Therefore, it has jurisdiction over wireless, long-distance telephone, and the Internet (including VoIP).

As discussed earlier in this chapter, 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, such as 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 was learned in the stakeholder workshops held to inform this framework, industry considers best practices voluntary good things to do. Furthermore, implementing best practices allows service providers to remain competitive in terms of 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 above ground 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 8-2 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 8-2 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.

**DISASTER RESILIENCE FRAMEWORK**  
**50% Draft for Norman, OK Workshop**  
**20 October 2014**  
**Communication and Information Sector, Standards and Codes**

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*Table 8-2. 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 8-2 are used in new construction for various parts of the communications infrastructure system. As discussed in Section Table 8-2, 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 Sector), 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. The 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, has included the biggest set of changes since the standard's inception (TIA 2014). Some of the 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 and ice loading are the predominant concerns for towers. However, earthquake loading was added so that it would be considered in highly seismic regions (Wahba 2003).

#### **8.5.1.1. Implied or Stated Performance Levels for Expected Hazard Levels**

As discussed in Chapter 5, the performance level for an expected disaster event depends on the type of hazard and the design philosophy used for said hazard.

For wind, the buildings and other structures are designed for serviceability. That is, in the expected wind event, such as a hurricane, the expectation is that the structure of the building will not fail nor will the building envelope. 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 that 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, the 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, then 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 5 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.

#### **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 towers, wind is the predominant hazard 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 towers would fail during an expected event.

For distribution lines, a key factor, more so than the standards, is the 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, limited 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. It is noted that this only accounts for repair of the communications distribution lines itself. Another major consideration is the recovery of external power lines so that 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 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 the 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 United States growth and construction of towers (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). It is noted that the use of fastest mile for the reference wind speed is consistent with ASCE 7 prior to the 1995 version (of ASCE).

#### **8.5.2.1. Implied or Stated Performance Levels for Expected Hazard Levels**

For existing Central Offices designed to an older version of ASCE 7 or ANSI criteria, these 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 earthquake does 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. It is noted 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 another standards, such as ASCE 7. However, this was not a requirement.

#### **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 8.6.4, service providers have the ability to provide cell on light trucks (COLTs) so that essential wireless communications can be brought online quickly after a disaster event in which the network experiences significant disruptions (AT&T 2014). However, the COLTs are only intended for an emergency situation. 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 that the cell towers can resist the earthquake loading criteria in the new ANSI/TIA standard.

With respect to performance of distribution lines, the performance and recovery time is largely dependent on the placement of the cables (i.e., overhead versus underground) as discussed in 8.5.1.2.

## **8.6. Resilience Assessment Methodology**

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 recommended 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.

Section 8.4 and 8.5 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 structures as well as building new structures for their communications network. The objective of this section is use the information from Section 8.2 through 8.5 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.

### **8.6.1. Assessment Methodology**

Recall that in the Section 8.2 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 for the community then becomes: How do we (the community) 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 expected 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 disaster 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 disaster 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 the 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 disaster 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 inter-dependencies with the infrastructure of other sectors. Fragilities could be developed for each component of the communications infrastructure system. A Tier 3 assessment would use model/tools to determine both the loading of infrastructure due to the hazard and the resulting performance including intra- and inter-dependencies. 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 the 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), then it is recommended that the component 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 be designed such that it can withstand the appropriate type and magnitude of disaster event(s) 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 and so designing for an extreme earthquake may not protect your 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 was 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 reduce the recovery time needed significantly. 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. Hence, for wind and ice, if the towers are designed and constructed in accordance with the appropriate standard(s), 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, it is recommended that they be designed to 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 has attempted to mandate a minimum of 8 hours of battery standby power to overcome this problem, but the requirement was removed by the courts. However, it is recommended that service providers follow the former FCC mandate.

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. Furthermore, impacts from uprooted trees or branches during high wind events and tsunamis could also result in failure of these towers. Therefore, it is recommended that the topography and surroundings (e.g., relative distance from trees or harbors to cell towers) be taken into consideration 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 (see Section 8.2.1). More and more, service providers are installing fiber optic wires to carry services to the customer.

There is an 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:

1. The building cluster to which the services are being distributed
2. The potential hazards to which the community is susceptible
3. Topography and surroundings of distribution lines
4. Redundancy or path diversity of distribution lines

Items 1-3, as listed, can be considered together. The building cluster to which the services are being delivered (item 1) 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 (item 2) can be used to determine how to best prevent interruption of service distribution to the building (i.e., end user). As an example, in regions that are susceptible to high winds events (i.e., item 2), 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 (item 3).

Redundancy or path diversity (item 4) 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 the continuation of services after a disaster event. For example, single points of failure in the last/first mile of distribution can be vulnerable to failure resulting in long term outages. It is recommended that redundancy (i.e., path diversity) is built into 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, then 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 owner (e.g., building owners) with competing needs for funding, it is not reasonable to expect that the capital is available for service providers (or third parties) to upgrade all of their infrastructure immediately. However, prioritization can be used to 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 that are 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 the 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, then 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, then 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 disaster event as previously described, then the service provider should take steps to harden the building. Although this is likely to be very expensive, if the Central Office is critical to the service provider's performance following a disaster event in both the short and long term, then 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.*** The 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 the disaster 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 discussed in Section 8.2.1, non-construction strategies can be used to successfully improve the performance of the critical equipment in disaster events. Recall that after 9-11, the Manhattan Verizon Central Office was hardened. However, 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, which had their 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. In terms of the performance goals shown for the expected event in Section 8.3, the 104 Broad Street did not meet the performance goals. However, with the relatively easy changes made in elevating the 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 that 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, it is recommended that the design loads for existing cell towers, particularly in earthquake prone regions, 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, then retrofits, such as the addition of vertical bracing, can be constructed to ensure that 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 (8+ hours) supply is available 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 a period of time. The immediate surroundings of cell sites should also be assessed to determine vulnerabilities to debris, either airborne or waterborne. If the cell site is located such that it is vulnerable to tree fall or other debris in a high wind or flood event, then it is recommended that additional protection 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 the wires, including the type, age, and condition of the wires should be recorded. When wires are found damaged or have deteriorated due to their age, they should be retired and/or replaced.

As discussed for new/future distribution lines, overhead v. underground wires is an ongoing debate in the industry. The distribution lines, particularly to critical buildings, should be assessed to determine whether overhead or underground wires are best for the communications infrastructure system. However, 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 the cost is much greater than the 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 the overhead distribution lines.

#### **8.6.4. Addressing Gaps in Resilience Plans**

After the community stakeholders (including service providers) establish performance goals for the communications infrastructure and an assessment of the critical infrastructure is complete, the mitigation strategies discussed in Sections 8.6.2 and 8.6.3 can be used to reduce the resilience gaps. These strategies include:

- Designing new/future buildings that house Central Offices and other exchanges/nodes in the communications infrastructure system to resist the loads associated with the appropriate disaster level and performance goals
  - When the service providers own these buildings, they can work directly with building designers to ensure the building meets appropriate loading criteria to meet performance goals for resilience.
  - When service providers commit to leasing a new/future building from a third party, service providers can attempt to work with the building owner to ensure the sections of the building they committed to leasing are designed (i.e., hardened) to resist the appropriate loads.
- Hardening existing buildings owned by service providers that house Central Offices and other exchanges/nodes in the communications infrastructure system to resist appropriate loads to meet performance goals
- Placing and securing critical equipment in Central Offices such that it is not vulnerable to hazards faced by the community, whether flooding, earthquake, etc.
- Designing or retrofitting cell towers, as needed, to ensure they resist the loads associated with the “expected” hazard level
- Ensuring 8+ hours of standby power is available for cell towers so that they can function for a reasonable period of time in the immediate aftermath of a disaster event
- Placing and securing cell tower standby power and switchgear such that they are not impacted by the “expected” event
- Ensuring distribution lines have redundancy (path diversity) built into the network
- Placing distribution lines so that their vulnerability to natural hazards is minimized



As can be seen, there are several mitigation strategies that can be used to reduce the resilience gaps of the communication infrastructure system. However, service providers and other stakeholders, such as third party building owners, responsible for infrastructure cannot make all recommended 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. That is, 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+ year), 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, other strategies can and should be used by service providers 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 to minimize downtime. AT&T's Natural 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 has been deployed after several disaster events to minimize service disruption where the downtime would have been long term, including after September 11<sup>th</sup>, 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 disaster event (AT&T 2014). Training and field exercises for emergency recovery crews are essential to helping reduce the communication 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 disaster 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.

### **8.7. Tools Needed for Resilience**

As with all design codes and standards, those applicable to communication and information infrastructure provide minimum requirements. However, to develop resilient infrastructure, vulnerabilities in the codes and standards must be identified and improvements recommended to narrow the resilience gaps. Furthermore, research in some areas is needed to develop new, innovative solutions to vulnerabilities that exist in current standards.

### **8.7.1. Standards and Codes**

The codes and standards identified in Section 8.5 are presented again in Table 8-3. The table identifies areas of the codes and standards that are recommended to be improved upon.

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**Communication and Information Sector, Tools Needed for Resilience**

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*Table 8-3. Communication and Information Sector Codes and Standards*

Codes/Standards	Vulnerabilities	Improvements
ANSI/TIA-222-G Structural Standards for Antennae Supporting Structures and Antennas		<i>This table is under development. To be completed for a future draft.</i>
ANSI/TIA-568-C.0 Generic Telecommunications Cabling for Customer Premises		
ANSI/TIA-568-C.1 Commercial Building Telecommunications Cabling Standard		
ANSI/TIA-569-C Commercial Building Standard for Telecommunication Pathways and Spaces		
ANSI/TIA-570-B Residential Telecommunications Cabling Standard		
ANSI/TIA-606-B Administration Standard for Commercial Telecommunications Infrastructure		
ANSI/TIA-942-A Telecommunications Infrastructure Standard for Data Centers		
ANSI/TIA-1005 Telecommunications Infrastructure for Industrial Premises		
ANSI/TIA-1019 Standard for Installation, Alteration & Maintenance of Antenna Supporting Structures and Antennas		
ANSI/TIA-1179 Healthcare Facility Telecommunications Infrastructure Standard		
ASCE 7-10 Minimum Design Loads for Buildings and Other Structures		
IEEE National Electrical Safety Code (NESC)		

### **8.7.2. Practice Gaps and Research Needs**

As discussed throughout this chapter, a number of practice gaps and research needs exist for the communication and information system infrastructure. The practice gaps discussed throughout this chapter can be broken down into construction and non-construction practice gaps.

*Construction Practice Gaps.* Some of the main construction practice gaps include:

- Partial or complete failures of buildings housing critical equipment (e.g., central offices, exchanges, nodes)
- Non-hardened rooms within buildings that house critical equipment
- Design loads of older cell towers that would not meet the ANSI/TIA-222-G (same as ASCE 7) criteria
- Single points of failure in the distribution system
- Placement of distribution lines

As seen in the above list, ensuring that buildings housing critical equipment (e.g., central offices and exchanges) are hardened to resist loads of the “extreme” natural disasters is not typically done. However, examples show that when a central office has been hardened, it has been successful (see Section 8.2.1 and [City of New York 2013](#)). In cases where it is not feasible to harden an entire building against the “extreme” loads as defined in Chapter 3, it may be sufficient to harden the rooms where the critical equipment is stored against extreme loads, whether they be wind, earthquake, fire, blast, etc.

Another practice gap that should be evaluated is earthquake loading criteria that was used for cell towers designed and constructed prior to the 2006 version of ANSI/TIA-222-G. Prior to the 2006 version of ANSI/TIA-222-G, this standard did not provide design loading for earthquake. It is assumed that the designer would use ASCE design loads in place of this, but it is possible that insufficient loads from another source were used in design or earthquake loads were not addressed. Therefore, older cell towers in earthquake prone regions should be evaluated to determine if they can resist the “expected” earthquake loading.

Placement of distribution lines is a practice gap that service providers are aware of and have been addressing in recent years. The overhead versus underground utilities debate is ongoing. Some communities have conducted studies and documented their evaluation of the social and financial factors that influenced their decisions. [The City of Urbana Public Works Department \(2001\)](#) report provides a good example of a community working with its service providers (electric power in the case of this study) to understand and weigh the advantages and disadvantages of converting from an overhead to underground distribution systems.

*Non-Construction Practice Gaps.* Non-construction practice gaps include:

- Poorly placed/secured critical equipment within central offices.
- Placing and securing cell tower standby power and switchgear such that they are not vulnerable to the expected event.
- Inadequate standby power availability for cell towers

As discussed in this chapter, Hurricane Sandy among other disaster events has made it evident that critical equipment within central offices or exchanges is not always placed to minimize its vulnerability to relevant disasters. However, some service providers have placed and secured their critical equipment successfully so that disasters such as flood and earthquake do not render it useless. The whole industry should be encouraged to learn from the success stories such as that of the Verizon central office in Manhattan after Hurricane Sandy ([City of New York 2013](#)).

Similarly, standby generators and switchgear used for cell towers in the event of a loss of external power should also be placed and secured such that they are not impacted by the “expected” event as defined in Chapter 3. However, as illustrated by Figure 8-7 in Section 8.2.3.1, standby generators and electrical switchgear are often located at the base on the cell tower because there is nowhere else to put them. This may be sufficient for some disaster events, such as a high wind event. However, flood events may lead to failure of the electrical switchgear and earthquakes could lead to failure if the generator and switchgear is not adequately mounted to the foundation.

Inadequate standby power supply for cell towers is another practice gap. As discussed in Section 8.2.3, the FCC attempted to mandate that all cell towers have a minimum of 8 hours of standby power for events when external power is lost; however, that mandate was overturned by the courts.

**Research Needs.** The main research need that is essential in improving the resilience of the communications networks is widely used and accepted tools and metrics. The tools and metrics that need to be developed and validated should be capable of supporting multiple end-users, including service providers, planners, and community stakeholder panels (such as those that would ideally develop the performance goals for a given community). The tools should have the capability of simulating scenarios input by the user and compute a resulting disruption of the network (i.e., a metric). The disruption time metric may not have to be as specific as hours, but should at least be quantified in days. An ideal tool would also account for intra- and interdependencies of the system as a whole.

Although to date there are not widely used tools that model the communications system and consider all of the intra- and interdependencies, tools have been developed that can model how a system will behave in a disaster event. The Network Simulation Modeling and Analysis Research Tool (N-SMART) developed by Bell Laboratories as a part of its work with the National Infrastructure Simulation and Analysis Center provides a great example of a tool that can be used to model and understand the impact that a given event will have on a communications network (Jrad et al. 2006). N-SMART has been used by Jard et al. (2005 and 2006) to simulate the capacity, blocking levels, retrying of calls (i.e., retrials), and time to complete calls for both wireline and wireless networks. One excellent aspect of the tool is that it takes into account behavior of the users in disaster events to reflect the potential overloads.

Jard et al. (2005) use N-SMART in a study to understand the impact of having different levels of a redundant telecommunications system in a mid-size metropolitan area. That is, the study uses the tool to compare the modeled performance of both the landline and cellular network for two cases: 1) The landline network has a large number of users and the cellular network has a small number of users, and 2) the landline and cellular networks have similar numbers of users. The results of the study showed that the resiliency of the overall communications network is best when the landline and cellular networks are approximately equal in terms of use and capacity. If one network is much larger than the other and that network experiences a disruption, the demand will shift to the other network and cause congestion/overload such that it also experiences a disruption (Jard et al. 2005).

Jard et al. (2006) also used N-SMART to model the resilience of telecommunications infrastructure during different types of disaster events, including a major earthquake or 9-11 event, a major evacuation such as that seen in Houston prior to Hurricane Rita in 2005, and another smaller event where the emergency response network (i.e., 9-1-1) was overloaded resulting in poor service. This study shows that diversity of disaster events for which the tool can be used and the findings illustrate that human behavior significantly impacts the capacity and functionality of the communications infrastructure in the wake of a disaster event.

A tool comparable to N-SMART would be very helpful to service providers so they could model their communications infrastructure system and understand how it will perform in a specific disaster event/scenario. By allowing the service provider to understand how their network will perform under increased demand due to a disaster event, mitigation techniques may be explored to limit the resulting

congestion/overload of the network. A tool with these capabilities could also help service providers in establishing its growth/marketing strategy so their network remains functional in the event of a disaster. In recent years, telecommunications services have been moving from a largely wireline (i.e., landline) service to cellular services (Jard et al. 2005 and 2006). Recalling that one of the key findings of Jard et al. (2005) was that roughly equal wireline and cellular network sizes improves resilience, service providers should be wary of growing their services such that a massive cellular network is available, with only a small wireline network.

Service providers and communities could jointly use a tool with similar capabilities to those of N-SMART to plan for and develop strategies for large evacuations, such as those that sometimes take place in advance of a hurricane's landfall. The community may use the model in combination with their designated emergency evacuation centers or designated evacuation routes to try to improve the capacity in those areas or along those routes. A community or service provider may decide that one of its strategies will be to educate end users so they understand how their devices work and that extreme demand may exceed the network capacity around disaster events. Making end users aware and educating them on strategies to avoid a complete loss of their communications device(s) may help reduce some of the frantic redialing that adds to the demand during disaster events (Jrad et al. 2006).

Although N-SMART provides an excellent example of the potential for a tool that could be used by service providers and/or communities to model the performance of the communications infrastructure during a given disaster event, the ideal tool would go beyond what Bell Labs has already accomplished. The tools developed for use by service providers and/or communities to evaluate/model their communications infrastructure should be expanded to include key interdependencies such as power and transportation networks so recovery times can be computed taking into account the appropriate interdependencies with other sectors.

### **8.8. Summary and Recommendations**

The telecommunications system has changed dramatically over the past 20-30 years. Constant communication has become an essential part of people's daily lives and becomes even more important in the immediate wake of a disaster.

- Emergency response personnel need to communicate with one another and those who are injured, trapped, etc.
- Individuals need to communicate with their loved ones and check on each other's safety.
- Low-income, elderly, and disabled or special needs populations are primary concerns during and after a disaster event.
- Businesses and organizations need to re-establish themselves quickly and re-connect with their customers and suppliers.
- Local government needs to continue governance, provide updates to the community, and coordinate with outside help via the state and/or federal government.

A number of key points are evident in this chapter with respect to the resilience of communications infrastructure:

1. Building redundancy into telecommunications infrastructure is key.
2. Ensuring buildings housing key components of the communication system are designed to, or brought up to current day standards, including the location of standby power, switchgear etc. is critical if these important parts of the communication network are to perform as desired during and after a natural hazards event. Adoption, administration and enforcement of the latest national standards and building codes at the community level are critical to ensure properly designed and built facilities.

3. If no redundancy is built into the network, critical components, such as a lone Central Office, should be designed or hardened to ensure that it can resist the extreme load (see Chapter 3) for a given hazard faced by the community.
4. Service providers (or communities) can implement a number of strategies to be successful in mitigating service interruptions during and after a disaster event. Both construction and non-construction strategies can and should be used.
5. There is a need for tools and metrics for use by service providers and communities to understand the capacity and expected performance during and after a disaster event. Research should be conducted to develop these tools and metrics.

The following are recommended for consideration by communities:

- Bring together a group of stakeholders to form a Communication Infrastructure Council.
    - The first step is to get key entities, such as the service providers, building officials, and local government, involved in the process early and often. If stakeholders work together so the entire community benefits, including themselves, the council is much more likely to succeed.
  - An assessment of the current state of the Communications Infrastructure and its vulnerabilities within the community should be completed.
    - This activity can be carried out by the Communication Infrastructure Council.
    - The example table of recommended performance goals in this chapter can be used as a tool to identify the gaps between the actual and desired levels of resilience of a component of the system. The community can then use their findings to prioritize their needs and develop an action plan to make improvements over time with available funding.
    - The community can also adjust the recommended performance goals to fit the needs of that individual community.
  - Look for opportunities to add redundancy to existing systems.
    - Funding is always an issue, so there is no expectation that everything will change at once. However, communities and service providers should work to look for opportunities to add redundancy to components of their infrastructure whenever possible. Redundant systems allow for a better chance of continued service in the event of a failure of a part of the system.
  - Buildings and structures are designed to minimum criteria to resist hazards based on the applicable codes and standards (e.g., ASCE 7). If the structure being designed is known to be a single point of failure in the last/first mile, the owner should consider having the structure hardened or designed to a higher standard. In Chapter 3 of this Framework, we provide definitions for different magnitudes of hazard. The nominal design criteria presented in correspond to the “expected” event but load and resistance factors (or safety factors) have been applied so it is expected that structures built to these standards will survive without damage sufficient to cause service interruption during the extreme event. However, for single points of failure, it is suggested that the design criteria should be consistent with the “extreme” event (ASCE Occupancy Category IV).
  - Service providers may be owners of Central Offices and/or other buildings, but these properties are often leased. Therefore, the building owners who lease to service providers should understand the needs of their tenants (i.e., service providers) to ensure their critical equipment is not crippled in a disaster event.
  - The design and placement of key electrical components, standby power, etc. needs to be consistent with the overall performance goals of the building as a whole. In the case of flooding, for example, meeting the ASCE 7 design criteria and providing a risk consistent structural design requires placing critical equipment, electric panels, emergency equipment etc., at the appropriate height above the BFE or flood proofing the structure to prevent water intrusion during the extreme event.
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Service providers and communities have a number of options so that they can successfully improve the resilience of their communications infrastructure. Service providers and communities are encouraged to consider the following mitigation strategies to improve their communication infrastructure resilience:

- Design new/future buildings that house Central Offices and other exchanges/nodes in the communications infrastructure system such that they resist the loads associated with the appropriate disaster level and performance goals.
  - When the service providers own these buildings, they can work directly with the building designers to ensure the building meets the appropriate loading criteria so that the performance goals for resilience can be met.
  - When service providers commit to leasing a new/future building from a third party, service providers can attempt to work with the building owner to ensure that the sections of the building they have committed to leasing are designed (i.e., hardened) to resist the appropriate loads.
- Harden existing buildings owned by service providers that house Central Offices and other exchanges/nodes in the communications infrastructure system to resist the appropriate loads to meet the performance goals.
- Place and secure critical equipment in Central Offices such that it is not vulnerable to the hazards faced by the community, whether flooding, earthquake, etc.
- Design or retrofit cell towers, as needed, to ensure they resist the loads associated with the “expected” hazard level
- Ensure 8+ hours of standby power is available for cell towers so that they can function for a reasonable period of time in the immediate aftermath of a disaster event
- Place and secure cell tower standby power and switchgear such that they are not impacted by the “expected” event.
- Ensure distribution lines have redundancy (path diversity) built into the network
- Place distribution lines so that their vulnerability to natural hazards is minimized.

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## **9. Water and Wastewater Sector**

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### **9.1. Introduction**

Water and wastewater systems play a critical role in our daily lives. They provide basic services for our homes, places of business, and industry. In the United States, most people take these services for granted because of the high level of service and reliability generally provided by water and wastewater utilities. It is not until a water main break or other disruption in service occurs, that we are reminded of the importance of water and wastewater systems.

This chapter addresses disaster resilience of utility-scale water and wastewater systems. While water and wastewater infrastructure that serve only a small number of households, such as groundwater wells and septic systems, are not specifically addressed, the basic resilience concepts are also generally applicable to these individual systems.

Utility-scale water and wastewater lifelines are often complex systems consisting of large distributed pipeline networks and localized facilities such as treatment plants and pump stations. The infrastructure for these systems was installed as communities developed and expanded over time. The American Society of Civil Engineers (ASCE) 2013 Report Card for America's Infrastructure gave the nation's water and wastewater systems a grade of D. A primary reason for this low grade is much of the water and wastewater infrastructure is reaching the end of its useful life; it is not uncommon for some system components to be over 100 years old.

While some utilities are already taking steps to improve the resilience of their system, capital improvement programs of many others often focus on emergency repairs, increasing system capacity to meet population growth, or making system improvements to satisfy public health and environmental regulations. Replacement of 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 improvements with retrofit or replacement of aging infrastructure over the coming years to improve the resilience of water and wastewater infrastructure.

#### **9.1.1. Social Needs and Systems Performance Goals**

The average person uses between 80–100 gallons of water per day. Personal uses include water for drinking and cooking, personal hygiene, flushing toilets, laundry, landscape irrigation, and many others. Many businesses and industries are also dependent on a continual supply of potable water and wastewater collection services. Without functioning water and wastewater systems the operation of restaurants, child care facilities, hotels, medical offices, food processing plants, paper mills, etc. is not possible. Additionally, water systems in urban and suburban areas provide emergency water supply for fire suppression. Chapter 2 discusses this societal dependence on water and wastewater systems and other lifelines in more detail.

In the United States, communities are generally willing to accommodate short-term (on the order of a few days) disruptions in water and wastewater services resulting from man-made or natural disasters. However, longer-term disruptions are less tolerable. The *Oregon Resilience Plan* (OSSPAC, 2013) indicated if business cannot reoccupy facilities (including functioning water and wastewater systems) within one month they will be forced to move or dissolve. This timeline likely varies depending on the needs of individual communities and the severity of the disaster. As detailed in Section 9.3, 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' current status in relation to those goals, and then develop strategies to close the identified resilience gaps.

#### **9.1.2. Interdependencies**

As described in Chapter 4, the operation and repair of water and wastewater systems is highly dependent

on other lifeline sectors. Other sectors are dependent on water and wastewater systems.

Water and Wastewater Systems depend on:

- **Transportation** – Water and wastewater utilities are dependent on roadway and bridge transportation systems for staff to access facilities for operation and repairs. Disaster damage to transportation infrastructure has the potential to complicate and lengthen repair times, or even prevent repairs in certain areas until roadways and bridges are accessible.
- **Transportation** – Water and wastewater buried pipelines are often co-located near other buried lifelines 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 when repairs are being made. Sometimes water and wastewater pipelines are co-located on bridges at river or other crossings. If not properly designed, relative movement between the bridge and surrounding soil could result in damage to the supported pipelines. Pipeline damage could result in damage to the bridge. For instance, if a supported water pipeline breaks due to relative movement between the bridge and surrounding soil, water flow from the broken pipe could cause scour of the soil supporting the bridge abutment and result in potential bridge collapse.
- **Transportation** – Water and wastewater utilities generally keep on hand a limited stock of pipe, fittings, and other repair materials. Depending on the size of the disaster, this stock may be quickly depleted. Utilities will rely on transportation networks to obtain additional repair materials from suppliers and other utilities. Also, utilities rely on a semi-regular delivery of water and wastewater treatment process chemicals. Supply chain disruption could lead to difficulty in meeting water quality and wastewater treatment regulations.
- **Energy** – Water and wastewater utilities rely on commercial electricity to run pumps, various components of processes equipment, and lab and office operations. Some of these functions have emergency backup generators, but overall power demands make it impractical to run a water or wastewater system entirely on backup generators.
- **Energy** – Water and wastewater utilities rely on a continual supply of fuel for trucks, equipment, and emergency generators. Disruption in fuel production, storage, or delivery could severely impact a utility's ability to continue limited operation on emergency generator power and perform repairs.
- **Communications and Information** – Water and wastewater utilities often rely on cellular networks for communication amongst operations staff and contractors. If the cellular network is down for an extended period of time, complications and delay in repairs can occur. This was observed in the 2010 Maule earthquake in Chile (Eidinger, 2012).
- **Customers** – Water and wastewater utilities rely on customers to pay bills as a continued source of operating capital. Utilities will potentially experience significant capital expenditures in the aftermath of a disaster and customers may not have the ability to pay bills, placing a large financial burden on the utilities.

Water and Wastewater Systems are required by:

- **Wastewater** – Wastewater collection systems are dependent on adequate water flow rates to keep sewage flowing. If the water system is down, sewer pipelines may quickly become plugged.
- **Communications and Information** – Air conditioning system cooling towers require water to keep sensitive electronic equipment in central offices at safe operating temperatures.
- **Hospitals** – Hospitals generally have a limited emergency water supply and ability to hold wastewater, but need water and wastewater services restored quickly to remain operational.
- **Fire Departments** – Fire Departments require a water supply with adequate fire flow and pressure for fire suppression.
- **Commercial Buildings** – Commercial buildings require a water supply with adequate fire flow and pressure for sprinkler systems; otherwise a fire watch may be necessary. Fire watch programs are expensive to maintain and may be cost prohibitive for any extended duration.

- **Restaurants** – Restaurants need water and wastewater service for cooking and cleaning.
- **Hotels** – Hotels need water and wastewater services for guest use and laundry.
- **Agriculture** – Horticulture crops and livestock need water for irrigation in areas where precipitation is insufficient.
- **Residential** – Residential water and wastewater use includes drinking, food preparation, bathing, etc.

These items illustrate how highly interdependent water and wastewater systems are with other lifeline systems and how dependent communities are on water and wastewater services to maintain normalcy.

## 9.2. Water Infrastructure

This section describes basic components of water and wastewater systems. Performance observations from past disaster events characterize some key disaster vulnerabilities in water and wastewater systems, especially for the high-seismicity regions of the western US, and areas around Charleston, South Carolina and Memphis, Tennessee. While seismic hazards can broadly impact water and wastewater systems given that earthquakes regularly cause damage to buried lifelines (e.g., water distribution and wastewater collection systems), other hazards can have major impacts on aboveground and below grade (unburied) facilities like treatment plants and pump stations. In fact, water and wastewater treatment facilities are vulnerable to flood hazards because they are often located in or near flood hazard areas by design, given their functional dependency on natural water resources. It is important to appropriately consider all identified hazards when evaluating disaster resilience of water and wastewater systems. System interdependencies (e.g., loss of commercial electrical power in a wind event) can have a significant impact on operability of water and wastewater systems (Elliott, T. and Tang, A., 2009).

### 9.2.1. Water Systems

Water systems provide potable water for household, commercial, and industrial use. Water is obtained from groundwater or surface water sources, treated to satisfy public health standards, and distributed to consumers by a network of pipelines. Some water utilities have their own supply and treatment infrastructure, while others buy wholesale water from neighboring agencies.

Water systems are composed of five general infrastructure categories: 1) Supply (i.e., groundwater wells and surface water), 2) transmission, 3) treatment, 4) pumping, and 5) storage. The basic function of each of these categories is briefly described below.

#### 9.2.1.1. Supply

**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 to keep its sides from caving in. 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 systems vary depending on source type. Increased turbidity (suspended solids) of surface water supplies can decrease the amount of raw water a treatment plant is able to process and may cause surface water sources to become temporarily unusable.

Typical damage to water supplies includes:

- Flooding can cause contamination of surface and ground water sources. Floodwaters are rarely “clean” and generally include contaminants like petroleum, nutrient/organic matter, bacteria, protozoa, and mold spores that pose significant health risks.

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- Earthquake-induced permanent ground displacement can cause well casing and well discharge piping damage. The force of moving ground can bend well casings and break well discharge piping.
- Increased turbidity of surface waters as a result of flooding can overwhelm water treatment systems. Water treatment processes include removal of particulates; however, their processes are based on a limited measure of turbidity existing prior to treatment. Floodwaters can have significantly increased turbidity that tax water systems and lead to treatment delays. Similarly, seismic events can trigger landslides which also impact turbidity. In the 2008 Wenchuan China earthquake, many landslides occurred in the mountainous region and led to increased turbidity in local waterways.
- In the 2011 Tohoku Japan earthquake, a tsunami inundated several freshwater intake facilities with seawater. These water intakes were unusable for a long period of time due to the high concentration of salts in the water (Miyajima, 2012). This type of salt water infiltration of water treatment systems is often experienced after storm surge events and as a result of coastal flooding in general.
- Reservoirs behind dams often serve as water supply features, but dam failure can present a secondary hazard in the wake of events including earthquakes, heavy rainfall, and flooding events.
  - Concentrated rainfall or precipitation and flooding can result in the most common means of dam failure: overtopping. While dams can control floods, many are specifically designed for other uses (e.g., water supply facilities), and therefore may not be equipped to contain large volumes of quickly accumulating surface water runoff. Additionally, older and poorly maintained dams are more vulnerable to overtopping or failure as the result of heavy precipitation and flooding.
  - In the 1971 San Fernando earthquake in Southern California, the Lower San Fernando Dam experienced a landslide and near failure. The event lowered the dam's crest about 30 ft and put 80,000 people at significant risk while the impounded water level was being lowered. These types of dam failures are rare, but present a significant life-safety risk to anyone downstream of a dam. Dams are critical infrastructure components that need to be designed to withstand extreme events.

#### 9.2.1.2. Transmission

Water system transmission and distribution pipelines are a significant asset class for water utilities. Large water utilities may have a network consisting of thousands of miles of pipelines. Typically these pipelines operate under pressure and are buried 2.5–6 feet or deeper underground, making them difficult to inspect and expensive and disruptive to repair. Pipeline material and joint type significantly influence the performance of a pipeline when it is located in an area subjected to permanent ground deformation occurring in an earthquake or landslide. Table 9-1 summarizes commonly in-place and currently used pipeline materials and joint types, along with their applicable American Water Works Association (AWWA) standard. Materials and joint types with no designated standard are no longer manufactured, but represent a significant portion of the installed pipelines in the US.

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*Table 9-1: Commonly Used Water Pipeline Materials, Standards, and Vulnerability To Ground Deformation (AWWA, 1994)*

Material Type and Diameter	AWWA Standard	Joint Type
<b>Low Vulnerability</b>		
Ductile Iron	C100 series	Bell-and-spigot, rubber gasket, restrained
Polyethylene	C906	Fused
Steel	C200 series	Arc welded
Steel	No designation	Riveted
Steel	C200 series	Bell-and-spigot, rubber gasket, restrained
<b>Low to Moderate Vulnerability</b>		
Concrete cylinder	C300, C303	Bell-and-spigot, restrained
Ductile iron	C100 series	Bell-and-spigot, rubber gasket, unrestrained
Polyvinyl chloride	C900, C905	Bell-and-spigot, restrained
<b>Moderate Vulnerability</b>		
Asbestos cement (> 8-in. diameter)	C400 series	Coupled
Cast iron (> 8-in. diameter)	No designation	Bell-and-spigot, rubber gasket
Polyvinyl chloride	C900, C905	Bell-and-spigot, unrestrained
Steel	C200 series	Bell-and-spigot, rubber gasket, unrestrained
<b>Moderate to High Vulnerability</b>		
Asbestos cement (≤ 8-in. diameter)	C400 series	Coupled
Cast iron (≤ 8-in. diameter)	No designation	Bell-and-spigot, rubber gasket
Concrete cylinder	C300, C303	Bell-and-spigot, unrestrained
Steel	No designation	Gas welded
<b>High Vulnerability</b>		
Cast iron	No designation	Bell-and-spigot, leaded or mortared

**Transmission Pipelines.** Large diameter (> 12 in) transmission pipelines carry raw water from a source to the treatment plant, and treated water to storage facilities and community sectors before branching out into smaller diameter distribution pipelines. Transmission pipelines can be thought of as the backbone of the pipeline system.

**Distribution Pipelines.** Smaller diameter (≤ 12 in) distribution pipelines carry treated water from transmission pipelines to neighborhoods and industrial areas. For some smaller utilities, major transmission lines may also fall in this diameter range. Service connections 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.

Buried pipelines are less vulnerable to some types of hazards (e.g., wind), but seismic events often result in widespread damage of buried infrastructure. Flood forces can also impact buried systems. Typical damage to water pipelines includes:

- Buried water pipelines can become exposed as a result of landslides (particularly in steeper terrain) or erosion associated with flood hazards. In these instances, pipe leaks, breaks and uncoupling of pipes are common. Breaks and leaks in buried water pipelines are one of the largest earthquake damage mechanisms in water systems.
  - “Leak” commonly refers to relatively minor damage to a pipe barrel or joint that results in minor to moderate water loss, but does not significantly impair the distribution system’s function.
  - “Break” commonly refers to major damage to a pipe barrel or joint that results in major water loss that may cause loss of pressure in a zone or nearby tanks to completely drain.

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- Pipeline leaks and breaks can cause collateral damage to adjacent infrastructure. Figure 9-1 shows the geyser from a water pipeline break in the 2011 Christchurch New Zealand earthquake and the damage it caused to the roadway. A major cause of pipeline breaks and leaks is liquefaction-induced permanent ground displacement. Large strains develop in pipelines at the movement boundaries between areas that did and did not experience permanent ground displacement. Another location of potential damage from permanent ground displacement is where pipelines cross active faults. Pipelines failed in past earthquakes at fault crossings that were not explicitly designed for the expected fault movement.
- Pipeline failures generally fall into one of several common types. Earthquake failure of pipe commonly initiates at locations of existing corrosion damage. For bell-and-spigot type joint pipe subjected to axial strains, pipe sections may pull apart (see Figure 9-2) or push together (“telescope”) resulting in damage to the pipe. Welded steel pipe may experience a similar axial compression failure where the walls of the pipe locally wrinkle to accommodate shortening of the pipe section (see Figure 9-3). Pipes may also fail in the middle of the pipe barrel, away from the joints (see Figure 9-4).



**Figure 9-1: Water Pipeline Break, Christchurch Earthquake, Christchurch, New Zealand, 2011**  
(Source: Eidinger & Tang, 2014)



**Figure 9-2: Pipeline Separated, Great Hyogoken-Nanbu Earthquake, Kobe, Japan, 1995** (Source: OSSPAC, 2013)



**Figure 9-3: Welded Steel Pipe Compression Failure, San Fernando Earthquake, California, 1971** (Source: OSSPAC, 2013)



**Figure 9-4: Water pipeline break, Christchurch earthquake, Christchurch, New Zealand, 2011**  
(Source: Eidinger & Tang, 2014)

- Pipeline damage is often concentrated at discontinuities such as pipe elbows, tees, in-line valves, reaction blocks, and service connections. Discontinuity creates a semi-support point that attempts to restrain movement of the pipe and causes locally high stresses in pipes and joints. If these stresses become too high the pipe or joint fails in a manner similar to one of the mechanisms described above.
- Major earthquakes continue to reveal new information about pipe material performance. For instance, in the City of Sendai in the 2011 Tohoku earthquake in Japan, polyvinyl chloride (PVC) pipe had twice the failure rate of steel or ductile iron pipe (Miyajima, 2012). Pipeline performance lessons

from past earthquakes have led to improvements in pipe materials and technology. Earthquake resistant ductile-iron pipe products have been developed in Japan. This pipe uses special restrained joints that accommodate axial and bending deformation in the joints. This type of pipe demonstrated good performance in the 1995 Kobe (NIST, 1996) and 2011 Tohoku (Tang & Edwards, 2014) earthquakes. High-Density Polyethylene (HDPE) pipe has been used by the natural gas industry for decades and is seeing increased use by water and wastewater utilities. HDPE water pipelines demonstrated good performance in the 2010 Chile (Eidinger, 2012) and 2011 Christchurch (Eidinger and Tang, 2014) earthquakes.

- Due to extensive damage to water distribution networks resulting in loss of service to individual customers, a system of emergency water distribution stations are often necessary after an earthquake. Figure 9-5 shows an example of a water distribution station employed after the 2010 Haiti earthquakes. Also, temporary small-scale water treatment plants were used after major earthquakes where the system treatment plant was not operational or operating at very limited capacity. Water systems typically rely on mutual aid and government resources to augment the limited trucked-in water distribution and treatment equipment that an individual utility may have available.
- In the Tohoku Japan earthquake, tsunami inundation resulted in erosion and several feet of scour that uncovered, undermined, and broke several large diameter (36 in and greater) pipelines (Tang & Edwards, 2014). It is expected that more tsunami damage to pipelines will be revealed as areas in the inundation zone are rebuilt.
- Water pipelines co-located on bridges often experience damage as a result of flood inundation and/or 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.
- Soil saturation combined with rising groundwater levels can result in uplift or buoyancy forces on buried pipelines and transmission structures leading to breaks within the system.



*Figure 9-5: Water Distribution Location, Haiti Earthquake, Port Au Prince, 2010  
(Source: Photo by Don Ballantyne)*

### 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. Various processes are used, depending on the raw water source, to remove pathogens, organic or inorganic contaminants, chemicals, and turbidity. 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.

Typical damage to water treatment plants includes:

- 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 as the result of flood inundation, leading to loss of functionality and service outages.
- Hydrodynamic forces generated from liquid movement within a process tank during an earthquake often cause damage to process tank covers, baffles, clarifiers, and other submerged equipment. This sloshing damage to process tank components has been observed in all recent major earthquakes (Ballantyne and Crouse, 1997; NIST, 1996; Schiff, 1997).



- Liquefaction-induced permanent ground displacement causes separation of process tank construction joints, damage to pipelines, pipe racks, etc. Figure 9-6 shows pipeline damage due to differential settlement between the ground and an adjacent pile supported building.
- Seismic performance of buildings at water treatment plants is dependent upon the type and year of original construction and any seismic retrofits that may have been completed. Unreinforced masonry and older tilt-up concrete buildings are particularly vulnerable to damage in earthquakes.
- Building performance as a result of wind events is also dependent on building construction type and year. Building codes continue to incorporate strengthened wind-resistant design and construction requirements, but older building stock is at a higher risk. Buildings with continuous load paths for all loads (gravity, uplift and lateral), protection for openings (windows, doors), and adequate roof and wall coverings are better protected against the wind hazard.
- Temporary, small-scale water treatment plants (see Figure 9-7) are sometimes used after major earthquakes in areas where the system treatment plant is not operational or operating at very limited capacity. Water systems typically rely on mutual aid and government resources to augment the limited temporary treatment equipment that an individual utility may have available.



**Figure 9-6: Pipeline Damage Due To Differential Settlement Between Ground and Pile Supported Building, Tohoku Earthquake, Japan, 2011**  
*(Source: Tang & Edwards, 2014)*



**Figure 9-7: Temporary Water Treatment Plant, Haiti Port Au Prince Earthquake, 2010**  
*(Source: Photo by 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.

Typical damage to water pump stations includes:

- Loss of commercial electrical power due to any type of hazard event prevents operation of pumps if there is no backup power supply.
- Floodwater inundation of pumps can disable and damage pumps and their motors.
- Floodwater inundation of electrical equipment and controls at pump stations located wholly or partially below grade and/or in flood-prone areas. Figure 9-8 shows a pump station adjacent to the Missouri River damaged by flood inundation.
- Seismic performance of pump station buildings is dependent upon the type and year of original construction and any seismic retrofits that may have been completed. Figure 9-9 shows significant cracking of the unreinforced masonry wall at a pump station after the 2011 Christchurch earthquake in New Zealand.



**Figure 9-8: Bismarck, ND Pump Station Damaged By Flood Inundation From Adjacent Missouri River (Source: FEMA)**



**Figure 9-9: Pump Station Damage Due To Differential Settlement, Christchurch New Zealand Earthquake, 2011 (Source: Eidinger & Tang, 2014)**

- Building performance as a result of wind events is dependent on building construction type and year and the overall ability of the building envelope to stay intact during high winds as well as having a continuous load path.

#### 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 average daily water demand is stored to satisfy increased usage demands from fire suppression or other emergency needs. Elevated storage tanks can be used to increase hydraulic head, as required by the characteristics of the distribution system.

Modern utility-scale storage tanks and reservoirs are constructed of steel or concrete. Typical construction types and their associated design standard are indicated in Table 9-2. Potable water in-ground reservoirs are often concrete-lined earthen structures. Security concerns require the reservoirs to be covered, typically with a concrete, metal, or wood roof supported by intermediate columns.

**Table 9-2: Tank/Reservoir Types And Design Standard**

Tank/Reservoir Type	Design Standard <sup>1</sup>
Ground-supported steel reservoir	AWWA D100
Steel standpipe	AWWA D100
Elevated steel tank	AWWA D100
Reinforced concrete tank	ACI 350
Wire- and strand- wound, circular, prestressed concrete tank	AWWA D110
Tendon-prestressed concrete tank	AWWA D115

Typical damage to water storage tanks and reservoirs includes:

- 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 resulting in sudden release of their contents. High winds present a higher hazard in coastal areas.
- At grade or partially underground storage tanks are more susceptible to flood damage, particularly if located in or near flood-prone areas. Hydrostatic forces from standing or slow moving water or hydrodynamic forces imposed by higher velocity flows or wave action can damage or cause failure of the tanks. Buoyancy forces can cause uplift of subgrade tanks if the soil becomes saturated.
- Inlet and outlet piping connections on water storage tanks and reservoirs are prone to damage from a variety of hazards, particularly when the storage tank itself is damaged or fails. Figure 9-10 shows mechanical piping joints adjacent to a steel tank that were separated during the 1994 Northridge

<sup>1</sup> AWWA is American Water Works Association. ACI is American Concrete Institute.

earthquake. This type of damage typically occurs because a tank/reservoir is not adequately anchored to the ground or because of permanent ground deformation in the area surrounding the tank.

- Earthquake shaking induces hydrodynamic forces in the liquid retained within a tank that must be resisted by the tank's walls. If the tank wall thickness is not adequate to resist these loads, the tank wall may buckle. This type of buckling damage is commonly referred to as elephant's foot buckling because the buckled shape (see Figure 9-11) resembles the foot on an elephant.

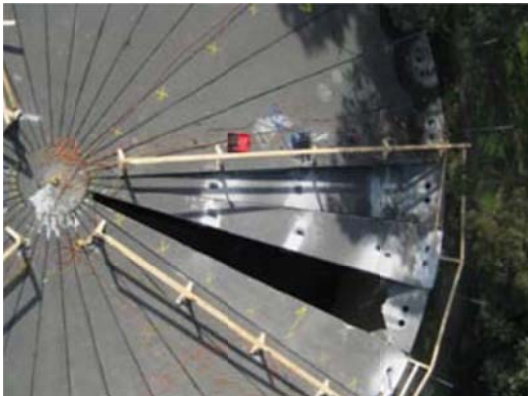


*Figure 9-10: Tank Piping Separated, Northridge Earthquake, California, 1994 (Source: Schiff, 1997)*



*Figure 9-11: Steel Tank "Elephant's Foot" Buckling, Northridge Earthquake, California, 1994 (Source: Photo by Don Ballantyne)*

- Hydrodynamic forces generated from liquid movement within a tank during an earthquake often cause damage to tank roofs and submerged piping and equipment within a tank. Figure 9-12 shows damage to a concrete roof panel due to water sloshing around inside the tank during the earthquake.
- Water storage tanks are often located on high ground to help maintain adequate water pressure for customers. The ground around these water storage tanks often slopes away from the tank at a moderate to steep grade and may present a geotechnical landslide hazard.



*(a) Overview*



*(b) Close-up*

*Figure 9-12: Segmented Concrete Reservoir Roof Damage, Christchurch Earthquake, Christchurch, New Zealand, 2010 (Source: Eidinger & Tang, 2014)*

- Water storage tanks (especially partially empty tanks) in a tsunami inundation zone may be subjected to buoyancy (uplift) and wave impact forces that may be much larger than the seismic anchorage the tank was designed to resist. Figure 9-13 shows an example of this behavior: two liquid fuel tanks in the foreground were floated and toppled by tsunami wave inundation after the 2011 Tohoku Japan earthquake. The tank in the background was on higher ground and does not appear to be damaged.



*Figure 9-13: Steel Tanks Displaced Due To Tsunami Inundation, Tohoku Earthquake, Japan, 2011 (Source: Tang & Edwards, 2014)*

### 9.2.2. Wastewater Systems

Wastewater systems collect domestic and industrial liquid waste products and convey them to a treatment plant in a sewer (pipeline). After separation of solids, processing and disinfection, treated wastewater is discharged as effluent into a receiving body of water or may be reused for irrigation or other purposes. Some utilities have separate collection systems for wastewater and storm water. Other utilities have collection systems that are combined and collect both wastewater and storm water in the same pipelines.

Wastewater systems are composed of three general categories of infrastructure: 1) collection, 2) treatment, and 3) pumping. The basic function of each of these categories is briefly described below.

#### 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. Also, as opposed to water pipelines that operate under

*Table 9-3: Wastewater Collection Pipe Types and Design Standard*

Wastewater Collection Pipe Type	Design Standard <sup>2</sup>
Clay pipe	ASTM C700
Prestressed concrete cylinder pipe	AWWA C301
Polyvinyl Chloride (PVC) pipe, gravity	ASTM D3034
Polyvinyl Chloride (PVC) pipe, force main	AWWA C900
Ductile iron pipe	ASTM A746 and AWWA C150
High-density polyethylene (HDPE) pipe	ASTM F714

pressure, sewer lines are generally gravity feed systems that are not under pressure. 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. In some instances pumps convey wastewater through pressurized force mains. A variety of pipe materials (see Table 9-3) are commonly used for constructing new collection pipelines and repair of existing pipes.

Buried pipelines are less vulnerable to some types of hazards, including wind, but seismic events can result in widespread damage of buried infrastructure. Flood forces can also impact buried systems. Typical damage to wastewater collection pipelines includes:

- Similar to water distribution systems, wastewater collection pipelines can be exposed and damaged as a result of landslides or erosion. This can lead to damage or breaks within the pipelines.

<sup>2</sup> ASTM is American Society for Testing and Materials. AWWA is American Water Works Association.

- Liquefaction-induced permanent ground displacement causes breaks and collapses of sewer pipelines. Observations from past earthquakes indicate approximately one sewer pipe collapse occurs for every 10 breaks and leaks in water pipelines (OSSPAC, 2013).
- Liquefaction often induces floating of manholes and sewer pipelines (see Figure 9-14). These changes in pipeline and structure invert elevations can cause disruption to the collection system gravity flow.
- Cracked and broken sections of pipe lead to significant increases in infiltration and inflow rates (see Figure 9-15). Increased flow rate creates excess demand on the already reduced capacity of wastewater treatment plants after earthquakes.



**Figure 9-14: Manhole Floated due to Liquefaction, Christchurch Earthquake, Christchurch, New Zealand, 2011 (Source: Eidinger & Tang, 2014)**



**Figure 9-15: Sewer Pipeline Break, Christchurch Earthquake, Christchurch, New Zealand, 2011 (Source: Eidinger & Tang, 2014)**

- Sometimes wastewater pipelines are co-located on bridges at river or other crossings. If not properly designed, relative movement between the bridge and surrounding soil could result in damage to the supported pipelines. Figure 9-16 shows a sewer pipeline attached to a bridge. The pipeline was damaged by differential settlement between adjacent bridge supports, resulting in discharge of raw wastewater directly to the river.
- Wastewater collection pipelines that are co-located on bridges experience damage as a result of 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.
- Soil saturation combined with rising groundwater levels can result in uplift or buoyancy forces on buried pipelines and collection system structures leading to ruptures and breaks within the system.



**Figure 9-16: Sewer Pipeline Break Due To Bridge Support Settlement, Christchurch Earthquake, Christchurch, New Zealand, 2011 (Source: Eidinger & Tang, 2014)**

#### 9.2.2.2. Treatment

Wastewater treatment plants process raw sewage from household and industrial sources so the resulting effluent discharge meets public health standards. Various screens, sedimentation tanks, aeration tanks, and clarifiers remove organic and inorganic components of the raw wastewater influent. Sludge removed from primary sedimentation tanks is typically processed in anaerobic digesters. Wastewater treatment plants typically consist of a number of process tanks, yard and plant piping, pumps, chemical storage and

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feed equipment, lab and office building space, and associated mechanical, electrical and control equipment.

Typical damage to wastewater treatment plants includes:

- Wastewater treatment plants are often located in or near flood-prone areas because they return large volumes of treated water to naturally occurring bodies of water via gravity (see Figure 9-17). Therefore, they can be vulnerable to flood inundation from riverine or coastal sources resulting in damages to buildings, equipment, and electrical and mechanical systems and loss of functionality. The New York City Department of Environmental Protection (NYC DEP) noted in a recent study that all 14 of the WWTPs it owns and operates are at risk of flood damage (NYCDEP, 2013).



**Figure 9-17: Wastewater Treatment Plants Are Often Located Adjacent To Or Along Waterways In Flood-Prone Areas. Hunts Point WWTP Along the East River In New York City Is Shown Here.**

*(Source: NYC DEP, 2013)*

- During Sandy over 560 million gallons of untreated and diluted sewage mixed with stormwater and seawater was released into waterways. This occurred as a result of infiltration of floodwaters into the sewer system, flood inundation of plant facilities, and power outages (NYC DEP, 2013).
- The Hurricane Sandy Mitigation Assessment Team (MAT) Report investigated damages at three WWTPs in the New Jersey and New York metropolitan area as a result of storm surge inundation including the Passaic Valley Sewerage Commission Wastewater Treatment Plant in Newark, NJ, the Bay Park Sewage Treatment Plant East Rockaway, NY and the Yonkers Wastewater Treatment Plant Yonkers, NY (FEMA, 2013). Some damage they experienced included:

- A clarifying tank located in a basin with a height of 13 feet was overtopped at the Passaic Valley Sewerage Commission Wastewater Treatment Plant in Newark, NJ.
- Electronic controls were inundated and damaged in many facilities, as shown in Figure 9-18, which delayed the facilities' recovery times significantly.
- Floodwater inundation damaged other mechanical and electrical systems and components of the wastewater treatment process including settling tanks and biological treatment systems.



**Figure 9-18: Subgrade Electric System Damaged By Floodwater at the Passaic Valley Sewerage Commission Wastewater Facility (FEMA, 2013)**

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- Many WWTPs are interconnected below grade via tunnels and utility conduits. During flood inundation, floodwaters can enter and travel via these pathways causing damage to utilities located within them and reaching some facilities and buildings that might otherwise be protected from floodwaters. Figure 9-19 shows floodwaters being pumped out of lower levels of WWTP.
- Wastewater collection systems are generally gravity feed, meaning that the wastewater treatment plant is at a low point in the elevation of the system. Unfortunately these low points often coincide with areas of greater liquefaction potential during earthquakes. Liquefaction induced permanent ground displacement has often caused process tank joint separation (see Figure 9-20 and Figure 9-21), damage to pipelines, pipe racks, etc.



*Figure 9-19: Floodwaters Are Pumped Out of Lower Levels of a WWTP In the Atlanta Area After Severe Storms Resulted In Significant Damage*



*Figure 9-20: Process Tank Joint Offset Due To Permanent Ground Deformation, Maule Earthquake, Chile, 2010 (Source: Photo by Kent Yu)*



*Figure 9-21: Chlorine Contact Tank Joint Separation Due To Permanent Ground Deformation, Maule Earthquake, Chile, 2010 (Source: Photo by Kent Yu)*

- The hydrodynamic forces generated from liquid movement within a tank during an earthquake often cause damage to process tank covers, baffles, and other submerged equipment. Figure 9-22 shows missing process tank roof panels due to damage from liquid sloshing around inside the tank during the earthquake. Figure 9-23 shows damage to clarifier equipment due to hydrodynamic forces of sloshing liquid within the tank.
- Damage to chain-driven solids collection systems (scrapers, etc.) has been observed in many past earthquakes. Damage consists of dislodged chains or sprockets and broken scraper blades caused by hydrodynamic forces from liquid movement within the tank (see Figure 9-24).
- Plant components are often connected by catwalks or other small access bridges. These bridges may support electrical conduit and process piping. Differential movement between components (i.e., two process tanks moving in different directions from seismic shaking) can damage these catwalks and supported utilities. Similarly, high wind events can damage these types of features. Figure 9-25 shows where one bridge experienced a permanent offset of about 12 inches and caused separation of electrical conduit and exposed wires during the 2010 Maule earthquake in Chile.

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**Figure 9-22: Process Tank Roof Damage Due To Sloshing, Maule Earthquake, Chile, 2010**  
(Source: Photo by Kent Yu)



**Figure 9-23: Clarifier Equipment Damage Due To Sloshing, Maule Earthquake, Chile, 2010**  
(Source: Photo by Kent Yu)



**Figure 9-24: Damage To Chain-Driven Scraper, Tohoku Earthquake, Japan, 2011** (Source: *Matsuhashi, et al., 2012*)



**Figure 9-25: Damage To Electrical Conduit Due To Bridge Movement, Maule Earthquake, Chile, 2010** (Source: Photo by Kent Yu)

- Seismic performance of buildings at wastewater treatment plants is dependent upon the type and year of original construction and any seismic retrofits. Unreinforced masonry and older tilt-up concrete buildings are particularly vulnerable to damage in earthquakes. Similarly, building performance during high wind events is dependent on the age and type of original construction and any retrofits. WWTPs in coastal areas are generally more vulnerable to high winds than those inland.
- Nonstructural damage to lab and office spaces at wastewater treatment plants may impact continued operation of the facility (especially the lab). If paper drawing files are water damaged by broken sprinkler lines or lab equipment topples onto the floor because it is not adequately anchored, the ability of staff to perform their jobs after an earthquake will be hampered.
- Tsunami inundation may flood aboveground infrastructure causing damage to pumps, motors, and other equipment. High velocity water flows around wastewater treatment plants may cause scour damage to pipe rack foundations, buried tanks, pipelines, etc. (see Figure 9-26 and Figure 9-27). A major seismic structural upgrade was performed at the main wastewater treatment plant for the City of Sendai. The 2011 Tohoku earthquake's shaking caused no damage to the plant. However, the tsunami completely inundated the plant causing significant damage and a complete shutdown. Repair costs were estimated to be \$1 billion US dollars (Tang & Edwards, 2014).





*Figure 9-26: Collapse of Pipe Rack next to Digesters due to Tsunami Scour, Tohoku Earthquake, Japan, 2011 (Source: Tang & Edwards, 2014)*



*Figure 9-27: Eroded Pipe Support Foundation due to Tsunami Scour, Tohoku Earthquake, Japan, 2011 (Source: Tang & Edwards, 2014)*

### **9.2.2.3. Pumping**

Pump or lift stations may be required in a predominately gravity feed system 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. Pump stations may have standby emergency generators to enable continued operation when the commercial power supply is interrupted.

Pump stations are often located in low-lying areas or below ground since they move water along below grade sewage collection pipelines. This makes them vulnerable to flooding and liquefaction during earthquakes.

Typical damage to wastewater pump stations includes:

- Floodwater inundation of pumps can disable and damage the pumps and their motors if they are not submersible type pumps. This was a common cause of pump station failure within New York City during flood inundation from Sandy (NYCDEP, 2013).
- Floodwater inundation of electrical equipment and controls.
- Liquefaction during seismic events can cause buried pump station wastewater collections wells to float and tilt (see Figure 9-28). This movement is also likely to damage connecting piping and possibly render the pump station inoperable.
- Loss of commercial electrical power prevents operation of pumps if there is no backup power supply.
- Tsunami inundation may flood aboveground infrastructure causing damage to pumps, motors, and other equipment. High velocity water flows around pump stations may cause scour damage to buried collection wells and pipelines.
- Tsunami inundation can cause significant damage to above-grade structures due to hydrodynamic wave forces and debris impact forces. Figure 9-29 and Figure 9-30 illustrate typical significant damage to pump stations from tsunami forces. Similar tsunami damage can be expected for other above-grade structures.



*Figure 9-28: Pump Station Well Floated and Tilted Due To Liquefaction, Christchurch Earthquake, Christchurch, New Zealand, 2011 (Source: Eidinger & Tang, 2014)*



*Figure 9-29: Structural Damage From Tsunami Wave and Debris Impact, Tohoku Earthquake, Japan, 2011 (Source: Tang & Edwards, 2014)*



*Figure 9-30: Structural Damage From Tsunami Wave and Debris Impact, Tohoku Earthquake, Japan, 2011 (Source: Tang & Edwards, 2014)*

### **9.2.3. Combined Storm and Sewer Lines**

A combined sewer system is designed to collect storm water runoff, domestic sewage, and industrial wastewater in the same pipe. When heavy rainfalls produce a volume of water that exceeds the capacity of the wastewater treatment plant, untreated sewer contents may flow directly into the receiving body of water. Combined sewer overflow (CSO) may contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. Over the last 25 plus years, wastewater utilities have made significant investments to minimize CSOs and meet requirements of the 1972 Clean Water Act. Various combinations of approaches have mitigated CSOs, including:

- **Expanded treatment capacity** – Adding treatment capacity to the wastewater system to handle the combined sewer flow associated with large storm events.
- **Sewer separation** – Adding a second separate piping system to decouple the sanitary and storm water collection systems.
- **CSO storage** – Adding storage capacity (typically one or more tunnels) to collect and store the combined sewer flow associated with large storm events. After the storm event the stored wastewater is then pumped to the wastewater treatment plant for processing as capacity is available.
- **Screening and disinfection** – Facilities are added to enable the flows to be treated with sodium hypochlorite for disinfection and solids greater than about 0.25 in. are removed with a series of screens. Solids are directed to the wastewater treatment plant for processing and the treated water effluent is directed to the receiving body of water.

### **9.3. Performance Goals**

The large and distributed nature of water and wastewater systems, combined with their interdependence on other lifelines, limits the practicality of maintaining 100 percent operational capacity in the aftermath of a major natural disaster. This section identifies a recommended level of service performance goals for water and wastewater systems.

We provide a recommended level of service performance goals as a starting point; they 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 specific community. It is critical that all water and wastewater stakeholders be engaged in establishing community-specific level of service performance goals for each of the three different hazard levels (*routine*, *expected*, and *extreme*) discussed in Section 2.1.2. This group of stakeholders should include representation from:

- Residential customers
- Business customers
- Industrial customers (if applicable)
- Water wholesale customers (if applicable)
- Hospital customers (if applicable)
- Firefighters
- 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 lifelines (power, liquid fuel, transportation, etc.)

The process of establishing performance goals involves a discussion amongst the stakeholders about their expectations for the availability of water and wastewater systems during post-disaster response and recover phases for different hazard levels (e.g., *routine*, *expected*, and *extreme*). The assumed expectation of the general public is that for *routine* disasters 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.

There may be elements in a system that are so critical to public safety that they need to be designed to remain operational after an *extreme* event. For example, failure of a water supply impoundment dam would present a significant life-safety hazard to downstream residents, and should be designed for an *extreme* event.

Interdependencies of water and wastewater systems with other lifelines 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 backup emergency generators and impacts the vehicles and equipment needed by repair crews. Delivery of liquid fuels is in turn dependent on the status of the highway and bridge transportation network.

Table 9-4 and Table 9-5 provide recommended water and wastewater system performance goals for post-disaster response and recovery for an *expected* wind or seismic event. 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.

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*Table 9-4: Detailed Infrastructure System Resilience Matrix – Water*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

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+			
<b>Source</b>		1												
Potable water at supply (WTP, wells, impoundment)			30%		60%	90%				X				
Water for fire suppression at key supply points			90%				X							
<b>Transmission (including Substations)</b>		1												
Backbone transmission facilities (pipelines, pump stations, and reservoirs)			90%						X					
<b>Distribution</b>														
<b>Critical Facilities</b>		1												
Hospitals, EOC, Police Station, Fire Stations				60%	90%				X					
<b>Emergency Housing</b>		1												
Emergency Shelters				60%	90%				X					
<b>Housing/Neighborhoods</b>		2												
Drink water available at community distribution centers					60%	90%								
Water for fire suppression at fire hydrants						90%						X		
<b>Community Recovery Infrastructure</b>		3												
All other clusters					30%	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

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**Table 9-5: Detailed Infrastructure System Resilience Matrix – Wastewater**

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

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+
<b>Treatment Plants</b>											
Treatment plants operating with primary treatment and disinfection					60%	90%					
Treatment plants operating to meet regulatory requirements						30%			60%	90%	X
<b>Trunk Lines</b>											
Backbone collection facilities (major trunklines and pump stations)						30%		60%	90%		X
<b>Collection Lines</b>											
<b>Critical Facilities</b>											
Hospitals, EOC, Police Station, Fire Stations					30%	90%					X
<b>Emergency Housing</b>											
Emergency Shelters					30%	90%					X
<b>Housing/Neighborhoods</b>											
Threats to public health and safety controlled by containing & routing raw sewage away from public				30%		60%	90%				X
<b>Community Recovery Infrastructure</b>											
All other clusters						30%		60%		90%	X

**Footnotes:**

- 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
- 30% 60% 90% Restoration times relate to number of elements of each cluster
- 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
- Indicate levels of support anticipated by plan  
R Regional  
S State  
MS Multi-state  
C Civil Corporate Citizenship
- Indicate minimum performance category for all new construction.  
See Section 3.2.6

It is assumed that 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 the concept of a hardened backbone system. This backbone network should be capable of supplying key health and safety related community needs shortly after a disaster, while more extensive repairs are being completed on the remainder of the system. Performance goals are based on a balance of societal needs and realistic expectations of system performance.

**9.4. Regulatory Environment**

Water and wastewater utilities are subject to rules and regulations that are generally intended to protect public health and safety and the environment. These regulatory requirements are administered by Federal, State, and Local governmental agencies.

#### 9.4.1. Federal

United States Environmental Protection Agency (EPA)

- **Safe Drinking Water Act**
  - **Contaminant Level Limits** – EPA sets limits on levels of certain chemical and microbial contaminants in drinking water.
  - **Underground Injection Control (UIC)** – EPA regulates construction, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal.
- **Clean Water Act**
  - **Analytical Methods** – EPA publishes laboratory test procedures for use by industry and municipalities to analyze the chemical, physical, and biological components of wastewater.
  - **Effluent Limitations Guidelines** – EPA establishes regulations for industrial wastewater discharges to surface waters and publicly owned treatment works.
  - **National Pollutant Discharge Elimination System (NPDES)** – EPA controls water pollution by regulating point sources of pollutant discharge through the NPDES permit system.

#### 9.4.2. State

- **State Drinking Water Programs (e.g., Oregon Health Authority, Drinking Water Services)**. States ensure water systems meet Safe Drinking Water Act standards. They ensure water systems test for contaminants, review plans for water system improvements, conduct on-site inspections and sanitary surveys, provide training and technical assistance, and take action against water systems not meeting standards.
- **State Water Quality Programs (e.g., Oregon Department of Environmental Quality, Water Quality Division)**. States ensure water systems meet water quality standards. 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 wastewater systems not meeting standards.

#### 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 industry uses codes, standards, and guidelines to establish minimum acceptable criteria for design, assessment, and construction. Table 9-6 summarizes available codes, standards, and guidelines for design, assessment, and retrofit of water systems components. Table 9-7 provides a similar summary for wastewater systems.

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*Table 9-6: Water System Codes, Standards, and Guidelines*

Component	Organization*	Code, Standard, or Guideline
General	ALA	Seismic Fragility Formulations for Water Systems (2001)
		Guidelines for Implementing Performance Assessments of Water Systems (2005)
	AWWA	Minimizing Earthquake Damage, A Guide for Water Utilities (1994)
		G430-09 Security Practices for Operation and Management
		J100-10 Risk Analysis and Management for Critical Asset Protection (RAMCAP) Standard for Risk and Resilience Management of Water and Wastewater Systems
		M19 Emergency Planning for Water Utilities
		M60 Drought Preparedness and Response
	ICC	2012 International Building Code or applicable jurisdictional building code (for buildings and other structures)
	MCEER	MCEER-08-0009 Fragility Analysis of Water Supply Systems (2008)
TCLEE	Monograph 22 Seismic Screening Checklists for Water and Wastewater Facilities (2002)	
Supply	AWWA	A100-06 Water Wells
		M21 Groundwater
Transmission	ACI	346-09 Specification for Cast-in-Place Concrete Pipe
	ALA	Guidelines for the Design of Buried Steel Pipe (2001)
		Seismic Guidelines for Water Pipelines (2005)
	ASCE	Guidelines for Seismic Design of Oil and Gas Pipeline Systems (1984)
	AWWA	C200-12 Steel Water Pipe 6 Inch (150 mm) and Larger
		C300-11 Reinforced Concrete Pressure Pipe, Steel-Cylinder Type
		C301-07 Prestressed Concrete Pressure Pipe, Steel-Cylinder Type
		C302-11 Reinforced Concrete Pressure Pipe, Noncylinder Type
		C303-08 Concrete Pressure Pipe, Bar-Wrapped, Steel Cylinder Type
		C304-07 Design of Prestressed Concrete Cylinder Pipe
		C600-10 Installation of Ductile-Iron Mains and Their Appurtenances
		C604-06 Installation of Steel Water Pipe – 4 In. (100 mm) and Large
		C905-10 Polyvinyl Chloride (PVC) Pressure Pipe & Fabricated Fittings, 14 in. Through 48 in. (350 mm Through 1,200 mm) for Water Transmission and Distribution
		C906-07 Polyethylene (PE) Pressure Pipe & Fittings 4 In (100 mm) Through 63 In (1,575 mm) for Water Distribution and Transmission
		C909-09 Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4” – 24” (100 mm Through 600 mm) for Water, Wastewater, and Reclaimed Water Service
		M9 Concrete Pressure Pipe
		M11 Steel Pipe: A Guide for Design and Installation
		M23 PVC Pipe – Design and Installation
		M31 Distribution System Requirements for Fire Protection
	M41 Ductile-Iron Pipe and Fittings	
	M42 Steel Water Storage Tanks	
	M55 PE Pipe – Design and Installation	
	MCEER	Monograph Series No. 3 Response of Buried Pipelines Subject to Earthquakes (1999)
Monograph Series No. 4 Seismic Design of Buried and Offshore Pipelines (2012)		
TCLEE	Monograph 15 Guidelines for the Seismic Evaluation and Upgrade of Water Transmission Facilities (1999)	
Treatment	ACI, AWWA	Storage tank documents indicated below, as applicable
	ALA	Seismic Design and Retrofit of Piping Systems (2002)
	WEF	MOP 28 Upgrading and Retrofitting Water and Wastewater Treatment Plants
Pumping	ALA	Seismic Design and Retrofit of Piping Systems (2002)

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Component	Organization*	Code, Standard, or Guideline
Storage	WEF	MOP 28 Upgrading and Retrofitting Water and Wastewater Treatment Plants
	ACI	350.3-06 Seismic Design of Liquid-Containing Concrete Structures and Commentary
		350.4R-04 Design Considerations for Environmental Engineering Concrete Structures
		371R-08 Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks
		372R-03 Design and Construction of Circular Wire- and Strand-Wrapped Prestressed Concrete Structures
	AWWA	D100-11 Welded Carbon Steel Tanks for Water Storage
		D110-13 Wire- and Strand-Wound, Circular, Prestressed Concrete Tanks
D115-06 Tendon-Prestressed Concrete Water Tanks		

*Table 9-7: Wastewater System Codes, Standards, and Guidelines*

Component	Organization <sup>3</sup>	Code, Standard, or Guideline
General	ALA	Wastewater System Performance Assessment Guideline (2004)
	AWWA	J100-10 Risk Analysis and Management for Critical Asset Protection (RAMCAP) Standard for Risk and Resilience Management of Water and Wastewater Systems
	WEF	Emergency Planning, Response, and Recovery
		Guide for Municipal Wet Weather Strategies
		MOP FD-17 Prevention and Control of Sewer System Overflows
	ICC	2012 International Building Code or applicable jurisdictional building code (for buildings and other structures)
TCLEE	Monograph 22 Seismic Screening Checklists for Water and Wastewater Facilities (2002)	
Collection	ACI	346-09 Specification for Cast-in-Place Concrete Pipe
	ALA	Guidelines for the Design of Buried Steel Pipe (2001)
	ASCE	Guidelines for Seismic Design of Oil and Gas Pipeline Systems (1984)
	MCEER	Monograph Series No. 3 Response of Buried Pipelines Subject to Earthquakes (1999)
		Monograph Series No. 4 Seismic Design of Buried and Offshore Pipelines (2012)
	WEF	MOP FD-5 Gravity Sanitary Sewer Design and Construction
MOP FD-6 Existing Sewer Evaluation and Rehabilitation		
Treatment	ACI	350-06 Code Requirements for Environmental Engineering Concrete Structures and Commentary
		350.3-06 Seismic Design of Liquid-Containing Concrete Structures and Commentary
		350.4R-04 Design Considerations for Environmental Engineering Concrete Structures
		372R-03 Design and Construction of Circular Wire- and Strand-Wrapped Prestressed Concrete Structures
	ALA	Seismic Design and Retrofit of Piping Systems (2002)
	WEF	MOP 8 Design of Municipal Wastewater Treatment Plants
		MOP 28 Upgrading and Retrofitting Water and Wastewater Treatment Plants
Pumping	ALA	Seismic Design and Retrofit of Piping Systems (2002)

One shortcoming is that codes and standards do not take into account differences in expected lifespan of infrastructure when defining the design hazard level. Pipelines and other components of water and wastewater systems often have a service lifespan of 100 years, compared with the typical service lifespan of 50 years for buildings. Therefore, the implied level of reliability of a pipeline designed for a particular hazard level (i.e., 500-year return period earthquake) is less than that of a building designed for the same

<sup>3</sup> ACI is American Concrete Institute. ASCE is American Society of Civil Engineers. AWWA is American Water Works Association. ICC is International Code Council. MCEER is Multidisciplinary Center for Earthquake Engineering Research. TCLEE is Technical Council on Lifeline Earthquake Engineering. WEF is Water Environment Federation.



hazard level due to longer expected service life of the pipeline (i.e., a pipeline in the ground for 100 years is more likely to experience the design earthquake than one in the ground for 50 years).

### 9.5.1. New Construction

#### 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 and seismic 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 or seismic event. By designing for this performance target for the *expected* level event it is assumed that water and wastewater systems would remain operational under a *routine* level event and may experience moderate to major damage during an *extreme* level event.

For the design of new underground pipelines there is a lack of a standard 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 design practices for their agency. While these agency-specific design practices are generally based on industry recommendations, variability in standards used by utilities results in variability between utilities in the intended system reliability for natural and man-made hazards.

Some utilities develop their own standards to specifically address significant local hazards. 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, but are intended to ensure the SFPUC is able to achieve its basic level of service performance goal of delivering winter day demand to their wholesale customers within 24 hours after a major earthquake.

#### 9.5.1.2. Recovery Levels

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 a water or wastewater system to return to normal operating status following a major disaster 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.). For instance, if a pump is damaged by an earthquake and will take six months to repair, but a redundant pump is undamaged, the system recovery time is not impacted by the six month repair time. Estimating system recovery times for a specific hazard requires in-depth engineering and operational knowledge of the system.

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Table 9-8 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 9-8: Water and Wastewater System Component Performance and Recovery Levels for Various Earthquake Hazard Levels as Implied by Current Codes and Standards for New Construction***

<b>System Component</b>	<b>Hazard Level</b>	<b>Performance Level</b>	<b>Recovery Level</b>
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 has been refined over time as the engineering and seismology communities understanding of the seismicity of the United States has 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 used by current codes and standards.

Expected seismic performance of water and wastewater system components is dependent on the hazard level and codes and standards used in original design. 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 earthquake behavior of structures. 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 where there has not been a significant increase in seismicity, are generally expected to perform similar to new construction as described above.

Expected performance of nonstructural components should be evaluated on a case-by-case basis, as engineers have only recently started to pay close attention to seismic design and construction of nonstructural components. Expected 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.

#### 9.5.2.2. Recovery Levels

In general, the recovery timeframe for system components will decrease for newer construction or retrofit. The *Oregon Resilience Plan* (OSSPAC, 2013) estimated the restoration time for pre-1975 structures to be 18 months to three years, 1975–1993 structures to be three to six months, and 1994 to present structures to be one to three months.

### 9.6. Resilience Assessment Methodology

#### 9.6.1. Assessment Methodology

Section 9.2 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. This information about past disaster performance of similar systems, combined with knowledge of current condition and original design standards of the system, helps a utility estimate the expected level of service they would be able to provide after a major disaster. There is likely to be a gap in the level of service a system would provide if a major disaster occurred today versus community-established performance goals. It is likely 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 design of new and upgrade of existing infrastructure.

To estimate the level of service a water or wastewater system would provide after a given scenario disaster, an assessment of expected damage to the system and restoration times is required. For instance, the *Oregon Resilience Plan* indicates the current estimated time to restore water and wastewater services after an *expected* level earthquake in the Willamette Valley (including Portland, Salem, and Eugene) is from one month to one year, and along the Oregon Coast the estimated time is from one to three years. Comparing these restoration estimates with a community's post-disaster level of service goals provides an indication of the resilience gap (OSSPAC, 2013).

The level of detail of this assessment can take one of three basic forms:

- **Tier 1** – A high level assessment of performance by persons knowledgeable about the system and anticipated hazard (chief engineer, operations manager, etc.)
- **Tier 2** – A more refined assessment based on typical system inventory (i.e., pipe type, length and soil type) using generalized component fragilities
- **Tier 3** – A detailed assessment of all components in a system, specific component fragilities, and the intra-dependencies of system components.

To appropriately characterize the current disaster resilience of water and wastewater systems, 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.

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AWWA J100-10 *Risk Analysis and Management for Critical Asset Protection (RAMCAP) Standard for Risk and Resilience Management of Water and Wastewater Systems* (AWWA, 2010) provides another methodology for conducting multi-hazard system resilience assessments. The RAMCAP Plus process was originally developed by the American Society of Mechanical Engineers – Innovative Technologies Institute (ASME-ITI) and is intended to be a consistent and comparable methodology for evaluating risk/resilience across various critical infrastructure sectors. It consists of a seven-step process for analyzing and managing risks associated with malevolent attacks and naturally occurring hazards (earthquake, hurricane, tornado, and flood).

1. Asset Characterization
2. Threat Characterization
3. Consequence Analysis
4. Vulnerability Analysis
5. Threat Analysis
6. Risk/Resilience Analysis
7. Risk/Resilience Management

AWWA J100-10 includes an optional Utility Resilience Index (URI). The URI includes two indices:

- An **operational resilience index** is based on a series of indicators that reflect a utility's organizational preparedness and capabilities to respond and restore critical functions/services following an incident.
- A **financial resilience index** is based on a series of indicators that reflect a utility's financial preparedness and capabilities to respond and restore critical functions/services following an incident.

URI can be used 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.

The EPA developed the Water Health and Economic Analysis Tool (WHEAT) to assist water and wastewater utilities in quantifying an adverse event's: 1) public health consequences, 2) utility-level financial consequences, and 3) direct and indirect regional economic consequences (EPA, 2014). This tool was developed to assist utilities in performing step 3 (consequence analysis) of the RAMCAP Plus process. WHEAT version 3.0 supports consequence analyses for three scenarios: 1) loss of one or more assets, 2) release of a stored hazardous gas, and 3) intentional contamination of a drinking water distribution system.

The EPA also developed the Vulnerability Self-Assessment Tool (VSAT) to assist water and wastewater utilities perform security threat and natural hazard risk assessments (EPA, 2010). The tool was developed to assist utilities in updating their Emergency Response Plans (ERPs). VSAT software uses an eight-step process to guide users through a risk assessment consistent with the 2007 RAMCAP framework.

1. Analysis setup and utility information
2. Asset identification
3. Countermeasure evaluation
4. Threat identification
5. Baseline assessment
6. Improvement assessment (propose new countermeasures)
7. Cost/Risk evaluations
8. Summaries and reports

An example Tier 1 plus (more detailed than Tier 1 but not as detailed as Tier 2) resilience assessment procedure for water systems, used in developing the *Oregon Resilience Plan*, is outlined below.

#### **9.6.1.1. Tier 1 Plus Resilience Assessment:**

1. Identify the appropriate earthquake hazard level

*For buried pipelines:*

2. Compile an inventory of system pipelines including pipe material, joint type, and length.
3. Superimpose the pipeline distribution system onto maps of the scenario hazard (peak ground acceleration, 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 distribution 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.
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 repair time for the system based on the repair times for buried pipelines and aboveground infrastructure estimated in steps 5 and 8.
10. 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.

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 appropriately characterize the expected performance of the system of systems in a major disaster.

### **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 current code requirements 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. The incremental cost of designing and constructing for improved disaster resilience is generally 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 greater 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.

#### 9.6.4. Addressing Resilience Performance Gaps

Once water and wastewater providers have worked with the community to establish resilience performance goals and completed baseline resilience assessments, there may be a number of goals not currently met due to the expected 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 time horizon) of new construction, retrofit of existing system components to better withstand disasters, 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. For major resilience improvements to take place on a shorter timeline a more extensive campaign of public outreach and education would be required.

#### 9.7. Tools Needed for Resilience

##### 9.7.1. Standards and Codes

Good design references are available for seismic design of water pipelines. However, there is no nationally adopted design standard that requires utilities to consider seismic design for their pipeline installations. The US water and wastewater industries need to develop and adopt design standards for new pipelines and retrofit standards for existing pipelines.

##### 9.7.2. Practice and Research Needs

###### 9.7.2.1. Current Research

- The Los Angeles Department of Water and Power (LADWP) and the Portland Water Bureau (PWB) are conducting demonstration projects with Kubota earthquake-resistant ductile iron pipe (ERDIP). This type of pipe has been used successfully in Japan for 40 years and recent earthquakes have demonstrated its superb performance with no documented breaks or leaks. LADWP and PWB have installed this pipe in two locations to become familiar with design and installation of ERDIP, evaluate field installation procedures, and enable a first-hand evaluation on the use of ERDIP to improve the resilience of the LADWP and PWB water distribution systems.
- Researchers are conducting large-scale experiments to fill gaps in the knowledge database on seismic performance of newer pipeline materials like restrained joint polyvinyl chloride.
- Academic researchers (O'Rourke, 2014) are beginning to investigate the next generation of disaster resilient pipelines. Hybrid pipelines like FlexSteel®, a steel reinforced and polyethylene lined pipe, are being evaluated for resistance to earthquakes and other disasters.

###### 9.7.2.2. Future Development Needs

- Benefit cost analysis is a useful method to provide economic justification for resilience improvement projects. However, most current tools do not adequately consider indirect economic losses. It is recommended that a tool be developed that explicitly considers indirect economic losses. This will allow communities to make informed decisions regarding the economic benefit of various resilience improvement project options and provide utilities with another means to justify the benefits of capital improvement expenditures.
- Seismic design of buried infrastructure is highly dependent on geotechnical engineering predictions of peak ground displacement. Refinements to these peak ground displacement prediction models based on data gathered in recent earthquakes would be helpful in prioritizing areas for retrofit of existing pipelines or installation of new pipelines that are more tolerant of ground movement.

- Gravity sewer systems are intolerant of shifts in vertical alignment due to permanent ground deformation and liquefaction. It is recommended that research be conducted on how to design sewer pipelines to be more resistant to the effects of permanent ground deformation and liquefaction.

### 9.8. Summary and Recommendations

Water and wastewater systems play a critical role in our daily lives. They provide basic services for our homes, places of business, and industry. Utility-scale water and wastewater lifelines are often complex systems consisting of large distributed pipeline networks and localized facilities such as treatment plants and pump stations. The large and distributed nature of water and wastewater systems, combined with their interdependence on other lifelines, limits the practicality of maintaining 100 percent operational capacity in the aftermath of a major natural disaster.

This chapter describes the basic components of water and wastewater systems, common weak links of these systems in major disasters, current design codes and standards, and a process by which communities can establish performance goals for their water and wastewater systems as well as evaluate their current level of disaster resilience. The following are recommendations to help communities, regions, states, and the nation improve the disaster resilience of water and wastewater systems.

**Hardened Backbone:** Performance goals can be established around the concept of a hardened backbone system. A backbone network should be capable of supplying key health and safety community needs shortly after a disaster, while more extensive repairs are being completed on the remainder of the system.

**Implementing Innovative Technologies:** The US water and wastewater industry should be encouraged to adopt promising new technologies into practice. Newer developments, such as earthquake resistant ductile iron pipe joints (see Figure 9-31) have demonstrated successful seismic performance in Japan and should be considered for implementation in US practice.

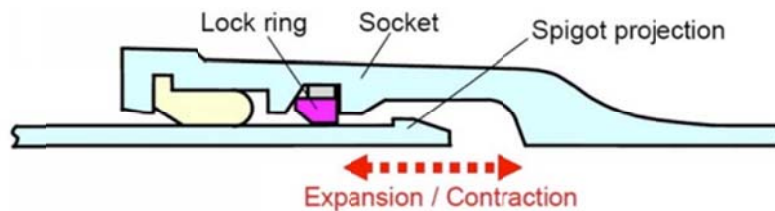


Figure 9-31: Earthquake Resistant Ductile Iron Pipe Joint (Source: Kubota)

**Interdependencies:** Communities should critically review co-located lifelines for impacts on resilience. For example, failure of a bridge supporting a water pipeline could result in failure of the pipe. Failure of pipe supported by a bridge may result in major leaks causing scour of the soil around the bridge abutment and potential failure of the bridge.

**Interdependencies:** Water and wastewater utilities should review plans for supplying critical facilities with emergency power for extended periods of time, potentially including on-site renewable options to enhance power supply redundancy.

**Interdependencies:** There is a current general lack of coordination of interdependencies amongst various lifeline providers. Communities should initiate discussion amongst lifeline providers and critically review interdependencies between various lifelines for impacts on disaster resilience.

**Standards Development:** Professional organizations (ASCE, AWWA, etc.) should be encouraged to take the leading role in development of missing standards. This standards development process should follow the typical path of prestandard or manual of practice to gain industry support and acceptance before balloting as a standard. In particular, it is critical that a standard should be developed for the seismic design of both water and wastewater pipelines.

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**Water Quality Impacts:** Communities should consider potential adverse water source quality impacts of a disaster. Runoff following wildfire has the potential to increase surface water source turbidity and render the water source unusable for drinking water. Man-made hazards, flooding, and earthquake events have potential to generate fuel spills from storage tanks, releases of untreated wastewater, and other adverse impacts for source water quality.

**Resiliency Assessment:** Utilities should be required to complete a resiliency assessment as part of periodic master planning updates and develop plans to mitigate identified resiliency deficiencies. It is recommended that current resilience assessment methods be evaluated and refined into one consistent methodology prior to implementation of nationwide resilience assessments. A strategy must also be developed to minimize potential liability concerns a utility may have if a disaster was to strike after a potential deficiency had been identified but before a utility had adequate time to address the deficiency.

**Capital Improvement Planning and Asset Management:** Utilities should be encouraged to consider disaster resilience in establishing priorities for capital improvement projects and asset management. It may not be economical to complete a project from a disaster resilience perspective alone, but the incremental cost of considering disaster resilience in planned retrofit and replacement projects is minor compared to the added resilience benefit. Using this phased approach to resilience improvement projects will greatly improve the resilience of a community's water and wastewater infrastructure over a period of years, while minimizing the financial burden of these improvements.

**Facility Site Planning:** Utilities should be encouraged to consider disaster resilience in site planning for new facilities and prior to significant capital improvement projects at existing facilities. New facilities should not be located in disaster prone locations, such as floodplain or tsunami inundation zones. Additionally, it may not be a wise economic investment to complete multi-hazard resilience upgrades to facilities in these disaster prone locations unless the locational hazard is also addressed.

**Redundancy:** The City of Sendai, Japan installed 21 buried water tanks after the 1995 Kobe earthquake. To prevent the tank from draining due to damage elsewhere in the system, these tanks include earthquake shutoff valves that close automatically when strong ground shaking is detected. The water saved in these tanks is then used as a source of potable water immediately after the earthquake. The majority of these tanks and earthquake valves performed well in the 2011 Tohoku earthquake and were able to serve as a water source for the local community after the earthquake. However, two tanks were in the tsunami inundation zone and therefore, not usable as a potable source after the earthquake and tsunami (Tang & Edwards, 2014). US utilities should consider various options, such as these added storage tanks, to improve system redundancy.

**Redundancy:** Redundant systems are inherently more resilient. In Japan, many water utilities are implementing loop transmission main systems to increase system redundancy. Water and wastewater utilities should evaluate this loop system approach, addition of isolation valves, and other methods to improve system redundancy. This is especially important for backbone system pipelines that serve critical locations (hospitals, large industrial customers, etc.) and need to be robust and redundant.

**Consequence-based planning:** When conducting *precovery* planning (pre-disaster and recovery) it is recommended that a consequence-based approach be adopted. By thoroughly considering the downstream physical, societal, and economic impacts of a given action from a disaster resilience perspective the optimum decision can be reached.

**Scenario Development:** When developing design and assessment standards for disaster resilience it is important to consider the appropriate hazard level. A system could be designed to remain operational after an extremely rare event, but the economic cost of system upgrades and required new infrastructure would be prohibitively costly. However, the system should be designed to have enough resilience to remain operational after a minor, semi-frequently occurring disaster (i.e., 50 year return period earthquake). Scenario development and consequence-based planning should be closely linked. The components of a



system where the consequence of failure is much higher should be designed for a less frequently occurring (more extreme) disaster. It is recommended that water and wastewater backbone components be designed or retrofit to be operational after an *extreme* level event.

**Rating System:** The water and wastewater industry should be encouraged to develop a disaster resiliency rating system to track how utilities are performing with respect to improvements in system resilience.

**Disaster Response Plan:** Utilities should be encouraged to create or update their disaster response plans based on community-established response and recovery goals. Community-wide training events should be conducted to exercise these plans and work out issues prior to implementing them in an actual disaster.

The Water and Wastewater Agency Response Network (WARN) is an established intrastate contractual relationship for sharing resources necessary to respond to a disaster. The WARN system is currently limited to intrastate mutual aid. However, disasters such as a potential Cascadia Subduction Zone earthquake in the Pacific Northwest have potential to significantly impact multistate regions and overwhelm local resources. It is recommended that the WARN system be expanded to facilitate easier sharing of resources across state lines.

**Regulatory Compliance:** Communities should work with regulatory agencies before a disaster to establish acceptable practices and operational standards for use during the disaster response phase. Planning should address questions like, “Will it be acceptable to discharge raw sewage to receiving bodies of water?”

**Temporary Sanitary Services:** Communities should work with utilities and public health agencies to identify, before the event, who will be responsible for temporary sanitation services (e.g., portable toilets).

**Temporary Water Supply:** Communities should work with utilities to plan for water supply at key distribution points for firefighting and distribution of emergency drinking water. This may require installation of valves and hydrants prior to the event to improve access after the event.

**Public and Business Community Education:** The general public and business community need to be educated about the potential risks and expected downtime for water and wastewater systems resulting from a disaster. Utility customers need to understand the potential economic consequences of inaction before they will be willing to support potential rate increases to pay for resilience improvements to water and wastewater systems.

**Emergency Kit:** It should be recommended that community members and employers maintain emergency kits with water and personal sanitation supplies adequate for the expected duration of service interruption.

**Business Continuity Plan:** Utilities should develop business continuity plans that include on-call contracts or agreements with contractors, consultants, and essential suppliers (fuel, equipment, repair materials, process chemicals, etc.). Utilities should evaluate if current emergency response contingency funds are adequate for the level of damage predicted by an analysis of the system for the disaster scenarios adopted by the community and modify funding levels as appropriate.

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