Functional Recovery for Lifeline Infrastructure Systems

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Institute for Catastrophic Loss Reduction
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• NEHRP Study requested by Congress
• Lifeline Infrastructure Systems
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• Developing Framework for Recovery-Based Objectives
What are Lifeline Infrastructure Systems?

- **Infrastructure Systems** = the physical and organizational structures and facilities needed for the operation of a society or enterprise

- Lifeline Infrastructure Systems:
  - Water
  - Wastewater
  - Electric Power
  - Communication
  - Gas and Liquid Fuels
  - Transportation
  - Storm Water/Inundation Protection
  - Solid Waste

- **Socio-Technical Systems**: Lifeline systems include the physical infrastructure and the organizations that manage them

Not specifically covered in report
Starting with some background...

**Introduction & Motivation**

- Natural hazard events cost U.S. $100B / year on average
- 150M people in 42 states at risk of a damaging earthquake within 50 years
- Desire to reduce vulnerability, minimize losses, and improve recovery time of communities

![Regions of the United States at risk of significant earthquake shaking (courtesy of N. Luco, USGS).](image)
Introduction & Motivation

- Scenarios predict undesirable levels of losses and disruption to individuals & communities
  - >1,000 deaths
  - >10,000 injuries
  - >100,000 displaced
  - >$100B direct economic losses
  - Additional long-term destabilizing impacts to individual, community, and regional services and functions
Where are we now???

Introduction & Motivation

• Safety-based approach to building codes results in significant post-earthquake downtime and cost
  ▪ 20-40% of modern code-conforming buildings unfit for occupancy
  ▪ 15-20% economically unrepairable
  ▪ Older buildings perform even worse

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Performance Expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design EQ</td>
</tr>
<tr>
<td>Repair Cost</td>
<td>10%</td>
</tr>
<tr>
<td>Repair Time</td>
<td>45 days</td>
</tr>
<tr>
<td>Casualty Rate</td>
<td>1.0%</td>
</tr>
<tr>
<td>Probability of Unsafe Placard</td>
<td>20%</td>
</tr>
<tr>
<td>Repairability</td>
<td>95%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Category II – Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair Cost</td>
</tr>
<tr>
<td>Repair Time</td>
</tr>
<tr>
<td>Casualty Rate</td>
</tr>
<tr>
<td>Probability of Unsafe Placard</td>
</tr>
<tr>
<td>Repairability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Category II – Healthcare (Medical Office Building or Laboratory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair Cost</td>
</tr>
<tr>
<td>Repair Time</td>
</tr>
<tr>
<td>Casualty Rate</td>
</tr>
<tr>
<td>Probability of Unsafe Placard</td>
</tr>
<tr>
<td>Repairability</td>
</tr>
</tbody>
</table>
Changing the Dynamic
NEHRP Reauthorization


• **SECTION 8: SEISMIC STANDARDS**

• *Not later than December 1, 2019, [NIST and FEMA] shall jointly convene a committee of experts from Federal agencies, nongovernmental organizations, private sector entities, disaster management professional associations, engineering professional associations, and professional construction and homebuilding industry associations, to assess and recommend options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake re-occupancy and functional recovery time.*

• *Not later than June 30, 2020, submit a report on recommended options ...*
Performance Levels - Buildings

• Post Earthquake Reoccupancy:
  • The ability to safely re-enter and occupy the building while repairs are being made. Building services are not necessarily functional, except those required for occupancy and needed for safety.
    • Alternative sources of these building services are permitted.
    • Reoccupancy Performance Objective is this Performance Level within an acceptable time.

• Post Earthquake Functional Recovery:
  • A step beyond reoccupancy (safe occupancy) and includes restoration of building components and services to support a significant measure of pre-earthquake functionality.
    • Functional Recovery Performance Objective is this Performance Level within an acceptable time.

• Full Recovery:
  • Restoration to a building’s pre-earthquake level of safety and functionality.
Performance Levels – Lifeline Systems

• **Lifeline Infrastructure Operability**
  • The ability of an infrastructure system to provide near-normal services to a customer, sufficient for supporting community activities (i.e., functional recovery). The system may still be in a damaged state.

• **Lifeline Infrastructure Functionality**
  • The ability of an infrastructure system working normally to provide its regular and reliable pre-earthquake services. Full functionality (i.e., full recovery) is when all repairs are completed.
FEMA-NIST (2021) definitions

• **Reoccupancy** is a post-earthquake performance state in which a building is maintained, or restored, to allow safe re-entry for the purposes of providing shelter or protecting building contents
  - Only deals with buildings within a lifeline system

• **Functional recovery** is a post-earthquake performance state in which a building or lifeline infrastructure system is maintained, or restored, to safely and adequately support the basic intended functions associated with the pre-earthquake use or occupancy of a building, or the pre-earthquake service level of a lifeline infrastructure system.
  - Functional Recovery is a performance state when basic services are restored. i.e., users receive services essentially as prior to earthquake and can use these services to undertake their activities in a relatively normal manner.
Outcomes from the FEMA-NIST Report

- To protect against future losses, a change in building codes, construction practices, and societal values is needed

- Functional recovery performance provides the link between design of individual buildings or infrastructure systems and the goals of community resilience

Report Recommendations

1. Develop a Framework for Post-Earthquake Reoccupancy and Functional Recovery Objectives.
2. Design New Buildings to Meet Recovery-Based Objectives.
3. Retrofit Existing Buildings to Meet Recovery-Based Objectives.
5. Develop and Implement Pre-Disaster Recovery Planning Focused on Recovery-Based Objectives.
6. Provide Education and Outreach to Enhance Awareness and Understanding of Earthquake Risk and Recovery-Based Objectives.
Where do we begin???

Framework for Functional Recovery

• Coordinated action is required across all recommendations

• Progress can, and should, be made in parallel

• Framework will provide core policy, including key technical information, to form the basis of all other activities

Figure 7-1 Interactions among the recommendations.
Recommendation 1

Develop a Framework for Post-Earthquake Reoccupancy and Functional Recovery Objectives

Tasks

• Develop a policy for recovery-based objectives
  ▪ Target recovery times for key functions / services
  ▪ May vary for new and existing buildings / systems

• Develop design criteria for recovery-based objectives
  ▪ Codes and standards for buildings and lifelines
  ▪ May be separate for buildings and lifelines but should be parallel and coordinated

• Determine appropriate hazard level(s)
Recommendation 1: Framework for Functional Recovery

Task 1.1: Develop a policy for recovery-based objectives

• What recovery time is needed for what functions and services to meet community resilience goals?
  ▪ Target recovery time is related to when those functions and services are needed in the overall community recovery spectrum

*Figure 4-1: National Disaster Recovery Framework (NDRF) recovery continuum [FEMA 2011]*
Recommendation 1: Framework for Functional Recovery

Task 1.1: Develop a policy for recovery-based objectives

• What recovery time is needed for what functions and services to meet community resilience goals?
  ▪ Not all functions and services need quick recovery
Recommendation 1: Framework for Functional Recovery

Task 1.1: Develop a policy for recovery-based objectives

• What recovery time is needed for what functions and services to meet community resilience goals?
  ▪ What functions / services are essential or critical to recovery for today’s communities?
  ▪ Current building codes use concept of “Risk Category” to apply higher design criteria and performance goals to functions / services deemed more important or higher risk
    o Risk Category IV applies to “essential facilities” which generally applies to those facilities containing or supporting immediate emergency response…
    o Hospitals, fire/ambulance/rescue, police, emergency communications/operations
  ▪ Unfortunately, the current building code definition of “essential” does not reflect overall recovery needs?
    o What can be learned from the COVID pandemic in terms of what is “essential”?
    o Urgent or routine healthcare, pharmacies, food supply, schools, construction, commercial/retail
Recommendation 1: Framework for Functional Recovery

Task 1.2: Develop design criteria for recovery-based objectives

- What design criteria will achieve desired recovery times?
  - Use of Functional Recovery Categories
  - Start with simple approach that groups functions/services based on relative recovery priority
  - Future/comprehensive solutions may be developed and refined, possibly with greater precision
  - Use of risk category criteria as interim approach

<table>
<thead>
<tr>
<th>Functional Recovery Category</th>
<th>Target Functional Recovery Time</th>
<th>Recovery Phase and Associated Functions and Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Recovery Category A (FRC-A)</td>
<td>Hours (or Less)</td>
<td>Near-Term (Nearly Immediate) and Emergency Response – rescue, safety, security, and event stabilization</td>
</tr>
<tr>
<td>Functional Recovery Category B (FRC-B)</td>
<td>Days to Weeks</td>
<td>Short-Term – shelter, governance, daily necessities, and care for vulnerable populations</td>
</tr>
<tr>
<td>Functional Recovery Category C (FRC-C)</td>
<td>Weeks to Months</td>
<td>Intermediate-Term – restoration of neighborhood activities and economic vitality</td>
</tr>
<tr>
<td>Functional Recovery Category D (FRC-D)</td>
<td>Months to Years</td>
<td>Long-Term – cultural, quality of life, and leisure activities</td>
</tr>
</tbody>
</table>
Recommendation 1: Framework for Functional Recovery

Task 1.3: Determine appropriate hazard level(s)

- Design is inherently at the asset level: building-by-building, component-by-component, system-by-system
- Performance will need to be measured at both the asset level and the community level
- Performance goals for new versus existing assets may involve different hazard level(s)
Recommendation 1: Framework for Functional Recovery

Task 1.3: Determine appropriate hazard level(s)

- Hazard level(s) may have different performance goals / recovery times
  - Will use of a single “design” earthquake or scenario also achieve satisfactory performance for a frequent earthquake and/or for a rare earthquake?

<table>
<thead>
<tr>
<th>Functional Recovery Category</th>
<th>Earthquake Hazard Level (Frequency of Occurrence)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent (return period of 50-100 years)</td>
</tr>
<tr>
<td>Functional Recovery Category A (FRC-A)</td>
<td>Hours (or less)</td>
</tr>
<tr>
<td>Functional Recovery Category B (FRC-B)</td>
<td>Hours to Days</td>
</tr>
<tr>
<td>Functional Recovery Category C (FRC-C)</td>
<td>Days to Weeks</td>
</tr>
<tr>
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<td>Weeks to Months</td>
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What are Lifeline Infrastructure Systems?

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  • Wastewater
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  • Communication
  • Gas and Liquid Fuels
  • Transportation
  • Storm Water/Inundation Protection
  • Solid Waste

• **Socio-Technical Systems**: Lifeline systems include the physical infrastructure and the organizations that manage them

Not specifically covered in report
Lifeline Infrastructure Systems Overview

• Large geographically distributed systems
  • Some cover multiple regions, states, or countries

• Made of numerous interlinked specialized components
  • Designed & built over long timeframes
  • Using a variety of standards, procedures, and materials

• Consist of a variety of subsystems
  • May have separate owners and operators (public and private)
  • All must coordinate to provide services to end users

• All Lifelines provide services
  • Not all services are for buildings or other lifeline systems
Lifeline Infrastructure Systems Overview

- Interdependent
  - Performance of one effects the others

- Colocations
  - Proximity means failure of one can result in unintended damage to others

- Failures in a single system can result in
  - Cascading failures in other systems
  - Public health and safety concerns
    - Flooding
    - Explosion
    - Fire
    - Electrocution
    - Contaminated water
    - Blocking mobility or communication
    - Wide loss of services
Lifeline Infrastructure Systems Overview

• Systems need intimate coordination
  • Yet tend to operate in silos

• Regulations
  • Numerous regulations and regulators
  • No single regulating authority across all lifelines
  • Some lifelines have multiple regulating authorities
    • Local, regional, state, federal
    • May cover similar or different aspects
  • May differ between public and privately owned systems
  • Most deal with safe and reliable operations, not extreme events
  • Earthquake regulations, where existent, differ between systems and across state lines
  • Some Eq. regs. deal with specific critical components (Nuclear Power, Dams,…)
Lifeline Infrastructure Systems Overview

• Earthquake-Related Performance Criteria
  • Mostly limited to structural components (buildings, bridges, piers, control towers)
  • Relatively no system-level seismic performance criteria dealing with services
  • Most systems are not designed for earthquakes (although some components may be)

• Variety of manuals, guidelines, and standards
  • Most don’t address earthquakes
  • Those covering earthquakes are inconsistent within systems and especially across systems
  • Few address post-earthquake recovery times, those that do, or imply, are inconsistent
  • Lifelines generally are not designed to provide more reliable service to any specific customer

• Aging & Deterioration is significant issue with all lifeline systems
Including Recovery Objectives for Lifelines

Means:

• Designing beyond safety
• Addressing for all Lifelines the:
  • Geo-spatial hazard exposure
  • Interdependencies
  • Operating in Silos
  • Lack of system-level design for services in extreme events
  • Deterioration
  • Range of regulatory requirements
  • Limited or lack of design manuals, guidelines, and standards for specialized systems and components
RECOMMENDATION 4: Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives

• The development of a recovery-based framework under Recommendation 1 is needed for implementation of Recommendation 4.

• Task 4.1: Provide National-Level Guidance on Regulatory Authority Across Lifeline Infrastructure Sectors
  • Review regulatory authorities across all lifeline infrastructure sectors
  • Define overlaps and gaps at local, state, tribal, and federal levels.
  • Create national level guidance developing a governance structure to provide a consistent set of regulations across all lifeline infrastructure systems.

Basis
• No common jurisdictional authorities
• Some lifelines may have no regulatory authority to oversee or mandate FR improvements
• Need consistent, no conflicting, regulations
RECOMMENDATION 4: Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives

• Task 4.2: Evaluate the Ability of Lifeline Infrastructure Systems to Meet Recovery-Based Objectives
  • Include entire system from source to delivery (collection to discharge) regardless of different subsystem owners, include dependencies and all plausible earthquake hazards.
  • Results must be transparent to users
  • Use current technologies and improve over time (periodically undertake re-evaluations)

Basis
• Most, if not all, lifelines do not know how their system will perform in an earthquake or how long it will take to recover
• Entire system, with all plausible hazards, are not normally included in evaluations
• Customers and authorities are not usually informed of what is known
RECOMMENDATION 4: Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives

• Task 4.3: Develop National-Level Seismic Design Standards for Lifeline Infrastructure Systems to Meet Recovery-Based Objectives
  • A consistent set of guidelines, standards, and codes for all lifeline infrastructure systems is needed – currently these do not exist
  • Implement the NEHRP Lifelines Roadmap (NIST GRC 14-917-33)
  • Re-Establish a National Lifelines Organization (like ALA)

• Task 4.4: Create Regional Lifelines Councils
  • Deals with local issues and significantly aids with interdependencies

• Recommendation 4 includes options to mandate, encourage voluntary/incentivize, or trigger upgrades
ENABLING MECHANISMS

- Planning
- Education & Outreach
- Financial Resources

- This involves the organizational aspects of the social-technical system
Planning

• Needed to achieve recovery-based objectives *beyond that achievable by design and construction alone*

• Making decisions **before** a disaster about how a lifeline infrastructure system, and thus a community, will recover **after** a disaster

• It’s all about the **process**
Recommendation 5

Develop and Implement Pre-Disaster Recovery Planning Focused on Recovery-Based Objectives

- Putting local lifeline system leadership at the helm to plan their system
- Possibly integrating into the responsibilities of existing positions (e.g., Director of System Planning and Development)
- For *lifelines*, this planning would be undertaken by each lifeline infrastructure system authority, individually or as part of a larger group effort (e.g. in collaboration with communities they serve)
Task 5.1

Develop and Implement Pre-Disaster Recovery Plans

• Incorporating recovery-based objectives into existing plans (e.g., Comprehensive Plans, Land Use Plans)
• Developing and implementing a Community Resilience Plan using the \textit{NIST Community Resilience Planning Guide}
• Incorporating recovery-based objectives into Hazard Mitigation Plans*

* Required for FEMA post-earthquake aid for public and non-profit facilities

Lifeline system organizations need to be involved and engaged in these broader activities
Task 5.2

Create and Promote Seismic Continuity Programs

- Lifeline Systems organizations need to prepare Business Continuity and/or Continuity of Operations Plans
- This is above & beyond the emergency response plans and exercises they should currently have in place
Task 5.4

Plan for Sufficient Staffing to Expedite Post-Earthquake Recovery
- Highlighting staffing issues and make them a priority for action before an earthquake occurs
- Recognizing that a temporary increase in staffing capacity after an earthquake may be needed
- Use Mutual Aid and Mutual Assistance Agreements
Education & Outreach

Needed to facilitate **demand** by stakeholders for uptake of voluntary measures and for regulatory change

- Considering people’s **pre-existing knowledge** and perceptions as well as their **propensity to change**
Task 6.1

Educate Building and Lifeline Infrastructure System Stakeholders about Earthquake Risk and Recovery-Based Objectives

• Giving all citizens information on earthquake risk, common secondary hazards triggered by earthquakes, and associated cascading effects
• Explain results of analyses the potential service loss durations for lifeline infrastructure systems (Task 4.2)
• Making customers and users aware of mitigation strategies for achieving recovery-based objectives
• Help make education accessible and actionable
Task 6.2

Educate Design and Construction Industry Professionals about Earthquake Risk and Recovery-Based Objectives

• Increasing knowledge about the means for designing, constructing, and retrofitting lifeline infrastructure systems to meet recovery-based objectives
• Providing tips for communicating the benefits of reoccupancy and functional recovery to end-users and implementing the actions needed to achieve the desired performance
Financial Resources

• Needed to **implement** functional recovery design, construction, and retrofitting actions and pre-disaster recovery planning and

• Response and Recovery activities during a disaster
Recommendation 7

Facilitate Access to Financial Resources Needed to Achieve Recovery-Based Objectives

• Shifting to recovery-based objectives costs money upfront (for planning and mitigation activities); those who bear these costs must have access to needed financial resources

• Despite an incremental increase in upfront costs, future costs should decrease. Which costs?
  • Losses associated with damage, business interruption, and reduced services
  • Operating and financing costs

• Lifelines organizations need access to cash reserves to carry through the post-event activities
  • Loss of revenue post-event
  • Expense of repairing damages and restoring services
Task 7.1

Develop and Deploy Pre-Disaster Financial Mechanisms to Achieve Recovery-Based Objectives

• Offsetting costs using financial incentives, insurance discounts, and public-sector assistance
• Offering utilities reduced insurance premiums; a public utility commission policy that allows for small rate increases; enhanced bond ratings; and federal, state, or local grants or loans

This is a broader aspect lifeline system organizations need to be involved and engaged in with State and Federal Agencies and the Financial & Insurance Sectors
Task 7.2

Develop and Deploy Post-Disaster Financial Mechanisms to Achieve Recovery-Based Objectives
There is no such thing as “earthquake-proof” design and construction
• Even in the best-case scenario, financial resources will be needed as part of post-earthquake recovery
• Need to enhance the existing mix of federal programs, private borrowing and savings, private development, charity, and private insurance
• Lifelines Organizations need plans (Task 5.2) for how to have funds at hand immediately in a disaster
1st Steps for Developing a Recovery-Based Framework
Developing a Framework for Lifeline System Recovery-Based Objectives

- Identify the service needs in community using concept of basic service categories (BSCs)
- Account for user adaptations after an event
- Understand that different users have different needs, & not all users are the same (e.g., providing medical services at Hospitals is more important than playing sports during a disaster)
- Determine when users need the different BSCs
- Focus on basic human needs as a priority
  - Physiological needs
  - Safety and security needs
Developing a Framework for Lifeline System Recovery-Based Objectives

• Set system-level goals to meet community-level needs
  • Safety
  • Property Protection
  • Basic Service outage times

• Goals may change for:
  • Different customer types
  • Different Earthquake sizes

• Design system components to ensure system-level goals are met
• Have consistency among all Lifelines and Buildings
• Address system assets (Rec. 1 & 4) and organizational actions (Rec. 5, 6, 7)
## System performance – Water Example

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water system services</td>
<td>Services meeting the public needs. Potential consequences to public health and safety from lack of these services is included in this performance category.</td>
</tr>
<tr>
<td>Life safety</td>
<td>Preventing injuries and casualties from direct or indirect damages to water system facilities; includes safety matters related to response and restoration activities, but not health and safety matters directly associated with use of water system services (e.g., fire protection).</td>
</tr>
<tr>
<td>Property protection</td>
<td>Preventing property damage because of damage to water system components; also includes preventing water system damage.</td>
</tr>
</tbody>
</table>
# Water system basic service categories

<table>
<thead>
<tr>
<th>BSC</th>
<th>Brief Def.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Delivery</td>
<td>Does water come out of tap?</td>
<td>System distributes water to customer service connections, but water may not be continuous, meet quality standards (requires water use/purification notice), pre-event volumes (requires water rationing), fire flow requirements (impacting firefighting capabilities), or pre-event functionality (inhibiting system performance reliability).</td>
</tr>
<tr>
<td>Quality</td>
<td>Is it safe to drink?</td>
<td>Water quality at service connections meets pre-event standards. Potable water meets health standards (water use/purification notices removed), including minimum pressure requirements to ensure contaminants do not enter the system.</td>
</tr>
<tr>
<td>Quantity</td>
<td>Get amount needed?</td>
<td>Water flow to customer service connections meets pre-event volumes (water rationing removed).</td>
</tr>
<tr>
<td>Fire Protection</td>
<td>Are firefighting needs met?</td>
<td>System able to provide pressure and flow of a suitable magnitude and duration to fight fires.</td>
</tr>
</tbody>
</table>
## Lifeline Basic Service Categories

<table>
<thead>
<tr>
<th>Lifeline System</th>
<th>Basic Service Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delivery</td>
</tr>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Wastewater</td>
<td>X</td>
</tr>
<tr>
<td>Storm water</td>
<td>X</td>
</tr>
<tr>
<td>Electric Power</td>
<td>X</td>
</tr>
<tr>
<td>Communications</td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
</tr>
<tr>
<td>Gas and Liquid Fuels</td>
<td>X</td>
</tr>
<tr>
<td>Solid Waste Management</td>
<td>X</td>
</tr>
</tbody>
</table>
1994 Northridge Earthquake ($M_W 6.7$) Example

- 80 transmission pipe repairs
- 1013 distribution pipe repairs
- 200 service connection repairs
- 7 damaged reservoirs...

GHT = Granada High Tank
BGT = Beverly Glen Tank
CCT = Coldwater Canyon Tank
GHT = Granada High Tank
TT = Topanga Tank
ZT = Zelzah Tank

Additional Damage
- High Speed Channel
- Bypass Channel
- Potor Plant Tailrace
- LA25 (MWD connection)
- LA31T (MWD connection)
- VNPS I Discharge Line
- VNPS II Discharge Line
1994 Northridge Earthquake ($M_W 6.7$) Example
Users and Uses / Target Performance Levels

**Users**
- Healthcare facilities
- Residential, by type
- Retail
- Industrial
- Schools

**Uses**
- Drinking/cooking
- Bathing/washing
- Toilet flushing
- Outdoors (lawn, pool)
- Goods production
- Equipment cooling

**BSCs required for each use**
- Water delivery
- Water quantity
- Water quality
- Fire protection

**Consequences if BSC not met**

**Adaptations**

**Target BSC performance levels**
Water Alternative Emergency Services

Providing prepackaged water while portable water cannot be provided through network

Aiding Fire Department with alternate sources when water not delivered through network with sufficient volume, pressure
Summary & Conclusions

• Addressing lifelines to include recovery-based objectives is difficult and complicated, requiring some differences in approach than historically undertaken
  • Requires addressing different issues than buildings. There are some parallels and many differences
  • Lifelines are interdependent, yet tend to operate in silos
  • Lack of system-level design for extreme events
  • Numerous specialized components with inconsistent seismic design criteria

• Lifelines are critical to community resilience

• Must address social & technical aspects equally

• This study identifies the need for a tremendous amount of long-term sustained improvement through research and implementation to meet Lifeline system-level recovery-based objectives

• Functional Recovery is applicable to other hazards