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County Level Resilience and Vulnerability Index

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Introduction

This working paper is a first contribution to The Missouri Transect Project Community Team's *Integrating Responses to Climate Change within a Regional Resilience Framework.* The eventual aim is to develop a Missouri subset of a national resilience indicator system so that communities can learn about their own vulnerability and resiliency relative to their peers across the state and the nation.
The primary purpose of this paper is to present a conceptual framework for a resilience and vulnerability index. Several key questions have been considered in the development of this framework:

- What are the goals of such an index? What are the main challenges to be addressed?
- How are the overarching concepts of resilience and vulnerability defined?
- What are generally accepted indicators that measure these concepts?
- What proposed indicators should be incorporated into an index?
- How should the index be constructed?

Goals (and Challenges) of a Resilience and Vulnerability Index

While there has been much work in this space, there seems to be no agreed upon definition for the concepts, nor a set of indicators to measure them. Quantifying the risks a community faces with regard to disasters of any sort is a useful tool for community leaders and planners. Risks are most often defined in terms of a probability of some event occurring. While a higher risk is not an assurance of occurrence, it gives a community a likelihood framework with which to work on preparedness. Risks (and hence vulnerabilities) are a probability of some event occurring *in the future*. The only way to develop data around these risks is with data on past events. Therefore, construction of a risk factor cannot fully predict events. Recent history shows natural events that are unprecedented in terms of their severity, duration, and damage impact (for example, droughts in the West, hurricanes, flooding through the Plains, etc.). In addition, more areas are experiencing compounding events, such as the earthquake and tsunami in Japan, which was followed by a nuclear disaster; as well as the effects of Hurricane Katrina in combination with severe flooding after levee failures. In such compounding events, it is difficult to isolate the impacts from one portion of the event.

The goals for the conceptual framework outlined in this paper are to:

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- Identify sets of indicators that quantify the concepts of resilience and vulnerability, and
- Recommend a course of action regarding indicator selection and measurement

These goals will assuredly meet with trade-offs. Selection of one geographic unit of analysis over another will certainly have shortfalls. Counties are often seen as a useful unit of analysis, partly because of the function of county governments, but mainly because of the availability of data at a national scale. To the extent that there is a desire to cover 100 percent of U.S. geography, there are few options available other than counties.

That said, a county level resilience and vulnerability index has to recognize the inherent challenges of using counties as a unit of analysis. Taking into account the geographic size, population density and concentration, and number of individual jurisdictions within the county can help to ameliorate potential bias that occur in geographically large and diverse counties. Though most data is collected and reported at the county level, GIS frameworks can allow the aggregation or separation of geographic units, so that more realistic regions can be examined.

Concepts of Resilience and Vulnerability

While commonly understood, there are variations in the definitions used in the literature around the concepts of resilience and vulnerability. One thorough definition of disaster resilience is provided by Renschler et al, "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." [4]

According to the National Institute of Standards and Technology, "Disaster resilience is defined as the ability to minimize the costs of a disaster, return to the status quo, and to do so in the shortest feasible time."[5] Finally, the Rockefeller Institute defines resilience within their *100 Resilience Cities* initiative as "the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience."[6]
These definitions all have several components in common.

- First, the subject of the resilience is not just one entity – no one geography, population, governmental unit, or business. Rather, it is the collective within a geographic area that creates a resilient whole.
- Second, each definition recognizes that the act of being resilient exists in several phases, from responding to disaster to recovering from its losses. It is important to recognize that, just as a community is not impacted uniformly during a disaster, nor will it recover uniformly. Some areas within a community will rebound quickly, while others may struggle.
- Finally, physical damages and costs are not the only component of potential disasters, but social disruption and adaptation to a new status quo are also important to resiliency.

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[4] Renschler, Chris S., Amy E. Frazier, Lucy A. Arendt, Gian-Paolo Cimellaro, Andrei M. Reinhorn and Michael Bruneau. 2010. *A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework*. Technical Report MCEER 10-0006. Multidisciplinary Center for Earthquake Engineering Research, University of Buffalo, State University of New York. Page 1.

[5] Gilbert, Stanley W. 2010. *Disaster Resilience: A Guide to the Literature.* NIST Special Publication 1117, U.S. Department of Commerce, National Institute of Standards and Technology. Page 2.

[6] http://www.100resilientcities.org/resilience

While many such indicators focus conceptually on resilience, the underlying indicators are often more directed at vulnerability. It may be argued that resilience is the flip side of vulnerability, but communities facing similar risk factors are likely to react in different ways as a result of differences in their leadership capacity, access to resources, and strength of their social networks.

The proposed framework draws from the Notre Dame Global Adaptation Index (ND-GAIN)[7] which uses a series of indicators reflecting the vulnerability to natural disasters and security risks of 177 countries together with their readiness to successfully implement adaptation solutions. The resulting set of indexes are presented in four potential quadrants. Figure 1 shows a similar approach by bringing together indicators of vulnerability and resilience into a matrix to provide broad but potentially useful categories for U.S. communities.

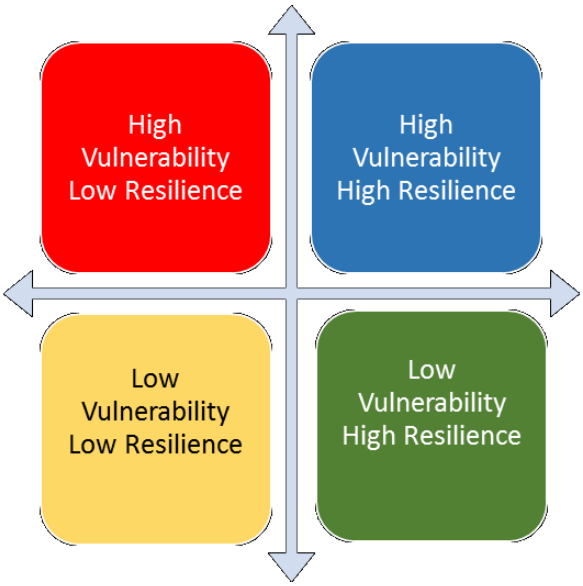

Figure 1: Vulnerability-Resilience Matrix

Generally Accepted Indicators

Much of the work examining resilience can be placed into two groups.

- A **community-focused approach**, by which the resilience of a particular community is ascertained through a mix of targeted quantitative and qualitative methods. This is valuable to individual communities as they assess their risks for events and seek to plan for response and recovery from them. The *Communities Advancing Resilience Toolkit (CART) Integrated System* includes a methodology for assessing the strength of a particular community through secondary data, key informant interviews, and structured surveys.[8]

- A **comparative approach**, where techniques are used to measure the vulnerability and/or resilience across a number of geographies (counties, cities, countries), and compare the characteristics of places *relative* to others. The goal is to develop a nationally inclusive composite index that can be used by both communities to assess their comparative status and

[7] University of Notre Dame Global Adaptation Index Detailed Methodology Report, December 2013. http://gain.org/
[8] Pfefferbaum RL, Pfefferbau B, and Van Horn RL (2011). Communities Advancing Resilience Toolkit (CART): The CART Integrated System. Oklahoma City, OK: Terrorism and Disaster Center at the University of Oklahoma Health Sciences Center

by agencies and investors to identify priorities. The *Community Resilience System's* "snapshot indicators" represent an easy-to-interpret example. The snapshot makes use of several secondary data sources, and compares individual counties to the state and nation, giving each a red, yellow, or green light gauge[9].

Susan Cutter and colleagues have constructed several vulnerability and disaster resilience indicators at the county level. These, along with the snapshot indicators, form a strong basis for resilience and vulnerability indicators. The Cutter indexes focus on secondary data at the county level, and are very useful in considering the framework proposed below. In fact, many of the proposed indicators are taken largely from work done by Cutter and colleagues.[10]

There are several categorizations of factors relating to resilience and/or vulnerability. Cutter *et al* utilize five sub categories: social, economic, institutional, infrastructure, community[11]. Renschler *et al* utilize a seven-category "PEOPLES" system: population and demographics, environmental/ecosystem, organized government services, physical infrastructure, lifestyle and community; economic development; and social/cultural capital.[12] The Notre Dame GAIN index categorizes eight vulnerability sectors: water, food, health, human habitat, ecosystem service, coastal infrastructure, energy infrastructure, and transport infrastructure; and three components of readiness: economic, governance, and social.[13] The Community Resilience Snapshot system divides resilience indicators into economic, environmental and social resilience.[14]

Table 1. Summary of Major Resilience and Vulnerability Indicators Utilized in Recent Literature

Concept	**Methods of Measuring**
Economic resilience	Populations above poverty; Population with incomes over $100,000; Median household income; In-migration, populations with high education attainment (B.S. or higher); household costs as a percentage of household income; housing affordability; economic diversification; favorable/entrepreneurial business environment; venture capital funding available for business startups; income categories and overall income distribution; employment levels; labor force participation rates; dependence on transfer payments; Indiana innovation index; business size
Economic vulnerability	High poverty households; populations with incomes under $40,000; dependence on single industry sector such as extractive or manufacturing); vacant housing; ratio of transfer payments to earned income
Environmental Resilience	Natural amenities; alternative fuel vehicle registrations; coastal restoration plans; natural amenities index; air quality index; biodiversity; biomass (vegetation); homes covered by flood insurance

[9] Community and Regional Resilience Institute, *Community Snapshot Mississippi Gulf Coast Counties*.

[10] Cutter, Susan L., Christopher G. Burton, and Christopher T. Emrich. 2010. "Disaster Resilience Indicators for Benchmarking Baseline Conditions." *Journal of Homeland Security and Management* 7(1), Article 51.
Cutter, Susan L, Bryan J. Boruff, and W. Lynn Shirley. 2003. "Social Vulnerability to Environmental Hazards." *Social Science Quarterly* 84(2): 242-261.

[11] Cutter, Susan L., Christopher G. Burton, and Christopher T. Emrich. 2010. "Disaster Resilience Indicators for Benchmarking Baseline Conditions." *Journal of Homeland Security and Management* 7(1), Article 51.

[12] Renschler, Chris S., Amy E. Frazier, Lucy A. Arendt, Gian-Paolo Cimellaro, Andrei M. Reinhorn and Michael Bruneau. 2010. *A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework*. Technical Report MCEER 10-0006. Multidisciplinary Center for Earthquake Engineering Research, University of Buffalo, State University of New York.

[13] University of Notre Dame Global Adaptation Index Detailed Methodology Report, December 2013. http://gain.org/

[14] Community and Regional Resilience Institute, *Community Snapshot Mississippi Gulf Coast Counties*.

Environmental vulnerability	Coastline at risk; floodplain; earthquake zones; history of damage information and hazard types (SHELDUS loss and hazard database); air quality; average commuting times; vacant housing
Social resilience	Educational attainment; percentage of population without a disability; percentage of population above poverty line; percentage of population with health insurance; health care infrastructure; place attachment; charitable giving; community health; create class employment; life expectancy; religious adherents; civic betterment; social advocacy; employment in arts, entertainment, and recreation
Social vulnerability	Flip side of many of the resilience indicators; population in vulnerable age groups; crimes rates and incidents; teen births; non-English speakers
Community/civic resilience	Voter participation; place attachment; political engagement (voter participation rates); civic organizations; social advocacy organizations; creative class occupations; organizations devoted to the arts, entertainment, recreation, civic betterment, social advocacy; religious organizations; landmarks
Community/civic vulnerability	Nursing home residents
Infrastructure resilience	Percentage of vacant rental units; hospital beds per 10,000; arterial miles per square mile
Infrastructure vulnerability	Mobile homes; access to transportation infrastructure; drinking water violations; substandard housing; households without internet access

There remains considerable overlap between resilience and vulnerability measures. For example, a low poverty rate appears in some literature as a resilience indicator, while a high poverty rate appears in others as a vulnerability index. In all cases, considered decisions will need to be made on the placement of indicators into resilience or vulnerability measures. A series of indicators is proposed here as a start to the conversation.

Proposed Indicators

The following list presents a proposed first step for constructing a resiliency and vulnerability index for counties in the U.S. Four major categories are listed below: social, environmental, infrastructure, and economic. As mentioned above, several indicators can be used to measure both resilience and vulnerability. For this framework, they are placed in a category consistent with the direction of values. Thus, if a higher value on an indicator is a desired outcome, then that indicator is placed in the resilience category. If a higher value on an indicator indicates a pressure point or weakness, then that indicator is placed in the vulnerability category. This largely follows the Community Resilience System Snapshot strategy that divides indicators into “high values preferable” and “low values preferable.”

Table 2: Proposed Measures of Resilience and Vulnerability

	RESILIENCE		VULNERABILITY	
	Concept	Measure	Concept	Measure
SOCIAL	Place attachment	Percentage of population living in same county as one year prior	Income inequality	County gini index
	Place attachment	Percentage of HH that are owner occupied	Political fragmentation	Number of political districts within county
	Educated population	Percentage of population with BS degree or higher	Language competency	Percentage of HH that are linguistically isolated
	Civic engagement	Voter participation rates	Special needs populations	Percentage of population with a disability
	Nonprofit capacity	Number of nonprofit organizations per capita	Vulnerable populations	Percentage of population lacking health insurance
	Health of citizens	Life expectancy		Percentage of population 65+
	Social Capital	Components of, or composite social capital index developed by Goetz		Percentage of population under 18
				Linguistically isolated households
			Community erosion	FBI Violent crime and property crime index
ENVIRONMENTAL	Natural amenities	Natural amenities scale	Likelihood of damages	Previous disasters (SHELDUS, FEMA)
	Mitigation planning	Coastal restoration plans	Potential for natural disasters /	Percentage of land area in flood plain
	Preparedness	Hazard mitigation plans	Vulnerable environments	Percentage of land area in earthquake zone
		Homes covered by flood insurance		Percentage of coastal land
	Ecosystem diversity	Normalized difference vegetation index; other USGS indicators?		Populations living below sea level
			Environmental quality	Watersheds
				Air quality index
INFRASTRUCTURE	Medical capacity	Hospital beds per capita	At risk infrastructure	Mobile homes
		Physicians per capita		Older homes
	Adequacy of roadways in potential evacuations	Miles of primary roads per square mile	Potential evacuation and rebuilding challenges	Populations living in group quarters
				Percentage of homes with no vehicle available
	Shelter capacity		Vulnerability of local infrastructure	Drinking water violations
	County fiscal preparedness	County budget data?		Substandard housing
	Built environment facilities			
ECONOMIC	Economic diversity	Diversity index	Economic hardships	Unemployment rate
	Economic activity	Creative class workers	Reliance on transfers	Percentage of Total County income from Transfer payments
	Entrepreneurial Environment	Labor force participation rate	Local tax revenue shortfalls	
				Housing vacancy rate
	Local ownership of companies	Number of entrepreneurs	Vulnerable industry dependence	
		Venture capital available for start ups		Percentage employed in extractive industry and/or manufacturing

Variables Rationale

Most indicators listed in the table above appear in peer reviewed resilience and vulnerability literature.

- **Social Measures** are intended to capture the degree to which a community has strong set of social and human capital with which to rebound from a potential hazard event. Social vulnerabilities are characteristics of the population or community that cause isolation or erosion of social capital, and therefore work against the community following a disaster. Several of the indicators included in the table above are often seen as social capital measures.
- **Environmental Measures**. Vulnerability measures are designed to capture the likelihood of disasters befalling communities. Careful thought has to be given to the number of disasters considered, and how to account for the bias that occurs in measuring disasters that are isolated in geographic regions (for example, Midwestern counties face limited risk for hurricane activity). Additional conceptual framing around these measures is needed. The Spatial Hazards Events and Losses Database for the United States (SHELDUS)[15] provides a comprehensive database of damages. The environmental resilience indicators are intended to capture the amount of mitigation planning that a community has undertaken, as well as the coverage in terms of flood insurance. In addition, some measures of environmental quality are included, although further investigation of data sources is needed.
- **Infrastructure Measures**. Resilience indicators measure the capacity of a community to withstand a natural disaster and manage evacuations and immediate repairs following a disaster event. The vulnerabilities indicators capture particular at-risk infrastructure as well as potential challenges to evacuation and rebuilding efforts.
- **Economic Measures** describe the economic strength (resilience) and vulnerability of a community or region.

Index Construction

A 2008 report from the Organization for Economic Co-operation and Development (OECD) regarding the construction of composite indicators describes important issues and caveats. The report stresses the need for a theoretical backing for indicator selection, assurance of data quality, understanding the underlying structure of the dataset, and imputation methods where necessary. The framework presented here will make heavy use of secondary, county level data based largely on prior studies of resilience and vulnerability measures.

There are several normalization methods for calculating an index.

[15] "SHELDUS™ is a county-level hazard loss data set for the U.S. for 18 different natural hazard events types such thunderstorms, hurricanes, floods, wildfires, and tornados. For each event the database includes the beginning date, location (county and state), property losses, crop losses, injuries, and fatalities that affected each county. The data set does not include Puerto Rico, Guam, or other U.S. territories….Depending on your query selection, the download will list the temporal information (year, month, and/or quarter), spatial information (FIPS code, county, state), damage information (crop and property damage, fatalities, injuries), and hazard type(s). Please see the metadata section for more detailed information on the naming convention of table columns SHELDUS™ is a loss and hazard database. The National Climatic Data Center's Storm Data database is an event database. SHELDUS™ includes any loss event across all types of natural hazards including geological. SHELDUS™ can be used to determine the frequency of loss-causing events."

- The Resilience Capacity Index utilizes z-scores to normalize the data. The z-score is the number of standard deviations from the mean value of the variable. For example, a z-score of 1.5 indicates a value that is 1.5 standard deviations from the mean. While a z-score can take on infinite values, most z-scores will be within the range of -3 to 3, assuming a normal distribution.
- Other methods compare county indicators to state and U.S. levels on the same indicators, thus showing if the county is above or below a state or national average.
- The Cutter indexes use a rescaling method, setting the minimum value in the dataset to zero, and the maximum value to one, then rescaling all indicators so the resultant value is between zero and one.

The OECD report discusses these, as well as additional, methods of normalization. The underlying reasoning for any normalization is to allow comparison across geographic places as well as across different types of measures.

Following the normalization, the overall index is created by either straight summing or averaging the individual indicators. The processes of summing or averaging each have strengths and weakness. Each creates a system where normalized indicators can "wash out" extreme values. However, when sub-indexes are employed, the use of averaging allows equal weighting between the different indexes, so that if a sub-index has more indicators, it does not receive higher weighting in the final composite index. Overall, indicators are weighted equally, as the literature provides little supporting evidence for differential weighting across indicators.

The proposed construction method is as follows:

1. Determine the set of indicators to include (using those in Table 2 as the starting point)
2. Assemble county level data sets as determined from table 2. (An appendix table listing data sources is under construction)
3. Examine pairwise correlations between all variables. Consider eliminating variables if correlation coefficients are very high (0.8 or higher).
4. Examine the distribution of each variable. Does each approximate a normal distribution? What percentage of observations are within 2 and 3 standard deviations from the mean?
5. Set the minimum and maximum values for each variable. While in many cases the actual minimum and maximum may make sense, it might be prudent to consider top and bottom coding the values at 3 standard deviations from the mean. This would reduce the influence from outliers in the dataset.
6. Recode variables based on minimum and maximum values from previous step. Set maximum equal to 1 (or to 100 for ease of interpretation), and minimum to zero.
7. If sub-indexes are of interest, average values within each sub index. Averaging instead of summing will keep all sub-indexes equally weighted.
8. Sum the values of all the sub-indexes for Resilience and Vulnerability. Note: if step 6 is not desired, then this step would average the values of all indicators across resilience and vulnerability.
9. All counties have a place on a four quadrant grid. High/low resilience and vulnerability can be set at halfway marks or other meaningful breaks in the data The OECD report stresses the importance of visualizations for composite indexes. Maps showing counties' placement on the grid would be valuable products.

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