ResilUS -- MODELING COMMUNITY CAPITAL LOSS AND RECOVERY

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ABSTRACT :

A resilient community is one that does not experience serious degradation in critical services when an earthquake or other natural hazard occurs and, in the event of degradation or failure, recovers to a similar or better level of service in a reasonable amount of time. Critical services with respect to community resilience are those derived from and required for community capital – physical, socio-cultural, human, economic, and ecological capital. If a community's critical services and capital are not resilient in the face of a severe economic or natural disturbance, the result will likely be disaster and serious impairment of personal livelihoods. The most efficient means of making a community resilient is to make its critical services and capital robust – minimize damage/loss probability or the consequences from damage/loss through mitigation. If a community's critical services and capital are not robust, efforts must be put into recovery. Based on the measurable aspects of community capital, we have developed a simulation model called ResilUS that operationalizes community resilience across multiple, hierarchical scales—household/business, neighborhood, and community—in relation to a range of policy and decision variables associated with each scale. The first application and calibration study of ResilUS was conducted for the 1994 Northridge earthquake disaster. ResilUS is currently being expanded to better represent socio-cultural, personal, and ecological capital to facilitate modeling the resilience of the Gulf Coast area of Louisiana, USA in association with the 2005 Hurricane Rita disaster.

KEYWORDS: *Resilience, loss estimation, recovery, modeling, disasters*

1. INTRODUCTION

A resilient community is one that does not experience serious degradation in critical services when an earthquake or other disturbance occurs and, in the event of degradation or failure, recovers to a similar or better level of service in a reasonable amount of time. Critical services with respect to community resilience are those derived from and required for community capital. If a community's critical services and capital are not resilient in the face of a severe economic or natural disturbance, the result will likely be disaster and serious impairment of personal livelihoods. The most efficient means of making a community resilient is to make its critical services and community capital robust – minimize damage/loss probability or the consequences from damage/loss through mitigation. If a community's critical services and capital are not robust, efforts then must go towards recovery of services and livelihoods, which often requires restoration of physical infrastructure. Modeling recovery facilitates "what if" analyses of resilience through comparison of different pre- and post-disaster scenarios. Specifically, it is valuable to be able to characterize the effects of different policies and management plans. Such decisions range from choosing whether to retrofit a neighborhood's gas pipelines to planning to employ short-term housing instead of temporary shelters.

Miles and Chang (2003; 2004) developed a prototype model that simulates the recovery dynamics of socio-economic agents (households and businesses), neighborhoods, and communities following a disaster. This model is distinctive from loss estimation models in its emphasis on recovery timepaths, spatial disparities, and linkages between different sectors of a community. It represents relationships across different scales – socio-economic agents, neighborhood, and community – after an earthquake or other hazard occurs, considering attributes and behaviors of households and businesses and how these affect and are affected by the built environment, policy decisions, and socio-political characteristics of a community. The implemented model was subjected to extensive sensitivity analysis and evaluation with respect to a case study of the 1995 Kobe, Japan earthquake to assist in determining priorities for model improvement (Chang and Miles 2004). The model was then evaluated during a focus group that involved

Seattle, WA (USA) area disaster planning and management professionals to solicit user needs to guide future model development efforts (Miles and Chang 2006).

This paper describes work subsequent to Miles and Chang (2006) on a version of the model called ResilUS. The following section focuses on the conceptual design of ResilUS and its relationship to the concepts of community capital. In the third section a brief overview of the implementation of ResilUS is provided. Next, a summary of the application and calibration of ResilUS to the 1994 Northridge earthquake disaster is. The paper concludes with a discussion of future work, including an introduction to current work applying the model to the Gulf Coast area of Louisiana, USA.

2. A MODEL OF COMMUNITY CAPITAL RESILIENCE

Capital refers to a stock of assets used to create or obtain additional assets. For a long time, this term has been used to refer to financial assets. But with the emergence of ecological economics (Daly, 1997) and the study of social capital (Putnam, 2001) a broader conception of the term is possible – community capital. In essence, community capital is anything that is tangible that a community requires for its existence or benefits from. There are many types of capital that a community relies on including, social, cultural, personal, political, organizational, physical, technical, economic, and natural. For this paper we will refer to five aggregate elements to community capital: 1) physical capital, 2) economic capital, 3) socio-cultural capital, 4) personal capital, and 5) ecological capital. Figure 1 shows a simple conceptual model illustrating some relationships between physical, natural, economic, personal, and socio-cultural elements of a community.

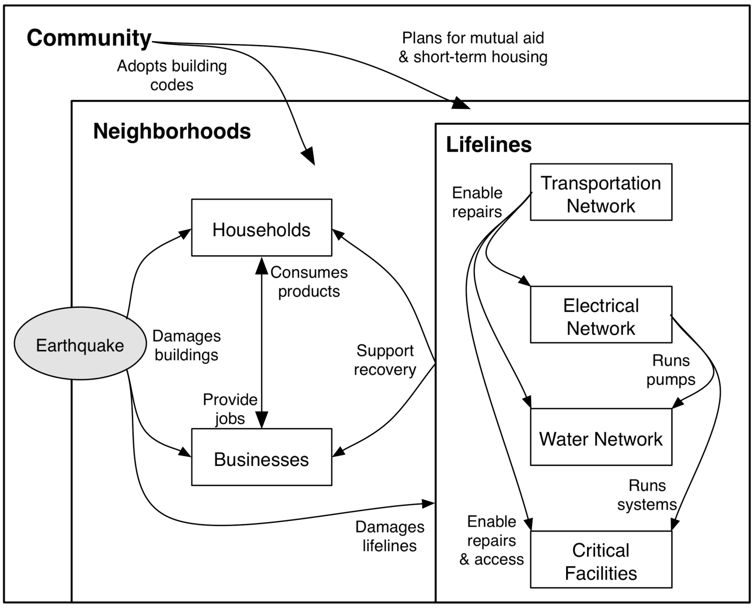

Figure 1. Generalized conceptual model of community dependencies with respect to disasters.

Table 1 gives a list of the important variables represented in ResilUS, along with a brief definition. (See Miles and Chang (2007) for all variables and a complete exposition of the model.) The variables are listed with respect to their association to the five elements of community capital described above. The organization of variables by community capital is not intended to be rigidly precise, as it is possible that variable might be related to multiple elements. The point of organizing ResilUS variables by community capital is to illustrate the breadth of the conceptual model, as well as elements of community capital that potential require further development in ResilUS.

Table 1. Definition of important ResilUS variables organized by community capitals.

Physical Capital

BYR = Year building or lifeline component built.
BL = Ratio of resources (materials, labor etc.) expended in reconstruction to building replacement value. Alternatively, percent to which reconstruction is complete. 0 to 1, with 1 being reconstructed.
CRIT = Probability that critical facilities network component service is fully restored.
CYR = year seismic (or other building) code effective
DMG = Damage of building or lifeline component expressed as ratio of building replacement value.
ELEC = Probability that electrical network component service is fully restored.
FACILITY = Service level of a business's facility. 0 to 1, with 1 indicating operation at pre-event service level.
MAINT = Probability that component has been well-maintained.
MIT = Pre-event structural mitigation of building or lifeline component. Currently 1 (maximum) indicates a 25% increase is fragility curve median.
SHEL = Probability that household has adequate shelter and associated services.
STH = Probability that short-term housing is available, Y/N.
TRNS = Probability transportation network component service is fully restored.
TYPE = Type of building or lifeline component—a proxy for size and/or complexity for reconstruction. 0 to 1, with 1 indicating largest or most

complex building/component type.
WAT = Probability that water network component service is fully restored.
WAT_ALT = Provision for alternate water sources (water trucks) for neighborhood. 0 to 1, with 1 being equivalent to maximum total water service in neighborhood (WATn = 1)

Economic Capital

AID = Normalized post-event grant amount.
DEBT = Normailzied level of debt. The inverse of LOAN.
DEMAND = Post-event demand for product. 0 to 1, with 1 indicating pre-event demand level.
EMPL = Probability that employment is available.
FAIL = Occurrence of business failure (Y(1)/N(0))
INC = Normalized annual income.
INS = Whether or not an agent has insurance.
LOAN = Normalized amount of reconstruction loan taken out. Implicitly related with DMG (ratio of building replacement value).
LOAN_MAX = Limit on post-event loan amount.
MARG = Pre-event financial marginality.
OUTLAY = Whether or not an agent has received an insurance payment. 1 is implicitly defined as the replacement value of their building.
PROD = Probability that business is at pre-event production level.
SAVINGS = Normalized savings or assets.
SECT = Type of business sector (0:local or 1:export).
SIZE = Normalized number of employees.

Socio-Cultural Capital

CAP = Recovery capacity of community (proxy for integration and consensus). 0 to 1, with 1 being highest capacity.
CONSTR = Probability that necessary construction resources available for restoration.
INSP = Time in weeks after event that safety inspections are completed.
MUT = Provision for mutual aid in lifeline restoration. 0 to 1, with 1 equal to maximum construction resources without mutual aid (i.,e., MUT can at most double construction resources)
PLAN = Probability of an effective restoration plan.
PRTY = An absolute score given at the neighborhood level, indicating priority. The score can range from NBRHD (number of neighborhoods) to 1, with higher numbers indicating higher priority.

Personal Capital

HEALTH = Probability that household is healthy
INJURY = Probability that household health or business demand has been injured.
LEAVE = Whether or not household has left region.

Ecological Capital

HAZ = Severity of earthquake's (or hazard event) physical effects. 0 to 10, Conceptually equivalent to ShakeMap intensiy/MMI

Conceptually, ResilUS relies on two generic indicators of recovery: (1) ability to perform and (2) opportunity to perform. These recovery concepts are specifically represented by multiple variables in ResilUS and are most robust with respect to the socio-economic agents of households and businesses. The specific variables for households and businesses are described below.

For households, the ability to perform is represented by household health (HLTH). Among other variables, Health is directly influenced by availability of critical facilities (CRIT) and serviceability of shelter (SHEL, either their own residence or short-term housing). Shelter serviceability is influenced not only by residence reconstruction (BL), but availability of lifeline services (WAT and ELEC). Reconstruction time is influenced by the size (TYPE, single-family vs. multi-family) of the respective building in addition to the construction capacity in the community (CONSTR). Reconstruction can only begin after inspections have been completed in the neighborhood (INSP), which is influenced by the quality of the preparedness plan, the recovery capacity of the community (CAP), and the neighborhood's priority (PRTY). Health influences a household's ability to pay off any incurred debt (DEBT). ResilUS accounts for whether or not a household owns their residence (OWNER) so that if they do not, they do not incur debt with respect to any reconstruction loans. The opportunity to perform is represented by employment level in their neighborhood and broader community (EMPL). Employment influences a household's opportunity to pay off any incurred debt. Debt is one of the main influences of whether a household is forced to leave their neighborhood (LEAVE).

For businesses, the ability to perform is represented by a businesses' capacity to be productive (not necessarily economic productivity or throughput) (PROD). The service level of a business's physical facility (FACILITY) influences this capacity, which is in turn influenced by a combination of infrastructure reconstruction (BL) and lifeline service restoration (WAT and ELEC). Reconstruction time is influenced by the complexity or size of the respective facility (BTYPE), in addition to the construction capacity in the community (CONSTR). Reconstruction can only begin after inspections have been completed in the neighborhood (INSP), which is influenced by the quality of the preparedness plan (PLAN), the recovery capacity of the community (CAP), and the neighborhood's priority (PRTY). The ability to perform is also influenced community-wide health level of households and by the transportation network reconstruction level (TRNS) within the neighborhood, if the business's sector (SECT) is locally oriented, or throughout the community if the sector is export-oriented. A business's ability to perform influences its ability to pay down any debt (DEBT). Similar to households, businesses do not incur debt from reconstruction loans if they do not own their facility (OWNER). The opportunity to perform is represented by the demand for a business's product or services (DEMAND). Recovery of demand is influenced by some proportion of household debt within the respective neighborhood or the entire community, depending on the business's size (SIZE). Demand influences a business's opportunity to pay down any incurred debt, which in turn influences whether the business fails (FAIL).

The ability that an agent is able to reconstruct their residence or facility is influenced by their financial resources (RES) – the sum of insurance (INS), reconstruction loans (LOAN), disaster aid in the form of grants (AID), and pre-event savings (SAVINGS). If the agent owns their building or facility, the maximum level of financial resources is implicitly related to the value of the building or facility. Whether or not an agent has insurance (and what amount) is now conceptually distinct from when the insurance is outlaid (OUTLAY). All elements of the financial resources are agent-specific, however a maximum value for loans (LOAN_MAX) can be specified at any resolution, from agent-specific to community-wide. In the previous version of the model there was no representation of grants. AID was conceptualized in the previous version as indicating the availability of loans.

Physical Capital

BL = f_{lcdf}(INSP, RES, BTYPE, CONSTR)
CRIT = f_{lcdf}(CRIT_TYPE, LL_RES)
DMG[households & businesses] = f_{lcdf}(SAVINGS, BYR, BMIT, CYR, EQ)
DMG[lifelines] = f_{lcdf}(MAINT, CRIT_BYR, MIT, CYR, EQ)
ELEC = f_{lcdf}(ELEC_TYPE, LL_RES, TRNSc)
FACILITY = f(ELECn, BL)
SHEL = f(STH, ELECn, WATn, BL)
TRNS = fm (TRNS_TYPE, LL_RES)
WAT = fm(WAT_TYPE, WAT_ALT, LL_RES, TRNSc, ELECn)

Economic Capital

DEBT[businesses] = f(DEM, SIZE, LOAN, PROD, LOAN_TIME, FAIL)
DEBT[households] = f(HEALTH, INC, LOAN, NBRHD EMPL, LOAN_TIME, LEAVE)
DEM = fm(SECT, DEBTc, DEBTn, SIZE)
EMPL = f(PRODn, DEMn)
INJURY[businesses] = fcdf(SIZE, EQ)
FAIL = fm(FACILITY, DEM, DEBT, PROD)
INS[businesses] = frand(OWNER, SIZE)
INS(households) = frand(MARG, INC, OWNER)
LOAN = f(OUTLAY, DMG, LOAN_TIME, MARG, LOAN_MAX, AID)
MAR[businesses] = frand(SIZE)
MARG[households] = frand(INC)
OUTLAY = f(INS, INSP)
PROD = fm(FACILITY, TRNSn, TRNSc, SIZE, HEALTHc, FAIL)
RES = f(LOAN, AID, SAVINGS, OUTLAY)

Socio-Cultural Capital

INSP = f(EQ_AVG, PLAN, CAP, REL_PRTY)
LOAN_TIME = f(EQ_AVG, PLAN, CAP, REL_PRTY)

Personal Capital

HEALTH = fm(CRITn, RES, SHEL, LEAVE)
INJURY[households] = fcdf(INC,DMG)
LEAVE = fm(SHEL, HEALTH, DEBT, NBRHD, EMPL)

Notes: n — variable averaged over the neighborhood. C — variabe averaged over the community. f_{lcdf} - Function implemented using log normal cumulative distribution function fragility curve(s). f_{rand} – Function implemented using uniform random number generator. f_{M} – Function implemented as a Markov Chain.

Table 2. Functional dependencies between important variables of ResilUS organized by community capitals.

To facilitate eventual representation of service outage for critical facilities, electricity, transportation, and water, all lifelines are represented as a set of components, with each component having respective values for attributes of construction age, maintenance level, component type, and degree of structural mitigation. Currently the model conceptually equates lifeline service restoration and lifeline component reconstruction for critical facilities, electricity, transportation, and water networks (CRIT, ELEC, TRNS, WAT). The time in which a particular lifeline component is reconstructed is influenced by new variables—the particular type of component (e.g., transformer vs. power line) (TYPE) and the overall lifeline restoration resources (LL_RES) available in the neighborhood. The neighborhood lifeline restoration resources are influenced by to the construction capacity in the community, the quality of the preparedness plan and mutual aid agreement the recovery capacity of the community, and the neighborhood's priority.

3. ResilUS IMPLEMENTATION

ResilUS separates representation of pre-event/co-event dynamics from post-event dynamics. The co-event model simulates an agent's pre-event financial marginality (MARG) and whether an agent has insurance at the time of the event. For household agents, the immediate effect of the hazard event on health—household injury is simulated. For business agents, the immediate effect of the event on business demand is simulated. For all agents and all lifelines, damage to built infrastructure (i.e., buildings or lifeline components) is simulated. The post-event model simulates restoration of built infrastructure with respect to agents and lifelines, as well as various the recovery indicators (and intermediate variables) described above. ResilUS is modular, meaning that the method in which a particular model is implemented can be changed without adversely affecting operation of the overall model. Further, the modularity facilitates substituting a data source for a model reference. For example, rather than modeling lifeline restoration, actual lifeline restoration time-series data can be used. Lastly, ResilUS is scalable to any number of neighborhoods and/or agents can be represented.

Currently, ResilUS is implemented and is run inside the modeling software MATLAB/Simulink. Input and output data compilation and visualization can either be done with MATLAB/Simulink or other spreadsheet and geographic information systems software. The majority of the simulated recovery dynamics of ResilUS are implemented using Markov chains. For a particular dynamic (time-based) output, each model state is calculated as a comparison between a uniform random number and the aggregation of all input variables (probabilities). Functions that Markov chains have been implemented include building and lifeline component restoration, health recovery, business demand recovery, business production recovery, and whether an agent leaves/fails. Like loss estimation models, such as HAZUS, fragility curves are used for calculating damage and injury. Each fragility curve is a lognormal cumulative distribution function. Structural mitigation of a buildings pr lifeline component is represented as a uniform increase in the median value of each damage level's fragility curve.

4. NORTHRIDGE EARTHQUAKE CASE STUDY

ResilUS has been applied to model the resilience of Los Angeles, CA (USA) with respect to the 1994 **M**=6.7 Northridge earthquake in order to calibrate portions of the model (based on available data) and better understand issues such as data development requirements and model sensitivity.

4.1 Data Development

Based on review of the literature, the maximum value (1) was assigned to the variables representing the recovery capacity (CAP), construction capacity resources (CONSTR), the effectiveness of mutual aid (MUT), the quality of a pre-disaster plan (PLAN), and the use of short-term housing (STH). Recovery capacity and general preparedness was high because of previous earthquakes in Southern California, such as the 1971 San Fernando earthquake. The pre-disaster plan had been adopted soon before the Northridge earthquake (Wu and Lindell 2003). For short-term housing, high apartment vacancy rates allowed effective use of rent vouchers to provide housing (Loukaitou-Sideris and Kamel 2004; McCarty, Perl et al. 2005). Mutual aid was either in place or set in motion with respect to at least emergency management, water network repair, building inspection (Comfort 1994; International 1995; Loukaitou-Sideris and Kamel 2004). We assumed

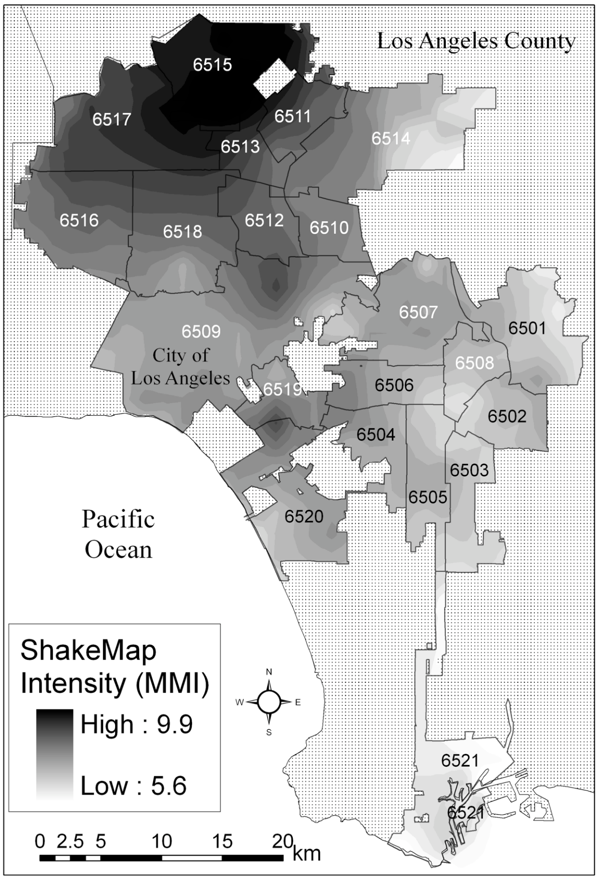

Figure 2. Instrumental intensity from the 1994 M=6.7 Northridge earthquake (USGS ShakeMap).

neighborhood restoration priority (PRTY) was equal for all neighborhoods. To our knowledge, no major alternative water source was employed after the earthquake to aid recovery. We chose to set the building code year (CYR) as 1976, reflecting the major improvements in building standards that were in place by that time as the result of the San Fernando earthquake. Data characterizing earthquake ground shaking (instrumental intensity) for the Northridge earthquake was gathered from the USGS TriNet ShakeMap system (Figure 2) clipped to the boundary of Los Angeles, and averaged for each neighborhood unit.

Data describing agent demographics and the lifeline system had to be gathered and processed for input into the model. Demographic data describing attributes of households and businesses were developed based on gathered census information and data simulation for variables lacking adequate primary data. The modules for modeling lifeline recovery were not evaluated as part of this study. Instead, times series data was developed describing the service restoration for each lifeline network—critical facilities (SSC 1995; Schultz, Koenig et al. 2003; FEMA 2004; OSHPD 2005), electrical network (Chang 2000; Davidson and Çagnan 2005), transportation network (Chang and Nojima 2001), and water network (LA Department of Water and Power, personal communication)—were replaced by time series data describing service recovery for each lifeline network. This facilitated focusing on the household and business aspects of the model, while demonstrating the modularity of the model—in this case substituting data for model modules.

4.2 Example Calibration and Outputs

ResilUS was run to simulate the impact and recovery of the Northridge earthquake. Results of both the co-event and post-event model were compared against various data gathered for evaluating the performance of each module. When data was available for a particular output variable, calibration was done by either varying model parameters, revising model algorithms, or in one case (MIT for businesses) the means in which the input data was simulated. Modules of ResilUS that have been calibrated against data sets related to the Northridge earthquake disaster include: building damage (DMG) for both households and businesses, injury to household members (INJURY), whether or not a household or business had insurance (INS), the speed and completeness of household and business building reconstruction (BL), whether a household leaves or stays as a result of the disaster (LEAVE), post-event employment (EMPL), demand for business products and services (DEMAND), and whether or not a business fails (FAIL). The quality of the data used for each calibration varies; for a more detailed explanation of ResilUS calibration to date, as well as additional model outputs, see Miles and Chang (2007). Below, selected examples of ResilUS calibration and outputs are described.

A poll found that 91% of homeowners within the San Fernando and Santa Clarita Valley's lived in the same place 18 months before the earthquake as they did before (Chu 1995). ResilUS was calibrated so that 18 months after the earthquake 9% of all

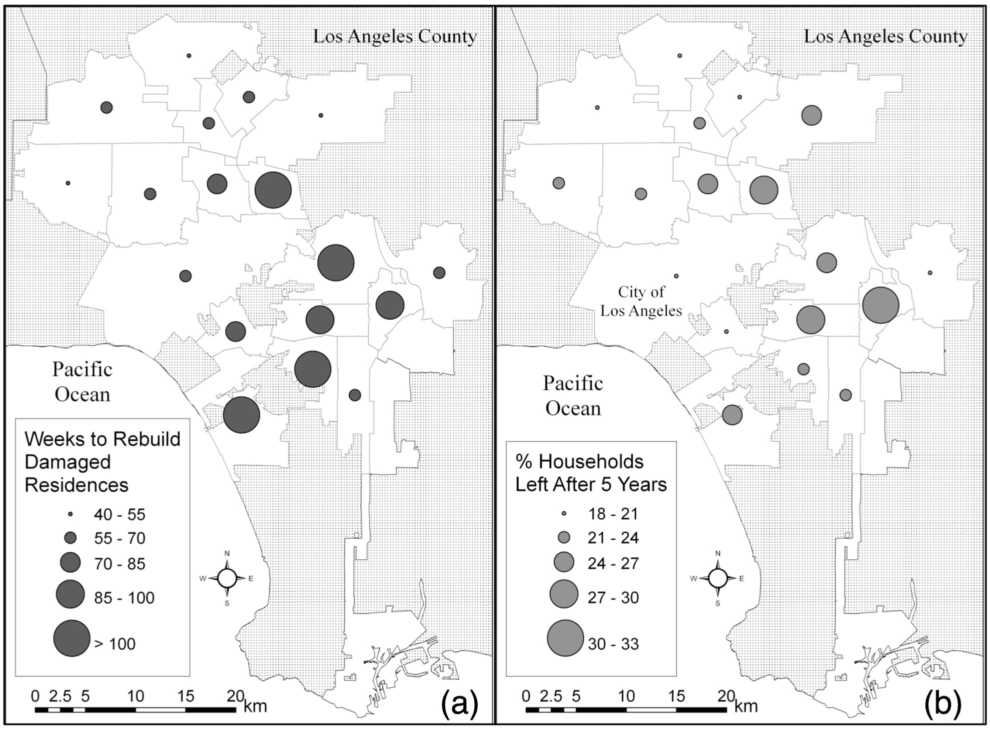

Figure 3. Partial household post-event model outputs for the Northridge earthquake disaster case study: (a) time to rebuild all damaged residential buildings. PUMAs

homeowners across the study area were predicted to have left their residence. Similarly, the poll found that 25% of renters in the same area had permanently moved out of their residence 18 months after the earthquake. ResilUS was calibrated so that 25% of renters left their residence at the same time. Note that the model does not currently represent where residents move to after leaving their residence.

The spatial distribution of the percentage of households leaving their residences five years after the earthquake is show in Figure 3b. The higher rate of residents leaving through the central part of Los Angles is largely associated with the slow rate of reconstruction. Loukaitou-Sideris and Kamel (2004) found that an above-average percentage of residents, especially renters, left their residences in neighborhoods with a slow pace of reconstruction. The neighborhoods with a relatively high percent of residents modeled to leave that are not associated with slow Table 3 lists statistics related to those residents modeled to leave and stay, providing insight into the relative influence of various exogenous and computed variables in ResilUS. The post-event module for modeling whether residents leave is the last module in the model hierarchy (for households) and thus is influenced by all other model outputs, including outputs not described here. The greatest relative difference between average variable values of residents modeled to leave and those modeled to stay are for building type, ownership, and insurance.

	Left	Stayed
% Live in MFRs	62%	29%
% Renter-occupied	74%	48%
% Have insurance	6%	13%
Mean normalized income	0.25	0.31
Mean MMI	7.4	7.5
Mean mitigation	0.21	0.19
Mean damage	0.017	0.016

Table 3. Statistics related to households modeled to leave or stay in their residence.

General observations from studies about business failure resulting from the Northridge earthquake were useful to calibrate the failure module of the post-event model of ResilUS. The modeled rate of failure significantly drops after about 20 weeks and failures stop completely after 140 weeks (2 years, 9 months). The period of business failure is consistent with the findings of Petak and Elahi (2000), who observed that small businesses were still failing two years after the earthquake. While Tierney (1995) found that businesses that suffered physical damage were more likely to report being worse off after the Northridge earthquake, Petak and Elahi (2000) note in their study that damage is not a reliable predictor of business failure. The strong influence of damage on the business failure module of the post-event model is clear from the statistics listed in Table 4. Modeled businesses are also more likely to fail if they are locally oriented, as well as if they don't have insurance or did not mitigate their facility. Petak and Elahi (2000) found that the locally-oriented businesses (e.g., retail and service) experienced a higher rate of failure than export-oriented businesses (e.g., manufacturing).

	Failed	Not Failed
% locally-oriented	80%	74%
% with insurance	11%	15%
Mean business size	0.02	0.2
Mean building size	0.08	0.08
Mean MMI	7.8	7.4
Mean mitigation	0.42	0.52
Mean damage	0.36	0.05

Table 4. Statistics on modeled business failure due to the Northridge earthquake.

5. FUTURE WORK

In the course of this study, several limitations became apparent. Limitations of the current model include a representation of decisions and policies that is somewhat simplistic. The lack of a capability for modeling relocation of households within the study region remains another key limitation. The overall reliability and performance of the model across a range of disasters is at present unknown. Some input variables in the model (e.g., household demographics) are associated with relatively reliable and complete data sources, while others (e.g., mitigation status of buildings) required simulation (at least for this study). Some elements and outputs of the model simply could not be verified empirically, much less calibrated, because of lack of empirical data.

With respect to the concept of resilience of community capital, areas for further improvement to ResilUS can be quickly ascertained by looking at Tables 1 and 2. These tables provide a list of the important variables and functionality of ResilUS with respect to physical, economic, socio-cultural, personal, and ecological capital. Currently, ResilUS is conceptually robust with respect to physical and economic capital, and less so socio-cultural. Clearly, improvements are required both conceptually (Table 1) and functionally (Table 2) with respect to socio-cultural, personal, and ecological capital.

Towards this goal, we are currently expanding ResilUS with respect to socio-cultural, personal, and ecological capital as part of a project funded by the National Oceanic and Atmospheric Administration (USA) with collaborators from University of Buffalo, Louisiana State University, University of Southern California, and ImageCAT. The case study for the next iteration of ResilUS's development is the coastal region of the USA portion of the Gulf of Mexico, including Beauregard, Calcasieu, Cameron, and Vermillion Parishes (Figure 4). The area's rich and complex community capital, which was impacted by Hurricane Rita in 2005, make it an ideal study location. The goal of the current project is to incorporate additional process-based environmental models and remote sensing methods within the ResilUS framework to better support management decisions towards community disaster resilience (Renschler et al., 2006).

This area has been the focus of hazards analysis over the last ten years with several assessments of hazardous chemicals, exposure to natural hazards, and social vulnerability (Pine et al., 1998; Pine, 1999; Pine et al. 2002). The geomorphologic, ecological, physical, and socio-economic conditions are representative for rural and urban communities in the coastline hinterland separated from the Gulf of Mexico by dunes, ship channels, lagoons and coastal wetlands. Episodic flooding, storm surge, and other coastal hazards impact the area. Calcasieu Parish is host to the southernmost East-West running interstate I-10 and to a large concentration of chemical processing operations including major refineries and specialty chemical manufacturing facilities. The Calcasieu ship channel serves one of the larger ports on the Gulf of Mexico. As a coastal community, Vermillion Parish has extensive wetland areas that supported thriving fishing and shrimping industries prior to Hurricane Rita in 2005. Although fishing and shrimping boats may have survived the storm, the processing support operations were destroyed. The flat coastal areas also serve as a major source of rice farming in Louisiana and the U.S. In addition to commercial fishing and petrochemical operations, the parish also is host to major state and federal wildlife areas and state and local recreational facilities.

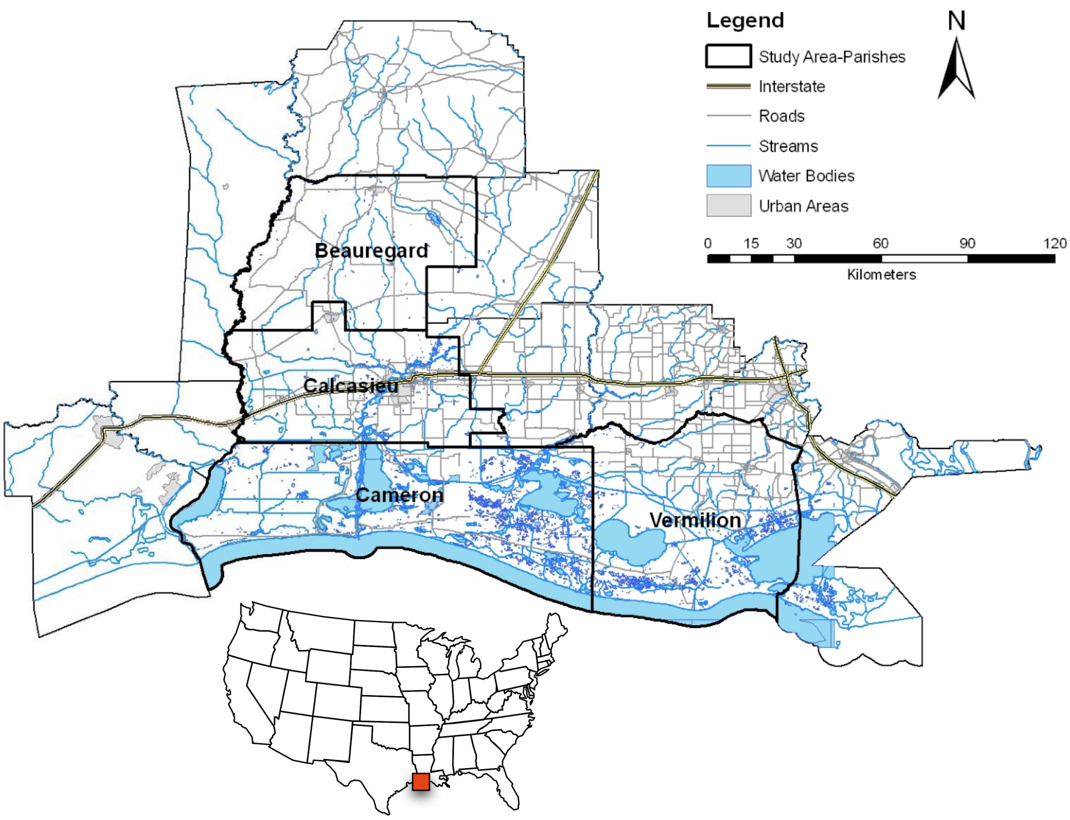

Figure 4. Map showing current study area in the Gulf Coast of Louisiana (USA), including Beauregard, Calcasieu, Cameron, and Vermillion Parishes.

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