NIST GCR 10-930

U.S. Department of Commerce
National Institute of Standards and Technology

Office of Applied Economics
Engineering Laboratory
Gaithersburg, Maryland 20899-8603

# A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework

Chris S. Renschler, Amy E. Fraizer, Lucy A. Arendt, Gian-Paolo Cimellaro,
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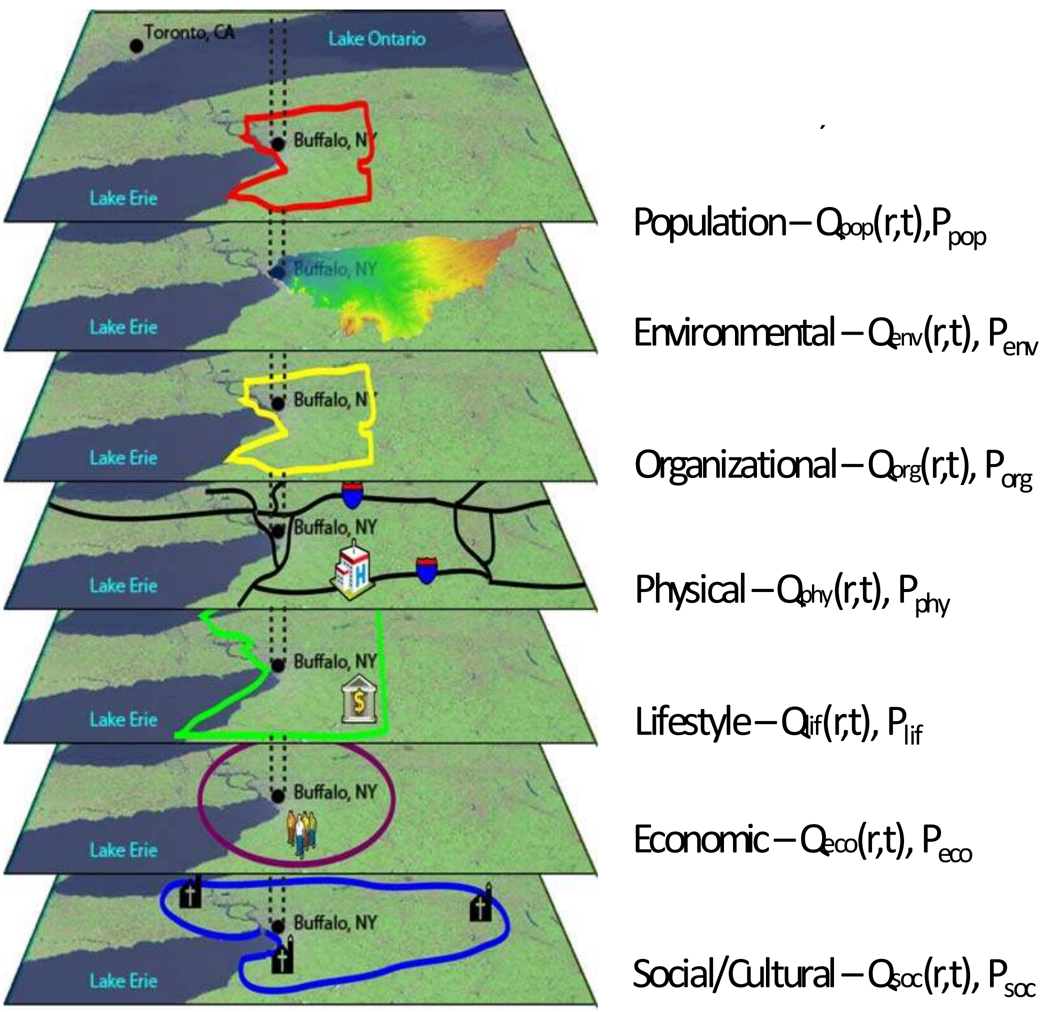

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Sponsored by:
National Institute of Standards and Tchonology
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Under Grant 60NANB9D9155

**October 2010**

# FOREWORD

Despite significant progress in disaster-related science and technology, natural and man-made disasters in the United States are responsible for an estimated $57 billion (and growing) in average annual costs in terms of injuries and lives lost, disruption of commerce and financial networks, property damaged or destroyed, the cost of mobilizing emergency response personnel and equipment, and recovery of essential services. Natural hazards—including earthquakes, community-scale fires, hurricane-strength winds and hurricane-borne storm surge, and tsunamis—are a continuing and significant threat to U.S. communities. Preventing natural and man-made hazards from becoming disasters depends upon the disaster resilience of our structures and communities.

To address this need, the National Institute of Standards and Technology's Engineering Laboratory, formerly the Building and Fire Research Laboratory, commissioned a study to establish a framework for defining and measuring disaster resilience at the community scale. The proposed framework, presented in this report, builds on and expands upon previous research linking resilience properties (robustness, redundancy, resourcefulness, and rapidity) and resilience dimensions (population, environmental, organizational, physical, lifestyle, economic, and social/cultural) so as to measure the disaster resilience of capital assets (e.g., hospitals) and asset classes (e.g., health care facilities). Once fully developed, the proposed framework will provide the basis for development of quantitative and qualitative models that measure the disaster resilience of communities. Over the longer term, these models will enable the development of decision-support software tools that help planners and other key decision makers and stakeholders to enhance the disaster resilience of their communities.

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# ABSTRACT

The objective of this research was to establish a holistic framework for defining and measuring disaster resilience for a community at various scales. Seven dimensions characterizing community functionality have been identified and are represented by the acronym PEOPLES: Population and Demographics, Environmental/Ecosystem, Organized Governmental Services, Physical Infrastructure, Lifestyle and Community Competence, Economic Development, and Social-Cultural Capital. The proposed PEOPLES Resilience Framework provides the basis for development of quantitative and qualitative models that measure continuously the functionality and resilience of communities against extreme events or disasters in any or a combination of the above-mentioned dimensions. Over the longer term, this framework will enable the development of geospatial and temporal decision-support software tools that help planners and other key decision makers and stakeholders to assess and enhance the resilience of their communities.

Keywords: Community functionality; disaster resilience; population and demographics; environment/ecosystem; organized governmental services; physical infrastructure; lifestyle, community competence; social and cultural services.

# PREFACE

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) is a national center of excellence in advanced technology applications that is dedicated to the reduction of earthquake losses nationwide. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission is to reduce earthquake losses through research and the application of advanced technologies that improve engineering, pre-earthquake planning and post-earthquake recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

MCEER's research is conducted under the sponsorship of two major federal agencies: the National Science Foundation (NSF) and the Federal Highway Administration (FHWA), and the State of New York. Significant support is derived from the Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), other state governments, academic institutions, foreign governments and private industry.

A Framework for Defining and Measuring Disaster Resilience at the Community Scale, funded by the National Institute of Standards and Technology (NIST), builds on previous MCEER research linking the four resilience properties (robustness, redundancy, resourcefulness, and rapidity) and resilience dimensions (technical, organizational, societal and economic). The project is developing quantitative and qualitative models to measure the disaster resilience of communities in terms of capital assets such as hospitals and asset classes such as health care facilities. Over the longer term, these models will enable the development of decision-support software tools to help planners, key decision makers and stakeholders enhance the disaster resilience of their communities.

## DISCLAIMER

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# ACKNOWLEDGEMENTS

Financial support for the work described in this report was provided by the National Institute of Standards and Technology (NIST), Engineering Laboratory, Award No. 60NANB9D9155. The support of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) is gratefully acknowledged.

The research leading to these results has also received funding from the European Community's Seventh Framework Programme - Marie Curie International Reintegration Actions - FP7/2007-2013 under the Grant Agreement n° PIRG06-GA-2009-256316 of the project ICRED - Integrated European Disaster Community Resilience.

The authors acknowledge also the advice received from representatives active in the specific professional areas (alphabetically): Daniel J. Alesch, Stephanie Chang, Gary Dargush, and Rachel Davidson who contributed to the discussion on the conceptual portion of this study and made valuable suggestions.

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# CHAPTER 1

# INTRODUCTION

The objective of this research is to establish a framework for defining and measuring disaster resilience at the community scale. Resilience, according to most dictionaries, is defined as the ability of systems to rebound after severe disturbances, disasters, or other forms of extreme events. The definition applies usually to physical, spiritual, ecological, engineering, social, and political systems. Community disaster resilience is defined as the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption, and mitigate the effects of future extreme events.

The objectives of enhancing disaster resilience are to minimize loss of life, injuries, and other economic losses, in short, to minimize any reduction in quality of life due to one or multiple hazards. Disaster resilience can be achieved by enhancing the ability of a community's infrastructure (e.g., lifelines, structures) to perform during and after a severe disturbance. It can also be achieved through emergency response and strategies that effectively cope with and contain losses and through recovery strategies that enable communities to return to levels of pre-disaster functioning (or other acceptable levels) as rapidly as possible (Bruneau et al., 2003).

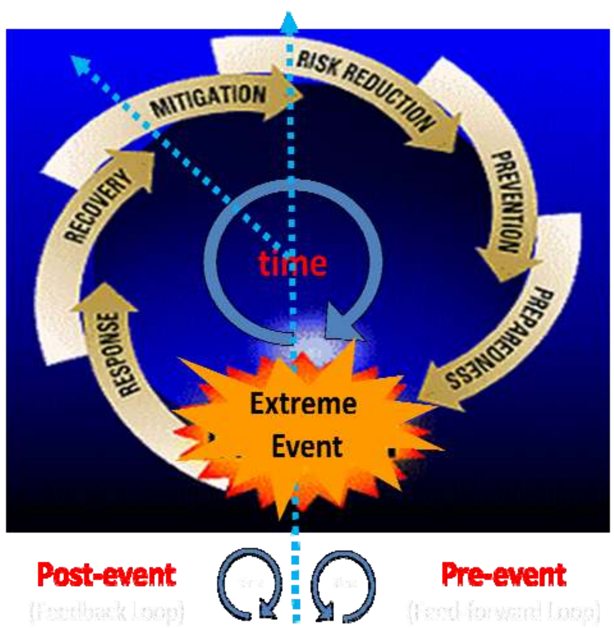



**Figure 1-1 The Extreme Events Management Cycle**

## 1.1 Background

The concept of resilience evolved first from the disciplines of psychology and psychiatry in the 1940s, and it is mainly accredited to Garmezy (1973), and Werner and Smith (1985). After that, the word resilience has been used broadly in the field of ecology, social science, economy and engineering.

In earlier work by Bruneau et al. (2003), resilience was defined including technical, organizational, economic, and social aspects and with four main properties of robustness, redundancy, resourcefulness, and rapidity. The quantification and evaluation of disaster resilience was based on non-dimensional analytical functions related to the variations of functionality during a "period of interest," including the losses in the disaster and the recovery path (Cimellaro et al., 2008). This evolution over time, including recovery, differentiates the resilience approach from other approaches addressing only loss estimation and its momentary effects.

Because of their potential for producing high losses and extensive community disruption, earthquakes and other hazards (e.g., hurricanes, flooding, tsunami, man-made disasters) have been given high priority in efforts to enhance community disaster resistance. The implementation of voluntary practices or mandatory policies aimed at reducing the consequences of an earthquake or other hazards, along with training and preparedness measures to optimize the efficiency of emergency response immediately after a severe event, all contribute to abating the risk and the potential for future losses. While these activities are important, justified, and clearly related to resilience enhancement, there is no explicit set of procedures in the existing literature for quantifying resilience in the context of multiple hazards. Likewise, there is no explicit means for comparing communities in terms of their resilience, or for determining whether individual communities are moving in the direction of becoming more resilient in the face of various hazards. Considerable research has assessed direct and indirect losses attributable to earthquakes, and estimated the reduction of these losses vis-à-vis specific actions, policies, or scenarios. However, the notion of resilience suggests a much broader framework than the reduction of monetary losses alone. Equally important, in addition to focusing on the losses produced by a wide array of hazards, research must also address the ways in which specific pre- and post-event measures and strategies can prevent and contain losses (Bruneau et al., 2003).

The framework developed in this report builds on and expands previous research linking resilience properties (i.e., robustness, redundancy, resourcefulness, and rapidity) and resilience dimensions (i.e., technical, organizational, societal, and economic) so as to measure the disaster resilience of capital assets (e.g., hospitals) and asset classes (e.g., health care facilities). Moreover, the framework addresses multiple hazards derived from multiple domains (e.g., natural: earthquake, hurricane; technical: grid/lifeline failure; cultural-social: migration/terrorists,) and their specific spatial (i.e., local, regional, national, global) and temporal scales (i.e., short- vs. long-term onset). While most previous research and frameworks were developed as capital assets centric (cf. Cimellaro et al., 2009 in re: health care facilities and networks), a framework that integrates multiple assets' resilience and the socio-economic infrastructure that forms the community is not yet available. In this report, asset-based resilience of capital assets are integrated with the socio-economic-organizational aspects to develop a resilience assessment of basic community units at the local scale (i.e., town, village, and city) and expand it to a regional scale (i.e., county, state, national). The basic concept developed at MCEER (see Figure 1-2, Bruneau et al., 2003) will serve as the basis for further formulation scaling from assets up to local and regional communities.

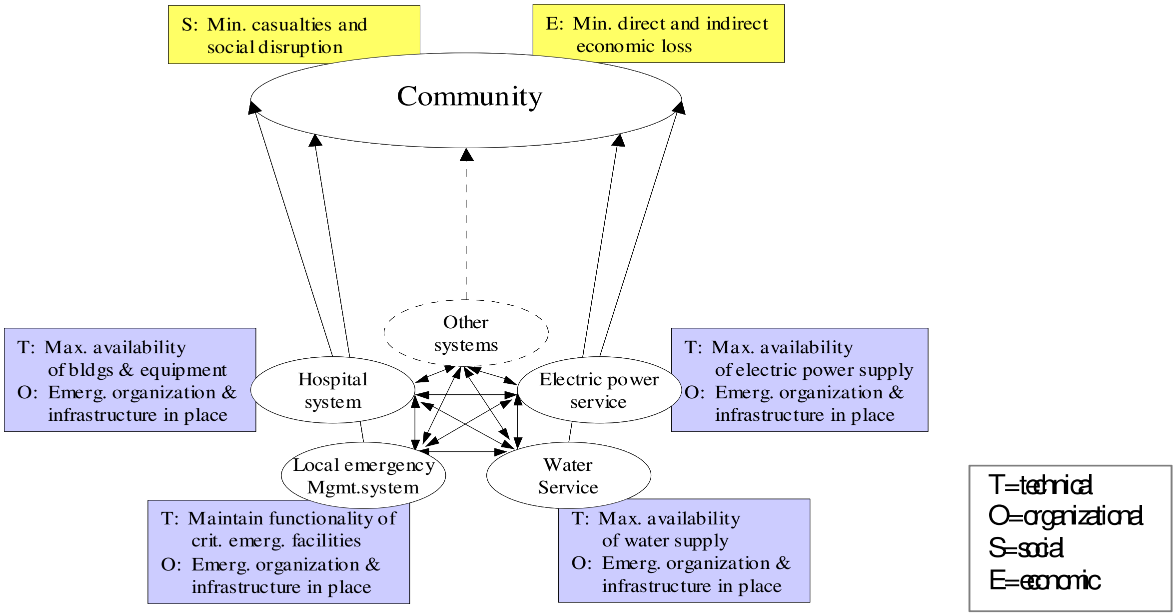



**Figure 1-2 System and community performance measures (Bruneau et al., 2003)**

As suggested by Alesch, Arendt, and Holly (2009), the consequences of an earthquake or other disaster typically go beyond the direct and obvious visible damage that captures the attention of the media. These systemic consequences are rooted in the socio-economic-organizational interdependencies that make up the core of a community's culture, the invisible norms and values that drive decisions around land use, architecture, business mix, and the like. One might imagine a community as one imagines an iceberg, with much of the substance lying beneath the water. In the case of a given community, what lies beneath is a uniquely arranged network of socio-economic-organizational interdependencies. In order to create a comprehensive framework for assessing community resilience, we must articulate - and to the extent that doing so is possible, quantify – the most critical and common socio-economic-organizational interdependencies. It may be the case, for example, that communities must have a certain number of available hospital beds within a given number of miles in order to support the healthcare needs of a working population that is at least 80 percent of the community's pre-disaster workforce. Or, it may be the case that certain types of businesses and organizations must be open and functional in order for the community to begin to return to its pre-disaster level of functioning. Related research examining the impact of hurricanes on communities suggests, for example, that gas stations, food markets, and healthcare clinics are essential to community functioning (Alesch et al., 2009). On further examination, it is clear that all of these organizations depend on potable water, reliable power, and navigable surface transportation routes.

The suggested integration is based on the concept (see Figure 1-3) that achieving community resilience depends on several factors. First, we must understand the basic disaster evolution due to multiple hazards, as shown in the flow for a "conventional system" going from an extreme event to response consequences. Second, we must be able to predict and measure the consequences of an extreme event (as shown in the "systems assessment"). Third, we must understand the preparedness and recovery process for asset components and networks (as shown in the "system actions" represented by the flow to the "system modifications" feeding back to the community). Fourth, we must be able to quantify, evaluate, and predict system resilience (as shown in the "assessment and decision system"). Fifth, we must use a rational decision system for actions. Finally, we must intervene, correct, and improve the community using specific pre- and post-event measures and strategies (as shown by the middle box in Figure 1-3**).**

The conceptual resilience framework developed here is designed to integrate various spatial and non-spatial data sources over time (e.g., survey data, remote sensing). The research team considered linkages to parallel research efforts in assessing the relationship of community resilience to the resilience of ecological systems (e.g., the impact of riparian and coastal wetlands on flooding and hurricane surges, respectively). GIS and remote sensing data play a major role in assessing the resilience of all integrated systems and feed a predictive resilience model.

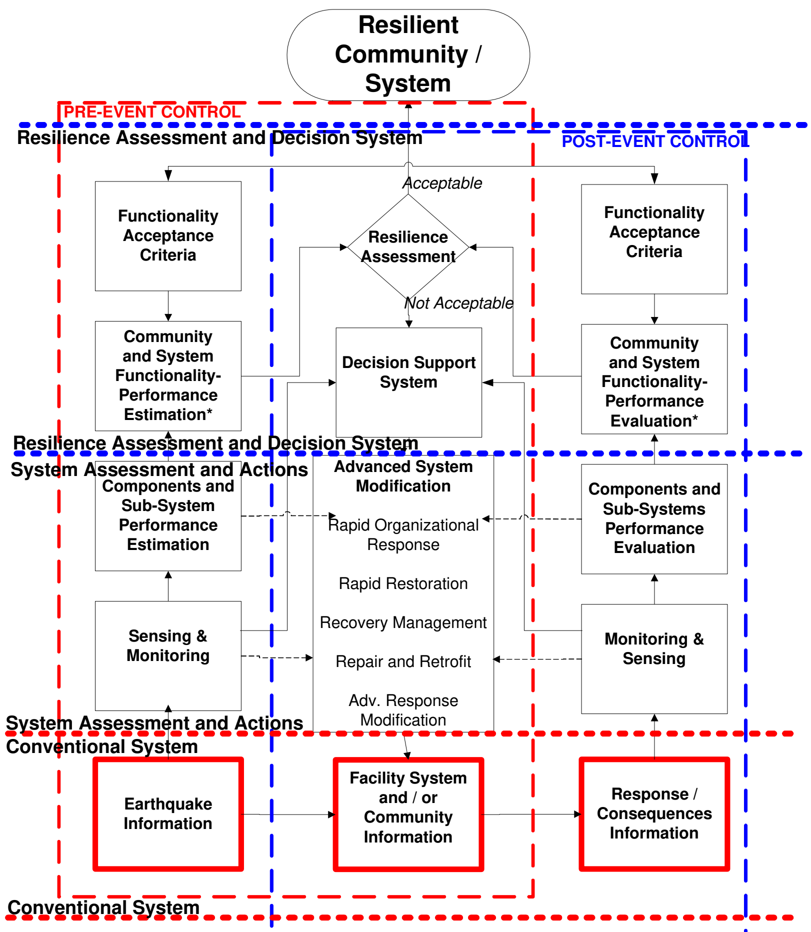



**Figure 1-3 System (community) resilience (adapted from Bruneau et al. 2003)**

To be able to expand the assessment of resilience to a community and landscape perspective, the integrated conceptual resilience assessment approach is based on basic community organizational units at a local (i.e., neighborhoods, villages, towns or cities) and regional scale (i.e., counties/parishes, regions, or states). This required the combination of qualitative and quantitative data sources at various temporal and spatial scales, and as a consequence, information needs to be aggregated or disaggregated to match the scales of a resilience model and the scales of interest for the model output. Renschler developed the concept and implementation of a collaborative research and teaching environment that assesses the scaling effect of transformation of information (Renschler, 2003, 2006). This interdisciplinary, holistic, information systems approach investigates the various representations of system properties and processes at various scales using commonly available data sources and remote sensing (measuring), GIS algorithms and indices (monitoring), and process-based environmental models (modeling) to support management decisions (Renschler et al., 2006).

In summary, the integrated conceptual framework described here provides the basis for development of quantitative and qualitative models that measure the disaster resilience of communities. Over the longer term, these models will enable the development of decision-support software tools that help planners and other key decision makers and stakeholders enhance the disaster resilience of their communities.

## 1.2 Scope

The concept of resilience was originally established in the field of ecology by Holling (1973). According to the author, "Resilience is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables. Stability represents the ability of a system to return to an equilibrium state after a temporary disturbance; the more rapidly it returns to equilibrium and the less it fluctuates, the more stable it would be" (Holling, 1973, p15). Holling (1973) distinguishes between two types of resilience: engineering resilience and ecological resilience. Engineering resilience "conceives ecological systems to exist close to a stable steady state and the time required to return to the steady state following a perturbation" (Gunderson et al., 2002, p4). In ecological or environmental resilience, a disturbance may cause the system to transform into a new state (Gunderson et al., 2002). However, according to Carpenter et al. (2001), resiliency is the magnitude of disturbance a system can absorb *before* it changes its space and is controlled by a different set of processes. Therefore, resilience must be measured based on the pre-existing state prior to disturbance.

In recent years, the concept of resilience has gained attention recognizing the fact that not all threats or disasters can be averted. Indeed, societies are turning their attention to efforts and ways that can enhance the community resilience of entire communities against various types of extreme events. Resilience is clearly becoming increasingly important for modern societies as communities come to accept that they cannot prevent every risk from being realized but rather must learn to adapt and manage risks in a way that minimizes impact on human and other systems. While studies on the disaster resilience of technical systems have been undertaken for quite some time (Chang and Shinozuka, 2004), the societal aspects and the inclusion of various and multiple types of extreme events are new developments. In this regard, communities around the world are increasingly debating ways to enhance their resilience.

At this time, there is no explicit set of procedures in the existing literature that suggests how to quantify resilience in the context of multiple hazards, how to compare communities with one another in terms of their resilience, or how to determine whether individual communities are moving in the direction of becoming more resilient in the face of various hazards. Considerable research has been accomplished to assess direct and indirect losses attributable to earthquakes, and to estimate the reduction of these losses as a result of specific actions, policies, or scenarios. However, the notion of resilience suggests a much broader framework than the reduction of monetary losses alone. Equally important, in addition to focusing on the losses produced by a wide range of hazards, research must also address the ways in which specific pre- and post-event measures and strategies can prevent and contain losses (Alesch, et al., 2009; Bruneau et al., 2003).

Resilience (R) may be defined as a function indicating the capability to sustain a level of functionality, or performance, for a given building, bridge, lifeline network, or community, over a period defined as the control time ($T_{LC}$). The control time is usually decided by building owners or society at large, for example, and corresponds to the expected life cycle or life span of the building or other system. Resilience, R, is defined graphically as the normalized shaded area underneath the function describing the **functionality** of a system, defined as Q(t). Q(t) is a non-stationary stochastic process, and each ensemble is a piecewise continuous function as shown in Figure 1-4, where Q(t) is the functionality of the region considered. The community functionality is an aggregation of all functionalities related to different facilities, lifelines, etc.

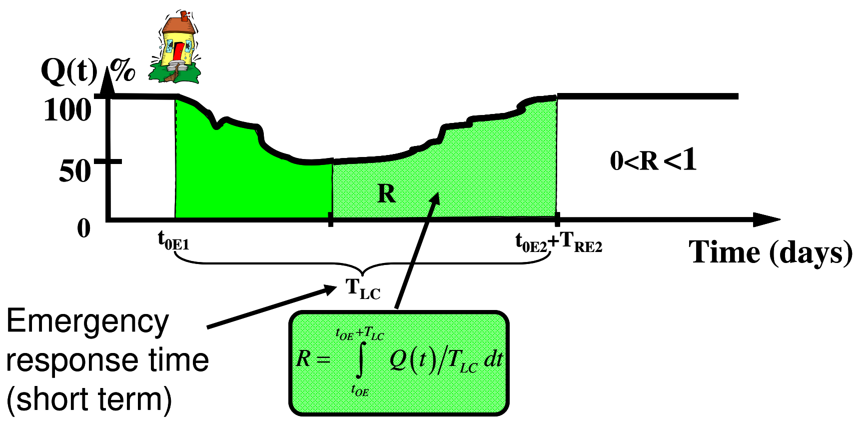



**Figure 1-4 Functionality Curve and Resilience**

The change in functionality due to extreme events is characterized by a drop, representing a loss of functionality, and a recovery. It should be noted that for communities, the loss of functionality can be gradual (as shown in Figure 1-4) or can be sudden, as well known for earthquakes for example (Bruneau and Reinhorn, 2007).

## 1.3 Key Literature References

The original definition of resilience included in the description of functionality multiple complex components, or dimensions, which includes technical, organizational, social, and economic facets (Bruneau et al., 2003). The two components, technical and economic, are related to the functionality of physical systems, such as lifeline systems and essential facilities. The other two components, organizational and social, are more related to the community affected by the physical systems. However, Bruneau et al. (2003) defined a fundamental framework for evaluating community resilience without a detailed quantification and definition. Various studies have been carried out subsequently, with the goal of practically evaluating the concept of resilience and identifying the main units of measurement.

The resilience quantification requires good definition of functionality and its variation in time. In case of extreme events when the drop of functionality, or loss, is sudden, it is important to determine clearly the change of functionality during the recovery. Miles and Chang (2003) present a comprehensive conceptual model of recovery, which establishes the relationships among a community's households, businesses, lifeline networks, and neighborhoods. The primary aim is to discuss issues of community recovery and to attempt to operationalize it. Davidson and Cagnan (2004) developed a model of the post earthquake restoration processes for an electric power system. A discrete event simulation model based on available data was built, with the goal of improving the quantitative estimates of restoration times that are required to evaluate economic losses, and identify ways to improve the restoration processes in future earthquakes. Chang and Shinozuka (2004) discuss a quantitative measure of resilience based on the case study of the Memphis water system, and they explored the extent to which earthquake loss estimation models can be used to measure functionality and resilience. Finally, Cimellaro et al. (2005) attempted to formulate the first framework to quantify disaster resilience for physical infrastructures, however only the uncertainties of the ground intensity measures were considered. More recently, a community resilience framework was proposed (Cimellaro et al., 2009), including a full range of uncertainties in the functionality parameters.

The Glossary of Resilience Terms (provided in the Appendix A) contains a comprehensive set of definitions of key terminology and concepts and commonly used acronyms. A detailed reference is provided for each definition to enable the user to refer to the complete source document to obtain further information/context where needed. Notable, some terms have different definitions although share same terms; addressing different aspects, or dimensions defined in this report. Thus the final communication of these terms must be clarified when used. For example, in many cases the technological (engineering) concepts of resilience refer to different aspects than those used to describe the social aspects of resilience. This report attempts to reconcile some of the differences by providing multiple dimensions and their interrelations, along with some methods of quantification.

Previous studies do not cover the wide range of components and dimensions affecting the functionality of an entire community. The objective of the next section is to suggest the dimensions that must be considered when dealing with community resilience.

# CHAPTER 2

# THE SEVEN DIMENSIONS OF COMMUNITY RESILIENCE

## 2.1 Introduction to PEOPLES

Disaster resilience is often divided between technological units and social systems. On a small scale, when considering critical infrastructures, the focus is mainly on technological aspects. On a greater scale, when considering an entire community, the focus is broadened to include the interplay of multiple systems – human, environmental, and others – which together add up to ensure the healthy functioning of a society. At the community level, the human component is central, because in the case of a major disruptive event, resilience depends first on the actions of people operating at the individual and neighborhood scale (see Figure 2-1). Community resilience also depends heavily on the actions of different levels of government and its agencies at the local and regional scales when a disruptive extreme event occurs (see geographic scales II and III in Figure 2-2).

In order to emphasize the primary role of the human system in community resilience and sustainability, the authors of this report suggest (Renschler et al, 2010) using the acronym "PEOPLES" (see Figure 2-1 ). This nomenclature highlights both the physical and environmental assets as well as the socio-economic-political/organizational aspects of a particular community.

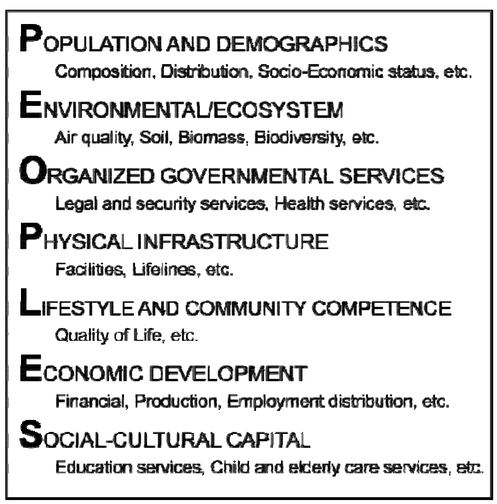



**Figure 2-1 PEOPLES Resilience Framework - Dimensions**

The PEOPLES Resilience Framework is built on, and expands, previous research at MCEER linking several previously identified resilience dimensions (i.e., technical, organizational, societal, and economic) and resilience properties (i.e., $\mathbf{R}^4$: robustness, redundancy, resourcefulness, and rapidity) (Bruneau et al., 2003). PEOPLES incorporates MCEER's widely accepted definitions of service functionality, its components (assets, services, demographics) and the parameters influencing their integrity and resilience. While the components have different weights and values, the order of these dimensions in the acronym is not indicative to their importance.

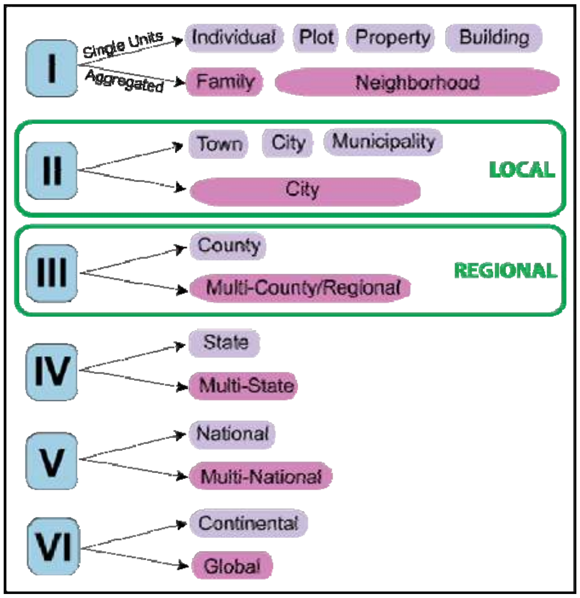
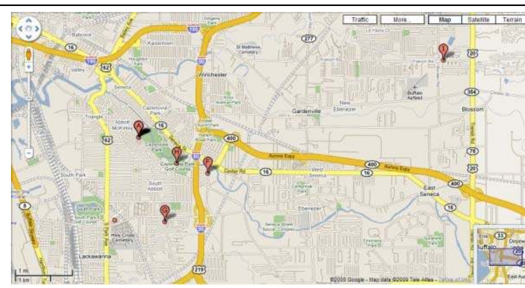
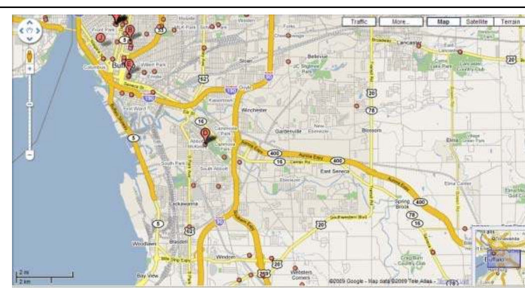



**Figure 2-2 PEOPLES Resilience Framework - Scales**

The PEOPLES Resilience Framework defines components of functionality using a geospatial-temporal distribution within its geographical influence boundaries. Interdependencies between and among these components are key to determining the resilience of communities. PEOPLES enables the use of various ***community resilience indices*** that integrate, over space and time, the system functionality and services of a community in a landscape setting. In this particular dimension, historical and continuously gathered information through remote sensing and Geographic Information Systems (GIS) play a major role in assessing the resilience of all integrated systems and feed a predictive resilience model. Resilience can be considered as a dynamic quantity that changes over time and across space. As shown in Figure 2-2 and Table 1,

Table 1 PEOPLES Resilience Framework – Scales I to V (Western New York)

| PEOPLES Community Scale | Healthcare and Veterinary Facilities |
|---|---|
| **Scale I – Neighborhood**<br>Neighborhoods directly surrounding<br>Mercy Hospital (A) in West Seneca<br>(note that this facility is the largest and<br>most important facility at this scale) |  |
| **Scale ii – Local (Town)**<br>Towns directly surrounding<br>Mercy Hospital (D) near the map center<br>(“ii” is subscale of “II” indicating that<br>there are facilities in similar size close by) |  |

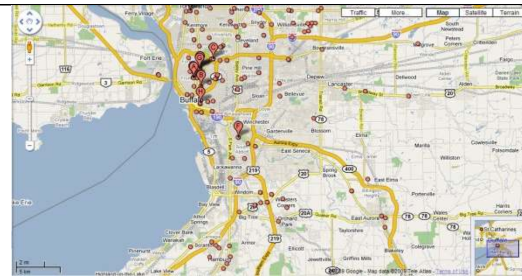
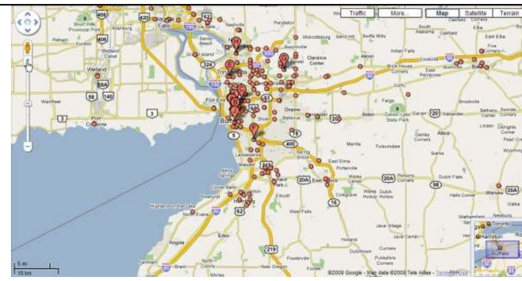
| | |
|---|---|
| **Scale II – Local (City)**<br>City close to Mercy Hospital (F)<br>(the facility is one of several in a<br>densely populated location, e.g. Buffalo) |  |
| **Scale iii – Regional (County)**:<br>Larger administrative boundary<br>surrounding Mercy Hospital (F)<br>(the facility is one of several in Erie County) |  |
| **Scale III – Regional (Multi-County)**<br>Mercy Hospital (mapped as a dot only) is<br>among a lot of facilities in Western New York<br>(Rochester, Pennsylvania and Southern Ontario<br>are in this map it includes also Scales IV and V) |  |

**Table 2 Complete list of components and subcomponents of PEOPLES framework**

**1) POPULATION AND DEMOGRAPHICS**
- a) Distribution/Density
  - i) Urban
  - ii) Suburban
  - iii) Rural
  - iv) Wildland
- b) Composition
  - i) Age
  - ii) Gender
  - iii) Immigrant Status
  - iv) Race/Ethnicity
- c) Socio-Economic Status
  - i) Educational Attainment
  - ii) Income
  - iii) Poverty
  - iv) Home Ownership
  - v) Housing Vacancies
  - vi) Occupation

**2) ENVIRONMENTAL/ECOSYSTEM**
- a) Water Quality/Quantity
- b) Air Quality
- c) Soil Quality
- d) Biodiversity
- e) Biomass (Vegetation)
- f) Other Natural Resources

**4) PHYSICAL INFRASTRUCTURE**
- a) Facilities
  - i) Residential
    - (1) Housing Units
    - (2) Shelters
  - ii) Commercial
    - (1) Distribution Facilities
    - (2) Hotels - Accommodations
    - (3) Manufacturing Facilities
    - (4) Office Buildings
  - iii) Cultural
    - (1) Entertainment Venues
    - (2) Museums
    - (3) Religious Institutions
    - (4) Schools
    - (5) Sports/Recreation Venues
- b) Lifelines
  - i) Communications
    - (1) Internet
    - (2) Phones
    - (3) TV
    - (4) Radio
    - (5) Postal
  - ii) Health Care
    - (1) Acute Care
    - (2) Long-Term Acute Care
    - (3) Primary Care
    - (4) Psychiatric
    - (5) Specialty

**5) LIFESTYLE AND COMMUNITY COMPETENCE**
- a) Collective Action and Decision Making
  - i) Conflict Resolution
  - ii) Self-Organization
- b.) Collective Efficacy and Empowerment
- c.) Quality of Life

**6) ECONOMIC DEVELOPMENT**
- a) Financial Services
  - i) Asset Base of Financial Institutions
  - ii) Checking Account Balances (Personal and Commercial)
  - iii) Consumer Price Index
  - iv) Insurance
  - v) Number and Average Amount of Loans
  - vi) Number of Bank and Credit Union Members
  - vii) Number of Banks and Credit Unions
  - viii) Savings Account Balances (Personal and Commercial)
  - ix) Stock Market
- b) Industry – Employment - Services
  - i) Agriculture
  - ii) Construction
  - iii) Education and Health Services
  - iv) Finance, Insurance and Real Estate
  - v) Fortune 1000

| | | |
|---|---|---|
| **3) ORGANIZED GOVERNMENTAL SERVICES**<br>a) Executive/Administrative<br>i) Emergency Response and Rescue<br>ii) Health and Hygiene<br>b) Judicial<br>c) Legal/Security | **PHYSICAL INFRASTRUCTURE** (cont'd)<br>iii) Food Supply<br>iv) Utilities<br>(1) Electrical<br>(2) Fuel/Gas/Energy<br>(3) Waste<br>(4) Water<br>v) Transportation<br>(1) Aviation<br>(2) Bridges<br>(3) Highways<br>(4) Railways<br>(5) Transit<br>(6) Vehicles<br>(7) Waterways | **ECONOMIC DEVELOPMENT** (cont'd)<br>vi) Fortune 500<br>vii) Information, Professional Business, Other<br>viii) Leisure and Hospitality<br>ix) Manufacturing<br>x) Number of Corporate Headquarters<br>xi) Other Business Services<br>xii) Professional and Business Services<br>(1) Employment Services<br>(a) Flexibilities<br>(b) Opportunities<br>(c) Placement<br>(2) Transport and Utilities<br>(3) Wholesale and Retail<br>c) Industry – Production<br>i) Food Supply<br>ii) Manufacturing<br><br>**7) SOCIAL/CULTURAL CAPITAL**<br>a) Child and Elderly Services<br>b) Commercial Centers<br>c) Community Participation<br>d) Cultural and Heritage Services<br>e) Education Services<br>f) Non-Profit Organizations<br>g) Place Attachment |

the landscape perspective in the PEOPLES Resilience Framework is based on basic community organizational units at a local (i.e., neighborhoods, villages, towns or cities) and regional scale (i.e., counties/parishes, regions, or states).

The following describes briefly each of the seven component-dimensions associated with the PEOPLES Resilience Framework and some potential indicators. The dimensions are neither orthogonal nor synonymous. While they are discussed as distinct dimensions and while we anticipate developing measures that are often independent, the nature of community resilience is such that interdependence between and among the dimensions is expected. The potential indicators are intended to be illustrative rather than exhaustive. Importantly, the indicators that are identified are those that may be used to describe a community and its resilience at any time, and not simply post-extreme event. Ultimately, the value of the PEOPLES Resilience Framework is that it (a) identifies the distinct dimensions and related key indicators but also (b) aggregates the dimensions in ways that reflect community realities.

The PEOPLES Resilience Framework requires the combination of qualitative and quantitative data sources at various temporal and spatial scales, and as a consequence, information needs to be aggregated or disaggregated to match the scales of the resilience model and the scales of interest for the model output.

Table 2 shows the complete list of components and sub-components. In the following sections a detailed description of each component is complemented by attempts of quantification.

## 2.2 Population and Demographics

Population and demographic data that describe and differentiate a focal community provide a context for understanding the remaining PEOPLES dimensions (see Table 3). Knowing, for example, the median income and age distribution for a community is critical to understanding its economic health and potential resilience. Communities tend to differ on key demographics; to the extent that two or more communities may be similar, Community A and Community B, we can predict Community B's hypothetical response to a disaster based on Community A's actual response to a disaster.

**Table 3 Elements of Population and Demographics Dimension**

1) POPULATION AND DEMOGRAPHICS
   a) Distribution/Density
      i) Urban
      ii) Suburban
      iii) Rural
      iv) Wildland
   b) Composition
      i) Age
      ii) Gender
      iii) Immigrant Status
      iv) Race/Ethnicity
   c) Socio-Economic Status
      i) Educational Attainment
      ii) Income
      iii) Poverty
      iv) Home Ownership
      v) Housing Vacancies
      vi) Occupation

One measure of functionality of population and demographics (Qp) within a given community can be quantified by using the social vulnerability index (SoVI) proposed by Cutter (1996). Social vulnerability (a counterpart of social resilience) is defined as the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed. These impacts are due in part to characteristics inherent in social interactions, institutions, and systems of cultural values. Social vulnerability is a pre-existing condition of the community that affects the society's ability to prepare for and recover from a disruptive event.

Resilience focuses on the quality of life of the people at risk and develops opportunities to enhance a better outcome, while vulnerability places stress on the production of nature (Smith and O'Keefe, 1996) to resist the natural hazard. Manyena (2006) evaluates all the possible definitions provided from the 90's up until the present, and compares the concept of resilience as the opposite of vulnerability.

This dimension of vulnerability can be measured using a social index that describes the socioeconomic status, the composition of the population (elderly and children), development density, rural agriculture, race, gender, ethnicity, infrastructure employment, and county debt/revenue. The social index described is based on Cutter's Hazards-of-Place Model of Vulnerability framework that integrates exposure to hazards with the social conditions that make people vulnerable to them (Cutter, 1996; Cutter et al., 2000). High SoVI indicates high vulnerability, and conversely, low SoVI indicates low vulnerability. Analytically, functionality of population can be given as follows:

$$Q_P(\mathbf{r},t) = 1/(f1 + f2 + f3 + f4 + f5 + f6 + f7 + f8 + f9 + f10 + f11) \quad (1)$$

where f1, f2, .., fn are the 11 independent factors considered. Among the 11 independent factors are socioeconomic status, elderly and children, development density, rural agriculture, race, gender, ethnicity, infrastructure employment, and county debt/revenue. Additionally, qualitative and quantitative measures about population and demographics from the US Census database are an essential component for this dimension of the PEOPLES Resilience Framework. Key indicators include educational attainment, marital status, annual income, age, gender, race/ethnicity distribution, and other data that describe and differentiate the focal population.

### 2.3 Environmental/Ecosystem

While resilience is a critical element of resource management and is necessary to sustain desirable ecosystem states in the face of unknown futures and variable environments (Elmqvist et al., 2003), it is not easily assessed (Adger, 2000). Resilience of a system depends on various factors such as time scale, the actual disturbance, the structure of the system, and control measures or polices that are available to be implemented (Ludwig et al., 2002). Ecological or ecosystem resilience is typically measured by the amount of disturbance an ecosystem can absorb without drastically altering its functions, processes, and structures (Gunderson, 2000), or by the ability of an ecosystem to cope with disturbance.

**Table 4 Elements of Environmental/Ecosystem Dimension**

2) ENVIRONMENTAL/ ECOSYSTEM
   a) Water Quality/Quantity
   b) Air Quality
   c) Soil Quality
   d) Biodiversity
   e) Biomass (Vegetation)
   f) Other Natural Resources

In the context of the *PEOPLES Resilience Framework*, environmental and ecosystem resources serve as indicators for measuring the ability of the ecological system to return to or near its pre-event state (Table 4). One such indicator is the Normalized Difference Vegetation Index (NDVI), which is calculated from satellite-derived remote sensing imagery that analyzes the density of green vegetation across a region. NDVI can be used in the framework as a proxy for ecosystem productivity and is calculated using the red (Red) and near infrared (NIR) absorption bands:

$$NDVI = (NIR - Red)/(NIR + Red) \quad (2)$$

NDVI correlates strongly with above-ground net primary productivity (NPP) (Pettorelli, 2005; Olofsson et al., 2007, Prince, 1991), which measures biomass accumulation and can be an indicator of ecosystem resilience. Simoniello et al., (2008) characterized the resilience of Italian landscapes using a time series to calculate NDVI trends, and Diaz-Delgado et al. (2002) used NDVI values derived from Landsat imagery to monitor vegetation recovery after fire disturbance.

Building on previous research, the *PEOPLES Resilience Framework* quantifies a portion of ecological resilience through a comparison of stable-state NDVI trends to post-disturbance NDVI trends to determine differences in ecosystem productivity across spatial-temporal scales. NDVI is applicable for quantifying ecosystem structure following disturbances such as fire, flooding, and hurricanes. In other types of disasters such as terrorist attacks or blizzards, vegetation density and ecosystem structure may not be altered. In these instances, ecological resilience quantification through NDVI would be negligible and other indicators would be more relevant. As with the other dimensions, ecological resilience is the integration of all key indicators that include air, water and soil quality, biodiversity, and other natural resources.

## 2.4 Organized Governmental Services

In contrast to the more or less spontaneous individual and neighborhood responses to extreme events, organized governmental services are designed to allow an orderly response (see Table 5).

**Table 5 Elements of Organized Governmental Services Dimension**

3) ORGANIZED GOVERNMENTAL SERVICES
   a) Executive/Administrative
      i) Emergency Response and Rescue
      ii) Health and Hygiene
   b) Judicial
   c) Legal/Security

Organized governmental services include traditional legal and security services such as police, emergency, and fire departments and increasingly, the military. In this dimension, we also include the services provided by public health and hygiene departments as well as cultural heritage departments. Each of these organized government services plays a key role in sustaining communities both before and after extreme events. A good example of the necessity of a well-functioning government may be seen in the devastating January 12, 2010 earthquake in Haiti. In the aftermath, the news media reported a lack of government services and orderly control, and a general perception that the government is not in a position to help its people (Schwartz, 2010). In contrast, the Darfield earthquake in New Zealand was followed by quick response on the part of local, territorial, and national government services.

Spontaneous helping behavior, convergence, mass volunteering, and emergent groups are sources of resilience, in that they infuse resources and creativity into disaster response activities (Stallings and Quarantelli, 1985; Drabek and McEntire, 2002). At the level of organizations and networks, organizational responses during crisis are most likely to be effective—and resilient—when they successfully blend discipline and agility (Harrald, 2006). Pre-existing plans, training, exercises, mutual aid agreements, and other concepts of operations help ensure disciplined and appropriate responses, but they do so not because they encourage the playing out of pre-determined scripts but rather because they facilitate collective sense-making and inspire action toward shared goals (Weick, 1995; Weick et al., 2005). Flexibility, adaptability, and improvisation among responding entities make their own distinctive contributions to resilience. Organizational expansion, extension, and emergence are key bases of resilient disaster responses (Sutton and Tierney, 2006).

The concept of collaborative emergency management seeks to engage all critical community sectors in preparing for and responding to disasters, including local elected and appointed officials; subject matter experts; community-based, faith based and other non-governmental organizations, the general public, including both community members that belong to groups such as community emergency response teams and volunteers; the private sector and business networks; and the mass media (Patton, 2007). Collaborative management, as opposed to top-down direction, is another characteristic of resilient systems. Hierarchies tend to stand in the way of upward information flow, the form of communication that is most essential during disasters. Less hierarchical forms of organization work best in all types of turbulent environments, including disasters, in part because they encourage a free flow of ideas, but also because flatter organizations and decentralized networks are more nimble in responding to those environments (Burns and Stalker, 1961; Waugh and Streib, 2006).

Key indicators for this dimension include the number of available response units and their capacity. Population and demographic numbers would be used to normalize the number and capacity of these services. In addition to assessing the availability of government services in terms of personnel and equipment, this dimension also includes an evaluation of emergency preparedness planning. For example, surveys may reveal the extent to which organized government services have developed memoranda of understanding (MOUs) and other types of mutual aid agreements, and the extent to which various organized government services participate in emergency and evacuation drills and table-top exercises (Tierney, 2009).

## 2.5 Physical Infrastructure

The physical infrastructure dimension focuses on a community's built environment. It incorporates both facilities and lifelines (Table 6).

Within the category of facilities, we include housing, commercial facilities, and cultural facilities. Within the category of lifelines, we include food supply, health care, utilities, transportation, and communication networks. Lifelines are those essential utility and transportation systems that serve communities across all jurisdictions and locales. Lifelines are thus components of the nation's critical infrastructure, which also includes medical, financial, and other infrastructure systems that create the fabric of modern society. For clarity, lifeline infrastructures are simply called in short *lifelines* in this report. Lifelines include: (a) energy utilities and companies (electric power and natural gas and liquid fuel pipelines); (b) transportation systems (roads and highways, railroads, airports, and seaports); (c) water, storm-water, and sewerage; (d) communication systems; and (e) health care facilities (hospitals, cliniques, emergency facilities, etc), most distributed in well linked networks.

Next to impacts on people, the physical infrastructure is often the most compelling "story" in the immediate aftermath of a disaster, as organized government services work to restore needed utilities and clear roadways of structural and other debris. After people had been evacuated from New Orleans after Hurricane Katrina in 2005, people focused on the physical infrastructure. Everywhere one looked, one saw destroyed houses, commercial buildings, and cultural and other critical facilities such as churches, schools, and hospitals. Photographs of destruction are used to communicate the devastating effects of the hurricane and subsequent flooding to the world outside New Orleans.

Without water and electricity, critical facilities such as hospitals cannot perform effectively their primary functions. Inaccessible roads make surface transportation impossible, creating an obstacle for supply chain management and efficient movement. When streets and buildings are cordoned off because of damage, businesses may be open, but will not be "in business." Even when businesses relocate for the short-term due to damage to facilities, customers may not find the businesses. Damaged schools shake a community's confidence in itself to overcome disasters and recover.

**Table 6 Elements of Physical Infrastructure Dimension**

4) PHYSICAL INFRASTRUCTURE
   a) Facilities
      i) Residential
         (1) Housing Units
         (2) Shelters
      ii) Commercial
         (1) Distribution Facilities
         (2) Hotels - Accommodations
         (3) Manufacturing Facilities
         (4) Office Buildings
      iii) Cultural
         (1) Entertainment Venues
         (2) Museums
         (3) Religious Institutions
         (4) Schools
         (5) Sports/Recreation Venues
   b) Lifelines
      i) Communications
         (1) Internet
         (2) Phones
         (3) TV
         (4) Radio
         (5) Postal
      ii) Health Care
         (1) Acute Care
         (2) Long-Term Acute Care
         (3) Primary Care
         (4) Psychiatric
         (5) Specialty
      iii) Food Supply
      iv) Utilities
         (1) Electrical
         (2) Fuel/Gas/Energy
         (3) Waste
         (4) Water
      v) Transportation
         (1) Aviation
         (2) Bridges
         (3) Highways
         (4) Railways
         (5) Transit

In terms of housing, key indicators may include proportion of housing stock not rated as substandard or hazardous and vacancy rates for rental housing (Tierney, 2009). In terms of communication networks, key indicators may include adequacy (or sufficiency) of procedures for communicating with the public and addressing the public's need for accurate information following disasters, adequacy of linkages between official and unofficial information sources, and adequacy of ties between emergency management entities and mass media serving diverse populations (Tierney, 2009).

In the aftermath of a disaster, the restoration and recovery of physical infrastructure remain by-and-large technical issues, however those are tightly related and often driven by organizations, economics and socio-political events. The resilience must consider these interactive dimensions in order to be relevant to the system.

## 2.6 Lifestyle and Community Competence

As suggested by Harrald (cited in Micale, 2010, para. 5), "Resilience … requires the building of collaborative relationships that will enable communities and businesses to better absorb, adapt, survive, and thrive when confronted with extreme events." Norris et al. (2008) describe community resilience as "a metaphor, theory, set of capabilities and strategy for disaster readiness" (p. 127). One of the capabilities they discuss is community competence. Community competence is essential to community resilience in the same way that individual competence is essential to personal hardiness. Community competence deals with community action, critical reflection and problem solving skills, flexibility and creativity, collective efficacy, empowerment, and political partnerships (Norris et al., 2008).

**Table 7 Elements of Lifestyle and Community Competence Dimension**

5) LIFESTYLE AND COMMUNITY COMPETENCE
   a) Collective Action and Decision Making
      i) Conflict Resolution
      ii) Self-Organization
   b.) Collective Efficacy and Empowerment
   c.) Quality of Life

This dimension reflects the reality that community resilience is not simply a passive "bouncing back" to pre-disaster conditions (Brown and Kulig, 1996/97) but rather a concerted and active effort that relies on peoples' ability to creatively imagine a new future and then take the requisite steps to achieve that desired future. It captures both the raw *abilities* of the community (e.g., ability to develop multifaceted solutions to complex problems, ability to engage in meaningful political networks) and the community's *perceptions* of its ability to effect positive change. Communities that collectively believe that they can rebuild, restructure, and revive themselves are more likely to be persistent in the face of environmental, governmental, and other obstacles.

Quality of life surveys often reveal whether members of a given community are committed to that community and willing to engage in the activities necessary to sustain the community, regardless of whether a disaster strikes. Less soft general indicators of community competence may include measures of migration, measures of citizen involvement in politics, and others. Disaster-specific indicators may include the comprehensiveness of community warning plans and procedures, and the extensiveness of citizen and organizational disaster training programs (Tierney, 2009).

## 2.7 Economic Development

According to Radloff (2006), "A community needs to have access to resources to grow and react to changes. The difference between resilient and non-resilient resources is that the former focus on addressing local needs and are often locally based sources of employment, skills, and finances" (p. 16). There are six points to this dimension of resilience:

1. Employment in the community is diversified beyond a single employer or employment sector;
2. Major employers in the community are locally owned;
3. The community has a strategy for increasing independent local ownership;
4. There is openness to alternative ways of earning a living and economic activity.
5. The community looks outside itself to seek and secure resources (skills, expertise, finance) to address areas of identified weakness;
6. The community is aware of its competitive position in the broader economy (The Centre for Community Enterprise, 2000: 15-16).

Economic development includes both the static assessment of a community's current economy (economic activity) and the dynamic assessment of a community's ability to continuously sustain economic growth (economic development) (see Table 8).

As described in the RICSA Poverty Project (2010), economic *activity* takes into account the supply of labor for the production of economic goods and services, which includes:

> "All production and processing of primary products whether for market, for barter or for own consumption, the production of all other goods for the market and, in the case of households which produce such goods and services for the market, the corresponding production for own consumption."

**Table 8 Elements of Economic Development Dimension**

6) ECONOMIC DEVELOPMENT
    - a) Financial Services
        - i) Asset Base of Financial Institutions
        - ii) Checking Account Balances (Personal and Commercial)
        - iii) Consumer Price Index
        - iv) Insurance
        - v) Number and Average Amount of Loans
        - vi) Number of Bank and Credit Union Members
        - vii) Number of Banks and Credit Unions
        - viii) Savings Account Balances (Personal and Commercial)
        - ix) Stock Market
    - b) Industry – Employment - Services
        - i) Agriculture
        - ii) Construction
        - iii) Education and Health Services
        - iv) Finance, Insurance and Real Estate
        - v) Fortune 1000
        - vi) Fortune 500
        - vii) Information, Professional Business, Other
        - viii) Leisure and Hospitality
        - ix) Manufacturing
        - x) Number of Corporate Headquarters
        - xi) Other Business Services
        - xii) Professional and Business Services
            - (1) Employment Services
                - (a) Flexibilities
                - (b) Opportunities
                - (c) Placement
            - (2) Transport and Utilities
            - (3) Wholesale and Retail
    - c) Industry – Production

Economic *development* addresses the future and growth. It addresses a community's efforts to increase its:

> "productive capacities ..., in terms of technologies (more efficient tools and machines), technical cultures (knowledge of nature, research and capacity to develop improved technologies), and the physical, technical and organizational capacities and skills of those engaged in production."

Resilient communities are characterized by their involvement in a diverse array of products and services that are both produced in and available to the community. Diversity in production and employment is linked to a community's ability to substitute goods and services and shift employment patterns as the situation demands. The *PEOPLES Resilience Framework* incorporates three illustrative subcategories within this dimension: Industry – Production, Industry – Employment Distribution, and Financial Services. Primary indicators of this dimension include the proportion of the population that is employed within the various industries, and the variability that might characterize a community's industrial employment distribution.

This dimension is closely interconnected with the Population and Demographics dimension. For example, key indicators of economic development beyond employment and industry distribution include literacy rates, life expectancy, and poverty rates. Disaster-specific indicators related to economic development include extent of evacuation plans and drills for high-occupancy structures, adequacy of plans for inspecting damaged buildings following disasters, and adequacy of plans for post-disaster commercial reconstruction (Tierney, 2009).

## 2.8 Social-Cultural Capital

Similar to the Norris et al. (2008) conceptualization of social support, the Community Resilience Model's first dimension is "Resilient People," which consists of nine points:

1. Leadership is diversified and representative of age, gender, and community cultural composition;
2. Elected community leadership is visionary, shares power, and builds consensus;
3. Community members are involved in significant community decisions;
4. The community feels a sense of pride;
5. People feel optimistic about their community's future;
6. There is a spirit of mutual assistance and co-operation in the community;
7. People feel a sense of attachment to their community;
8. The community is self-reliant and looks to itself and its own resources to address major issues; and
9. There is a strong belief in and support for education at all levels (The Centre for Community Enterprise, 2000: 13-15).

According to Norris and her colleagues (2008), "individuals invest, access, and use resources embedded in social networks to gain returns" (p. 137). For our purposes, social/cultural capital incorporates several subcategories, including education service, child and elderly services, cultural and heritage services, and community participation (see Table 9). Social/cultural capital is prerequisite to community competence (Norris et al., 2008) in that it incorporates the array of services that the community has chosen to provide for itself, understanding that community health requires more than good jobs and infrastructure. It also includes several intangible "goods," such as social support, sense of community, place attachment, and citizen participation (Norris et al. 2008).

**Table 9 Elements of Social/Cultural Capital Dimension**

7) SOCIAL/CULTURAL CAPITAL
   a) Child and Elderly Services
   b) Commercial Centers
   c) Community Participation
   d) Cultural and Heritage Services
   e) Education Services
   f) Non-Profit Organizations
   g) Place Attachment

For example, social support underlies many of the services associated with social/cultural capital. It includes both the "helping behaviors within family and friendship networks" and the "relationships between individuals and their larger neighborhoods and communities" (Norris et al., 2008, p. 139). People choose to provide social and cultural services that manifest and extend their sense of community, defined as an attitude of bonding with other members of one's group or locale (Perkins et al., 2002, cited in Norris et al., 2008). They may feel an emotional connection to their neighborhood or city, which may or may not relate to the people who inhabit those places (Manzo and Perkins, 2006). For example, after Hurricane Katrina, many displaced residents of New Orleans expressed a strong desire to return home, irrespective of the people they knew or the jobs they once had. It seems likely that people with a strong "place attachment" would be more willing to act in order to help their community bounce back after a disaster, assuming that other essential factors such as employment and housing were available. Citizen participation takes into account the "engagement of community members in formal organizations, including religious congregations, school and resident associations, neighborhood watches, and self-help groups" (Norris et al., 2008, p. 139). Participation in community organizations is a means of demonstrating one's care for one's community. Pragmatically, participation in community organizations is a means for meeting and understanding one's fellow citizens. It increases individuals' circle of influence and perception of control.

Measuring social/cultural capital requires acquisition of tallies, such as the number of members belonging to various civil and community organizations. It also requires surveys of community leaders and their perceptions (e.g., quality of life surveys). Disaster-specific indicators include existence of community plans targeting transportation-disadvantaged populations, adequacy of post-disaster sheltering plans, adequacy of plans for incorporating volunteers and others into official response activities, adequacy of donations management plans, and the community's plans to coordinate across diverse community networks (Tierney, 2009).

# CHAPTER 3

# VISUALIZATION OF PEOPLES FRAMEWORK

## 3.1 PersonalBrain™ Conceptual Dynamic Diagrams

Mind mapping is a way that depicts concepts as a graphical visualization of hierarchies and interdependencies. A software platform is used which is capable of linking and dynamically visualizing all seven PEOPLES dimensions in multiple layers of components and properties of functionality and resilience as well as pointing to information about quantitative and qualitative concepts, algorithms or models in various databases.

The software, Personal Brain™, allows for the visualization of the interactions of resilience dimensions (see Figure 3-1), components (see Figure 3-2), and indicators, and the organization of accompanying references, databases, equations and other materials (see menus at bottom of Figure 3-1). The scheme is able to accept any formulation that may be developed in the future.

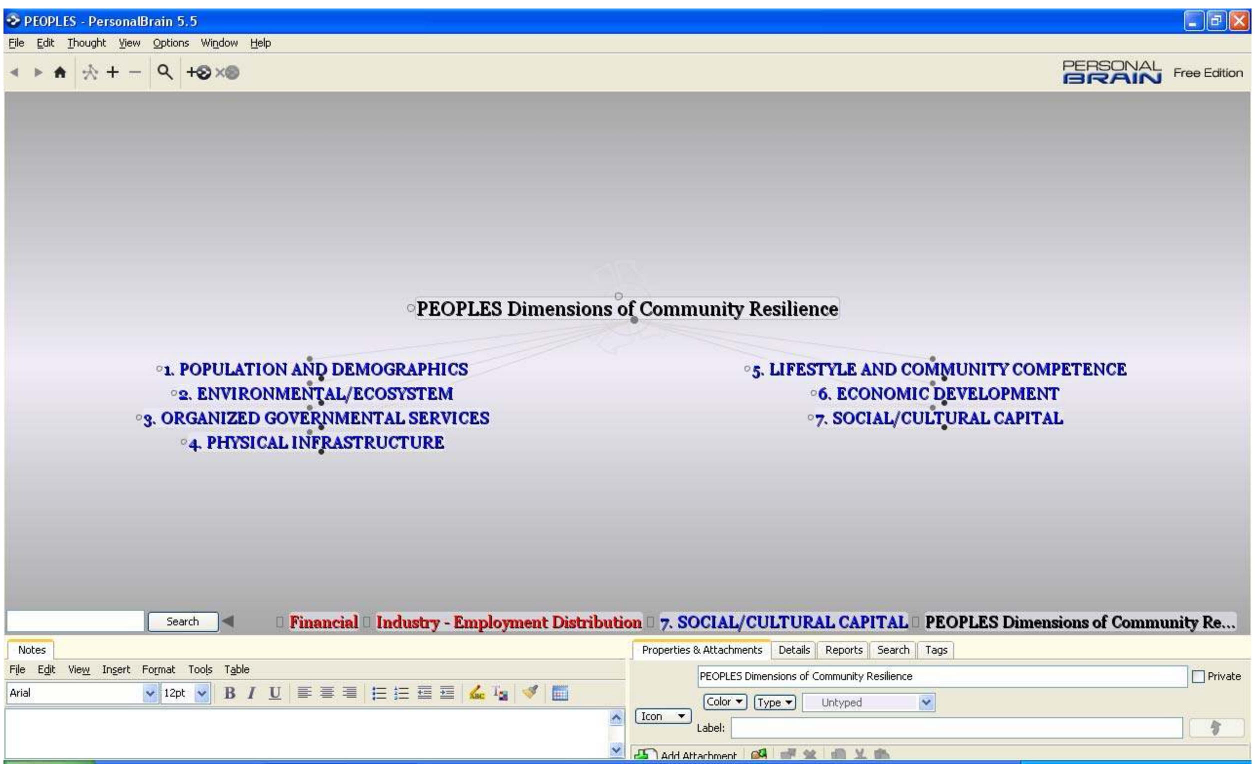



**Figure 3-1 Resilience Framework Dimensions as Personal Brain Visualization**

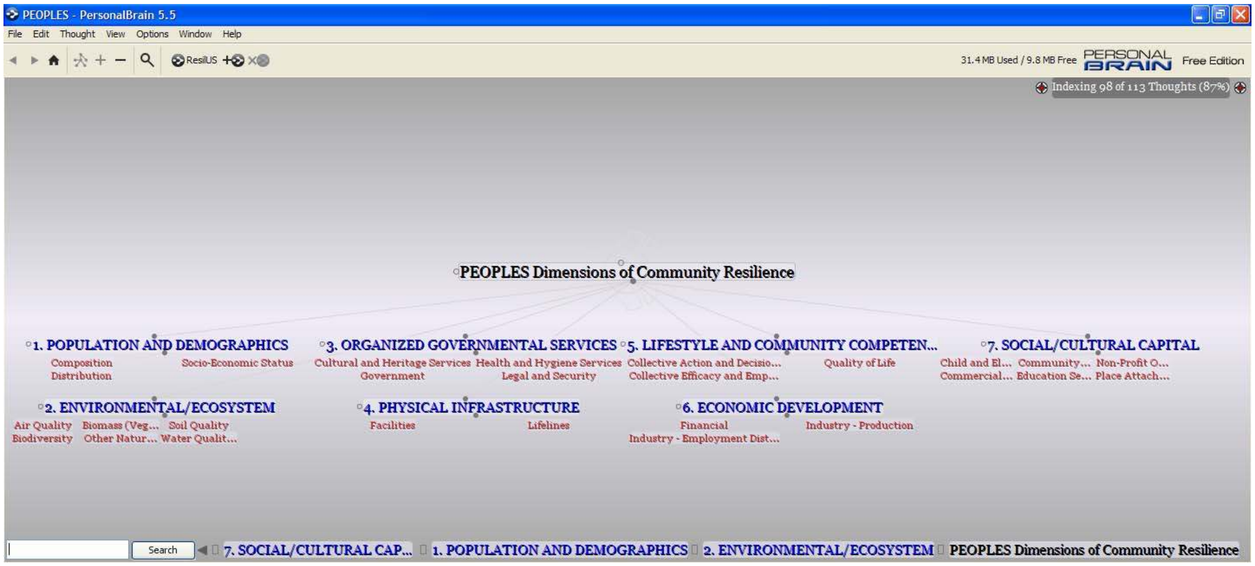



**Figure 3-2 Resilience Framework Components**

The primary advantage in using the PersonalBrain$^{TM}$ software is its ability to automatically create multiple links between and among the elements that mimic the complex interdependencies that characterize communities. Figure 3-3 illustrates the physical infrastructure dimension with its "Lifelines" and "Facilities" components as well as the resilience framework elements at the next lower hierarchical level. A mouse click on the element "Food Supply" will lead to the visualization in Figure 3-4, that depicts the interdependency of this element to other resilience dimensions such as the "Economic Development" dimension.

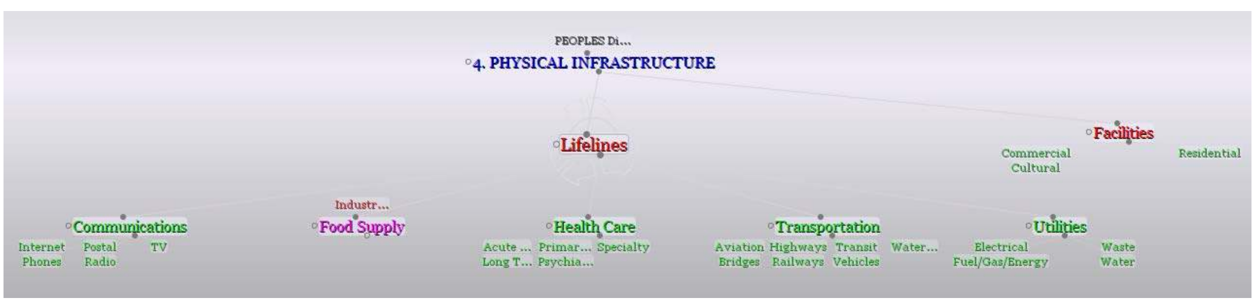



**Figure 3-3 Physical Infrastructure Resilience Dimension, Components and Elements**

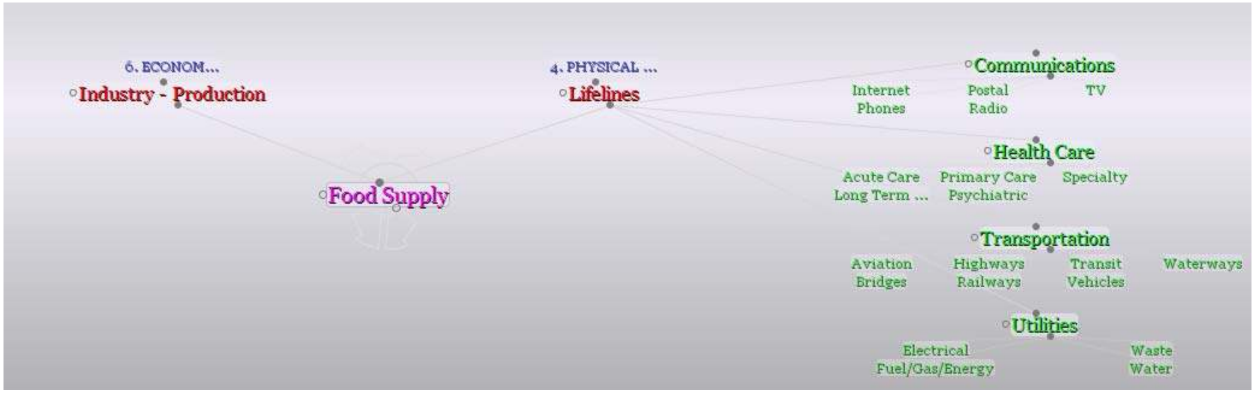



**Figure 3-4 Interdependency of Resilience Components – Example "Food Supply"**

The mind mapping and information storage capabilities enable tracking changes and merging of several experts' thoughts. As a collaborative tool the software creates a vital component in the further development of the PEOPLES Resilience Framework. A freely downloadable reader allows interested parties to explore and understand PEOPLES in an animated, interactive manner.

# CHAPTER 4
# KEY INTERDEPENDENCIES

## 4.1 Interdependencies

Interdependencies appear between all components and subcomponents described in the framework in CHAPTER 2 and CHAPTER 3. Each component and subcomponent can be represented by spatial- temporal functions describing their functionality. The interdependencies appear globally between their functionalities or more directly between the parameters (or variables) describing their functionality.

In order to begin understanding the interdependency an illustration is made using parts of the ***physical infrastructure components***, more precisely for well known interacting lifelines.

Public- and private-sector lifeline owners, operators, and others involved in protection and regulation of lifelines and other elements of the critical infrastructure of society need to develop a greater awareness of interdependencies and a more complete understanding of what they mean.

The appropriate role of local, state, and federal governments in support of the private-sector response to disruptions also needs to be defined. The failure to understand how disruptions to one lifeline system can cascade to other lifelines, compromise response and recovery efforts, or result in common-cause failures can leave planners, operators, and emergency response personnel unprepared to deal effectively with the impacts of such disruptions. For example, economically disasters can be catastrophic without proper planning for redundancy and alternative resources affected by the interaction of various lifelines, organizations, populations and social fabrics. Either public or private business may become economically obsolete although not directly affected by a disaster.

Interdependencies are discussed in the current project to illustrate the broader aspects of functionality using *lifelines* for the following reasons:

- Lifeline infrastructure interdependencies can often lead to cascading failures and area failures in disasters, with consequences far greater than those presented exclusively by the initial point failure;
- Analysis of lifeline networks through which failures are propagated can assist in reducing disaster impacts;
- Understanding network dependencies can be used to reduce disaster impacts; and
- Lifeline system failures and resulting loss of service constitutes a major component of disaster loss.

The purpose of this section is to illustrate how the performance of each component, such as utility and transportation system for example, may be affected by disruption of services from other critical lifelines, and to identify initial lessons that could be learned for improving lifeline system serviceability and reliability during extreme events. Some suggestions in this report for further data compilation and assessment activities may eventually lead to industry guidance for enabling (for example utility and transportation lifelines) owners and operators to better account for lifeline interdependencies during future extreme events.

## 4.2 Example of Interdependencies of Lifeline Systems

Lifeline interdependencies are manifested when, due to either geographical proximity or shared operations, an impact on one lifeline system has an impact on one or more other lifeline systems. Service supplier-customer relationship for lifelines is a "dependent" relationship as shown in Figure 4-1. In the event of a problem or failure in the first lifeline, the product or service to the second can be degraded or interrupted. An example of this type of connection is the cellular phone tower failure when individual cell towers had single power feeds from electric utility and they are not equipped with on-site generation and or battery backup systems when power is lost.

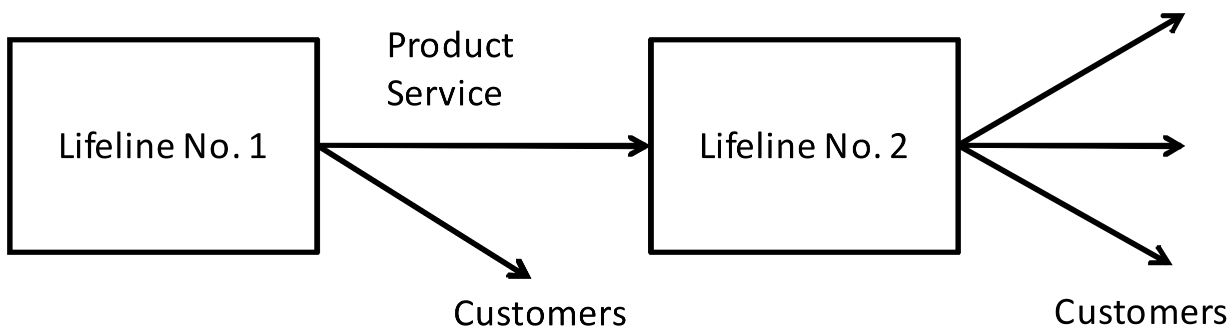



**Figure 4-1 First Order-Dependency**

A closed loop interdependent relationship is one where a lifeline system provides a product or service to a second lifeline, which in turn supplies the first with a critical product or service as shown in Figure 4-2. An example of this type of interdependency is the failure of the electric distribution systems that also results in the inability to deliver coal to power plants in a timely manner, which, in turn, affects electric generation.

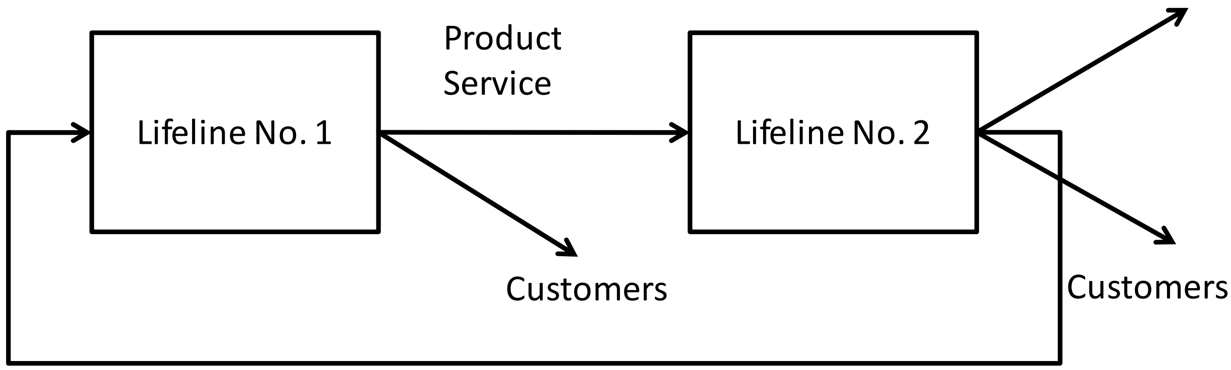



**Figure 4-2 Closed-Loop interdependency**

**Type of Lifelines failures:** Two types of lifeline failures are defined below: (i) cascading and (ii) common cause.

**Cascading**: A cascading failure involves second-order, third-order, etc., dependent relationships amongst lifelines (Figure 4-3). It occurs where a change in state in the first lifeline (e.g., reduction in output or failure) causes a change in state in the second lifeline (e.g., degraded performance or failure) which, in turn, causes a change in state in a third lifeline (e.g., reduction in output or failure).

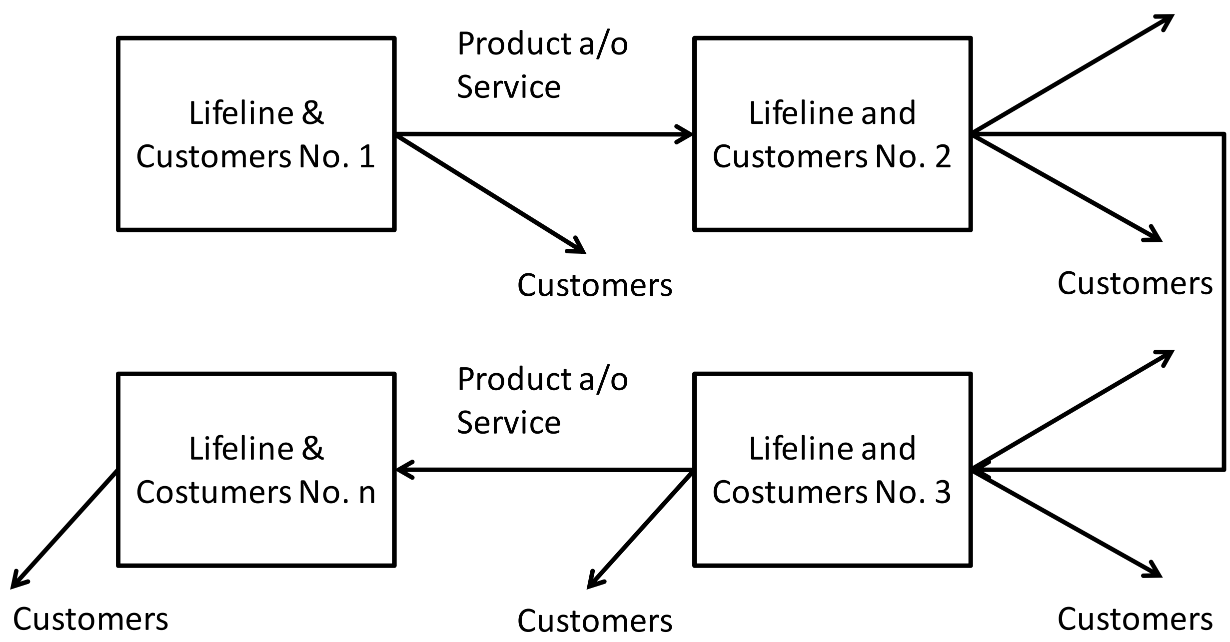



**Figure 4-3 Cascading lifeline Failures**

**Common Cause**: Common cause failures were also frequently reported. They occur where a single event disrupts two or more lifelines. Typical examples are:

A tree is blown over by high winds and the root ball rips up water and natural gas pipelines running in a single right-of-way along a street.
A tree is blown over by high winds and takes down electric distribution lines, television cable, and telephone cable with it.

In summary, at the community level interdependencies among different lifelines are very complex and they can have negative consequences of direct and indirect physical damage to individual components of the lifelines systems. In fact, lifelines are able to distribute services, but they are also capable of distributing the consequences of loss of services. Therefore, it is evident that in the resilience evaluation, we must include dependencies and interdependencies between lifeline types such as energy, transportation, communication and water.

Critical lifelines interdependencies significantly reduce the resilience index at the community level (see quantification of resilience in CHAPTER 5), because they slow down the response and recovery process. A key strategy to increase resilience at the community level is to decouple lifeline systems, by providing alternative supply through redundancy or distributed supply.

The PEOPLES framework assists users in identifying sources of quantitative and qualitative information to assess the resilience of each system as well as interconnected systems. Figure 4-4 shows the interdependencies of various physical infrastructure systems and their respective resilience dimensions of a community.

| PEOPLES: Physical Infrastructure: Utilities and Lifelines | P | E | O | P | L | E | S |
|---|---|---|---|---|---|---|---|
| 1. Water distribution system | X | X | X | X | | | X |
| 2. Electric power systems | | X | X | X | X | | |
| 3. Health care facilities | X | | X | X | X | | |
| 4. Road network | | | X | X | X | X | |

X = Quantification measures or indicators

**Figure 4-4 Interdependencies of physical infrastructural systems**

In Figure 4-5, we pick one of the previous identified physical infrastructure systems (the water distribution system) and investigate in more detail its dimensions, components and indicators. Each community will have very basic needs for information about a certain level of functionality of a system, e.g., 100% functionality would be to provide water to the entire population. In an extreme event, one would count the number of people that are not provided with this service and receive a lower percentage of service. However, each community is different and has different values; therefore a community would need to account for different dimensions of water supply when they value landscape and environment as part of their, life style, or value race horses, llamas, etc, as investments or as part of their cultural heritage (tribal values in a particular animal species). PEOPLES will allow each community to identify, define, and assess their needs in a framework that they customize to their needs for an integrated community resilience assessment.

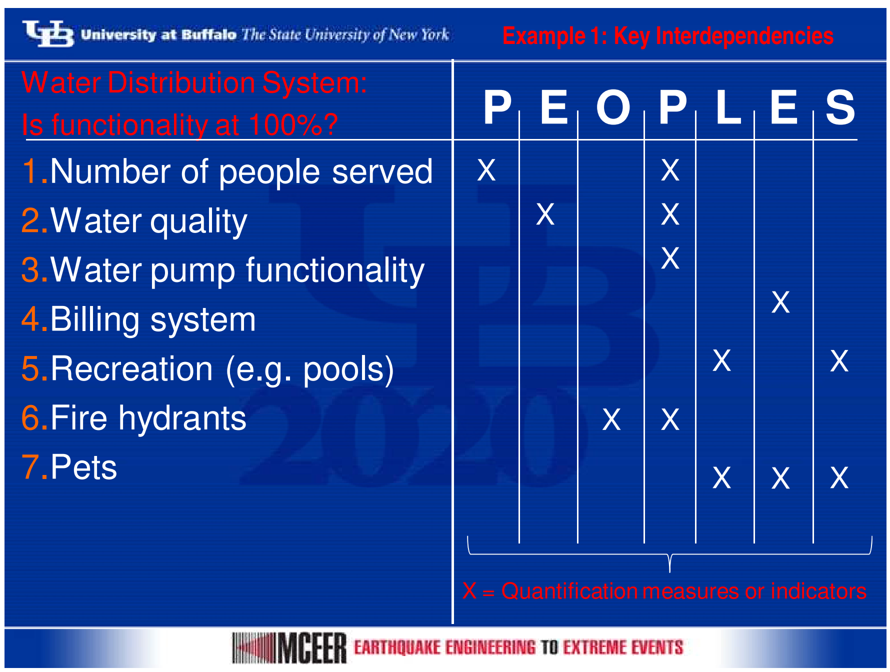



**Figure 4-5 Interdependencies of water distribution system**


**Figure 4-6 Interdependencies in coastal community resilience**

Figure 4-6 shows the elements that can improve coastal community resilience and how they can be grouped within the PEOPLES framework showing the interdependencies among different dimensions which are

- Governance: Leadership, legal framework, and institutions provide enabling conditions for resilience through community involvement with government.
- Society and Economy: Communities are engaged in diverse and environmentally sustainable livelihoods resistant to hazards.
- Coastal Resource Management: Active management of coastal resources sustains environmental services and livelihoods and reduces risks from coastal hazards.
- Land Use and Structural Design: Effective land use and structural design that complement environmental, economic, and community goals and reduce risks from hazards.
- Risk Knowledge: Leadership and community members are aware of hazards and risk information is utilized when making decisions.
- Warning and Evacuation: Community is capable of receiving notifications and alerts of coastal hazards, warning at-risk populations, and individuals acting on the alert.

- Emergency Response: Mechanisms and networks are established and maintained to respond quickly to coastal disasters and address emergency needs at the community level.
- Disaster Recovery: Plans are in place prior to hazard events that accelerate disaster recovery, engage communities in the recovery process, and minimize negative environmental, social, and economic impacts.

# CHAPTER 5
# INTEGRATION

## 5.1 Integrating Functionalities of the Seven Dimensions

Within the *PEOPLES Resilience Framework,* each dimension and/or service and its indicators or terms of functionality will be represented with a GIS layer of the area of interest as suggested in the example portrayed in Figure 5-1. In that figure, $Q_{POP}$ = functionality of population in the community; $Q_{ENV}$= functionality of environmental fabric; $Q_{ORG}$= functionality of organizations; $Q_{PHY}$= functionality of physical infrastructure systems; all terms are function of location (r) and of time (t). The other temporal functionality maps include lifestyles, economics, and social / cultural aspects. For each layer is possible to define a *resilience index contour map* after integrating the functionality for the control time ($T_{LC}$) period as shown further in this section.

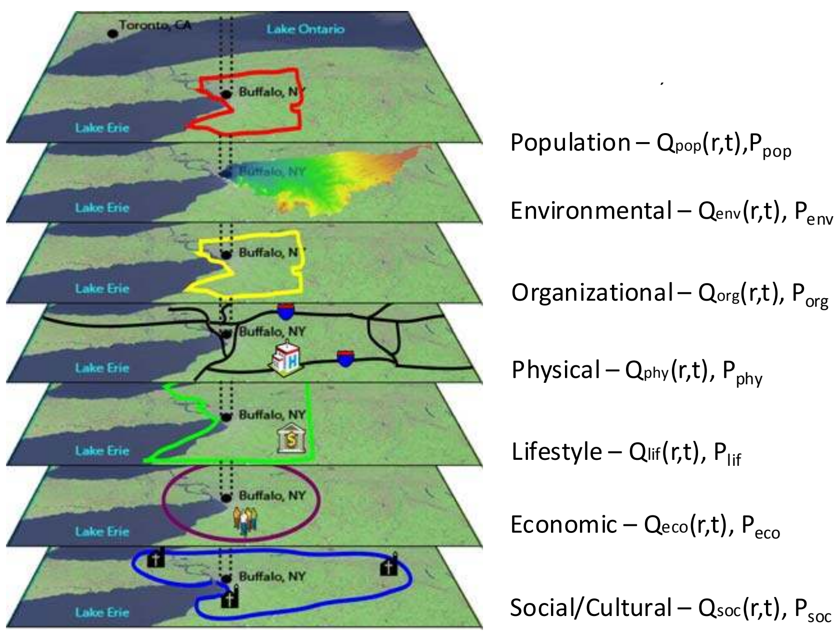



**Figure 5-1 Schematic representation of time dependent community functionality maps**

Each dimensional layer has a specific spatial functionality dictated by the influence area of the grid, jurisdiction, economic environment, social cultural fabric, etc., as shown in Figure 5-1.

Moreover, each layer of component functionality in Figure 5-1 can be represented by a combination of sub-dimensions (or layers), each having spatial-temporal dependent functionalities, each representing a subcomponent.  For example the physical infrastructure layer can be subdivided into layers representing the housing, transportation, electric power, water, sewage, communications, etc.

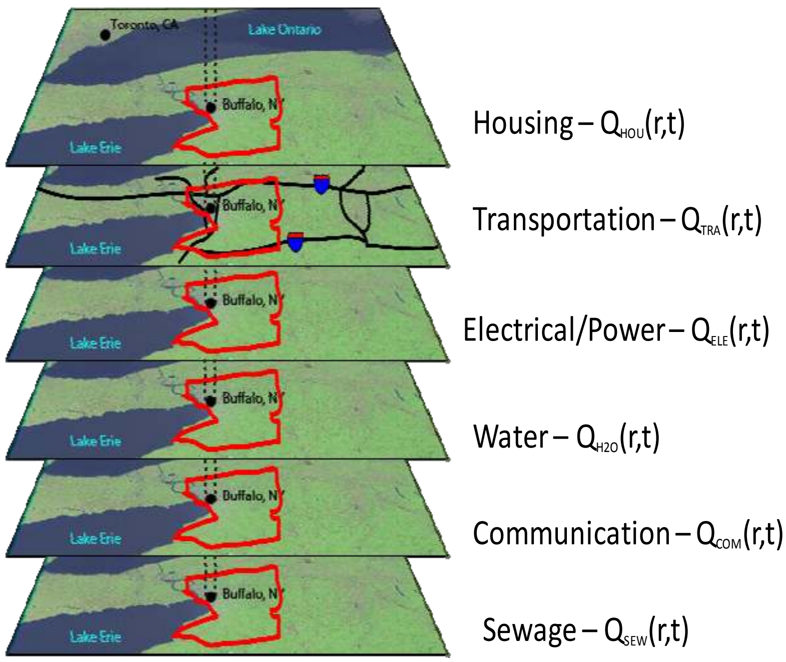



**Figure 5-2 Schematic Representation of Physical Infrastructure Functionality Maps**

Figure 5-2 presents the dimensional layers included in the physical infrastructure. This list of functionality terms that is inserted within the physical infrastructure is not exhaustive. Additional terms can be added, such as functionality of schools, dams, fire stations, oil and natural gas systems, emergency centers, etc.

## 5.2 Spatial Distribution of Components

The spatial distribution of functionalities in each dimensional layer is also specific to the area of influence of the network of lifelines that it represents. For example the highway network and the electric grid have different boundaries as well as the areas served by the water system and by the communication system. These areas of influence are not same for each layer and can be national, regional or local, dependent on the service provided.

## 5.3 Community Boundaries: Region of Interest

Multiple community resilience indices, $R_i$, for each component, i, or a single combined index, R, would be dependent on a defined temporal and geographic size or scale defined by community boundaries. The community will include in its boundaries an entire network, or several networks, but most likely will include only parts of the larger national or regional networks. Therefore in determining resilience, first, the boundaries of the region of interest should be defined. Geographic Information Systems (GIS) are increasingly being used to map vulnerability, and to better understand how various phenomena (hydrological, meteorological, geophysical, social, political and economic) effect human populations. The region of interest is further divided in grid cells and inside each cell, **r**, a definition of functionality $Q_i(r,t)$ at a given time instant, t, is given for each dimension (Figure 5-3). For example, if the community resilience index of the electric power network has to be calculated for a given region, first the definition of functionality $Q_{ELE}$ needs to be defined, for example as

$$Q_{ELE}(\mathbf{r},t) = \frac{N_{CP}(\mathbf{r},t)}{N_C(\mathbf{r},t)} \qquad (3)$$

where $N_{CP}$=number of households receiving power in the grid cell and $N_C$= total number of households in the grid cell.

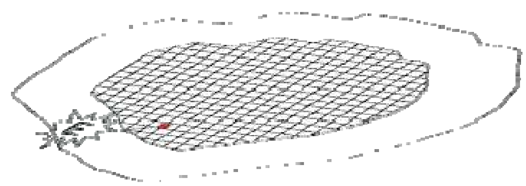


**Figure 5-3 Example of region of interest divided in grid cells**

Then, after evaluating the functionality $Q_{ELE}(\mathbf{r},t)$ in each grid cell for the entire period of control, $T_{LC}$, different ways of representing the data are available.

## 5.4 Resilience maps

At every instant $t_0$ a given ***functionality maps*** $Q_{ELE}(\mathbf{r},t_0)$ (or contour plots) can be plotted over the region of interest. These maps can be used during the entire recovery process, especially in the days immediately after the extreme events and they can be updated on regular basis for example. They can be used to direct resources and personnel toward the zones more affected by the extreme event in the region.

At different time periods defined also by the control time, $T_{LC}$, it is possible integrate the functionality for the given control time and calculate the resilience at each location r.

$$R_{ELE}(\mathbf{r}) = \int_{t_{OE}}^{t_{OE}+T_{LC}} Q_{ELE}(\mathbf{r},t) / T_{LC}\, dt$$

(4)

Then the resilience indices can be used to develop the ***resilience maps*** in the form of contour plots. These maps can be used as information during the entire recovery process, or during any given control period. At the end of the emergency period they give you a status on the level of achieved resiliency of the component/dimension in the aftermath of the extreme event.

Finaly, a global ***community resilience index for the specific dimension*** (*electric power system* in the example below) can be provided by double integrating over the entire region, $r_{LC}$, and the control period, $T_{LC}$..

$$R_{ELE} = \int_{\mathbf{r}_{LC}(t)} R_{ELE}(\mathbf{r})\, dr = \int_{\mathbf{r}_{LC}(t)} \int_{T_{LC}(t)} Q_{ELE}(\mathbf{r},t) / T_{LC}\, dtdr$$

(5)

All equations above are presented for the functionality of the ***electric power network***, only, but formulation can be easily extended to all components/dimensions.

## 5.5 Global Community Resilience Index

When a global resilience index is required to assess the entire community, as a result of all components and dimensions, this index can be obtained using the total functionality $Q_{TOT}$ (r,t), that combines the different dimensions, so the final ***community resilience index*** is given by:

$$R = \int_{\mathbf{r}_{LC}(t)} R(\mathbf{r})\, dr = \int_{\mathbf{r}_{LC}(t)} \int_{T_{LC}(t)} Q_{TOT}(\mathbf{r},t) / T_{LC}\, dtdr$$

(6)

where $Q_{TOT}(\mathbf{r},t)$ is the global functionality that is a function of time and space and combines **all** functionality terms considered; $\mathbf{r}_{LC}$ is the region of interest that can change with time; ***t*** is the time parameter; $T_{LC}$= control time that can change through the time.

Note that the selection of ***all*** functionalities contributing to the total would be in most cases only ***a smaller but relevant subset*** of ***all dimensions*** describing communities.

All resilience dimensions and their respective indices to measure their performances are interdependent (Figure 5-4).

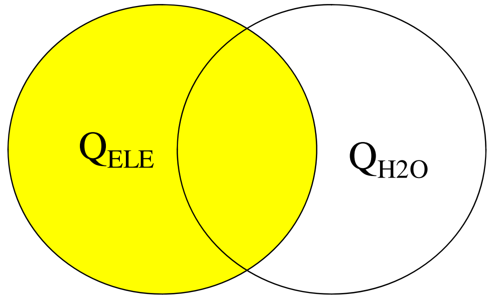



**Figure 5-4 Interdependencies among different functionalities**

A simple way of combining different functionalities is using the analogy with the probability axiom of arbitrary events therefore the global definition of functionality is given by

$$Q_{TOT} = \sum_{j=1}^{n} Q_j - \sum_{i=1}^{n}\sum_{j=2}^{n} Q_i Q_J + \sum_{i=1}^{n}\sum_{j=2}^{n}\sum_{k=3}^{n}(Q_i Q_j Q_k) - \ldots + (-1)^{n-1}\sum_{i=1}^{n}\sum_{j=2}^{n}\sum_{k=3}^{n}\ldots\ldots\sum_{l=n-1}^{n}(Q_i Q_j Q_k \ldots Q_l Q_n)$$

(7)

It is obvious that not all functionalities might have the same weight; therefore the global functionality can be determined using the mathematical expectation denoted by $E\{Q(\mathbf{r},t)\}$ that is defined by

$$Q_{TOT} = E\{Q(\mathbf{r},t)\} = \sum_{i=1}^{n} p_i(\mathbf{r},t) Q_i(\mathbf{r},t)$$

(8)

where *n* is the number of dimensions considered relevant in the functionality, $p_i(\mathbf{r},t)$=priority (probability) factors; $Q_i$=functionality associated to a given dimension of PEOPLE framework (see CHAPTER 2 and Table 2). Notable, for the total system functionality, the number of dimensions can be maximum seven *(n=7)* as indicated in the PEOPLES framework. However, the same formulation (recurrence formula), with suitable adjustment of the meaning of the indices, applies to the total functionality of a single component/dimension such as the physical infrastructure, or the organizational system, thus allowing to determine the resilience index of just that component/dimension.

The formulation suggested above provides the base for further development of the resilience indices for various locations using a probability framework while considering inherent uncertainties in the systems.

# CHAPTER 6
# SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

## 6.1 Summary

The purpose of this study is to identify gaps in the definitions and quantification of resilience at the community scale with the goal of developing a consistent framework that can address simultaneously the assets of the community and their functionality at various geographic and temporal scales. From the outset of this study it was clear that the current state of the art addresses only limited aspects of community resilience, with little, or no, capability to address continuously changing components of various sizes. Therefore, a new framework was suggested including an attempt to mix the multiple dimensions contributing to the functionality of the community system. Moreover, each component is described also as a system with its functionality contributing to the overall community system functionality. As such, a "system of systems" was created. The elements of the new framework were defined and justified based on available information. However, much of the quantification is still in its infancy and requires aggregation of widely used methods in systems analysis and management.

The framework visualizes integration of multiple components that can be viewed as interacting layers of functions in space and time, representing functionality of component dimensions, which can be overlaid with proper interactive connections and interactions.

The framework presented in this report uses as a central part in the definition and quantification of resilience, the basic ***functionality*** of various components contributing to community resilience. These ***functionalities*** are complex functions of various parameters, which need to be yet defined and quantified. Previous attempts of such quantifications (Cimellaro et al, 2009) indicate that there is still much to be done before the implementation of this concept is feasible and efficient. However, the initial framework defined in this report, can serve as guide for definitions of functionalities, parameters identifications, data collection, computational evaluations, etc.

## 6.2 Recommendations for Future Research

The report suggests the base of a new framework defining resilience at the community level, considering multiple dimensions and their interactions. The PEOPLES framework suggested here attempts to identify and group all the important components with common roles in the community welfare. However to better and consistently represent the resilience of communities more details of the above mentioned framework need to be developed.

First and foremost it is suggested to develop a consistent formulation for the quantification of resilience with focus on ***a subset of PEOPLES Resilience Framework's dimensions*** that includes only the Population and Demographics, Physical Infrastructure, and Economic Development. These relevant dimensions may allow developing key interrelations and their mathematical formulations as well as defining relevant data through sensitivity formulations. Note that the interaction between these three dimensions, as well as the other four dimensions, will be the major driver for the development. The consistent formulation for quantification of resilience indices (or indicators) should use a temporal-spatial probabilistic framework. Note also that an interdisciplinary team with knowledge of engineering, social sciences, management and economics, well motivated and coordinated for an integrated approach is necessary. The further developments, although addressing only three dimensions, should not exclude any of the other dimensions of *PEOPLES* by way of interactions and correlations where proven relevant. If any of the dimensions are excluded, the new formulation may default to the prior, much simplified, definitions by MCEER and others.

An illustration using a case study can clarify the new concepts and their comprehensive approach. Therefore, it is recommended to select and develop a strong case study supporting the value and effect of the *PEOPLES Resilience Framework*. A region of interest was identified by the authors as a possible case study, a site in Western New York that includes already established physical infrastructure resilience and environmental projects on hospitals and the impacts of natural hazards (earthquake and flooding). Proximity of researchers to the sites in the case study may prove to be a key factor in the selection of the project. Case studies may choose desired "regions of interest" depending on access and security of the sensitive information and data needed for success of such studies. The authors of this report will continue the development of this approach along the lines of these recommendations.

# CHAPTER 7

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# Appendix A
# GLOSSARY

The Glossary of Resilience Terms contains a comprehensive set of definitions of key terminology and concepts and commonly used acronyms.

A detailed reference is provided for each definition to enable the user to refer to the complete source document to obtain further information/context where needed. The source information provided relates to the source from where the definition was extracted for inclusion in the Glossary. This source document may not in fact have been the original source of the definition but it is the medium that promoted it recently. Interested party may search in more depth for the original source.

Notable, some terms have different definitions although share same terms; addressing different aspects, or dimensions defined in this report. Thus the final communication of these terms must be clarified when used. For example, in many cases the engineering concepts of resilience refer to different aspects than the social aspects of resilience. This report attempts to reconcile some of the differences by providing multiple dimensions and their interrelations, along with some methods of quantification.

To continue the assembly of this glosary, contributions and other related information should be sent to the original collector:

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| Term | Definition | Source |
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| Anticipation | Continuous risk identification and analysis so that you have a good appreciation of the dynamic risk environment in which you operate and are able, as far as is reasonable, to foresee potential consequences (direct, indirect and interdependent) and arrangements for managing these. | |
| Community | A social group of any size whose members reside in a specific locality, share government, and often have a common cultural and historical heritage. | www.dictionary.com |
| Community | A group of people (1) who share social interaction and (2) some common ties between themselves and the other members of the group and (3) who share an area for at least some of the time. | Hillery 1955 |
| Community | An entity that has geographic boundaries and shared fate. Communities are composed of built, natural, social, and economic environments that influence one another in complex ways. | Norris et al. 2008 |
| Community | A social, religious, occupational, or other group sharing common characteristics or interests and perceived or perceiving itself as distinct in some respect from the larger society within which it exists. | www.dictionary.com |
| Community resilience | The process through which mediating structures (schools, peer groups, family) and activity settings moderate the impact of oppressive systems. | Sonn 1998 |
| Community resilience | The development of material, physical, socio-political, socio-cultural, and psychological resources that promote safety of residents and buffer adversity. | Ahmed 2004 |
| Community Resilience | The capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures. | Subcommittee on Disaster Reduction (SDR) 2005 |
| Community Resilience | A community is an open system, comprising individuals and institutions (elements) with patterned relationships among themselves and with the external environment. | Alesch, Arendt, and Holly 2009 |
| Community Resilience | A community or region's capability to prepare for, respond to, and recover from significant disturbance-driven changes: while maintaining community character, cohesion and capacity, and without permanent impairment of the community's public safety and health, economic, social, and national security | SERRI (www.serri.org/ community_resilience.html) |

| Term | Definition | Source |
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| | functions, thus, accelerating recovery. | |
| Community resilience | A process linking a set of networked adaptive capacities to a positive trajectory of functioning and adaptation in constituent populations after a disturbance. | Norris et al. 2008 |
| Community Seismic Resilience | The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes. | Bruneau et al. 2003 |
| Complex adaptive systems | Systems of people and nature in which complexity emerges from a small set of critical processes which create and maintain the self-organizing properties of the system. | Holling, C.S. 2001 |
| Control period | The period during which the community resilience is evaluated. | Cimellaro et al. 2009 MCEER Report |
| Crisis | What happens when a surprise reveals a failure of the rules, norms, behavior or infrastructure used to handle that type of surprise. | Longstaff 2005 |
| Disaster | A potentially traumatic event that is collectively experienced, has an acute onset, and is time delimited; disasters may be attributed to natural, technological, or human causes. | McFarlane and Norris 2006 |
| Ecological resilience | The persistence of relationships within a system; a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist. | Holling 1973 |
| Ecological Resilience | Positive adaptation in response to adversity; it is not the absence of vulnerability, not an inherent characteristic, and not static. | Waller 2001 |
| Ecologic Resilience | The ability of an ecosystem to absorb and adapt to change and maintain its existing state of functioning. | Holling 1973 |
| Engineering Resilience | A measure of a system's capacity to absorb and recover from the occurrence of a hazardous event; virtually synonymous with "elasticity"; reflective of a society's ability to cope and continue to cope in the future. | Timmerman 1981 |
| Engineering Resilience | The ability of a material to return to a pre-existing state after being stressed. | Pimm 1984 |
| Indicator | Specific, descriptive items of information that are used to track changes in a condition or function of a community, agency, or family. | CSBG 1999 |
| Indicators | Measures intended to represent a characteristic or a parameter of a system of interest. An indicator may be composed of a single variable (e.g., income) or a combination of variables (e.g., gross domestic product). Multiple indicators can be combined to construct composite indicators, or indices, which attempt to distill the complexity of an entire system to a single metric. | Birkmann 2006; Villagrán de León 2006 |
| Physical Resilience | The ability to store strain energy and deflect elastically under a load without breaking or | Gordon 1978 |

| Term | Definition | Source |
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| | being deformed. | |
| Physical Resilience | The speed with which a system returns to equilibrium after displacement, irrespective of how many oscillations are required. | Bodin 2004 |
| Preparedness | Having a plan for identified risks, identifying the resources required and any gaps, training and exercising, having a process for updating plans and capability assessments, and being ready to respond. | |
| Quality of life | One component of wellness that captures how people generally feel about their lives as a whole and in domains of work or school, family, health, leisure, and neighborhood. | Norris et al. 2008 |
| 4 dimensions of Resilience according to CARRI (Community and Regional Resilience Initiative) | Anticipate<br>Reduce vulnerability<br>Respond efficiently<br>Recover faster | CARRI |
| Robustness | The ability of elements, systems or other units of analysis to withstand a given level of stress, or demand without suffering degradation or loss of function. | Bruneau et al. 2003 |
| Rapidity | Capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption. | Bruneau et al. 2003 |
| Resourcefulness | The capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis. | Bruneau et al. 2003 |
| Redundancy | The quality of having alternative paths in the structure by which the lateral forces can be transferred, which allows the structure to remain stable following the failure of any single element. | FEMA 356 2000 |
| Recovery period/downtime | The time necessary to return to the initial value of functionality before the extreme event. | Cimellaro et al. MCEER 2009 |
| Regional Economic Resilience | The ability of a regional economy to maintain a pre-existing state (typically assumed to be an equilibrium state) in the presence of some type of exogenous shock. | Hill et al. 2008 |
| Resilience | The amount of disturbance a system can absorb and still remain within the same state…the degree to which the system is capable of self-organization (p. 35)…the degree to which the system can build and increase the capacity for learning and adaptation | Klein, Nicholls, and Thomalla 2003 |
| Resilience | The ability of a human system to respond and recover. It includes those inherent conditions that allow the system to absorb impacts and cope with the event, as well as postevent adaptive processes that facilitate the ability of the system to reorganize, change, and learn in response to the event. | Cutter et al.2008 |
| Resilience | A process linking a set of adaptive capacities to | Norris et al. 2008 |

| Term | Definition | Source |
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| | a positive trajectory of functioning and adaptation after a disturbance. | |
| Resilience of institutions | The ability of institutions of common property management to cope with external pressures and stress. | |
| Social Community Resilience | The ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change (p. 347)… ability of communities to withstand external shocks to their social infrastructure. | Adger 2000 |
| Sustainability | The ability of a locality to tolerate—and overcome—damage, diminished productivity and reduced quality of life inflicted by an extreme event without significant outside assistance. | Mileti and Gailus 2005 |
| Sustainability | The ability to sustain the use of facilities, equipment and staffing arrangements, which is important because emergencies sometimes require a prolonged response and/or recovery effort. | |
| Vulnerability (resilience) | The pre-event, inherent characteristics or qualities of systems that create the potential for harm or differential ability to recover following an event. Vulnerability is a function of the exposure (who or what is at risk) and the sensitivity of the system (the degree to which people and places can be harmed). | Cutter et al.2008 |