Framework for Resilience Reconnaissance

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Introduction

WHY A RESILIENCE FRAMEWORK?

The **GOAL** of this framework is to provide guidance for earthquake reconnaissance teams or individual researchers who want to observe, document, and measure community resilience through field investigation and data collection in the months and years following a major earthquake. The framework provides recommendations on what to observe over time to: (a) understand the overall performance of systems within a community after a major earthquake, (b) identify critical elements that drive system performance, (c) describe interdependences between systems, and (d) determine transformative changes enacted to mitigate possible future disasters.

Through the implementation of this framework after future earthquakes, it is expected that the following can be achieved:

- Collection of consistent data across different earthquakes, thus enabling cross-comparison. This comparison would be facilitated by using the framework as a backbone for a data collection repository that could be queried by researchers and other stakeholders.
- Analysis of the observations and data to draw conclusions about the resilience of impacted communities, lessons learned to be share with other communities, and newly identified research needs. Eventually this may lead to the development of earthquake resilience indicators.

HOW TO USE THIS FRAMEWORK

Resilience is a **SYSTEMS** concept, so this framework is built upon a backbone hierarchy of systems, subsystems, and their elements. Communities are a system of systems that function due to interrelationships between aspects such as economic health, strong infrastructure, social equity, etc. This project thus considers the five primary community systems to be (1) built environment system, (2) social system, (3) economic system, (4) natural environment system, and (5) institutional system. The framework considers what typical interactions occur within these systems and how these systems impact one another.

Multiple **SUBSYSTEMS** are associated with each system. The word "subsystem" is used to identify the main branches that comprise each system to allow reasonable data collection.

Data collection is supported by two sets of questions for each subsystem. **GENERAL RESEARCH QUESTIONS** are provided at the start of each subsystem section in the framework based on the following:

- *What was the overall performance of the subsystem?*
- *Which elements or components proved to be critical to the function of the subsystem and why?*
- *Did the subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the subsystem (or any policies/codes/plans influencing its operation)* before *the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

In the framework, users will note that the general questions are slightly refined for each subsystem because processes can be very different from system to system. These general research questions are intended to help users to keep the overarching concepts and characteristics of resilience in mind as they enter the process of data collection.

Following the general research questions, **SPECIFIC RESEARCH QUESTIONS** are provided for each of the following seven resilience themes: baseline information, damage and functionality, consequences and interdependences, pre-quake mitigation, post-earthquake recovery techniques, resources, and transformative changes. The specific research questions for each of these themes are detailed and intended to guide the user through the data collection process. The specific questions are supported with a list of suggested Data Examples that will help user answer the questions, though users should rely on their own expertise and the earthquake characteristics to identify additional data sets to gather.

Data collection **TIMELINES** are included in the framework to provide guidance on data collection time windows for the specific research question data examples. The data collection timelines in this framework are based on three general response phases: response, restoration, and recovery, and include idealized time ranges for these phases based on a significant earthquake. Framework users must recognize that (1) post-recovery phases have a varying duration depending on many factors, (2) data can become available at different times for different events, (3) one system or subsystem can be in one phase while another system can be in a different phase, (4) there may be differentials to recognize within a subsystem at any point in time, and (5) that some types of data require repeated collection over time. Thus, the timelines are intended only as guides so each data gathering effort should carefully consider and customize the timelines and data collection frequency based on the specific situation.

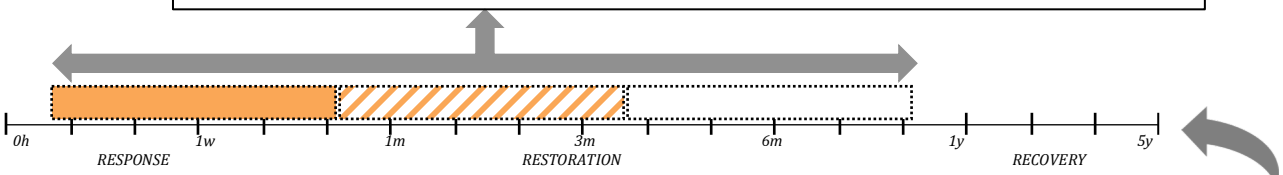
EXAMPLE TIMELINE:

A time window identifies when data collection can or should take place. The color and hatching of this window identifies how frequently data collection should be repeated:

= high data collection frequency or as often as reasonably possible

= low data collection frequency or a few times depending on user expertise

= single data collection effort needed once within this window



The time bar shows generic time ranges and the three phases a community faces after an earthquake

As shown by the example timeline above, the bar chart is nonlinear. The leading thread is that during the response phase, which may takes several days to weeks, high intensity data collection would begin as soon as practical over the first weeks after the earthquake. On the other hand in the recovery phase data collection essential to resilience understanding is less frequent.

Data should be collected across space, preferably over the whole geographic extent of the earthquake damage. Reconnaissance teams should identify the extent of the area affected before their investigation taking advantage of aerial views, local jurisdiction reports, and firsthand accounts.

Each subsystem section concludes with a list of **DATA COLLECTION METHODS**, possible **DATA SOURCES**, and **REFERENCES** to guide the user and help them brainstorm possible data collection approaches.

In the post-earthquake environment it is important to recognize that data can be ephemeral and has varying levels of importance, thus this framework establishes **DATA COLLECTION PRIORITIZATION** in tables at the end of each system section. Data collection priorities are coded by a number of asterisks, from one (lowest priority) to three (highest priority), based on both data perishability and criticality. The priorities included in this document are intended only as guides so teams or individuals involved in data gathering efforts should carefully consider and customize the priorities based on the specific situation and earthquake location.

A **GLOSSARY**, **FRAMEWORK OUTLINE**, and **APPENDIX** (with background, commentary, and theoretical justification for the framework) are also included at the end of this document.

NEXT STEPS

While the framework outline for all systems is complete, not all subsystems in this version have been fully developed in the format described above. An attempt has been made to complete at least one subsystem for each of the systems, and for some systems, several subsystems have been completed. For the various subsystems not yet complete, users are encouraged to use the completed subsystems as an example to guide their data collection.

With 9 of subsystems completed (highlighted in the framework outline), this first version of the framework is ready to be implemented and tested by using it to conduct resilience reconnaissance for several case study earthquakes. Pending the outcome of these case studies or other implementation efforts, it is expected that the document may be updated to incorporate feedback and refined over time as new findings are discovered to improve the framework guidance. New versions of this framework will be issued pending the outcome of these efforts and the feedback received.

Built Environment System

SYSTEM OUTLINE

- **Buildings**
  - *Residential*
    - Housing
    - Shelters
    - Hotels/Motels
  - *Business*
    - Banks/Financial Institutions
    - Medical Office/Clinic
    - Professional/Technical/Business Services
  - *Mercantile/Storage*
    - Critical Retail (groceries)
    - Retail/Wholesale
    - Food Distribution Centers
    - Other Distribution Centers
    - Gas Stations
    - Garages
  - *Government*
    - Police/Fire Stations
    - Town Hall
    - County Administrative Buildings
    - Courts
    - Disaster Debris and Recycling Centers
    - Emergency Operation Centers
  - *Cultural/Education*
    - Schools K-12
    - Higher Education Facilities
    - Entertainment Venues
    - Community Centers
    - Churches, Mosques, Temples, etc.
  - *Industrial/Agriculture*
    - Agriculture
    - Food
    - Construction
    - Technology
  - *Institutional*
    - Hospitals
    - Health Care Facilities
    - Penitentiaries
- **Transportation**
  - *Subways*
  - *Airports*
  - *Bridges*
  - *Highways*
  - *Railways*
  - *Ships/Ports/Harbors*
  - *Roads*
  - *Road Tunnels*
  - *Mass Transit Stations*
  - *Bike Pathways*
- **Electricity**
- **Fuel/Natural Gas**
- **Communication**
- **Water**
- **Waste**
- **Geotechnical Structures**
  - *Embankments/Levees*
  - *Earth Dams*
  - *Retaining Walls*
  - *Slopes*

BUILDINGS SUBSYSTEM

Important notes for this subsystem:

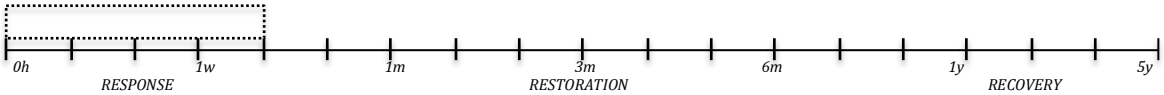
- *This framework attempts to focus on community resilience thus the questions below require users to observe and document data that reflects the collective performance of large networks of buildings within the community, not just individual buildings.*
- *The questions below are not customized for specific building types or occupancies because these distinctions are not necessary to evaluate the functionality of the buildings subsystem. Though each building/occupancy type has different performance requirements to be considered functional, data necessary to identify whether the building is functional (or not) are implied in the same list of questions.*
- *The performance of utilities is not considered as direct damage to building. Utility performance should be captured when looking at the interdependencies between buildings and other subsystems in question 3. Utility performance will also be captured in their specific subsystems and in the business subsystem (because that utility's damage is critical to business loss of functionality).*

General Research Questions

- *What was the overall performance of the buildings subsystem in the region affected?*
- *Which elements or components proved to be critical to the function of the subsystem and why?*
- *What unique impact (positive or negative) did the building have upon the whole buildings subsystem and other community systems and vice versa?*
- *Were transformative improvements made to the buildings subsystem (or any policies/codes/building technology/construction/plans influencing its operation)* before *the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

Specific Research Questions with Suggested Data to Collect

1. **Baseline data and facts.** What are the building's structural/non-structural components? What is the building occupancy? Which type of content inventory is in the building? What is the occupancy sector? Was the role played by the building before the earthquake critical for the community?

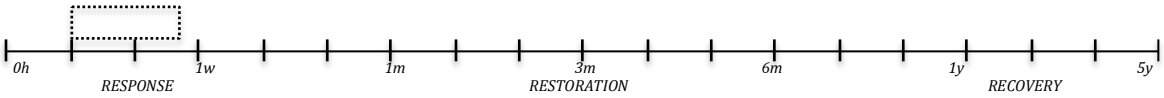


2. **Damage and functionality.** What percentage of the building is functional (in terms of space and functions)? Is the building more important than other buildings in its occupancy class/type? Does the building's damage affect or influence the broader

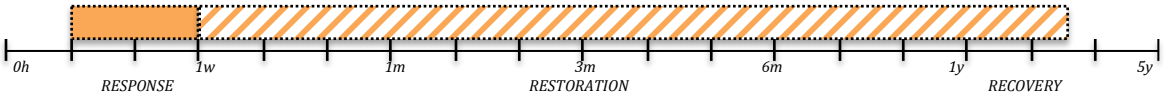
performance of its occupancy type? Is there any substantial difference in the damage across buildings of the same occupancy or structural type, and if so, why? Were the undamaged buildings and temporary facilities that were provided adequate to replace the functions of the damaged buildings? Did the building show disproportionate failure or progressive collapse?

Possible data/measures are:

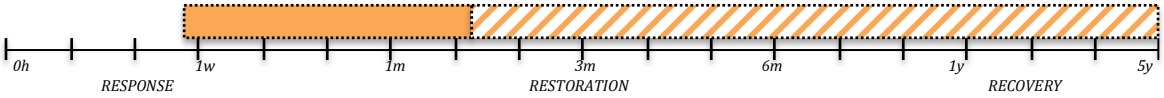
a. Hotel, Shelters, K-12 Schools safe to accommodate displaced people.



b. Percentage of the building usable.
c. Building tags.
d. Percentages of housing types/occupancies tagged as unoccupiable or hazardous after the earthquake.



e. Capacity of the buildings in terms of people which may use it such as number of patients that could be treated in a hospital, number of students which can attend classes in a school, number of workers that can work at different facilities, etc.
f. Vacancy or occupancy rates.

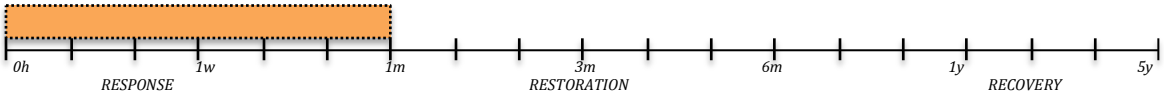


3. **<u>Consequences and interdependencies.</u>** What is the main reason for building inoperability (bureaucracy, structural/non-structural/contents damage, utilities disruption, employee unavailability, impact of surrounding structures) or operability? What is the level of damage to the utilities that serve the building? What are the consequences of this inoperability/operability on the building function or on other community systems? What are the consequences of other community systems or functions on the building? Were the buildings that were key to restoring the economic engine of the community damaged? Was the damage relevant and able to affect the economic activity of the region? Were the occupants adequately protected during the event? How did after-shocks and fore-shocks contribute to the total impact on the built environment or community members?

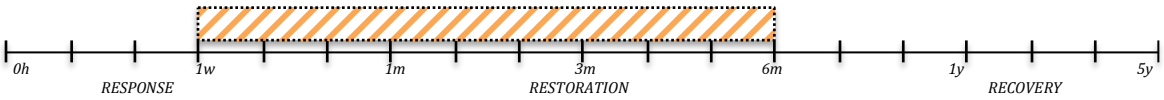
   Possible data/measures are:

   a. Earthquake induced-damage.
   b. Number of emergency responders accommodated and location.
   c. Disruption of ingress/egress transportation networks.
   d. Number of gas stations closed due to impacts from other systems (i.e. fuel shortage due to supply chain interruption).

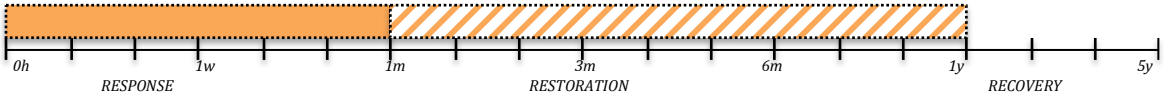
e. Function moved permanently, no longer needed.



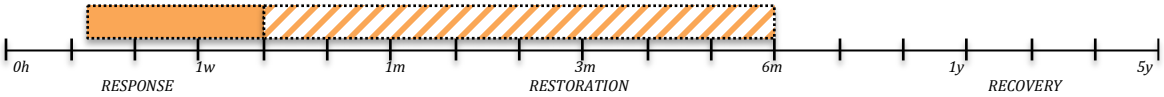
f. Fatalities, injuries and reason of accidents.
g. Impact of building damage on the ecosystem.
h. Variation of impact due to aftershocks and impact of foreshocks such as weakening of structures, etc. (NB: Aftershocks are likely to continue beyond the recommended timeframe for data collection; however, the process for collecting data and assessing impacts should be established within the recommended timeframe)



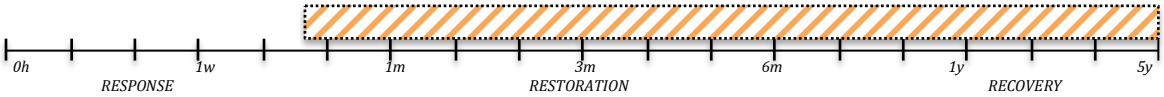
i. Number of workers that cannot reach work place and reason.
j. Number of displaced workers.



k. Identify the performance of utilities and the most important utilities for the building occupancy observed.



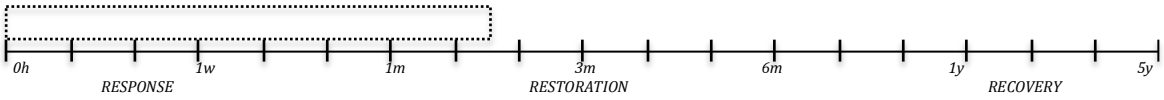
l. Document if the time-frame in which people can shelter in place matches the time-frame in which local retailers, schools, professional services and worship recovers.
m. Document if the buildings was key to the economic activity of the region and if its restoration has been adequately prioritized or if there have been delays.
n. Effectiveness of bureaucratic processes to speed up rebuilding (number of building permits for new housing units, etc.).



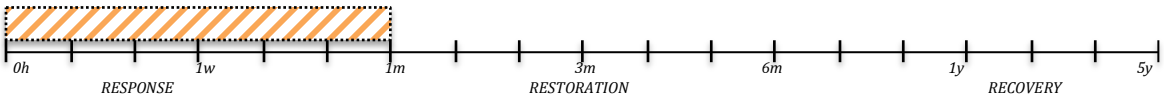
4. **<u>Pre-quake mitigation.</u>** Did the building management/owner implement pre-earthquake mitigation procedures or measures before the earthquake aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the building? Attempt to document or at least estimate any costs and benefits from these efforts.

Possible data/measures are:

a. Implementation of evacuation drills.
b. Ensure availability of liquid funds to make repairs quickly and avoid dependency and delays from financing.
c. Earthquake-induced damage prevention (adequate installation of fire sprinklers, stabilization of soils, elevation of important contents if tsunami-risk, etc.).
d. Building Occupancy Resumption Programs (BORP): pre-certified post-earthquake inspection with licensed engineers.
e. Contractors and engineers retained on an annual basis to perform post-earthquake repairs.
f. Information about frequency of maintenance.
g. Structural/non-structural precautions (exposition of structural components, anchorage of non-structural components and heavy building contents, ability to accommodate displacements, protection of facades).
h. Building instrumentation to monitor earthquake response enabling quick decision for continuation of operation (diagnostic and damage detection technology).
i. Advance planning to consider rerouting of ingress/egress people in case of disruption of transportation network.
j. Reducing reliance on external resources that can be impacted by earthquakes, i.e. Closed-loop water (rainwater harvesting, on-site wells); on-site renewable energy or microgrids; low-use plumbing fixtures; passive heating/cooling/lighting strategies.



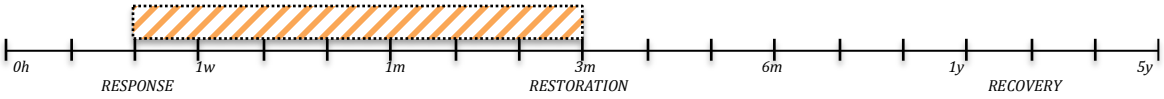
k. Installation, protection, and functionality of back-up systems (emergency power, independent communication network, on-site housing and subsistence for staff, water and waste tank, dual fuel boilers, back-up systems in safe locations within building, etc.).
l. Treatment and protection of critical equipment that could take months to procure, repair or replace.



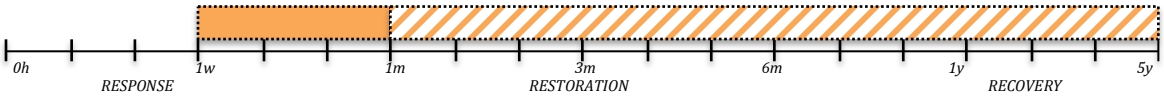
5. **<u>Post-quake recovery techniques.</u>** Did the building management/owner implement post-disaster techniques other than repairs to drive recovery in a timely fashion? If not, why? Attempt to document costs and benefits from these efforts.

Possible data/measures are:

a. Realization of emergency access routes.
b. Reallocation of spaces and functions to speed up repairs without shutting down the business done in the building.
c. Installation of composting toilets.



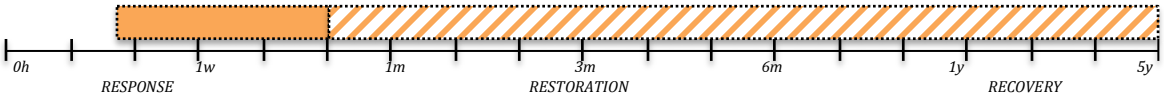
d. Mobile houses and temporary houses (keep track of variation of density and location).



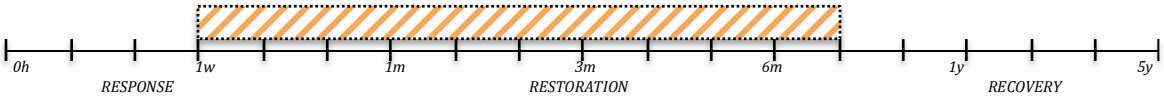
6. **Resources.** What were the total resources used in the recovery effort? Document the flow of financial resources used to facilitate recovery.

   Possible data/measures are:

   a. How repairs and replacements were developed, approved, funded and implemented.
   b. Ask owners where they got money to perform repairs.
   c. Ask owners whether they own coverage, insurance policies and about timeliness of insurance claims processing.



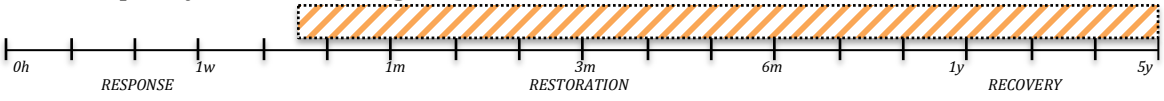
   d. Equipment required for restoration.
   e. Number of repair crews and workers allocated to repair operations, and associated increased salary costs.



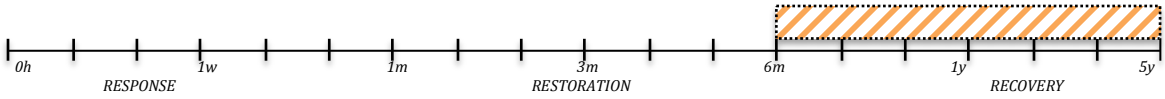
7. **<u>Transformative changes.</u>** What changes occurred that surpassed or differed from the pre-disaster state? Were business recovery barriers identified then addressed through preparedness policies or actions that mitigate negative impacts of future disasters due to buildings damage?

   Possible data/measures are:

   a. Variation of housing and building locations.
   b. Variation of building use or function.
   c. Improvements observed or actions taken that increased the restorative capacity of the building.



   d. How new building codes, mandatory instances, etc. were developed, approved, funded, and implemented.



Data collection methods or data types

In order of possible applicability or timeliness to the data collection effort.

- Field observations, face-to-face interviews, informal surveys, notes.
- Geo-Tagged Photo/Video to identify overall story of damage, demolition, and reconstruction.
- Use of the ATC-38/ATC-20 Post Earthquake Building Performance Assessment Form.
- Store documentation of damage (Geo-tagged photos, building evaluation forms, etc.) using EERI data collection tools to populate GIS spatial data layers.
- Media investigation (newspapers, social networks, etc.).
- Establish relationship with building managers/owners and design teams doing repairs.
- Create connections with utility operators or find data to document the utility restoration timeline.
- High resolution satellite images.
- Structured surveys.
- Aerial imagery
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.

Possible Data Sources

- Assessors' records.
- Media reports.
- Social Media.
- Housing Departments/Authorities.
- Department of Building Inspection.
- Building Management/Owner.
- Architects and engineers doing repairs and retrofits.
- Professional organization studying the impacts.
- Utility, Lifeline, and Transportation companies with building portfolios.
- Companies and organizations with building portfolios.
- School districts.
- Hospital operators.
- Governmental or non-profit Rent Boards or organizations.
- Ministry of Civil Defense.
- Emergency Management Contractors.
- Possible agencies established by the Government to lead and coordinate the ongoing recovery effort.
- City Councils.

References to support this topic area

T.B.D.

TRANSPORTATION SUBSYSTEM

Important notes for this subsystem:

- *The transportation system in the proposed framework encompasses all the different modes which can be used by customers, workers, businesses during their everyday lives to reach their destinations (roads, railways, subways, ships, etc.).*
- *In the questions below, components of the transportation subsystem are considered all the features which allow a transportation network to be usable and used (physical structures with structural and non-structural components, users, operators and management, etc.).*

General Research Question

- *What was the overall performance of the transportation subsystem in the region affected?*
- *Which elements or components affect the performance of each mode of transportation the most? Did the transportation subsystem have enough redundancy to adequately support emergency support needs immediately following the earthquake?*
- *Did the transportation subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the transportation subsystem (or any policies/codes/building technology/construction/plans influencing its operation) before the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

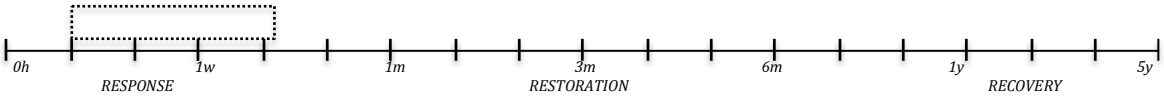
Specific Research Questions with Suggested Data Collection

1. **Baseline data and facts.** What are the modes of transportation in the region? What are the most utilized modes of transportation? What is the pre-quake transportation subsystem capacity? What is the geographical area covered?

   Possible data/measures are:

   a. Roads/Highways/Subways/Railways.
   b. Bridges/Road Tunnels/Mass Transit Stations.
   c. Airport/Ports.
   d. Trains/Cabs/Buses/Coaches/Cars.
   e. Topology and Layout of the mode of transportation.
   f. Operators/Drivers/Staff.
   g. Users.

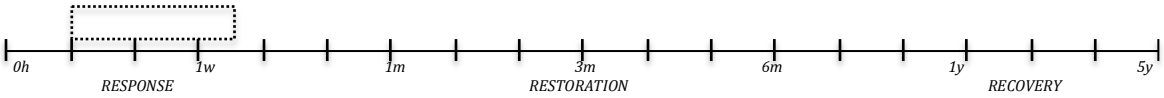
h. Facilities characteristics (number of entrances in stations, structural types, density of the subsystem, etc.).
i. Network characteristics (routes or lines and their redundancy, density of transfer points, capacity and baseline number of users, etc.).



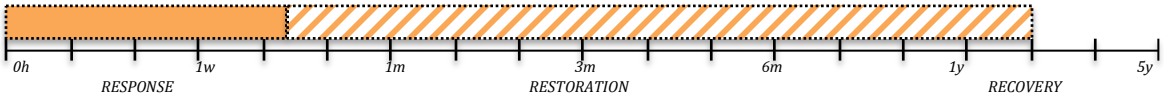
2. **<u>Damage and functionality.</u>** What is the level of the transportation subsystem functionality? What damage has been suffered by the transportation subsystem components? How does this damage affect the normal functioning of the network to which it refers? Which transportation components are most critical for each mode of transportation? Is there any damage variation amongst transportation components across the region, and if so, why? Are there improvements observed or actions taken that increased the restorative capacity of this transportation network? Do the transportation networks satisfy the needs of people and responders after the quake?

   Possible data/measures are:

   a. Damage to the components of each mode of transportation (i.e. station facility, trucks, landing trips, aerial or underground structure that support the trucks, trains, cars, buses, planes, etc.).



   b. Keep track of functionality (share of users, number of network disruptions, variation in capacity, variation in goods transported, etc.) until full restoration.
   c. Keep track of the demand for different transportation modes.
   d. Keep track of people that switch from one network to another.
   e. Average increase in travel-time (temporal and spatial).

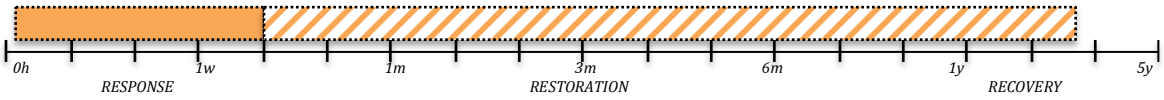


3. **<u>Consequences and interdependencies.</u>** Which is the main reason of transportation disruption (bureaucracy, structural/non-structural/contents damage, utilities disruption, employee unavailability, impact of surrounding structures, bad maintenance)? What are the interdependencies between the transportation subsystem and other community systems ("upstream" and "downstream" subsystems)? What are the reasons for delay in restoration?

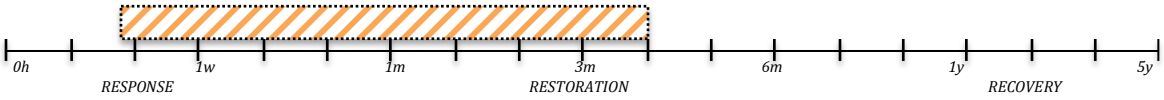
   Possible data/measures are:

   a. Percentage of workers that cannot reach work place due to transportation problems.

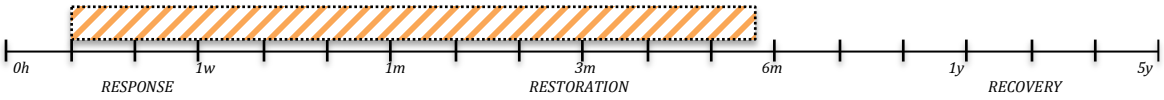
b. Share of commuters using public transit (reduces congestion and harmful emissions, and saves money relative to commuting via car in many cases, increase labor market flexibility across a metro area and support the clustering of businesses, which in turn enhances innovation and ultimately productivity).
c. Document if the time-frame in which transportation subsystem is restored matches the time-frame in which housing, local retailers, schools, professional services and worship recovers.
d. Miles of bikeways, evolution and role (sustainability, natural environment, social and wellbeing).



e. Transit designed for special categories of users (i.e. School-buses capacity and students using them, hospital shuttles, paratransit, etc.).
f. Impact of transportation damage on the ecosystem.



g. What is the most affected category of users (minorities, race, neighborhoods, vulnerable groups, etc.).
h. Fatalities, injuries and reason of accidents.
i. Earthquake induced-damage (liquefaction, slope failure, etc.).

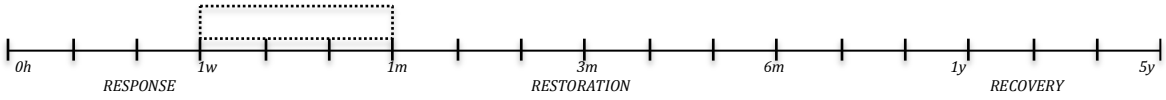


4. **<u>Pre-quake mitigation.</u>** Did the transportation subsystem management implement pre-earthquake mitigation procedures aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the transportation subsystem? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

   a. Substitution, and/or retrofitting of network physical components located nearby fault areas.
   b. Implementation of evacuation drills.
   c. Installation, protection, and functionality of back-up systems in the transportation facilities (emergency power, independent communication network, water and waste tank, dual fuel boilers, etc.).
   d. Development of a local or regional emergency response or recovery plans, (i.e. transit plans to assign trains, buses to their most productive use; pre-identification of emergency park-and-ride locations).

e. Reducing reliance of transportation facilities on external resources that can be impacted by earthquakes, i.e. Closed-loop water (rainwater harvesting, on-site wells); on-site renewable energy or microgrids; low-use plumbing fixtures; passive heating/cooling/lighting strategies.
f. Ensure availability of liquid funds to make repairs quickly and avoid dependency and delays from financing.
g. Pre-certified post-earthquake inspection with licensed engineers.
h. Contractors and engineers retained on an annual basis to perform post-earthquake repairs.
i. Protection measure against geological hazard (landslides stabilization, re-shaping of the layout to increase redundancy in influential areas or avoid areas prone to flooding and liquefaction).
j. Installation of supplemental fire suppression systems.
k. Implementation of earthquake improvements along with regular upgrades and maintenance of the network.
l. Regular maintenance, signage, and creation of redundancy for stairs and egress paths.
m. Structural/non-structural precautions (exposition of structural components, anchorage of non-structural components and heavy building contents, ability to accommodate displacements, protection of facades).
n. Subsystem instrumentation to monitor earthquake impacts enabling quick decision for continuation of operation (diagnostic and damage detection technology).
o. Mitigation against spill of hazard material, i.e. fuel tanks, ships with hazardous loads, etc.

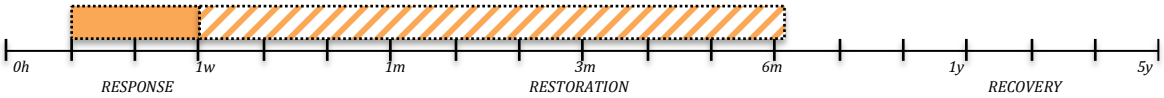


5. **<u>Post-quake recovery techniques.</u>** Did the transportation management/owner implement post-disaster techniques in a timely fashion? If not, why? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

   a. Variation with respect to the pre-event schedules, frequencies, and increase of capacity.
   b. Realization of emergency access routes.
   c. Establishment of service in areas previously not served.
   d. Substitution of the network service with another mass transit service among two points of the network service disrupted (subway/bus/trains).
   e. Identification of alternative routes to freeways and highways (via street-level routes).
   f. Identification of emergency park-and-ride locations to facilitate efficient alternate mass transit options
   g. Establishment of an authority that prioritize actions and coordinate planning across transportation systems

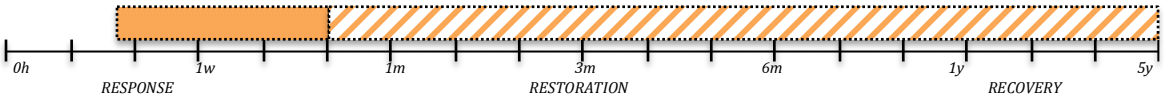
h. Establishment of partnership with regional, state, and private sector entities to address multi-jurisdictional and regional systems (e.g. ferries from external regions).
i. Creation of transit plans to assign trains, buses to their most productive use
j. Procedures that strategically restrict vehicle traffic and shift of passengers among alternate modes of transportation.
k. Installation of composting toilets.
l. Network reconfiguration.



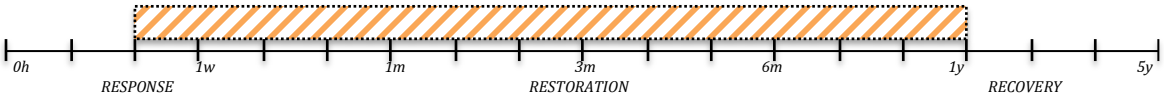
6. **<u>Resources.</u>** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.

Possible data/measures are:

a. How repairs and replacements were developed, approved, funded and implemented.
b. Cost per additional mile traveled by trains, cars, airplanes, boats, etc.
c. Ask owners where they got money to perform repairs (reserve funds, governmental assistance, insurance, etc.).



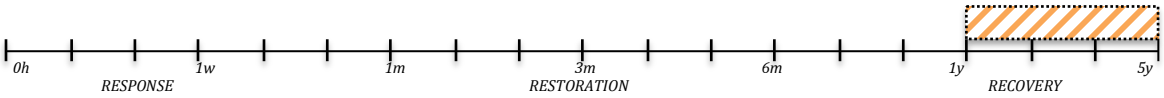
d. Equipment required for recovery.
e. Repair crews and workers allocated to repair operations, and associated increased salary costs.



7. **<u>Transformative changes.</u>** What changes occurred that surpassed or differed from the pre-disaster state? Were recovery barriers identified then addressed through preparedness policies or actions that mitigate negative impacts of future disasters due to transportation failures?

Possible data/measures are:

a. Permanent variation of network layout or schedule.
b. New transit sources emerged.
c. Old transit sources ended or became obsolete.
d. New regional transit and transportation response or recovery plans for future disasters.



Data collection methods or data types

- Field observations, face-to-face interviews, informal surveys, notes.
- Automated Analysis of social media information (Natural Language Processing).
- Mapping of failure points and evolution of subsystem restoration.
- Geo-Tagged Photo/Video documentation of damage and archiving using EERI data collection tools.
- Establish relationship with transportation networks managers/owners.
- Media investigation (newspapers, social networks, etc.).
- High resolution satellite images.
- Structured surveys.
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.

Possible Data Sources

- Assessors' records.
- Media reports (including social media trends).
- BTS (Bureau of Transportation Statistics – Commodity Flow Survey).
- Municipal Transportation Agencies.
- Regional Planning Commissions.
- US Census Bureau.
- American Community Survey.
- R-NAS (Rail Network Analysis System).
- Surface Transportation Board (Carload Waybill Sample, Rail Rate Index, etc.).

References to support this topic area

T.B.D.

ELECTRICITY SUBSYSTEM

General Research Question

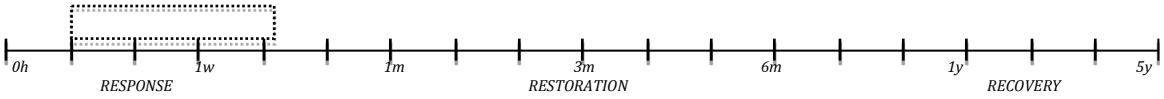
- *What was the overall performance of the electricity subsystem in the region affected?*
- *Which elements or components affect the performance of the network the most?*
- *Did the electricity subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the electricity subsystem (or any policies/codes/building technology/construction/plans influencing its operation)* before *the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the electricity network to surpass its pre-disaster state/condition?*

Specific Research Questions with Suggested Data Collection

1. **<u>Baseline data and facts.</u>** What is the geographical layout of the electricity network (generation, transmission, and distribution)? What is the pre-quake electricity subsystem capacity? What is the technology used to provide the community with the electricity? Does the technology used for the electricity network varies between different areas in the region affected?

   Possible data/measures are:

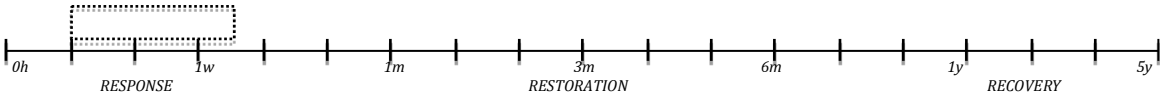
   a. Generation facilities, substations, transmission and distribution components (wire, towers, pipelines, etc.)
   b. Topology and Layout of the electricity network.
   c. Operators/Drivers/Staff.
   d. Users.
   e. Facilities characteristics (number of entrances in stations, structural types, etc.).
   f. Network characteristics (age, redundancy, diversity of energy sources, modular or loosely-coupled architecture, distance from generation facilities to productive areas, hardened where appropriate, etc.).



2. **<u>Damage and functionality.</u>** What is the level of the electricity subsystem functionality? What damage has been suffered by the electricity subsystem components? How does this damage affect the normal functioning of the electricity network? Does the restoration of the network prioritize emergency facilities and services and critical public works or right of way for critical infrastructure restoration crews? Is there any damage variation amongst electricity networks components across the region, and if so, why? Was the extent and impact of the failures disproportionate to the magnitude of the event that occurred?

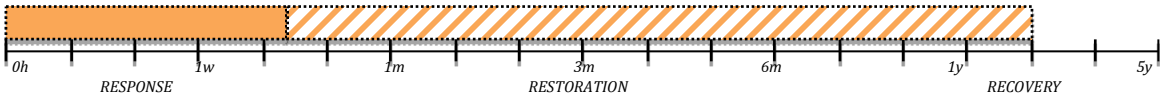
   Possible data/measures are:

   a. Damage to the components of the electricity networks (i.e. generation facilities, transmission facilities components such as towers and wires, distribution systems components such as wires and poles, pipelines or roads to supply liquid fuel or natural gas, storage tanks, control systems, etc.)
   b. Document components that behave particularly well and proved to be earthquake-resilient and the reason of their resilient behavior.



   c. Keep track of functionality (% of pre-quake users without electricity, location of network disruptions and reasons, variation in capacity, etc.) until full restoration.

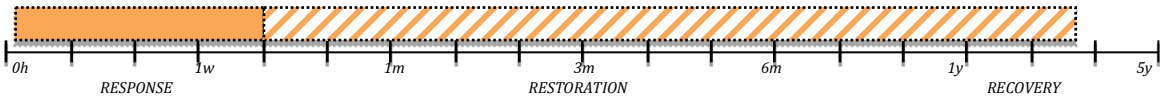
d. Functionality of generation facilities by generation methods (natural gas, liquid fuels, renewable energy, etc.)
e. Evaluate the performance and the usefulness of the standby power.



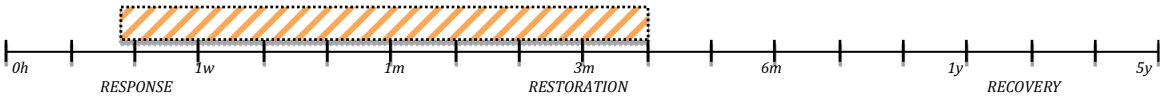
3. **<u>Consequences and interdependencies.</u>** Which is the main reason of electricity disruption, structural/non-structural/contents damage, other utilities disruption, impact of surrounding structures, bad maintenance, poor design, and poles overloaded by wires and system components by local service providers)? What are the interdependencies between the electricity subsystem and other community systems? What are the reasons for delay in restoration (bureaucracy, restoration crew unavailability)?

   Possible data/measures are:

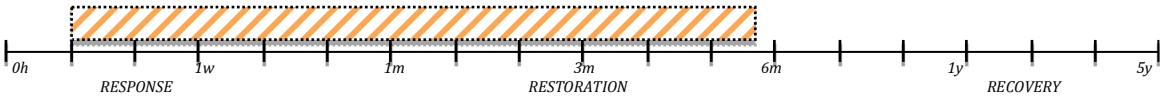
   a. Percentage of electricity network disrupted by cause of disruption (tsunami, fire, other earthquake-induced effects, ground shaking and snapping of the lines due to absence of slack to allow them to flex with the movement of the fault line, interaction with building, etc.)
   b. Ground rupture/ground shaking/liquefaction-induced damage to pipelines and distribution lines.
   c. Document vulnerabilities showed by constructions due to old design codes (clustered transformers, single pole substations with high and low voltage feeds, underground ducts run close together and crossing in many shallow manholes, etc.).
   d. Percentage of workers that cannot reach work place due to transportation problems.
   e. Unavailability of liquid fuels or power pipelines exposed due to transportation disruption.
   f. Electricity network's Operational and Control Centers disruption due to outage of communication and information systems.
   g. Verify the availability of stand-by power for cell tower.
   h. Document impact of electricity disruption on water system (pumping, treatment, etc.)
   i. Document if the time-frame in which electricity subsystem is restored matches the time-frame in which housing, local retailers, schools, professional services and worship recovers.



   j. Transit designed for special categories of users (i.e. School-buses capacity and students using them, hospital shuttles, paratransit, etc.).
   k. Impact of electricity network damage on the ecosystem.



l. Document possible social impacts due to electricity outage (increase in the number of crimes due to disruptions of alarm systems, etc.).
m. What is the most affected category of users (minorities, race, neighborhoods, vulnerable groups, etc.).
n. Fatalities, injuries and reason of accidents.

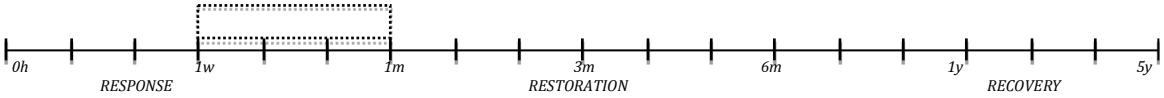


4. **<u>Pre-quake mitigation.</u>** Did the electricity subsystem management implement pre-earthquake mitigation procedures aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the electricity subsystem? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

   a. Inspection Programs (pole inspection cycles with new inspection tools and techniques).
   b. Substitution, retrofitting or mitigation techniques for network physical components located nearby fault areas such as positioning of pole's equipment (transformers, voltage regulators, etc.) on the ground.
   c. Upgrading piping from iron or plastic or even steel.
   d. Switching from underground lines to overhead lines if the earthquake risk is prevalent than wind, storm, flood risk.
   e. Implementation of smart grid technologies to identify power outages and allow for predictability as well as corrective action.
   f. Installation and protection of standby power (elevation of all electrical components above a design flood level, proper ventilation of combustion products and cooling system components, prioritization of power needs, etc.) and availability of uninterruptable power supply.
   g. Ensure availability of liquid funds to make repairs quickly and avoid dependency and delays from financing.
   h. Protection measure against geological hazard (landslides stabilization, re-shaping of the layout to increase redundancy in influential areas or avoid areas prone to flooding and liquefaction).
   i. Installation of supplemental fire suppression systems.
   j. Implementation of earthquake improvements along with regular upgrades and maintenance of the network.
   k. Structural/non-structural precautions (bracing of poles, ability to accommodate displacements, etc).
   l. Implementation of Management Programs to maintain a reliable transmission systems (tree maintenance program, etc.).

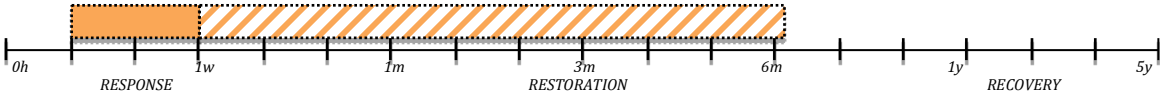
m. Cyber-based monitoring systems to reduce the impact of any possible hazard enabling quick decision-making.
n. Development and extension of microgrids, renewable energy generation (solar photovoltaic, wind power, biomass, hydropower, etc.), fuel cells and battery energy storage.



5. **<u>Post-quake recovery techniques.</u>** Did the utility management/owner implement post-disaster techniques in a timely fashion? If not, why? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

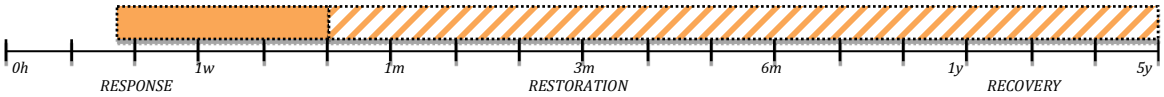
   a. Timely execution of inspection, damage assessment, repair, and reenergizing.
   b. Effective refueling for the standby power generators based on the prioritizations of the critical facilities necessary to emergency response
   c. Substitution of the network service with another mass transit service among two points of the network service disrupted (subway/bus/trains).
   d. Establishment of an authority that prioritize actions and coordinate planning.
   e. Establishment of partnership with regional, state, and private sector entities to address multi-jurisdictional and regional systems.
   f. Procedures that strategically restrict electricity distribution.
   g. Network reconfiguration.



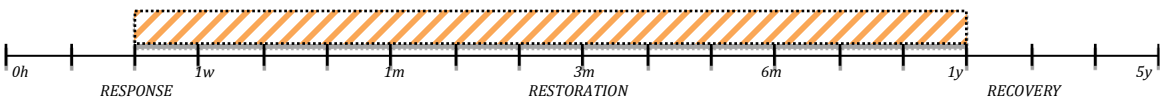
6. **<u>Resources.</u>** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.

   Possible data/measures are:

   a. How repairs and replacements were developed, approved, funded and implemented.
   b. Ask utility owners/managers where they got money to perform repairs (reserve funds, governmental assistance, insurance, etc.).



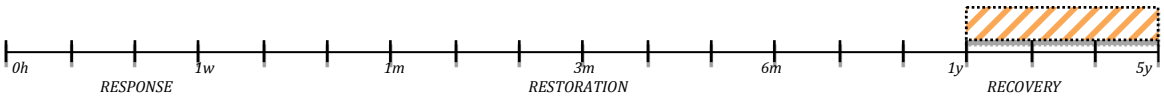
   c. Equipment required for recovery.
   d. Repair crews and workers allocated to repair operations, and associated increased salary costs.



7. **<u>Transformative changes.</u>** What changes occurred that surpassed or differed from the pre-disaster state? Were business recovery barriers identified then addressed through preparedness policies or actions that mitigate negative impacts of future disasters due to electricity outages?

   Possible data/measures are:

   a. Funding of Programs to harden distribution systems and employ technologies such as backup generation (with the establishment of Retail Fuel Stations) renewable energy, or microgrids to ensure facilities can be rapidly restored.
   b. Funding of Programs to ensure key elements protection such as sewage lift stations and water pumping stations.
   c. Permanent variation of network layout.
   d. New regional transit and transportation response or recovery plans for future disasters.
   e. Fostering of new construction strategies such as the establishment of pole depth standards based on local soil condition, strengthening of critical lines leading to population centers, undergrounding, etc. based on main previous causes of disruption
   f. Fostering of techniques to improve resilience of power system such as trimming of potential dangerous tree, use of submersible equipment in underground station, consider heavy wall insulation cables based on main previous causes of disruption.



Data collection methods or data types

- Field observations, face-to-face interviews, informal surveys, notes.
- Automated Analysis of social media information (Natural Language Processing).
- Mapping of failure points and evolution of subsystem restoration.
- Geo-Tagged Photo/Video documentation of damage and archiving using EERI data collection tools.
- Establish relationship with electric networks managers/owners.
- Media investigation (newspapers, social networks, etc.).
- High resolution satellite images.
- Structured surveys.
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.

Possible Data Sources

- Assessors' records.
- Media reports (including social media trends).
- Utility providers.

References to support this topic area

T.B.D.

FUEL/NATURAL GAS

Framework general questions, specific research questions, data collection methods, data sources, and references re not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

COMMUNICATION

Framework general questions, specific research questions, data collection methods, data sources, and references re not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

WATER

Framework general questions, specific research questions, data collection methods, data sources, and references re not yet complete. Until this section becomes available, use the other subsystems in this system as a guide..

WASTE

Framework general questions, specific research questions, data collection methods, data sources, and references re not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

GEOTECHNICAL STRUCTURES

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

DATA COLLECTION PRIORITIZATION FOR THE BUILT ENVIRONMENT SYSTEM

	Phase I - Response	Phase II - Restoration	Phase III - Recovery
BUILDINGS			
Residential			
Shelters	***	**	*
Hotels/Motels	*	**	**
Housing	**	***	***
Government			
Police/Fire Stations	***	**	*
Town Hall	***	**	**
County Administrative Buildings	***	**	**
Courts	**	**	**
Disaster Debris and Recycling Centers	***	**	*
Emergency Operation Centers	***	**	*
Institutional			
Hospitals	***	**	*
Health Care Facilities, Nursing Homes	***	**	*
Penitentiaries	**	**	**
Business			
Banks/Financial Institutions	**	***	**
Medical Office/Clinic	**	***	*
Professional/Technical/Business Services	*	**	***
Mercantile/Storage			
Critical Retail (groceries)	**	***	**
Gas Stations	**	***	*
Garages	*	***	**
Food Distribution Centers	**	***	**
Retail/Wholesale	*	**	***
Other Distribution Centers	*	**	***
Cultural/Education			
Schools K-12	**	***	*
Higher Education Facilities	*	**	***
Entertainment Venues	*	**	***
Churches, Mosques, Temples, etc.	**	**	**
Community Centers	*	**	***
Industrial/Agriculture			
Construction	*	***	**
Agriculture	*	**	***
Food	*	**	***
Light/Heavy/High Technology	*	**	***
TRANSPORTATION			
Subways	*	**	**
Airports	***	**	*
Bridges	***	**	*
Highways	***	**	**
Railways	*	**	**
Ships/Ports/Harbors	*	**	**
Roads	***	***	**
Road Tunnels	**	**	*

Mass Transit Stations	*	***	**
Bike Pathways	*	***	*
ELECTRICITY	***	**	**
GAS/FUEL	*	**	***
COMMUNICATION	**	***	**
WATER	**	***	*
WASTE	*	**	**
GEOTECHNICAL STRUCTURES			
Embankments/Levees	**	**	**
Earth Dams	*	*	**
Retaining Walls	***	**	*

Social System

SYSTEM OUTLINE

SOCIAL SYSTEM

- **Population Demographics**
  - *Distribution/Density*
    - Urban/Suburban/Rural/Wild
  - *Composition*
    - Age/Gender/Race
    - Language (Limited English Proficiency)
  - *Socioeconomic Status*
    - Education/Income/Homeownership/Housing Vacancies/Renters/Public Housing Residents
    - Unemployment/ /Employment Rates
  - *Vulnerable Groups*
    - Children
    - Elderly
    - Homeless
    - Disabled (mental/physical)
    - Chronically Ill
    - Poor
    - People without Transportation
    - Racial/Ethnic Minorities
    - Religious Minorities
    - Women
- **Social Services**
  - *Education services (Pre-K-12, college and university)*
  - *Job/Employment services*
  - *Foster care/Adoption services*
  - *Criminal Justice services*
  - *Domestic violence services*
  - *Mental health services*
  - *Food banks*
  - *Welfare services*
  - *Healthcare and Clinic services*
  - *Childcare*
- **Recovery Resources**
  - *Insurance*
  - *Savings/Checking Account Balances*
  - *Developer Interests*
  - *Faith-based Services*
- **Quality of Life**
  - *Life Expectancy*
  - *Infant Mortality Rates*
  - *Acoustic/Emissions*
  - *Health Facilities and Emergency Services*
  - *Crime Rates*
  - *Marriage/Divorce Rates*
  - *Labor Force Participation*
  - *Social Networks*
- **Community Participation**
  - *Citizen Involvement in Politics*
  - *Civil and Community Organizations*
  - *Place Attachment*
  - *Collective Action, Efficacy, Empowerment*
- **Cultural/Heritage and Non-Profit Services**
  - *Cultural Property, Historic Sites*
  - *Arts Organizations and Events*
  - *Spiritual Organizations*

POPULATION DEMOGRAPHICS

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

SOCIAL SERVICES

Important notes for this subsystem:

- *This section provides questions and data that should be collected in the aftermath of the earthquake to capture the behavior of the public services that aim to create more*

effective organizations, build stronger communities, and promote equity and opportunity for all but with a special emphasis on disadvantaged populations.

- *Examples of the social services included are: domestic violence services, mental health services, food banks, healthcare clinics, and nursing homes.*
- *Other services like public housing, fire, and other municipal functions are addressed in the "Institutional System" rather than in the "Built Environment".*

General Research Questions

- *What was the overall performance of the social services subsystem?*
- *Which social services experienced the biggest changes (positive or negative) in their performance/use/activity? What factors or forces influenced these outcomes?*
- *Did the social services subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the social services subsystem (or any policies/codes/plans influencing its operation) before the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the social services subsystem to surpass its pre-disaster state/condition?*

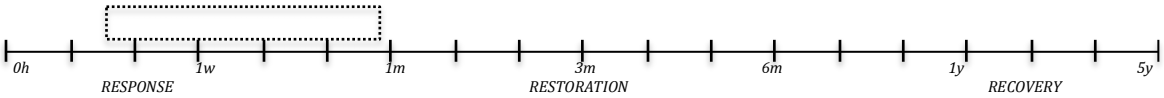
Specific Research Questions with Suggested Data Collection

1. **Baseline data and facts.** Which social services are active in the community pre-quake? What is the average non-disaster activity of the social services? Which social services are most critical within the subsystem in the pre-quake context?

   Possible data/measures are:

   a. Number of operators (agencies, their staff and providers).
   b. Number of users.
   c. Budgets of service providers.
   d. Childcare.
   e. Education services.
   f. Job/Employment services.
   g. Adoption services.
   h. Criminal Justice services (offices aimed at reducing and preventing crime, saving lives and reducing injuries on roads; resources offering justice and drug-related information to support research, policy, and program development)
   i. Domestic violence services.
   j. Mental health services.
   k. Food banks.
   l. Welfare services.
   m. Emergency Room services.

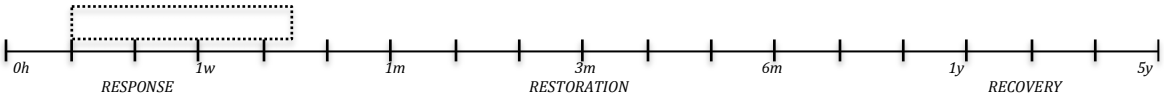
n. Healthcare Clinics (free or subsidized).
o. Nursing homes, independent living facilities, etc.



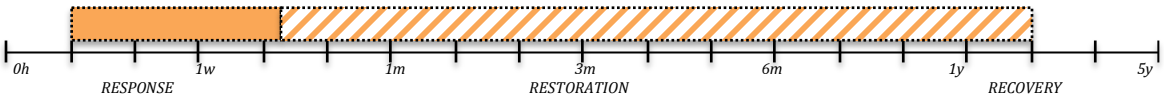
2. **<u>Damage and functionality.</u>** What is the level of the social services subsystem functionality? What types of damage impacted the social service subsystem elements? Was the service disrupted and if so, to what degree? Does damage prevent users from utilizing social services? Which social services are most critical within the subsystem in the response and recovery phase? Is there any impact variation amongst social services across the region, and if so, why?

   Possible data/measures are:

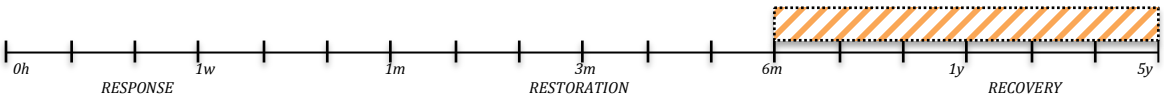
   a. Structural/Non-Structural damage to social services' facilities.



   b. Keep track of functionality (share of users, variation in capacity, etc.) until full restoration.
   c. Density of social services organizations.



   d. Welfare-dependent households per capita.

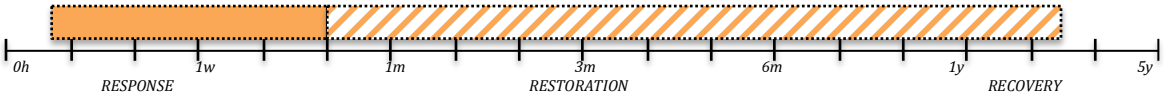


3. **<u>Consequences and interdependencies.</u>** What is the main reason for social service disruption (bureaucracy, structural/non-structural/contents damage, utilities disruption, employee unavailability due to death, injury or displacement, impact of surrounding structures, bad maintenance)? What are the consequences of social service disruption on the social system or on other community systems? What are the consequences of other community systems or functions on the social services subsystem?

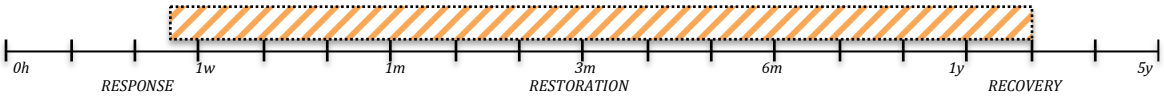
   Possible data/measures are:

   a. Category of people using social services affected by the earthquake (by demographic characteristics, social status, etc.).
   b. Local areas affected (neighborhoods, districts, etc.)
   c. Percentage of workers that cannot reach work place and reason.
   d. Differences in the amount of people using social services and reasons.

e. Percentage of displaced people by category (workers, elderly, non-employed, etc.).
f. Damage to welfare building requires relocation to alternate site that is difficult to access by public transit thus welfare visits decrease.



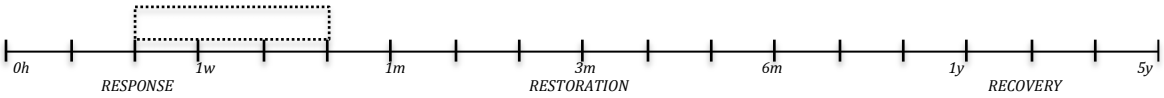
g. Document if the time-frame in which social services are restored matches the time-frame in which quality of life, community participation recovers and vice-versa, economy growths.
e. Variation of impact due to aftershocks and impact of foreshocks such as rise of the alert, etc. (NB: Aftershocks are likely to continue beyond the recommended timeframe for data collection; however, the process for collecting data and assessing impacts should be established within the recommended timeframe)



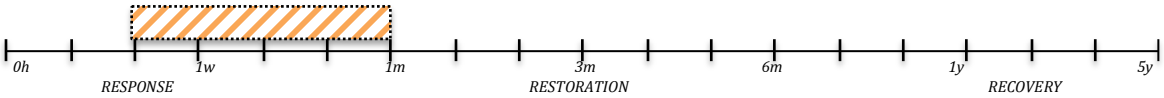
4. **<u>Pre-quake mitigation.</u>** Did the social services subsystem management implement pre-earthquake mitigation procedures aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the social services subsystem? Attempt to document any costs and benefits from these efforts.

Possible data/measures are:

a. Earthquake preparedness literature or informational programs distributed
b. Service delivery building retrofitting and non-structural content bracing for post-earthquake operations.



c. Presence and effectiveness of plans for portable service delivery in place, i.e. portable trucks, temporary loan of neighboring community staff, emergency hiring fast-tracking procedure, etc.

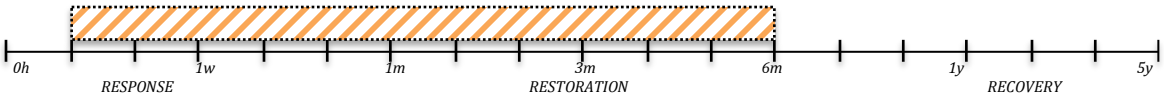


5. **<u>Post-quake recovery techniques.</u>** Did the social system management/agency implement any post-disaster coping strategies in a timely fashion? If not, why? Attempt to document any costs and benefits from these efforts.

Possible data/measures are:

a. Relocation of facilities and activities if the original location was damaged.

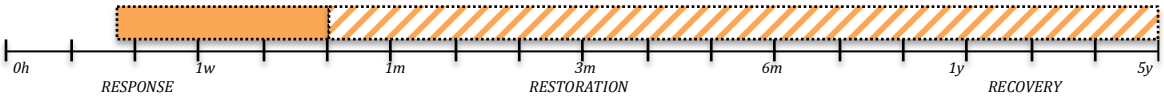
b. Relocation of the activities in order to follow the change of locations in which these services are much needed after the earthquake.



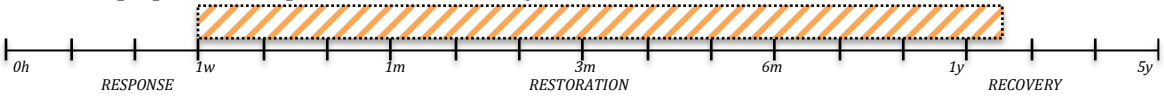
6. **<u>Resources.</u>** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.

   Possible data/measures are:

   a. How repairs and replacements were developed, approved, funded and implemented.
   b. Ask owners/managers where they got money to perform repairs.



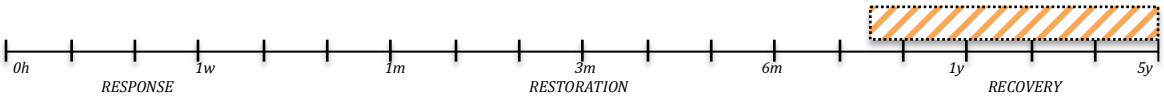
   c. Emotional support.
   d. Financial assistance to individuals (from formal sources, or from informal networks).
   e. Equipment required for recovery.



7. **<u>Transformative changes.</u>** What changes occurred that surpassed or differed from the pre-disaster state? What were the drivers of these changes? How will these changes will contribute to mitigate future disasters?

   Possible data/measures are:

   a. Variation of services capacities.
   b. Variation of services location based on possible variation of the geography of poverty.
   c. How new program to help vulnerable people dealing with post-earthquake situation were developed, approved, funded and implemented.



Data collection methods or data types

- Field observations, face-to-face interviews, informal surveys, notes.
- Geo-Tagged Photo/Video documentation of damage and archiving using EERI data collection tools.
- Establish relationship with social services providers and managers, rely on key stakeholder interviews.
- Media investigation and content analysis (newspapers, social networks, etc.)

- Structured, close-ended surveys.
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.
- Interviews with business owners

Possible Data Sources

- Assessors' records.
- Media reports.
- U.S. Census Bureau (Population Estimates Program; Decennial Census, American Community Survey).
- National Center for Charitable Statistics.
- Institute for Health Metrics and Evaluation.
- Municipal and Police Statistics.
- Centers for Disease Control and Prevention
- Health and Human Services
- U.S. Environmental Protection Program
- U.S. Department of Education

References to support this topic area

T.B.D.

RECOVERY RESOURCES

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

VULNERABLE GROUPS

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

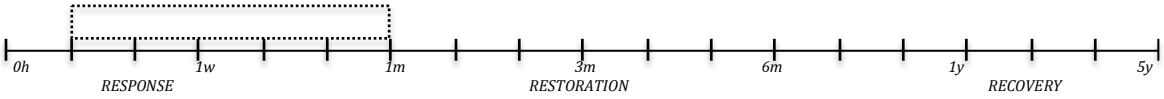
QUALITY OF LIFE

General Research Question

- *How were trends for quality of life metrics measured or modified after the earthquake?*
  - *Which elements of the quality of life experienced the biggest changes (positive or negative) in their performance/use/activity? What factors or forces influenced these outcomes?*
- *Did the quality of life subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
  - *Were transformative improvements made to the quality of life subsystem (or any policies/codes/plans influencing its operation) before the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the quality of life metrics to surpass their pre-disaster state/condition?*

Specific Research Questions with Suggested Data Collection

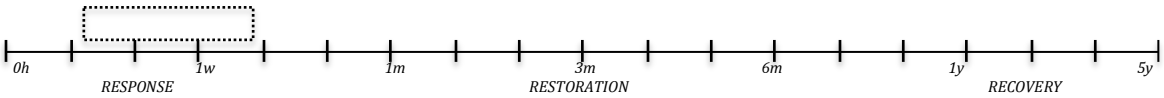
1. **Baseline data and facts.** Which elements give information about the quality of life? What was the pre-event levels for these elements?
   Possible data/measures are:
   a. Life expectancy.
   b. Infant mortality rates.
   c. Acoustic/Emissions
   d. Health Facilities and Emergency Services.
   e. Number of crimes, incarceration rates.
   f. Divorce rates.
   g. Employment (labor force participation, rates of absenteeism and presenteeism, etc.).
   h. Educational outcomes (test scores, graduation rates, educational continuity, etc.)



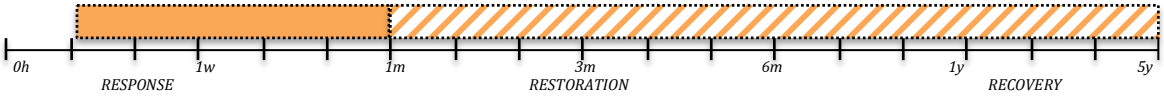
2. **<u>Damage and functionality.</u>** What earthquake impacts altered or changed the elements that measure the quality of life? To what degree did these impacts change the quality of life? Which elements are most critical within the subsystem? Is there any impact variation across the region, and if so, why? Are there any new quality of life trends observed?

   Possible data/measures are:

   a. Structural/Non-Structural damage to the community facilities that influence quality of life (prisons, health centers, industries that use hazardous materials, etc.).



   b. Change in the psychological state of people, especially vulnerable people.
   c. Disruption of social services.
   d. Utility quality of service.
   e. Children school enrollment.
   f. Share of adults with bachelor's degree.
   g. Quality of education based on test scores, attendants, and dropouts.
   h. Population pride and satisfaction about facilities and homes.
   i. Mean years of schooling, expected years of schooling.
   j. Free-time activities (gym accesses verifiable online).
   k. Number of injures treated in the first day (rapidity).
   l. Number of people who lost utilities.
   m. Lower number of injured people treated.
   n. Increase of social services request.

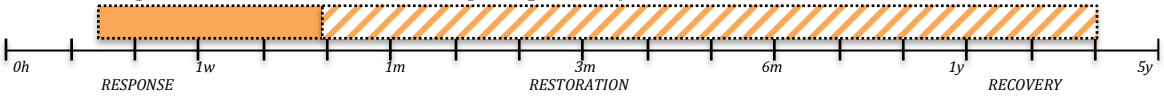


3. **<u>Consequences and interdependencies.</u>** What are the consequences of quality of life disruption on the social system or on other community systems? What are the consequences of other community systems or functions on the quality of life subsystem?

   Possible data/measures are:

   a. Evacuation, long-term displacement, permanent migration.
   b. Increased number of vulnerable people (e.g., changes in the poverty rate, wealth loss, higher incarceration rates, etc.)
   c. If large numbers of schools are destroyed or closed down, track educational outcomes (e.g., test scores, graduation rates, etc.)

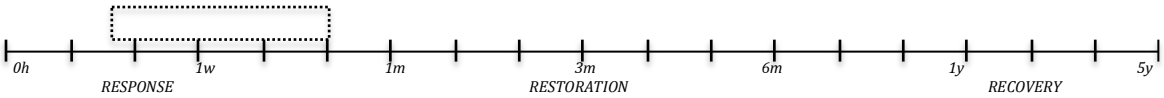
d. Document if the time-frame in which quality of life metrics have positive trends matches the time-frame in which quality of life, community participation recovers and vice-versa, economy growths (education level).
e. Document the interdependence between incarceration rates and economy growth (incarcerations stiff employment and suppress labor force participation).
f. Document the interdependence between safer community and private sectors investment which support an overall higher quality of life in the form of stable, healthier neighborhoods.
g. Document the long-term effects of a high quality K-12 public education (workforce development) and the short-term effects of school accessibility (families and firms based their choice to relocate in other communities based on that).
h. Document if older, educated and marries individual receive on average more aid.
i. Document discrepancies in the category of users affected (minorities, race, neighborhoods, vulnerable groups, etc.).



4. **<u>Pre-quake mitigation.</u>** Did organizations implement pre-earthquake mitigation procedures aimed at increasing robustness of the quality of life? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

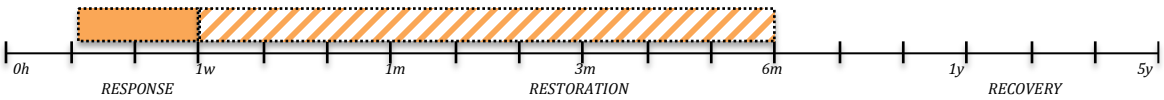
   a. Pre-quake plans to reduce disruption of impact on quality of life metrics.



5. **<u>Post-quake recovery techniques.</u>** Were any post-disaster techniques applied to reduce impact on life quality? If not, why? Were efforts attempted in a timely fashion? Would a different prioritization of actions have improved the quality of life? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

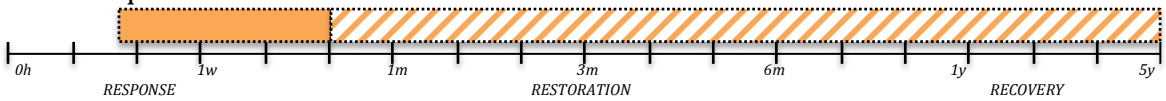
   a. Prioritization of activities to reduce impact on quality of life (quick repair of hazard material spills, hazard industry damages, jails, etc.).
   b. Policy to foster specific employment areas.
   c. Policies to foster relocation away from locations where infrastructure or building damage has reduced quality of life, and towards areas that promote higher quality of life (such as safe regions, better environmental quality, etc.)
   d. Policies to foster physical health and healthcare services.



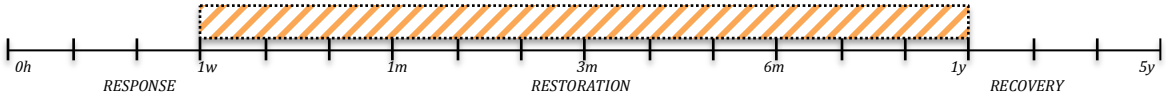
6. **<u>Resources.</u>** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.

   Possible data/measures are:

   a. How repairs and replacements were developed, approved, funded and implemented.



   b. Emotional support.

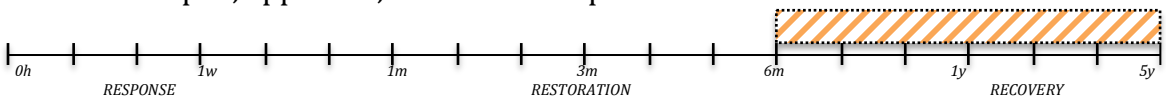


7. **<u>Transformative changes.</u>** What changes occurred that surpassed or differed from the pre-disaster state?

   Possible data/measures are:

   a. Variation of services location based on possible variation of the geography of quality of life.

   b. How policies to promote quality of life and address shortcomings (environmental policies, ecosystem management, food security, etc.) were developed, approved, funded and implemented.



Data collection methods or data types

- Field observations, face-to-face interviews, informal surveys, notes.
- Geo-Tagged Photo/Video documentation of damage and archiving using EERI data collection tools.
- Establish relationship with social services providers and managers.
- Media investigation (newspapers, social networks, etc.).
- Structured surveys.
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.
- Analysis of reports.
- Key informant interviews

Possible Data Sources

- Assessors' records.
- Media reports.
- US Census Bureau (Population Estimates Program; Decennial Census, American Community Survey).
- Centers for Disease Control and Prevention

- Health and Human Services
- U.S. Environmental Protection Program
- National Center for Charitable Statistics.
- Institute for Health Metrics and Evaluation.
- Municipal and Police Statistics.
- FBI's rate of violent and property crimes.
- Social Capital Community Survey 2006 (University of Connecticut).
- Social Capital Community Survey 2006 (Duluth-Superior Area Community Foundation).
- Social Capital Benchmark Survey 2000 (University of Connecticut).
- Social Capital Assessment Tool (SOCAT, The World Bank).
- Survey of Neighborhood Associations (LSU Weil).
- Post-Hurricane Katrina Community Survey (LSU Weil).
- Bureau of Justice Statistics (Annual Survey of Jails and Prisoners Series).
- IPUMS USA.
- HUD Fair Market Rents.
- FBI (Crime in the United States and Criminal Justice Information Services).
- Households Survey.

References to support this topic area

T.B.D.

COMMUNITY PARTICIPATION

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

CULTURAL/HERITAGE SERVICES

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

DATA COLLECTION PRIORITIZATION FOR SOCIAL SYSTEM

	Phase I - Response	Phase II - Restoration	Phase III - Recovery
Population Demographics	**	***	**
Social Services	*	**	***
Recovery Resources	***	***	**
Vulnerable Groups	***	**	*
Quality of Life	**	***	**
Community Participation/Social Capital	***	***	**
Cultural/Heritage/Non-Profit Services	*	**	***

Economic System

SYSTEM OUTLINE

- **Businesses (micro scale)**
  - *Business Sector (based upon NAICS classification)*
    - *Agriculture, Forestry, Fishing and Hunting*
    - *Mining*
    - *Utilities*
    - *Construction*
    - *Manufacturing*
    - *Wholesale Trade*
    - *Retail Trade*
    - *Transportation and Warehousing*
    - *Information*
    - *Finance and Insurance*
    - *Real Estate Rental and Leasing*
    - *Professional, Scientific, and Technical Services*
    - *Management of Companies and Enterprises*
    - *Administrative and Support*
    - *Waste Management and Remediation Services*
    - *Educational Services*
    - *Health Care and Social Assistance*
    - *Arts, Entertainment, and Recreation*
    - *Accommodation and Food Services*
    - *Other Services (except Public Administration)*
    - *Public Administration*
  - *Annual Revenue*
  - *# of Employees*
  - *Insurance coverage*
  - *Business failures*
  - *Location / relocation*

- **Local and Regional Economy (meso scale)**
  - *Gross Product by economic sectors*
  - *Employment*
  - *Key industries*
  - *Business interruption costs*
  - *Change in economic structure*
  - *Reconstruction financing*
  - *Integration with state and national economy*
  - *Local government economic programs and policies for response, restoration, and recovery*

- **State and National Economy (macro scale)**
  - *State (provincial) and national government economic programs and policies for response, restoration, and recovery*
  - *Macroeconomic indicators (e.g., interest rates, exchange rates, GDP growth rates)*

BUSINESSES SUBSYSTEM

<u>Important notes for this subsystem:</u>

- *The specific research questions address individual businesses or business sectors but the user should consider that it may be useful to classify businesses by alternate metrics other than sectors for future data analysis, i.e. age of business, annual revenue, number of employees or other meaningful classifications.*

General Research Questions

- *What was the overall performance of the business subsystem?*
- *Which elements or components proved to be critical to the function of the subsystem and why?*
- *Did specific businesses or groups of similar businesses have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the businesses subsystem (or any policies/codes/plans influencing its operation) before the disaster that somehow*

changed the subsystem and its function in the disaster?

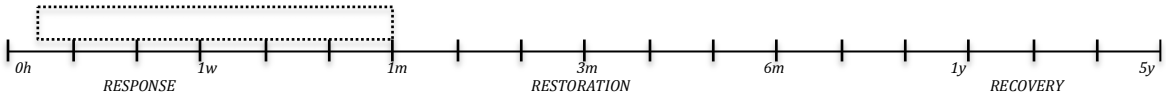
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

Specific Research Questions with Suggested Data to Collect

1. **Baseline data and facts.** What are the primary business sectors in the region? What are the characteristics of businesses in these sectors (e.g., size, customer base, financial condition)? Are any businesses especially important and why (e.g., major employer)? Are any businesses and sectors financially unstable or at risk of failure prior to the earthquake?

   Possible data/measures are:

   a. Ownership structure (single owner, partnership, corporation or franchise)
   b. Turnovers (volume of trade handled), and level of exports
   c. Annual Revenue (<$1 million, $1 - $3 million, $3 – 10 million, $10 - $25 million, > $25 million)
   d. # of Employees (<10, 10 – 50, 50 -100, > 100)
   e. Customer characteristics (tourists, local residents, other businesses, etc.)
   f. Age of Business
   g. Financial condition (growing, stable, declining)
   h. Factors underlying pre-earthquake financial condition (lack of demand, increase in material or inventory prices, high overhead costs, expensive or cheap labor, etc.)
   i. Owner/Manager with past experience of crisis management
   j. Building or facility ownership (own or lease)
   k. Business association joined by the business (Local Chamber of Commerce, etc.)
   l. Customers served by the business (rough estimates)

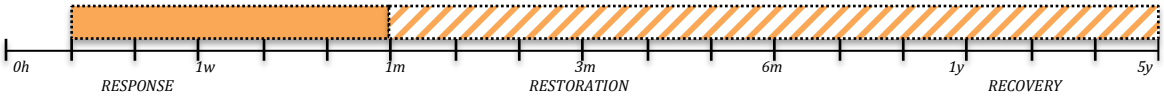


2. **Damage and functionality.** How many businesses have disrupted functionality due to site, location, facility damage, and/or contents damage? How many businesses are affected by utility disruption and to what extent and duration? Does individual business performance affect or influence the broader performance of its economic sector? Is there any substantial difference or similarities in damage across businesses of the same sector, and why? What types of businesses were especially hard hit?

   Possible data/measures are:

   a. Volume (reduced or increased) of business
   b. Permanent or temporary business closure and length of closure
   c. Permanent or temporary business relocation

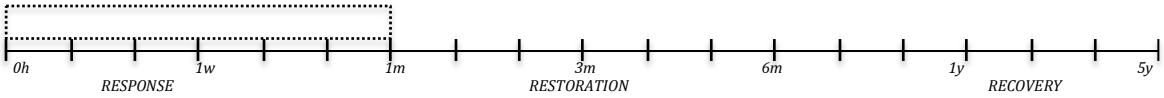
d. Number of displaced workers and length of displacement
e. Keep track of assistance sought by employers and sole traders



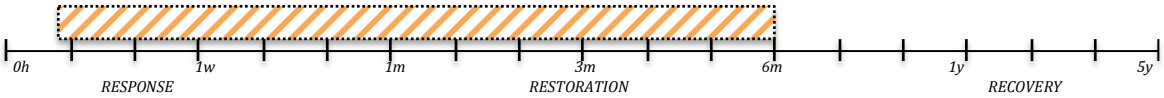
3. **<u>Consequences and interdependencies.</u>** How severe were business interruption losses, how long did they last, and what were the main reasons behind these losses (bureaucracy, building/equipment damage, utilities disruption, staff unavailability, impact of surrounding structures, lack of suppliers/demand, etc.)? What types of businesses experienced windfall gains (e.g., from reconstruction demand)? What are the main consequences for business relocation or permanent closure? What are the consequences of this inoperability/operability on the business system? What are the consequences of other community systems or functions on the business?

   Possible data/measures are:

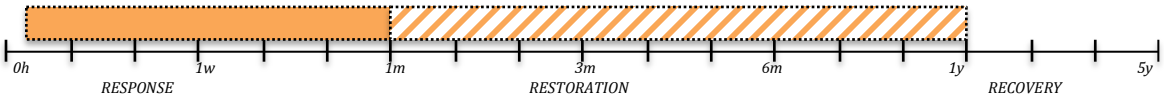
   a. Building structural, non-structural damage (tag)
   b. Damage to equipment.
   c. Fatalities, injuries and reasons for casualties.
   d. Ground-surface damage



   e. Delays due to inspections and bureaucracy.
   f. Impact of business damage on the environment and surrounding ecosystem.
   g. Staff unavailability and reasons

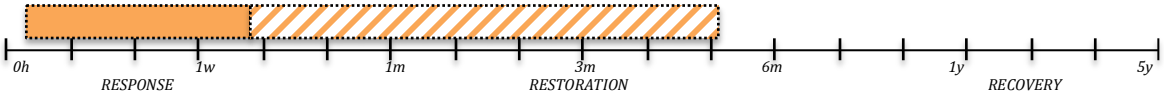


   h. Impact of surrounding structures
   i. Increased costs of doing business, inability to relocate, lack of demand, lack of suppliers
   j. Collect data about service needs required to conduct business
   k. Transportation delays, impacts or issues
   l. Financial and regulatory issues
   m. Failure of competitors, influx of new customers, increased demand from local customers and reason.

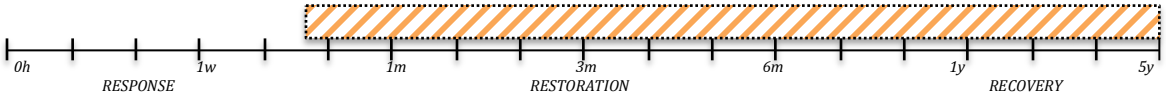


   n. Identify the performance of utilities and the most important utilities for the business.

o. Expectations for future business volume and reason.



p. Document if the time-frame in which people can shelter in place matches the time-frame in which local retailers, schools, professional services and worship recovers.
q. Document if the business was key to the economic activity of the region and if its restoration has been adequately prioritized or if there have been delays.
r. Change in the business size (revenue, profit, # of employees, etc.).

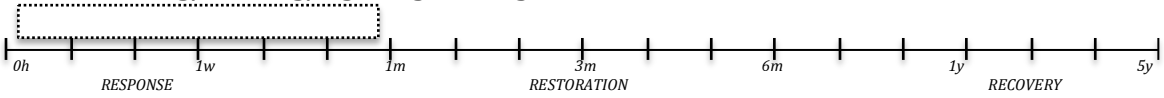


4. **Pre-quake mitigation.** Did business management/owners implement pre-earthquake mitigation procedures or measures before the earthquake aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the business? Are there any differences in adoption and implementation of mitigation measures across the sectors or business types and if so, why? Attempt to document or at least estimate any costs and benefits from these efforts.

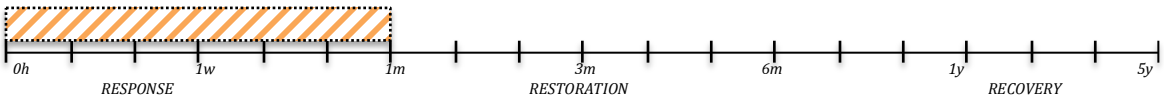
   Possible data/measures (examples of efforts) are:

   a. Acquisition of insurance policies with earthquake coverage for building structure, contents, business income interruption, business liability insurance.
   b. Contingency planning aimed at business continuity (employees provided with earthquake preparedness training/information, supply of earthquake preparedness kits including medical supplies, % of employees prepared for post-earthquake business resumption, planning to consider in advance possible rerouting of goods movement in case of disruption to the transportation network, find new suppliers and demand, estimate losses of goods not delivered and people not being able to access the facility, temporary housing, loss assessment to evaluate benefits from planning, etc.)
   c. Implementation of evacuation drills.
   d. Ensuring availability of liquid funds to make repairs quickly and avoid dependency and delays from financing.
   e. Earthquake-induced damage prevention (retrofit of structures/facilities, stabilization of soils, elevation of important contents if at risk from tsunami, early warning systems/sirens, etc.).
   f. Building Occupancy Resumption Programs (BORP): pre-certified post-earthquake inspection with licensed engineers.
   g. Contractors and engineers retained on an annual basis to perform post-earthquake repairs.
   h. Information about regular maintenance of the building to check for deterioration of components that could lead to disproportionate damages.

i. Structural/non-structural precautions (exposition of structural elements, anchorage of non-structural components and heavy building contents, ability to accommodate displacement, protection of facades).
j. Building instrumentation to monitor earthquake response enabling quick decision for continuation of operation (diagnostic and damage detection technology).
k. Advance planning to consider alternative means of ingress/egress of employees or goods in case of disruption to transportation network.
l. Reducing reliance on external resources that can be impacted by earthquakes, e.g., closed-loop water (rainwater harvesting, on-site wells); on-site renewable energy or microgrids; low-use plumbing fixtures; passive heating/cooling/lighting strategies.



m. Installation, protection, and functionality of back-up systems (emergency power, surge protectors, uninterruptible power supply, unplugged equipment to prevent damage due to lighting strikes, independent communication network, on-site housing and subsistence for staff, water and waste tank, dual fuel boilers, back-up systems in safe locations within building, etc.)
n. Effectiveness of the treatment and protection of critical equipment that could take months to procure, repair or replace
o. Effectiveness of the segregation (keep key infrastructure components separate and diversify their dependencies by purchasing raw material from external, geographically dispersed sources).
p. Effectiveness of the storage of large inventories of finished goods or raw materials (manufacturing storing, coal-fired power plants storing of coal, etc.)

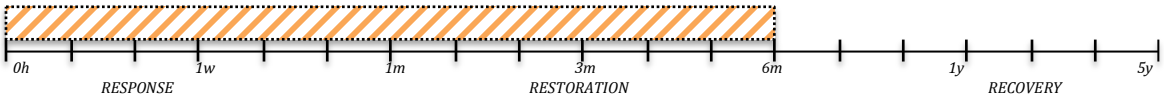


5. **<u>Post-quake recovery techniques.</u>** Did business management/owners implement post-disaster techniques other than repairs to drive recovery in a timely fashion? If not, why? What are the factors that govern business recovery decisions such as relocation or change of business line? Carefully document any costs and benefits from these efforts.

Possible data/measures are:

a. Change of business line, type, sector or services provided (permanent or temporary)
b. Change in hours of operation.
c. Reduction or increase in employees.

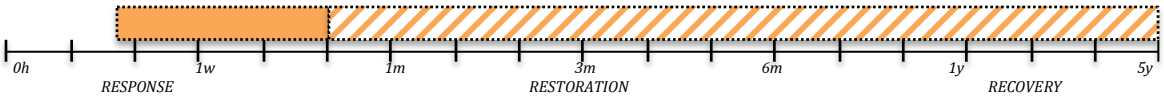
d. Reach out to new suppliers to cope with increasing demand or failure of current suppliers.
e. Relocation (where, temporary or permanent and length of period, etc.) and reason (predicted depopulation of the area, predicted increase in rents, etc.),
f. Reallocation of spaces and functions to speed up repairs without shutting down the business done in the building.
g. Compensation of buildings dysfunctionalities (installation of composting toilets, realization of emergency access routes, etc.)
h. Adoption of techniques such as conservation of input (or rationing) that could lead to less total business losses rather than maintain full production for a shorter period, or substitution (changes in supplies such as switching from natural gas to other heating fuels that require the pre-configuration of the new production line)
i. Increase in exports.
j. Modification of the organizational structure to speed up decision making (attribution of powers to experienced managers with crisis experience) or hiring of experienced consultants to deal with post-disaster management.
k. Acquisition of business recovery grants, locally-crafted loans, or other business loans.



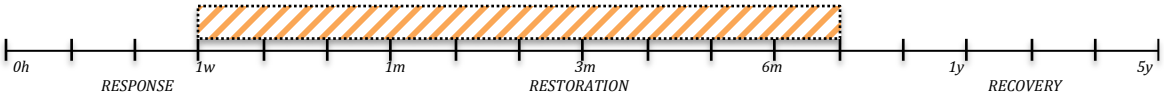
6. **Resources.** What were the total resources used to encourage or facilitate the recovery of the business subsystem or individual businesses? Which strategies and resources were the most useful to individual business or various business sectors? Document the flow of financial resources used to facilitate recovery.

Possible data/measures are:

a. How repairs and replacements were developed, approved, funded and implemented.
b. Ask businesses where they got money to perform repairs (personal savings, business revenue, credit card debts, insurance payouts, SBA loans, friends or family, local, state, and federal assistance, etc.).
c. Resource challenges or bottlenecks



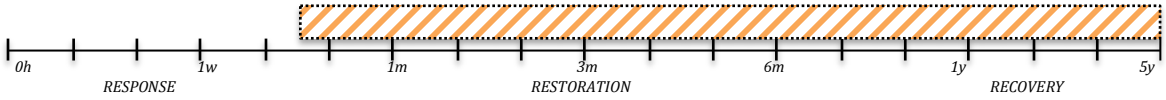
d. Equipment required for restoration.
e. Number of repair crews and workers allocated to repair operations, and associated increased salary costs.



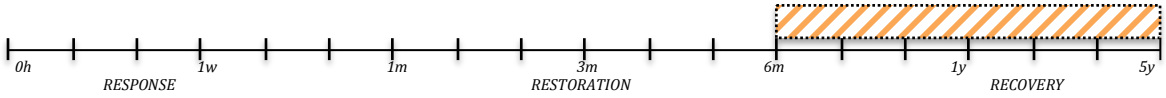
7. **<u>Transformative changes.</u>** What changes occurred that allowed the business subsystem to surpass or differ from its pre-disaster state? Were business recovery barriers identified then addressed through preparedness policies or actions that mitigate negative impacts from future disasters?

   Possible data/measures are:

   a. Permanent relocation of businesses towards safer zones.
   b. Variation of businesses structure (more businesses but smaller, few businesses but bigger and in safer areas, etc.).
   c. Change in ownership.
   d. Change in customers.
   e. New technologies.
   f. Closure of unprofitable lines.
   g. New delivery channels.
   h. New insurance policies.
   i. New business association memberships.
   j. Change in the organizational structure.
   k. Change in the management of business (more experienced directors, etc.)
   l. Increase and diversification of suppliers.



   m. How new policies, mandatory instances, etc. were developed, approved, funded, and implemented.
   n. New recovery funds or 'rainy day' accounts created to support businesses after future disasters.



Data collection methods or data types

In order of possible applicability or timeliness to the data collection effort.

- Statistical databases, business registries, etc. for information on pre-earthquake baseline conditions
- Field observations, face-to-face interviews, informal surveys, notes.
- Structured economic surveys of business owners, managers, or displaced employees working from home after the disaster.
- Studies on small businesses to understand the dynamics which govern decisions
- Establish relationship with impacted business managers/owners and associations, local economic development agencies, etc.
- Geo-Tagged Photo/Video to identify overall story of damage, demolition, and reconstruction.

- Use of ATC-38/ATC-20 Post-Earthquake Building Performance Assessment Guide.
- Store documentation of damage (Geo-tagged photos, building evaluation forms, etc.) using EERI data collection tools to populate GIS spatial data layers.
- Media investigation (newspapers, social networks, etc.).
- Create connections with utility operators or find data to document the utility restoration timeline.
- Aerial imagery or web-maps of businesses (Google Maps)
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.

Possible Data Sources

- Web-based business review tools (Yelp, Angie's List, Zagat, etc.)
- Mail forwarding data from Post Offices to understand business movements.
- Economic Development Agencies.
- Chambers of Commerce.
- Studies from Consulting Firms, Universities.
- Banks.
- Assessors' records.
- Media reports.
- Social Media.
- Department of Building Inspection.
- Building Management/Owner.
- Architects and engineers doing repairs and retrofits.
- Professional organization studying the impacts.
- Utility, Lifeline, and Transportation companies with building portfolios.
- Companies and organizations with building portfolios.
- Emergency Management Contractors.
- Any agencies established by the Government to lead and coordinate the ongoing recovery effort.
- City Councils.

References to support this topic area

- The North American Industry Classification System (NAICS) Association (*http://www.naics.com/naics-drilldown-table/)*.
- Chang, S.E. and A.Z. Rose. 2012. "Towards a Theory of Economic Recovery from Disasters," *International Journal of Mass Emergencies and Disasters*. Vol.30, No.2, pp.171-181.

LOCAL AND REGIONAL ECONOMY

Framework general questions, specific research questions, data collection methods, data sources, and references to be added.

STATE AND NATIONAL ECONOMY

Framework general questions, specific research questions, data collection methods, data sources, and references to be added.

DATA PRIORITIZATION FOR THE ECONOMIC SYSTEM

	Phase I - Response	Phase II - Restoration	Phase III - Recovery
Businesses			
Agriculture, Forestry, Fishing and Hunting			
Mining			
Utilities			
Construction			
Manufacturing			
Wholesale Trade			
Retail Trade			
Transportation and Warehousing			
Information			
Finance and Insurance			
Real Estate Rental and Leasing			
Professional, Scientific, and Technical Services			
Management of Companies and Enterprises			
Administrative and Support			
Waste Management and Remediation Services			
Educational Services			
Health Care and Social Assistance			
Arts, Entertainment, and Recreation			
Accommodation and Food Services			
Other Services (except Public Administration)			
Public Administration			
Regional and Global Economy			
Gross Product by Economic Sectors			
Employment Data			
Key Industries			
Business Interruption Costs			
Change in Economic Structure			
Financial Services (Banks, Credit Union Members)			
Inward Investment			
Integration with Regional and Global Economy			
Gross Product by Economic Sectors			
Employment Data			

Natural Environment System

SYSTEM OUTLINE

- **Seismic Hazard and Geologic Phenomena**
  - *Surface Fault Rupture*
  - *Ground Failure*
  - *Tsunami*
  - *Fire*
  - *Earthquake-induced landslides*
  - *Aftershocks and foreshocks*
- **Natural Resources**
  - Water Quality
  - Air Quality
  - Soil Quality
  - Biomass
  - Other Natural Resources

SEISMIC HAZARD AND GEOLOGIC PHENOMENA

General Research Question

- *What are the characteristics of the seismic event and how does they compare to the pre-quake seismic hazard characterizations for the region?*
- *Did any earthquake-induced geologic phenomena affect community systems or functions?*
- *Did the hazard level have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made before the disaster that somehow changed the hazard level?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (new hazard maps, land use plans, building codes, and policies) to allow the community to surpass its pre-disaster state/condition?*

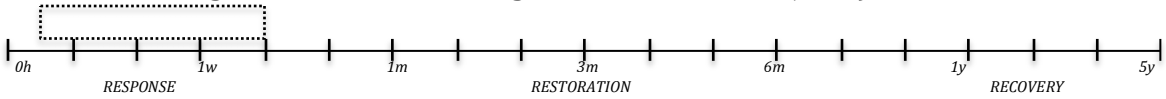
Specific Research Questions with Suggested Data to Collect

1. **Baseline data and facts.** What are the characteristics of the earthquake? What are the characteristics of the ground shaking at different locations? What are the characteristics of aftershocks and foreshocks? How do the earthquake characteristics compare to the pre-quake seismic and geologic hazard characterizations for the region?

   Possible data/measures are:

   a. Magnitude and epicenter, depth, focal mechanism, fault length.
   b. Time of the day in which the earthquake happened.
   c. PGA, length of shaking, frequency content.
   d. Number of foreshocks, magnitude and epicenter.
   e. Associated faults and characteristics.
   f. Regional soil characteristics.
   g. Maximum credible earthquake (MCE).

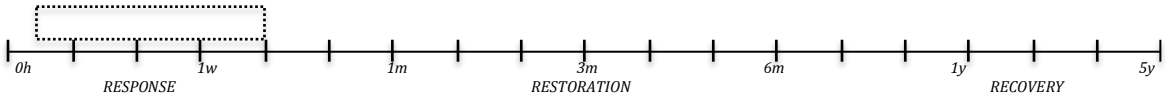
h. Earthquake hazard map or scenario assessments (including liquefaction hazard maps, landslide hazard maps, etc.).
i. Seismic instrumentation present in the region to measure the seismic intensity.
j. Exposure of the area affected (density of population, etc.).
k. Other hazards present in the region (floods, fires, storms, tornadoes, volcanic eruptions, lahars and ash falls, pyroclastic flows, shoreline and streams erosion, ground subsidence, sags and sinkholes, ice jams).



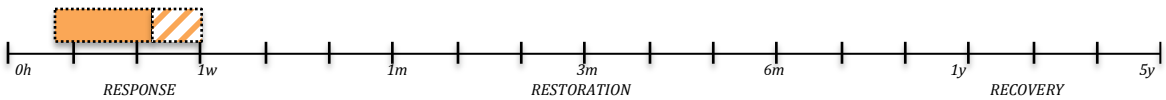
2. **<u>Damage and functionality.</u>** What are the geologic or other natural effects induced by the earthquake? What shaking intensity is observed in the geographic area affected by the earthquake? To what characteristics of shaking/local conditions can be ascribed possible incongruences between magnitude and intensity? Did the earthquake trigger other hazards as secondary effects? Did the other hazard condition exasperate or reduce the impact from earthquake-induced effects?

Possible data/measures are:

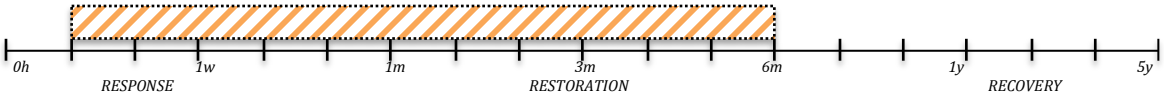
a. Surface Fault Rupture (possible new faults observed, position of the new faults respect to structures such as dams, bridge, nuclear power stations, length and location of fault expression).
b. Ground Failure (regions that experienced liquefaction, rapid earth-flows, lateral spreading, etc.).
c. Tsunami (travel time, polarity of the first movement, maximum run-up height, period, number of waves, duration of the sea disturbance, extent of flooding, and impacts on flora due to tsunami run-up, and subsequent impacts on animal habitat).
d. Earthquake-induced landslides (rock avalanches, rock falls, mud flows, etc.).
e. Time of the day, month of the year effects.
f. Intensity of the earthquake measured with the MMI scale.
g. Seismic shaking amplification due to soil composition.



h. Fires induced by shaking impact on infrastructure such as power lines, power poles, electric distribution centers, gas lines, gas distribution centers, household or business water heaters (duration, region, impact)



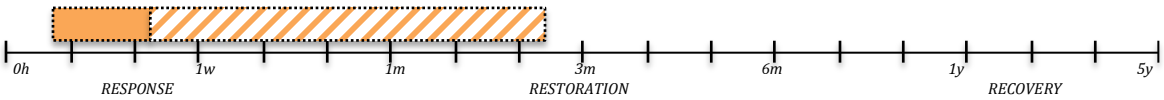
i. Number, magnitude, location, of aftershocks and foreshocks.



3. **<u>Consequences and interdependencies.</u>** What are the consequences of the shaking and of the geologic effects induced by the earthquake on other natural hazard management systems, and community systems and vice versa? Which effects contribute to the community damage the most? What other critical interdependencies can be identified? What is the influence of the earthquake event on the management of other unrelated hazards?

   Possible data/measures are:

   a. Impacts of fault rupture on buildings and infrastructure.
   b. Impacts of ground failure (liquefaction, lateral spreading, etc.) on buildings and infrastructure.
   c. The types and locations of impacts to roads or bridges disrupted by landslides.
   d. Buildings inaccessible due to geologic-induced effects.
   e. The types and locations of disruptions in the utility distribution networks due to geologic and other earthquake induced damage.
   f. Psychological effects of foreshocks or aftershocks on the population, government, business owners, etc.
   g. Impacts on business access or government operation due to geologic-induced effects.
   h. Damage to emergency response systems, resources, and mitigation structures that impact ability to deal with other natural hazards (damage to water mains and loss of pressure that impacts fire response, etc.).
   i. Subtraction of efforts to the earthquake emergency response due to other actual or possible natural hazards.
   j. Subtraction of fire emergency crews to the fires response due to the need of people for rescue.

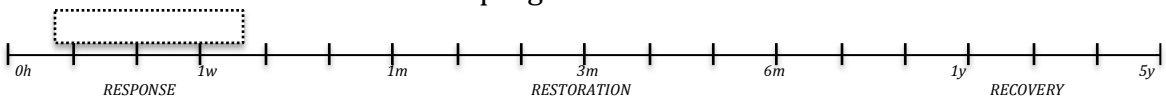


4. **<u>Pre-quake mitigation.</u>** Were pre-earthquake mitigation procedures implemented before the earthquake to address geologic earthquake effects? How did these procedures or measures affect the overall impact? Was earthquake mitigation delayed or expedited due to mitigation actions regarding other hazards? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

   a. Existence and quality of seismic and geologic hazard maps (i.e. active faulting, and landslide and liquefaction susceptibility) and their reference in land use planning and building codes, policies or other documents.
   b. Existence and quality of policies that require a setback distance from active fault traces or zones prone to earthquake-induced hazards.

c. Stabilization of soils prone to ground failure like liquefaction or lateral spreading (e.g. densification methods, modifications leading to improving the cohesive properties of the soil such as hardening or mixing, removal and replacement, or permanent dewatering, reinforcement of the soil or use of shallow or deep foundations, modification of site geometry to reduce the risk of translational site instability).
d. Stabilization of soils prone to landslides (grading to improve slope stability, reinforcement of the slope or improvement of the soil within the slope, and reinforcement of the structure built on the slope to tolerate the anticipated displacement, catchment and/or protective structures such as basins, embankments, diversion or barrier walls, and fences).
e. Protection against possible tsunamis (planning of evacuation routes and posting of areas that are in a tsunami hazard inundation area, installation or signage indicating vertical evacuation structures, etc.).
f. Implementation of a seismic measurement network to carefully document shaking intensity at different sites or improvement to an existing network.
g. Installation of alarm systems to reduce damage severity or earthquake induced impacts due to rock falls, avalanches, mud flows, fires or other geologic effects. Number of alarm systems activated during the event and possible damages avoided.
h. Evacuation plans and enhancement of landscaping and design measures due to education and awareness programs to deal with other hazards.

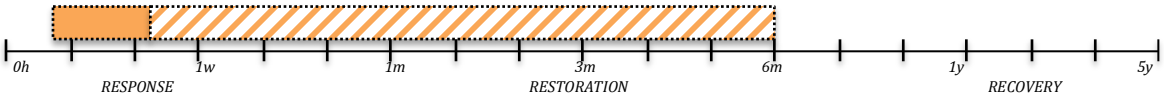


5. **<u>Post-quake recovery techniques.</u>** Were post-disaster techniques implemented to minimize further geologic impacts or mitigate impacts from aftershocks? Were post-earthquake techniques or policies implemented that had impacts on response or preparedness to other natural hazards?

   Possible data/measures are:

   a. Assessment of landslides stability (e.g. conduct of field assessments, outcomes of assessment).
   b. Assessment of liquefaction effects (e.g. conduct of field assessments, outcomes of assessment).
   c. Assessment of co-seismic subsidence, lateral spreading, or after-slip (e.g. conduct of field assessment, outcomes of assessment).
   d. Policies implemented to reduce the ongoing or future impacts of earthquake aftershocks
   e. Implementation of post-earthquake risk analysis to identify critical areas, based on geologic and soil maps and seismic records.
   f. Ground and slope stabilization (temporary or permanent).
   g. Land use pattern modification and zoning (deforestation of areas that used to function as natural wind barrier, increased erosion and aquifer pollution due to new excavations, prohibition of construction in flood plains due to liquefaction impacts, etc.).

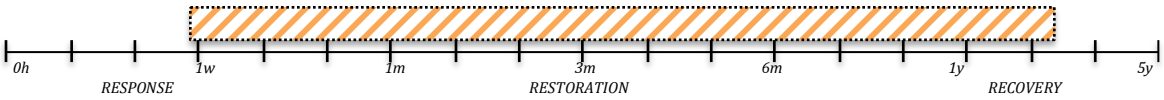
h. New geotechnical structures, which changed the morphology of the region increasing the risk of erosion, floods, etc.
i. Retrofit policies that impacted also wind or fire resistance of structures.



6. **<u>Resources.</u>** What resources were available and used in the pre-quake seismic hazard assessment and mitigation of geologic effects? What resources were available and used in the post-disaster techniques or repairs for geologic effects? Document the flow of financial resources used to improve response and recovery.

   Possible data/measures are:

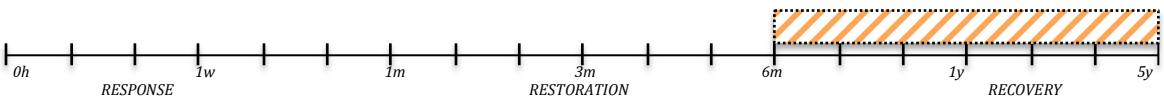
   a. How were pre-quake seismic hazard assessment studies and scenarios, or post-quake risk analyses developed, approved, funded and implemented? Focus on identifying the key lessons in agency/political leadership, sources and amounts of funding, and innovative approaches taken to implementing the analyses. How were the analyses used?.
   b. How new post-disaster land use and building policies related to geologic issues were developed, approved, funded and implemented.
   c. How pre-disaster mitigation measures and post-disaster measures (i.e. temporary seismic instrument deployment, slope stability improvements, liquefaction clean up, tsunami debris removal, etc.) were developed, approved, funded and implemented.
   d. How studies on other hazards were developed, approved, funded and implemented after the earthquake raise of awareness.



7. **<u>Transformative changes.</u>** Changes that will affect future community resilience? Are policies passed that will allow the region to surpass the pre-earthquake preparedness condition?

   Possible data/measures are:

   a. How policies to promote earthquake-induced effects mitigation were developed, approved, funded and implemented.
   b. How plans to increase the network on instruments to measure seismic hazards and related earthquake-induced effects were developed, approved, funded and implemented.
   c. How modifications to land use plans and policies were developed, approved, funded and implemented.



Data collection methods or data types

In order of possible applicability or timeliness to the data collection effort.

- Field observations, face-to-face interviews, informal surveys, notes.
- Geo-Tagged Photo/Video to identify overall story of damage, demolition, and reconstruction
- Store documentation of damage (Geo-tagged photos, building evaluation forms, etc.) using EERI data collection tools to populate GIS spatial data layers
- Media investigation (newspapers, social networks, etc.).
- Establish relationship with teams doing assessments.
- High resolution satellite images.
- Structured surveys.
- Aerial imagery
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.

Possible Data Sources

- Assessors' records.
- Media reports.
- Housing Departments/Authorities.
- Department of Building Inspection.
- Assessment teams.
- Architects and engineers doing repairs and retrofits.
- Professional organization studying the impacts.
- Utility, Lifeline, and Transportation companies with building portfolios.
- Companies and organizations with building portfolios.
- Ministry of Civil Defense.
- Emergency Management Contractors.
- Possible agencies established by the Government to lead and coordinate the ongoing recovery effort.
- City Councils.
- USGS.

References to support this topic area

T.B.D.

NATURAL RESOURCES

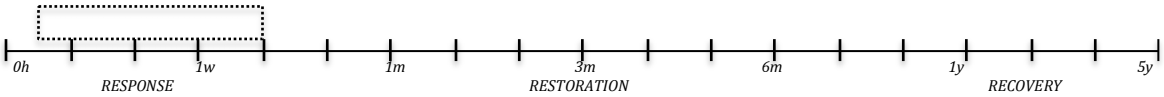
General Research Question

- *What was the overall environment quality level before the earthquake?*
- *Did any earthquake-induced geologic phenomena affect the natural environment or other natural hazard management systems?*
- *Did the environment quality have any cascading impacts—positive or negative—on other community systems or functions?*

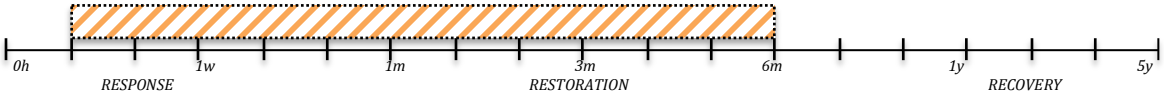
- *Were transformative improvements made to the subsystem (or any policies/codes/plans influencing its operation)* before *the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

Specific Research Questions with Suggested Data to Collect

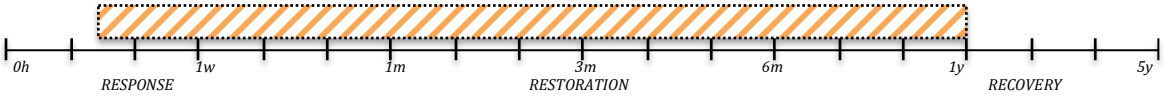
1. **Baseline data and facts.** What was the pre-event level of quality of the environment?
   Possible data/measures are:
   a. Water Quality
   b. Air Quality
   c. Soil Quality
   d. Biomass
   e. Natural Resources



2. **Damage and functionality.** What is the impact of earthquake on the environment quality?
   Possible data/measures are:
   a. Floods due to earthquake-induced landslides (water's spill from dams, deviation of rivers, damage to water retention structures).

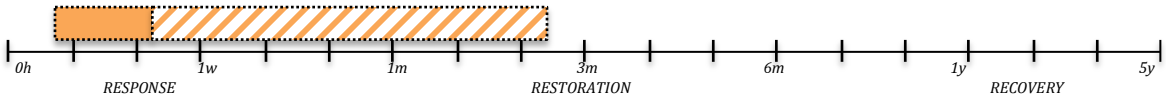


   b. Water pollutants from waste effluent, run off, or other sources
   c. Soil contamination due to leeching of toxins from factory or utility damage.
   d. Air pollutants or particulate matter from dust, toxic gas released from factory damage, smoke, asbestos from damaged buildings, etc.



3. **Consequences and interdependencies.** What are the consequences of the shaking and of the geologic effects induced by the earthquake on the natural environment and vice versa? Which effects contribute to the community damage the most? What other critical interdependencies can be identified?
   Possible data/measures are:
   a. Impacts of fault rupture on natural environment

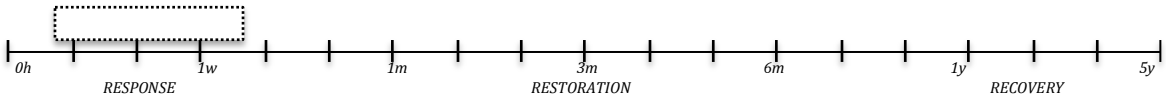
b. Impacts of ground failure (liquefaction, lateral spreading, etc.) on natural environment.
c. Damage to rivers, coastal habitat, ecology, aquifers and other characteristics of the natural environment.
d. Impact of the environment quality changes due to the earthquake on households and businesses decisions



4. **Pre-quake mitigation.** Were pre-earthquake mitigation procedures implemented before the earthquake protect the natural environment? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

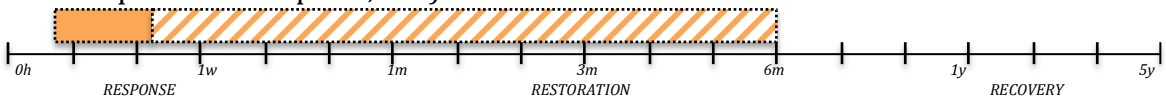
   a. Preparedness procedures and measures implemented to prevent environmental quality reduction due to earthquakes or earthquake-induced effects.



5. **Post-quake recovery techniques.** Were post-disaster techniques implemented to minimize further natural environment impacts or mitigate impacts from aftershocks? Were post-earthquake techniques or policies prioritized to avoid deterioration or facilitate the restoration of environment quality?

   Possible data/measures are:

   a. Rapid assessment of changes in natural environment quality metrics.
   b. Policies implemented to reduce the ongoing or future impacts of earthquake aftershocks
   c. Land use pattern modification and zoning (deforestation of areas that used to function as natural wind barrier, increased erosion and aquifer pollution due to new excavations, prohibition of construction in flood plains due to liquefaction impacts, etc.).



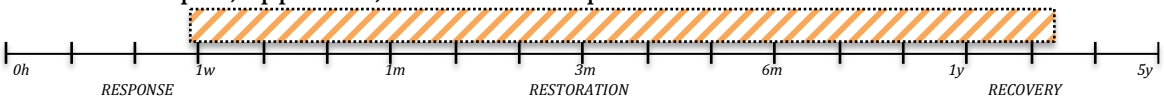
6. **Resources.** What resources were available and used in the pre-quake environment quality assessment and mitigation of impact on natural environment? What resources were available and used in the post-disaster techniques or repairs for geologic effects? Document the flow of financial resources used to improve response and recovery.

   Possible data/measures are:

   a. How were pre-quake environment quality studies and scenarios, or post-quake risk analyses developed, approved, funded and implemented? Focus on identifying the key lessons in agency/political leadership, sources and

amounts of funding, and innovative approaches taken to implementing the analyses. How were the analyses used?.

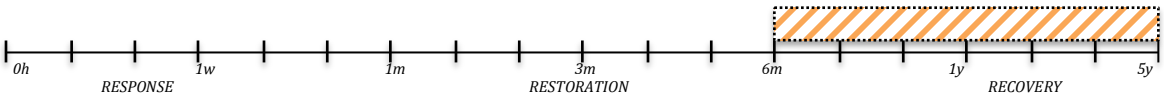
b. How new post-disaster land use and building policies related to natural environment were developed, approved, funded and implemented.
c. How pre-disaster mitigation measures and post-disaster measures were developed, approved, funded and implemented.



7. **Transformative changes.** Changes that will affect future community resilience? Are policies passed that will allow the region to surpass the pre-earthquake preparedness condition?

   Possible data/measures are:

   a. How policies to promote environment quality mitigation were developed, approved, funded and implemented.



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- Companies and organizations with building portfolios.

- Ministry of Civil Defense.
- Emergency Management Contractors.
- Possible agencies established by the Government to lead and coordinate the ongoing recovery effort.
- City Councils.
- USGS.

References to support this topic area

T.B.D.

DATA PRIORITIZATION FOR THE NATURAL ENVIRONMENT SYSTEM

	Phase I - Response	Phase II - Restoration	Phase III - Recovery
Seismic Hazard and Geologic Phenomena			
Ground Failure			
Tsunami			
Fire			
Earthquake-induced landslides			
Aftershocks and foreshocks			
Surface Fault Rupture			
Natural Resources			
Water Quality			
Air Quality			
Soil Quality			
Biomass			
Other Natural Resources			

Institutional System

SYSTEM OUTLINE

- **Government & Civic Organizations at the local level**
  - *Elected leadership & legislators*
    - *Mayor*
    - *City Council*
    - *County Supervisors*
    - *City Administrator/Manager*
  - *Fire Departments*
  - *Police Departments*
  - *City Planning & Building Departments*
  - *Public Works Department*
  - *Finance Departments*
  - *Housing & Community Services*
  - *Economic Development*
  - *Human Services Department*
  - *Public Health Departments*
  - *Parks & Recreation Departments*
  - *Public Library*
  - *Animal Services Departments*
  - *Judicial*
  - *Administration (IT, Human Resources, etc.)*
  - *School Districts*
    - *Public K-12 Schools*
    - *Public Community Colleges*
- **Government & Civic Organizations at the regional/state level**
  - *Elected leadership*
    - *Governor*
    - *State Senate*
    - *State Assembly*
    - *Regional Leaders*
  - *Office of Emergency Services*
  - *Department of Transportation*
  - *Department of Education*
    - *Public Universities*
  - *Department of Justice*
  - *Department of Human Services*
  - *Departments of Forestry, Fish & Wildlife, Geology, Fire Protection*
  - *Department of Public Safety*
  - *Environmental Protection Agency*
- **Government & Civic Organizations at the national level**
  - *Elected leadership*
    - *President*
    - *US Senate*
    - *US House of Representatives*
  - *Federal Emergency Management Agency*
  - *Department of Transportation*
  - *Department Homeland Security*
  - *Department of Education*
  - *Housing and Urban Development*
  - *Department of Energy*
  - *Department of Labor*
  - *Department of Defense*
    - *Army*
    - *Coast Guard*
    - *Navy*
    - *Air Force*
    - *U.S. Army Corps of Engineers*
  - *Department of Agriculture*
    - *Food and Nutrition Service*
  - *Department of Health and Human Services*
    - *U.S. Public Health Service*
  - *Environmental Protection Agency*
  - *General Service Administration*
  - *U.S. Forest Service*
  - *Department of Justice*
  - *Department of State*
  - *Agency for International Development (USAID)*
- **NGOs: Non-Governmental Organizations**
  - *Local NGOs*
    - *Service Club Chapters (i.e. Rotary Club, Lions Club, Boy Scouts, Girl Scouts)*
    - *Food Banks*
    - *Animal Shelters*
    - *Professional Association Chapters (i.e. EERI, Structural Engineers Associations, etc.)*
    - *Private Universities and Trade Schools*
    - *Private K-12 schools*
    - *Private Pre-schools & Childcare providers*
    - *News Media*
  - *Non-local NGOs*
    - *Red Cross*
    - *Charitable Societies (i.e. Goodwill, Saint Vincent DePaul)*
    - *Research Teams & Investigators*
    - *News Media*

GOVERNMENT & CIVIC ORGANIZATIONS AT THE LOCAL LEVEL

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

GOVERNMENT & CIVIC ORGANIZATIONS AT THE REGIONAL/STATE LEVEL

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

GOVERNMENT & CIVIC ORGANIZATIONS AT THE NATIONAL LEVEL

Framework general questions, specific research questions, data collection methods, data sources, and references are not yet complete. Until this section becomes available, use the other subsystems in this system as a guide.

NGOS: NON-GOVERNMENTAL ORGANIZATIONS

General Research Questions

- *What was the overall performance of the NGO subsystem after the earthquake?*
- *Which elements of the NGO proved to be critical to the function of the subsystem and why?*
- *Did the NGO subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to NGOs* before *the disaster that somehow changed the subsystem and its function in the disaster?*
- *Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?*

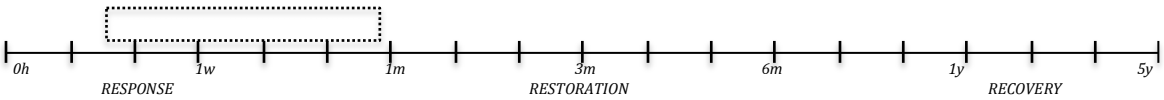
Specific Research Questions with Suggested Data Collection

1. **Baseline data and facts.** Which NGOs were active in the community pre-quake? What was the average non-disaster activity of the NGOs? Which populations utilized their services or benefited from their activities?

   Possible data/measures are:

   a. Number of NGOs and number of NGO staff/employees.
   b. Number of users.
   c. Annual operation budgets of NGOs
   d. Typical annual donations to NGOs
   e. Service Club Chapters (i.e. Rotary Club, Lions Club, Boy Scouts, Girl Scouts)
   f. Food Banks

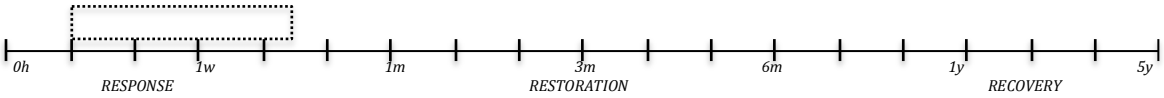
g. Animal Shelters
h. Professional Association Chapters (i.e. EERI, Structural Engineers Associations, etc.)
i. Private Universities and Trade Schools
j. Private K-12 schools
k. Private Pre-schools & Childcare providers
l. Red Cross
m. Charitable Societies (i.e. Goodwill, Saint Vincent DePaul)



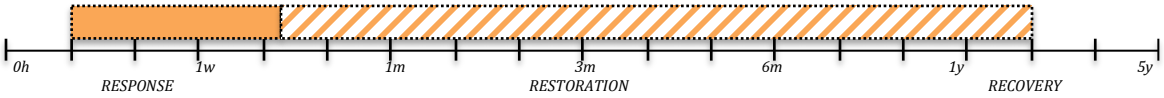
2. **<u>Damage and functionality.</u>** What is the level of the NGO functionality post-quake? What types of damage impacted NGOs or their outreach/delivery systems? Was any service disrupted and if so, to what degree and for what reasons? What new NGOs entered the community to provide services? Did particular NGOs become more critical or have greater impacts on subsystem performance/recovery than others? Did NGOs focus on any particular populations or regions for their services, and if so, were any areas or groups missed? For which NGOs was there a saturation of NGO services, or not enough services to meet demand? Did NGOs provide assistance to facilitate recovery of other systems or subsystems?

Possible data/measures are:

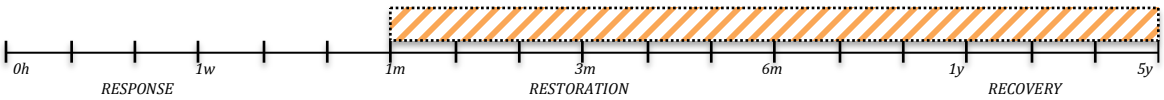
a. Structural/Non-Structural damage to NGO facilities.



b. Timeline of non-local NGO entry and departure from the region
c. Provision of equipment, supplies, facilities, and personnel
d. Provision of technical assistance, housing assistance, medical and dental expenses
e. Water, sewage, and other essential services rebuilding
f. Debris cleaning, roads and bridges repair
g. Provision of heating fuel, vehicle repair, clothing, moving storage



h. Loans or Grants from the United States Small Business Administration
i. Tax relief, unemployment assistance, mitigation funds

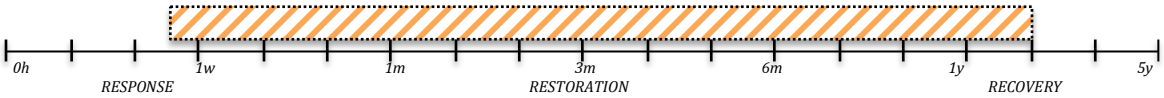


3. **<u>Consequences and interdependencies.</u>** What are reasons for NGO disruption (bureaucracy, structural/non-structural/contents damage, utilities disruption,

employee unavailability due to death, injury or displacement, impact of surrounding structures, bad maintenance) or growth (increased demand, emergency response mission, recovery assistance provider, etc.)? What are the consequences and cascading impacts of NGO disruption, growth, or establishment (of new NGOs) in the institutional system or on other community systems? What are the consequences of other community systems or functions on the NGO subsystem? Did NGOs draw upon the resources and time of staff or members from outside the impacted region, and if so, did this have any consequences? How heavily did the community rely on non-local NGOs for emergency response and recovery tasks, and what are the consequences of this reliance?

Possible data/measures are:

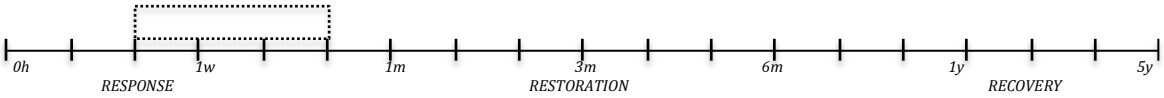
a. Did delays in assistance impact the total damage in terms of lives and losses?
b. Did businesses result insolvent or relocate due to assistance delays or absence of assistance? Was any other system impacted by organisation's bad management?



4. **<u>Pre-quake mitigation.</u>** Did the NGOs implement pre-earthquake mitigation procedures or emergency response planning aimed at increasing redundancy, rapidity, robustness, or resourcefulness of the NGO or its clients/stakeholders? How did these procedures or planning affect operation and functionality of the NGO subsystem? Did mitigation or planning efforts for other hazards provide benefits to their earthquake response? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

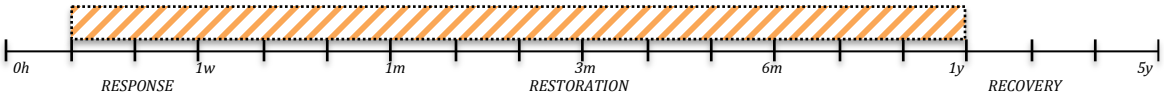
   a. Earthquake preparedness literature or informational programs distributed to staff, clients, or other stakeholders.
   b. Operational procedures or emergency plans available and implemented.
   c. Building retrofitting and non-structural content bracing for post-earthquake operations.
   d. Pre-existing cohorts of trained volunteers to staff shelters, medical clinics, debris cleanup efforts, etc.



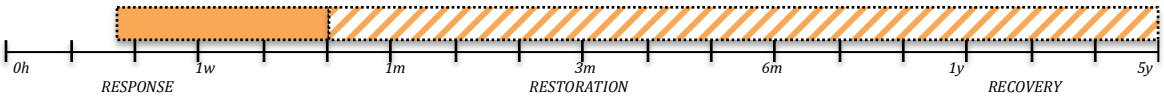
5. **<u>Post-quake recovery techniques.</u>** Did NGOs implement any post-disaster coping strategies in a timely fashion? If not, why? Did any local NGOs expand services or increase staff to respond to the earthquake impacts? Did NGOs with an emergency response mission react and begin providing services in a timely fashion? Attempt to document any costs and benefits from these efforts.

   Possible data/measures are:

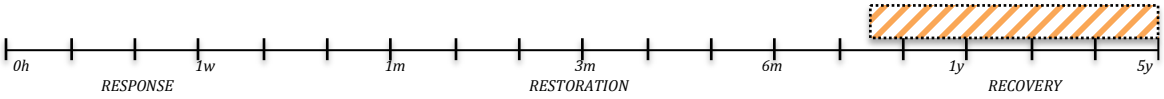
a. Actions that demonstrates the flexibility and ingenuity in the adaptive response of the organizations.
b. Recognition and reward of innovative efforts.
c. Ability to incorporate new response-related agencies and groups as situations evolve.
d. Identification and timely address of new problems that emerged over the course of the disaster event.



6. **Resources.** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.
   Possible data/measures are:
   a. Documentation of assistance grant funds offered by NGOs and utilization rates.
   b. Ask local NGOs where they got money to perform repairs to local NGO physical infrastructure.
   c. Sources and amounts of financial capital that supported NGO emergency response staffing level increases, goods, service delivery, mission accomplishment, etc.
   d. Number of volunteers mobilized by relevant NGOs
   e. Equipment provided by NGOs.



7. **Transformative changes.** What changes occurred that surpassed or differed from the pre-disaster state? What were the drivers of these changes? How will these changes will contribute to mitigation of future disasters?
   Possible data/measures are:
   a. Variation of NGO services capacities.
   b. Variation of services location to better align with regional needs.
   c. New programs or NGOs established in local region.



Data collection methods or data types

- Field observations, face-to-face interviews, informal surveys, notes.
- Geo-Tagged Photo/Video documentation of damage and archiving using EERI data collection tools.
- Establish relationship with NGO staff, volunteers, clients or stakeholders.

- Media investigation (newspapers, social networks, etc.)
- Structured surveys.
- Analysis of data archives (research and collection of data provided by governmental agencies or other organizations, subsystem related web-sites, etc.) or statistics.
- Interviews with business owners

Possible Data Sources

- Assessors' records.
- Media reports.
- US Census Bureau (Population Estimates Program; Decennial Census, American Community Survey).
- National Center for Charitable Statistics.
- Institute for Health Metrics and Evaluation.
- Municipal and Police Statistics.
- Centers for Disease Control and Prevention
- Health and Human Services
- U.S. Environmental Protection Program

References to support this topic area

T.B.D.

DATA COLLECTION PRIORITIZATION FOR INSTITUTIONAL SYSTEM

	Phase I - Response	Phase II - Restoration	Phase III - Recovery
Government & Civic Organizations at the local level	**	***	**
Elected Leadership	*	**	***
Administrative roles or departments	***	***	**
Government & Civic Organizations at regional/state level	**	***	**
Elected Leadership	*	**	***
Administrative roles or departments	***	***	**
Government & Civic Organizations at the national level	**	***	**
Elected Leadership	*	**	***
Administrative roles or departments	***	***	**
NGOs: Non-Governmental Organizations	***	**	*
Local NGOs	**	***	**
Non-local NGOs	***	***	**

Glossary

- **System**: is used to represent one of the 5 systems that form the community (built, natural, social, economic, and institutional). "Community Systems" are considered as the groups of related parts of a community that work together to perform different functions.
- **Subsystem**: is used to identify the main branches that divide each system to allow reasonable data collection. For example, Buildings, Electricity, Power, and Transportation are subsystems of the Built Environment System.
- **Elements**: are used to further clarify and define the makeup of each subsystem, as shown in the framework outline for each subsystem. While these elements are intended to comprehensively describe the subsystem, they are not exhaustive. For example, Residential, Business, Government are elements of the buildings subsystem.
- **Sub-Elements**: are used to further refine and describe a subsystem element. i.e., Buildings subsystem contains multiple elements such as residential and business that describe building occupancies and each of these elements also have several example sub-elements such as single family housing, rental housing, shelters, and hotels.
- **Component**: is used to identify the things that are needed by each subsystem element to be functional. In this framework, this term is most commonly used within the subsystem sections of the Built Environment system. For example, in the context of the buildings subsystem, components can represent structural and non-structural items within a structure, building contents, occupants, utilities within a building, etc. In the context of the transportation subsystem, it can represents traffic lights, users, tracks, cars, stations, etc.
- **Community Functions**: define the functions that must be carried out or provided to the population such as production, distribution, consumption, socialization (through which norms and values are instilled), social control (to enforce adherence to community values), social participation (to fulfill the need for companionship), mutual support (enables cooperation among & between members).

Theoretical justification, background, and commentary to support the Framework

OVERVIEW: PURPOSE, GOAL, SCOPE, & AUDIENCE

The goal of the actionable resilience framework is to provide guidance for earthquake reconnaissance teams or individual researchers who want to observe, document, and measure community resilience through field investigation and data collection in the months and years following a major earthquake. Guidelines help to identify drivers of the system's performance (critical components) and describe interdependences between systems through data collection.

This requires creating an action-oriented list of what topics and priorities should be investigated to study resilience and providing recommendations for the framework audience about what questions to ask, what observations to document, what types of data to collect, and how to synthesize data to measure resilience in their subject area of expertise.

The scope of the resilience framework then is the community and the reason is because most disasters are local and affect communities differently. Therefore community level makes possible a reasonable case-study comparison though acknowledging community behavior is influenced by the individual level as well as by the regional/national level.

EERI's primary role within this project is to provide guidance to people (not necessarily EERI members but also volunteers or researchers) with some degree of expertise and interest in resilience with a document that helps them to think more broadly beyond their discipline and observe the interrelated processes among *systems*. These guidelines are meant to be used during field reconnaissance effort by individual researchers who want to contribute to post-earthquake resilience reconnaissance in their respective disciplinary area of interest.

A secondary goal of the project is to optimize data collection efforts. In fact, providing people with information about things to see, questions to ask, and data to collect will allow the gathering of comprehensive measures which describe the recovery rate of systems and the processes behind the recovery. These measures will be uniform across different events, enabling cross case-study comparison.

This document is composed by different sections which describe the resilience background from which the actionable framework approach originates, the structure of the framework, and the methodology advocated to make the framework actionable by the audience.

The resulting actionable framework is provided as a series of bulleted lists that guide the audience in resilience data collection and photo documentation over time, by creating an action-oriented list of topics that need to be investigated and with suggestions on how to do it.

The document has not been conceived exclusively for team investigations. It can be used by teams as well as by individual members with interest in a specific area.

The analysis of the data to draw conclusions (about how resilient a community is, about lessons learned, about research needs) is beyond the purpose of this resilience framework though a tertiary goal of the framework is to provide a backbone for a data collection repository (virtual clearinghouse) that could be queried by other stakeholders.

As this framework is used and implemented in the field, it is expected that this document may evolve and become more refined over time as new findings are discovered to improve the many criteria and suggestions included in the framework.

BACKGROUND: DEFINING RESILIENCE

To find an actionable framework there is the need to agree on the definition of resilience. The definition influences the types of quantitative/qualitative data that can be collected to measure resilience. Several definitions which focus on different aspect of community resilience have recently been introduced by various scholars. See the Appendix for a selection of the definitions introduced in this past research.
The resilience definitions can be classified into two categories: the ones which consider mitigation or preparedness procedures and the ones which do not.
An example of a definition which omits explicit mention of preparation is the one published in the Presidential directive of March 30, 2011 that describes resilience as:

> *The ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.*
>
> *Barack Obama*

However, to focus on *Disaster Resilience* and in particular on *Earthquake Resilience*, the definition should:

- Address building resilience at the community level;
- Address both pre-disaster mitigation (activities to reduce the amount of loss in an event) and the ability to reduce post-event losses and rapidly recover from an event;
- Allow for systemic change, especially in low-probability, high-consequence events. Resilience does not necessarily entail a return to "normal" or "pre-disaster" conditions. Reducing future risk should also be a goal of recovery activities.

Based on this reasoning, the definition used for this framework considers resilience as:

> *The ability of social units (e.g., organizations, communities) to mitigate risk and contain the effects of disasters, and carry out recovery activities in ways that minimize social disruption while also minimizing the effects of future disasters.*
>
> *Bruneau et al. (2003)*

RESILIENCE MEASURES

TYPES OF MEASURES

Two types of measures can be useful to evaluate and understand resilience:

- Performance-based measures
    - Quantitative measures which examine direct observations of the performance of a system after a disruption
- Conceptual measures

- Qualitative measures which provide insight but do not provide quantitative evaluations of performance (e.g. Resilience Alliance Framework[1])
- Semi-quantitative measures which translate subjective evaluations into numerical quantities to provide quantitative results (e.g. SCRAM™[2])
- Quantitative measures based on research that describes attributes and features of resilient systems, but where there is a lack of research into how well these indexes predict the performance of a system after a disruption. Until this validation occurs, these quantitative measures can help identify capacities in which the system may have deficiencies but do not provide an actionable understanding of the system's weaknesses (e.g. BRICs[3])

Since different measures could refer to actions that influence resilience in different ways and at different levels, it is useful to keep the distinction between:

- Static Resilience: which describes the initial damage
- Dynamic Resilience: which describes the recovery path

The distinction was introduced in these terms in the field of economic resilience by Rose (2007) though the original concept stems from the different resilience properties listed by Bruneau et al. (2003). In his work he identified four properties of the resilience. Two properties can be seen as the desired *ends* of the recovery process and are robustness (static resilience) and rapidity (dynamic resilience) while the other two properties can be seen as the *means* to reach the *ends* and are redundancy and resourcefulness.
For example, the implementation of emergency plans in advance of a disaster which provides alternative mass transit in the event of a possible subway disruption can be seen as a qualitative conceptual measure which influences the dynamic resilience of the whole transportation sector, that is the rapidity of the sector to bounce back to pre-event level of functionality (considering its role within the community). Alternately, the retrofitting of non-ductile concrete buildings is a qualitative/quantitative indicator that can influence both the static and dynamic resilience of the built environment system.
For more details on the difference between performance-based and conceptual measures see the Appendix.

MULTISCALE RESILIENCE

Another distinction that has to be recognized for the field reconnaissance effort is that data are available and need to be collected at different scales. As stated before, the focus of this project is on the community level. However, some data are not available at the community level, and communities are influenced by the behavior of individuals and the actions/decisions made at higher levels (regional/national). Thus, the framework encompasses four scales: individual, neighborhood, community, regional/national. Within one system different scales influence each other (vertical influence). Within one level different systems influence each other (horizontal influence). The result is then the total interconnectedness between systems.

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[1] Resilience Alliance Social-Ecological Resilience Workbooks (Practitioners, Scientists)
[2] Supply Chain Resilience Assessment Method (.pdf)
[3] BRICs (.pdf)

For instance, local actions add together to "drive" larger-scale processes, while the local actions themselves are shaped by "driving forces" such as government policies and market signals that arise at larger scales. When these interactions reinforce the right kinds of perspectives and actions, rather than working at cross-purposes, the likelihood of resilience is much greater. For example, although a great many of the specific actions that shape resilience take place at a local scale, this local action occurs in a context of larger-scale structures, such as economic markets, national and state public policies, and available technologies and information.

For these reasons, the questions and data collection suggested in the framework aims at capturing information at different scale levels.

Understanding complex relationships among environmental, economic, and social processes is more likely to be tractable in a place-specific context. Moreover, observations at a relatively local scale are likely to detect more variance from one situation to another than observations at a relatively large scale, where differences tend to average out; and this variance is itself an opportunity for learning about how to achieve resilience in particular places.

COMMUNITY SYSTEMS AND SUBSYSTEMS

Resilience is a systems concept. Communities themselves are also a system of systems that function due to interrelated actions of features like economic health, strong infrastructure, social equity, etc. This project considers the five primary community systems to be (1) built environment system, (2) social system, (3) economic system, (4) natural environment system, and (5) institutional system, thus a framework must consider both what typical interactions occur between these systems and how these systems affect one another. Systems performance can be thought of in terms of concepts such as lost capacity, impact, restoration time and impact of time to restore.

Data collection is then conceptually framed to distinguish between community systems and scale levels (see Table 1). The entire framework intends to measure community resilience by collecting data about each system and about how systems affect differently community functionality after an earthquake.

Table 1 – Examples of information at different scales for each of the community system.

SCALE SYSTEM	**Individual**	**Neighborhood**	**Community**	**Regional/National**
Built	Individual building/lifeline component performance, characteristics that make components (structural, non-structural, contents) more vulnerable, key characteristics that gave components more "restorative capacity", etc.	Overall performance of buildings and lifelines in each neighborhood, critical buildings which played critical roles for the neighborhood recovery and damages which were not relevant, reasons of discrepancies between neighborhoods physical assets.	Overall performance of buildings by building type, Infrastructures which proved to be critical for the functioning of the entire system.	Actual overall performances and current performance objectives implicit US Codes, achievement of standards, efficiency of codes for new and older (retrofitting) buildings/lifelines for resilience objectives, possible need of standards improvement, etc.
Social	Ability of individual to deal with emotions and personal health during the negative event, characteristics which sustained this ability (positive self-concepts, future expectations, problem solving skills, personal connections, adaptability, human and economic capital, etc.)	Neighborhoods that recovered sooner, Time neighbors are present in the neighborhood, quality programs for educational enrichment, number of people that each resident know on his/her street, active block watch program, burglary/robbery rate, volunteers available to take on a leadership role, social capital, etc.	Social Capital, quality of life, non-profit organizations, social services, etc.	Regional/National population patterns, demographic changes, quality of life, etc.
Natural	Characteristics of hazards events (size, disruptiveness, etc.)	Degree at which each neighborhood was affected by earthquake and earthquake-induced effects, soil/water quality, biomass, etc.	Overall earthquake and earthquake-induced effects characteristics, Air quality, biodiversity, Natural Resources	
Economic	Single business performance (reason of possible disruptions, ability to cope with damages and bureaucracy, etc.)	Types of businesses in each neighborhood, criticality of businesses and possible need of activity diversification, integration with community and regional economy, etc.	Recovery services (external support, emergency funds, etc.), GDP by economic sectors, change in economic structure, integration with global economy, etc.	
Institutional	Involvement of citizens into politics affairs, self-organizations capability, etc.	Relationship between neighborhood civic associations and residential community associations with local government officials (response rate from city officials when a code compliance issue is raised, etc.)	Extent and quality of community evacuation education programs, ability to provide timely information and emergency response services, ability in coping with legal issues	

The five primary systems and their associated subsystems and elements are defined below. This hierarchical structure will be the basis of the framework.

OUTLINE AND RESILIENCE DATA PRIORITIZATION

BUILT ENVIRONMENT SYSTEM

- **Buildings**
  - *Residential*
    - *Housing*
    - *Shelters*
    - *Hotels/Motels*
  - *Business*
    - *Banks/Financial Institutions*
    - *Medical Office/Clinic*
    - *Professional/Technical/Business Services*
  - *Mercantile/Storage*
    - *Critical Retail (groceries)*
    - *Retail/Wholesale*
    - *Food Distribution Centers*
    - *Other Distribution Centers*
    - *Gas Stations*
    - *Garages*
  - *Government*
    - *Police/Fire Stations*
    - *Town Hall*
    - *County Administrative Buildings*
    - *Courts*
    - *Disaster Debris and Recycling Centers*
    - *Emergency Operation Centers*
  - *Cultural/Education*
    - *Schools K-12*
    - *Higher Education Facilities*
    - *Entertainment Venues*
    - *Community Centers*
    - *Churches, Mosques, Temples, etc.*
  - *Industrial/Agriculture*
    - *Agriculture*
    - *Food*
    - *Construction*
    - *Technology*
  - *Institutional*
    - *Hospitals*
    - *Health Care Facilities,*
    - *Penitentiaries*
- **Transportation**
  - *Subways*
  - *Airports*
  - *Bridges*
  - *Highways*
  - *Railways*
  - *Ships/Ports/Harbors*
  - *Roads*
  - *Road Tunnels*
  - *Mass Transit Stations*
  - *Bike Pathways*
- **Electricity**
- **Fuel/Natural Gas**
- **Communication**
- **Water**
- **Waste**
- **Geotechnical Structures**
  - *Embankments/Levees*
  - *Earth Dams*
  - *Retaining Walls*
  - *Slopes*

SOCIAL SYSTEM

- **Population Demographics**
  - *Distribution/Density*
    - Urban/Suburban/Rural/Wild
  - *Composition*
    - Age/Gender/Race
    - Language (Limited English Proficiency)
  - *Socioeconomic Status*
    - Education/Income/Homeownership/Housing Vacancies/Renters/Public Housing Residents
    - Unemployment/ /Employment Rates
  - *Vulnerable Groups*
    - Children
    - Elderly
    - Homeless
    - Disabled (mental/physical)
    - Chronically Ill

        - Poor
        - People without Transportation
        - Racial/Ethnic Minorities
        - Religious Minorities
        - Women
- **Social Services**
    - *Education services (Pre-K-12, college and university)*
    - *Job/Employment services*
    - *Foster care/Adoption services*
    - *Criminal Justice services*
    - *Domestic violence services*
    - *Mental health services*
    - *Food banks*
    - *Welfare services*
    - *Healthcare and Clinic services*
    - *Childcare*
- **Recovery Resources**
    - *Insurance*
    - *Savings/Checking Account Balances*
    - *Developer Interests*
    - *Faith-based Services*
- **Quality of Life**
    - *Life Expectancy*
    - *Infant Mortality Rates*
    - *Acoustic/Emissions*
    - *Health Facilities and Emergency Services*
    - *Crime Rates*
    - *Marriage/Divorce Rates*
    - *Labor Force Participation*
    - *Social Networks*
- **Community Participation**
    - *Citizen Involvement in Politics*
    - *Civil and Community Organizations*
    - *Place Attachment*
    - *Collective Action, Efficacy, Empowerment*
- **Cultural/Heritage and Non-Profit Services**
    - *Cultural Property, Historic Sites*
    - *Arts Organizations and Events*
    - *Spiritual Organizations*

ECONOMIC SYSTEM

- **Businesses (micro scale)**
    - *Business Sector (based upon NAICS classification)*
        - *Agriculture, Forestry, Fishing and Hunting*
        - *Mining*
        - *Utilities*
        - *Construction*
        - *Manufacturing*
        - *Wholesale Trade*
        - *Retail Trade*
        - *Transportation and Warehousing*
        - *Information*
        - *Finance and Insurance*
        - *Real Estate Rental and Leasing*
        - *Professional, Scientific, and Technical Services*
        - *Management of Companies and Enterprises*
        - *Administrative and Support*
        - *Waste Management and Remediation Services*
        - *Educational Services*
        - *Health Care and Social Assistance*
        - *Arts, Entertainment, and Recreation*
        - *Accommodation and Food Services*
        - *Other Services (except Public Administration)*
        - *Public Administration*
    - *Annual Revenue*
    - *# of Employees*
    - *Insurance coverage*
    - *Business failures*
    - *Location / relocation*
- **Local and Regional Economy (meso scale)**
    - *Gross Product by economic sectors*
    - *Employment*
    - *Key industries*
    - *Business interruption costs*
    - *Change in economic structure*
    - *Reconstruction financing*
    - *Integration with state and national economy*
    - *Local government economic programs and policies for response, restoration, and recovery*
- **State and National Economy (macro scale)**
    - *State (provincial) and national government economic programs and policies for response, restoration, and recovery*
    - *Macroeconomic indicators (e.g., interest rates, exchange rates, GDP growth rates)*

NATURAL ENVIRONMENT SYSTEM

- **Seismic Hazard and Geologic Phenomena**
  - *Surface Fault Rupture*
  - *Ground Failure*
  - *Tsunami*
  - *Fire*
  - *Earthquake-induced landslides*
  - *Aftershocks and foreshocks*
- **Natural Resources**
  - Water Quality
  - Air Quality
  - Soil Quality
  - Biomass
  - Other Natural Resources

INSTITUTIONAL SYSTEM

- **Government & Civic Organizations at the local level**
  - *Elected leadership & legislators*
    - *Mayor*
    - *City Council*
    - *County Supervisors*
    - *City Administrator/Manager*
  - *Fire Departments*
  - *Police Departments*
  - *City Planning & Building Departments*
  - *Public Works Department*
  - *Finance Departments*
  - *Housing & Community Services*
  - *Economic Development*
  - *Human Services Department*
  - *Public Health Departments*
  - *Parks & Recreation Departments*
  - *Public Library*
  - *Animal Services Departments*
  - *Judicial*
  - *Administration (i.e. IT, Human Resources, etc.)*
  - *School Districts*
    - *Public K-12 Schools*
    - *Public Community Colleges*
- **Government & Civic Organizations at the regional/state level**
  - *Elected leadership*
    - *Governor*
    - *State Senate*
    - *State Assembly*
    - *Regional Leaders*
  - *Office of Emergency Services*
  - *Department of Transportation*
  - *Department of Education*
    - *Public Universities*
  - *Department of Justice*
  - *Department of Human Services*
  - *Departments of Forestry, Fish & Wildlife, Geology, Fire Protection*
  - *Department of Public Safety*
  - *Environmental Protection Agency*
- **Government & Civic Organizations at the national level**
  - *Elected leadership*
    - *President*
    - *US Senate*
    - *US House of Representatives*
  - *Federal Emergency Management Agency (FEMA)*
  - *Department of Transportation*
  - *Department Homeland Security*
  - *Department of Education*
  - *Housing and Urban Development*
  - *Department of Energy*
  - *Department of Labor*
  - *Department of Defense*
    - *Army*
    - *Coast Guard*
    - *Navy*
    - *Air Force*
    - *U.S. Army Corps of Engineers*
  - *Department of Agriculture*
    - *Food and Nutrition Service*
  - *Department of Health and Human Services*
    - *U.S. Public Health Service*
  - *Environmental Protection Agency*
  - *General Service Administration*
  - *U.S. Forest Service*
  - *Department of Justice*
  - *Department of State*
  - *Agency for International Development (USAID)*
- **NGOs: Non-Governmental Organizations**
  - *Local NGOs*
    - *Service Club Chapters (i.e. Rotary Club, Lions Club, Boy Scouts, Girl Scouts)*
    - *Food Banks*
    - *Animal Shelters*

- *Professional Association Chapters (i.e. EERI, Structural Engineers Associations, etc.)*
- *Private Universities and Trade Schools*
- *Private K-12 schools*
- *Private Pre-schools & Childcare providers*
- *News Media*

- *Non-local NGOs*
  - *Red Cross*
  - *Charitable Societies (i.e. Goodwill, Saint Vincent DePaul)*
  - *Research Teams & Investigators*
  - *News Media*

To obtain reliable information, data need to be collected in a timely and meaningful way. Due to time constraints and limited resources (both in terms of personnel and economic resources), all the possible types of data need to be carefully analyzed in order to give priority to those which are ephemeral and more significant, while identifying data that can be collected afterward. In other words, other than the two macro-categories of ephemeral and not ephemeral information, data could be further listed and prioritized in order to give greater importance to the ones that demonstrated to be critical in the description and explanation of the different recovery phases and of the recovery process. This should at least allow the collection of the same data from different events allowing for cross case-study comparison of community performances and the identification of resilience shortcomings which could be used to implement mitigation or prioritize post-disaster actions in order to speed up the recovery process and make systems more resilient to future disasters.
To prioritize data collection in the actionable framework, perishability is considered a stronger criteria than significance. This means that data should be collected based on the following order in each phase:

1. Significant and ephemeral data
2. ephemeral data
3. Significant and not-ephemeral data
4. Not-ephemeral data

EPHEMERAL DATA

Examples of ephemeral data are provided below:

- Households and businesses recovery decisions: reconstruct, wait, and relocate (generate contacts for future research);
- Evidence of social capital (mutual assistance, collective actions, volunteerism, establish relationship with organizations to be investigated, etc.);
- Evidence of politics effectiveness and involvement (key planning meetings at highly secured facilities such as Emergency Operation Centers, establish relationship with organizations to be investigated);
- Building and infrastructures damage data in the first days, weeks and reason of businesses interruption, as cleanup and recovery activities start and accelerate;
- Psychological state of individuals and their expectations for the future (fleeting situations and people attitudes and feelings toward them);
- Data capturing the emergency response activities (Police, Firefighters, Debris Management, Shelters, supply and food staging areas, assistance centers for victims' families and rescue workers' respite centers, pumping records etc.);

- Details of the impacts of earthquake-induced phenomena such as liquefaction on well-built structures. Understanding how local geologic conditions influenced the observed damage patterns.

SIGNIFICANT DATA:

Examples of significant data are provided below:

- Data which proved to be driver of community recovery from past studies (social capital, population and businesses migration, effectiveness of emergency response, etc.);
- Data describing the interdependencies among subsystems (education level and incarceration rates capture the interdependencies of social-economic systems; ability to shelter in the neighborhood capture the interdependencies of built-economic-social, etc.);
- Data which are recognized to better represent a measure of recovery (social → population return, economic/social → employment and income, natural → sustainability, built → housing).
- Data which help to identify the transition from one phase to another (number of emergency operations or interventions for the response phase; number of repairs crews for the restoration phase, etc.).

The last criteria has been given particular relevance in the framework because each phase is characterized by different types of activities which determine the length of the phase. For example the response phase is characterized by the emergency operations such as evacuations, debris removal, and emergency medical care. The response phase cannot be considered over until these operations cease or come back to pre-disaster level.
For this reason, data about built, natural, social, economic and institutional systems are prioritized depending on each phase. This facilitates the identification of varying phase lengths which follow any particular disaster event.
A priority table has been built for each system in the framework to help prioritize data collection based on perishability and significance. The table should be read in the vertical direction. This general prioritization should be adapted and customized to the specific features of the affected community since each community will have specific characteristics that could lead to a different prioritization. Nevertheless, the tables provided can be used as general guidelines.
The priority is assigned through a number of stars which goes from one to three. One star means lowest priority. It is important to note, the number of stars could depend on different aspects. For example, for the built environment, in the response phase, shelters and electricity network have three stars, while entertainment venues and waste have one star. This aims to reflect that shelters play a more critical role than entertainment venues in the response phase, while power network has priority respect to waste because usually it gets repaired quicker, within hours/days from the disruption, and for this reason it is more ephemeral data.

RESEARCH QUESTIONS

As stated before, the framework's goal is to provide guidelines on data collection to measure resilience. Thus, the framework must capture the following four characteristics of the resilience process:

- Systemic Nature
- Time Dimension
- Functionality
- Interdependencies

These characteristics can be observed by collecting data to support a series of General Research Questions for each subsystem:

- *What was the overall performance of the subsystem?*
- *Which elements or components proved to be critical to the function of the subsystem and why?*
- *Did the subsystem have any cascading impacts—positive or negative—on other community systems or functions?*
- *Were transformative improvements made to the subsystem (or any policies/codes/plans influencing its operation)* before *the disaster that somehow changed the subsystem and its function in the disaster?*

Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?

The general research questions above are kept vague so that they are adaptable to the different characteristics of the systems and subsystems of a community. For example, words like "performance" are useful to encompass the comprehensiveness of the subject since they include all the resilience characteristics mentioned before such as robustness, redundancy, resourcefulness, and rapidity.

In the framework, users will note that the general questions are slightly refined for each subsystem. This is done to recognize that processes can have unique features depending on the subsystem. These general research questions also help users to keep the big picture concepts and characteristics of resilience in mind as they collect data.

Following the general research questions in the framework, supplemental questions are provided for each subsystem called Specific Research Questions. These subsystem specific research questions are supplemented by a list of possible measures, data, and examples that are useful to answer the questions as well as quantify resilience metrics.

DATA COLLECTION TIMELINE

The lists of possible measures, data, and examples that follow the specific research questions are supported with recommended timelines for collecting information in a meaningful way.

The data collection timelines are included to provide guidance on which data need or can be collected at different times. Post-recovery phases have a varying duration depending on

size of the event, preparedness of the community, and ability of the community to deal with post-disaster management. Thus, data can become available at different times for different events. To acknowledge that, the data collection timelines are based on three general response phases: response, restoration, and recovery.

The response phase represents the timeframe that goes from the event occurrence until the disaster condition is stabilized.

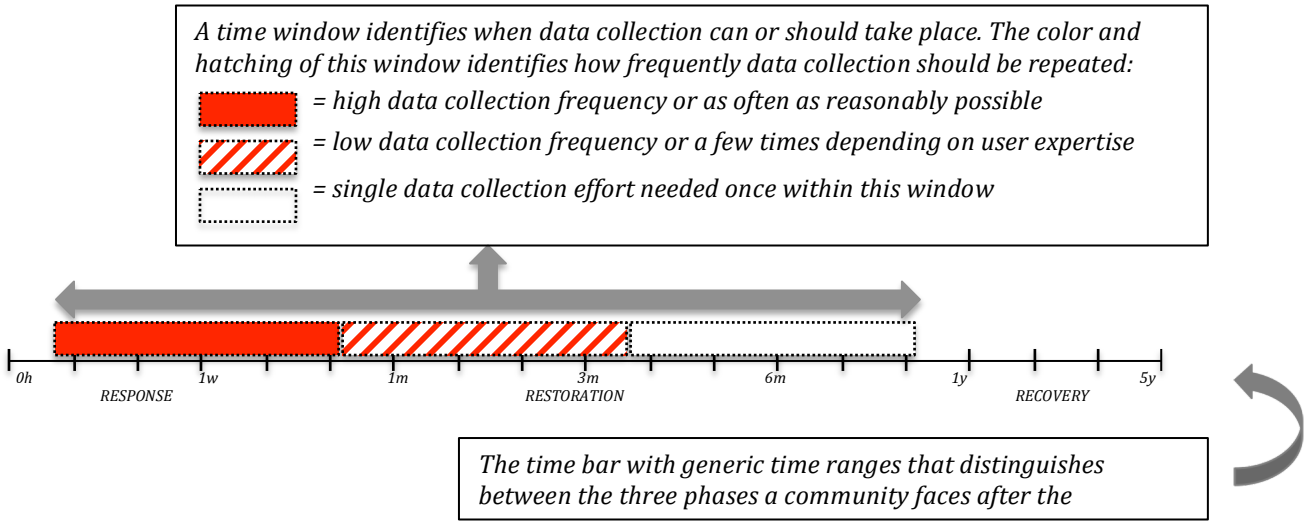
The restoration phase goes from the point in time at which the immediate threats to human safety and property resulting from the physical impacts of the hazard agents have been resolved, the affected population is in a more stable period of transition. They have a place to get food and water and a temporary or transitional shelter that can withstand wind and rain. They can go about their daily lives, beginning to resume some kind of normal existence. Children go back to school though their classes may be held in a church, a tent, or some other temporary accommodation. Those affected may not have yet recovered fully, but they have begun to adapt to a "new normalcy".

The recovery phase represents the timeframe in which the community returns to its normal routines or reaches a stable new normalcy. Then recovery also considers the community development phase as a means of improving on the "normal". The population is back to a relatively stable daily life and can address some of the root causes of circumstances that pose significant challenges to the community.

The guidelines provide approximate ranges of time associated with that phases based on a significant event however these are intended only as an approximate guide being that the boundaries between phases are not neat, phases can overlap and their length is highly dependent on the size of the event. Framework users must also recognize that at one system can be in one phase while another system can be in a different phase.

Field reconnaissance efforts and data collection should repeated over time, and the time lapse between the two subsequent data collection efforts should be evaluated depending on size of the event and ability of the community to recover. Areas were repeated data collection efforts should be considered are indicated on the timelines in the framework. Also included in the framework for each subsystem are sections that suggest possible Data Collection Methods and Data Sources for the questions.

EXAMPLE TIMELINE



After this framework has been implemented and used for several earthquakes, it will allow through cross case-studies comparison the identification among resilience measures collected of data and information that could be considered or proved to be indicators and drivers of the community resilience. It will also allow to identify both the processes behind indicators and the actions that lead to good or bad system's performances. For example, it is important to monitor the evolution of reconstruction of lifelines services, as well as it is useful to evaluate the reconstruction process based on the context of capital investment, well-being and community's identity restoration.
The indicators could then be used to compare the expected performances of a community in terms of its resilience with the desired performances and goals that need to be developed in consultation with decision-makers and the public. The comparison might then be used to prioritize actions and decisions that aim at increasing resilience (Chang and Shinozuka, 2004).

LITERARY REVIEW

Resilience definitions

- 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 this capacity for learning from past disasters for better future protection and to improve risk reduction measures (**UN ISDR, 2006; also SDR, 2005**).
- The capability of an asset, system, or network to maintain its function or recover from a terrorist attack or any other incident (**DHS, 2006**).
- The capability to prevent or protect against significant multihazard threats and incidents, including terrorist attacks, and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy and national security (**The Infrastructure Security Partnership, 2006**)
- Static economic resilience is the ability of an entity or system to maintain function (e.g., continue producing) when shocked. It's primarily a demand-side phenomenon involving users of inputs (customers) rather than producers (suppliers). It pertains to ways to use resources available as effectively as possible. This is in contrast to supply-side considerations, which definitely require the repair or reconstruction of critical inputs (**Rose, 2007**).
- Dynamic economic resilience is the speed at which an entity or system recovers from a severe shock to achieve a desired state (**Rose, 2007**).
- Its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur. (**National Academy of Sciences, 2011**).

- 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 post-event adaptive processes that facilitate the ability of the system to reorganize, change, and learn in response to the event (**Cutter, 2008**).

It is possible to graphically represent the resilience concept:

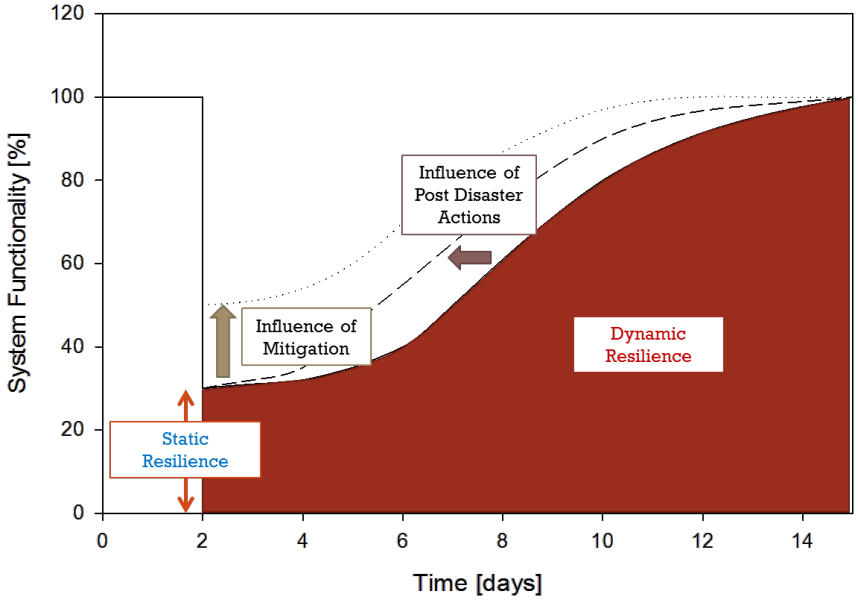


Figure 1 – Measuring resilience (adapted from National Academy of Sciences, 2011).

This graph addresses specifically earthquakes because systems after earthquakes usually have an initial and sudden drop in their functionality, allowing for the distinction between static and dynamic resilience. Resilience measures should capture both aspect of the process:

- The initial damages (static resilience, which includes both the inherent resilience and the possible influence of pre disaster mitigation procedures).
- The recovery path (dynamic resilience, which includes the possible influence of post disaster actions that hasten recovery).

The definition of static resilience is straightforward and can be described using the functionality of the system right after the event. The definition of dynamic resilience is more controversial.
The following graph represents a definition proposed in 2010 (Renschler et al.) which can be used to describe dynamic resilience.

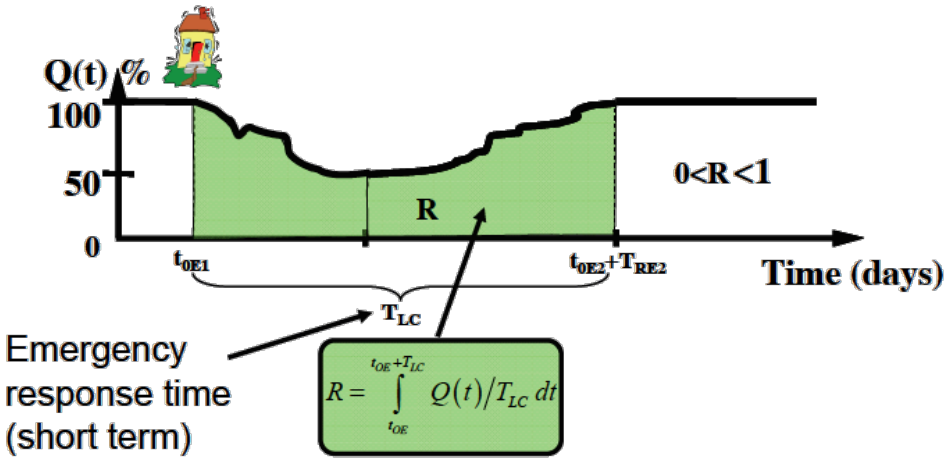
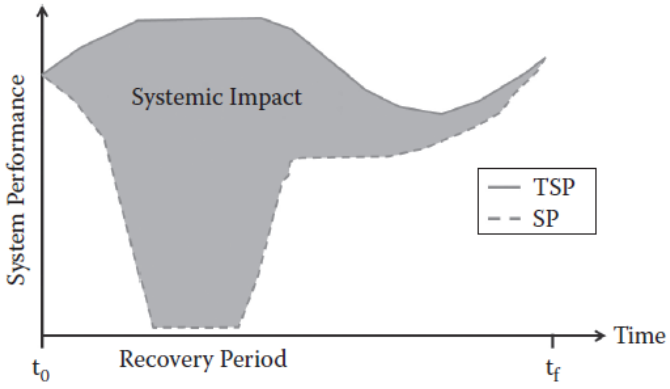


Figure 2 – Definition of dynamic resilience.

It is clear how this definition can be generalized for different types of systems since Resilience, R, is defined graphically as the normalized shaded area underneath the function describing the functionality of a system, defined as Q(t). In other words it represents the flip side of the loss triangle.
In recent years it is becoming more common to define resilience with respect to the targeted system performance as shown in the graph below.
As can be seen from the definition of the systemic impact in Figure 3 (which represents what was previously called "loss triangle" and is not a normalized value), the evaluation of the disaster effect is based on the targeted system performance (TSP). SP represents the actual system performance.
In order to understand the resilience of different systems it can be useful to take into account the efficiency of the systems. Efficiency is part of resilience. More efficient systems are more resilient since resources are limited and they are able to optimize their use. Efficiency is proportional to the inverse of TRE which represent the total recovery effort.



$$SI = \int_{t_o}^{t_f} [TSP(t) - SP(t)]dt$$

$$TRE = \int_{t_o}^{t_f} [RE(t)]dt$$

$$Norm = \int_{t_o}^{t_f} TSP(t)dt$$

$$RDR = \frac{SI + \alpha \times TRE}{Norm}$$

Figure 3 – Definition of the disaster impact with respect to the targeted system performance (Vugrin et al., 2013).

Vugrin also describes how to compute recovery-dependent resilience costs (RDR) making it possible to compare the resilience of different systems using SI and TRE where α is a weighting factor.

Performance-based measures and conceptual measures

Looking at the performance of each system it is possible to compute static and dynamic resilience but it is not possible to make a distinction between inherent resilience and adaptive resilience that represents the effect of pre disaster mitigation and post disaster recovery measures. It is very difficult to do that. Broader measures of resilience characterize resilience through identifying specific actions, adaptations, or tactics both pre and post disaster which are able to affect the behavior of the system.
In other words the performance measures represent quantitative measures of the resilience of a system. Quantitative measures are more suitable to describe the actual performance of the system since they provide a numerical evaluation, which is more comparable across events due to its nature. However they do not provide any kind of information about why and how this level of resilience is obtained. Conceptual measures can be thought as a prediction of how a system may exhibit resilience (pre-disaster measures) and why a system exhibit resilience after the fact (post-disaster measures).
The two kinds of measures are thus complementary. The conceptual analysis provides an explanation of the quantitative results, especially if more data from different events are available.
We recommend keeping the distinction between static and dynamic resilience since some conceptual measures could have an effect just on the initial drop and not on the recovery path. This distinction will help understand the influence of the actions that drive resilience.

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