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Disaster resilience and water system

Water & Waste Engineering

2019/05/31

名古屋大学減災連携研究センター
Disaster Mitigation Research Center, NAGOYA UNIVERSITY

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Japanese Experiences from 1995 & 2011

2011 Tohoku Disaster and 1995 Kobe Earthquake

	The 2011 Tohoku Disaster	1995 Great Hanshin-Awaji Earthquake
Earthquake	The 2011 off the Pacific Coast of Tohoku Earthquake	Hyogo Nanbu Earthquake
Time and Date	11 March, 2011 14:46	17 January 1995 5:46
Magnitude	Mw 9.0	Mj 7.3
Earthquake Type	Inter-plate earthquake	Intra-plate earthquake
Death	15,821 (Missing 3,926)	6,434
Damaged Municipal Governments	8 prefectures under Disaster Aid Law	Hyogo and Osaka
Economy Loss	16 – 25 trillion JPY (210 – 326 billion US$)	10 trillion JPY (130 billion US$)
Cause of Death	Tsunami	Death from crushing and/or suffocation by building collapse

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1995 Kobe Earthquake

Damages to Water Distribution System in 1995

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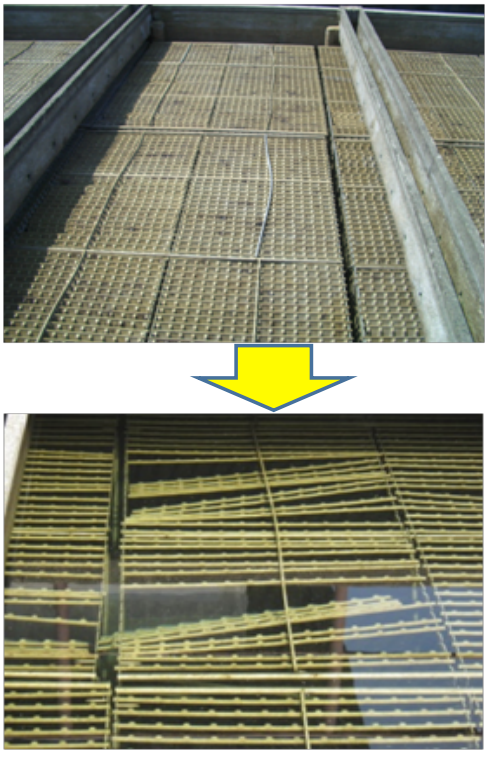
Damage of Moniwa WTP in City of Sendai in 2011

Inclined Plates in Sedimentation Pond

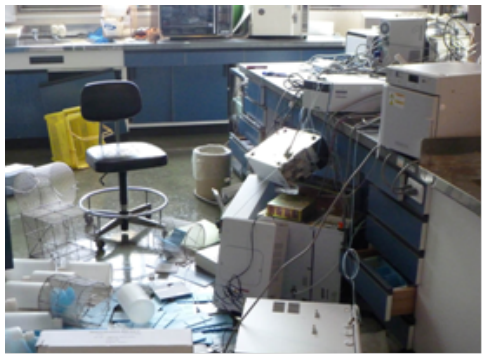


Baffle Plates in Sedimentation Pond

Damage to Facilities in City of Sendai







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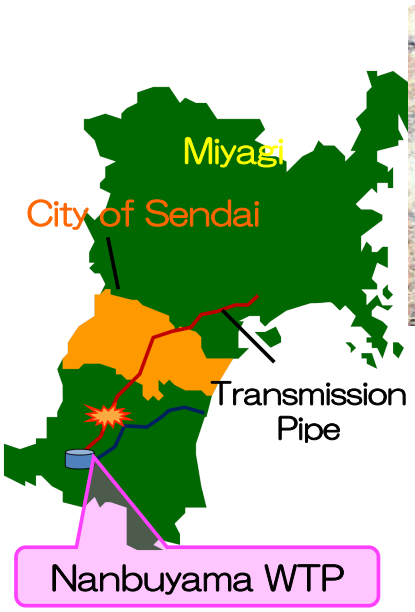
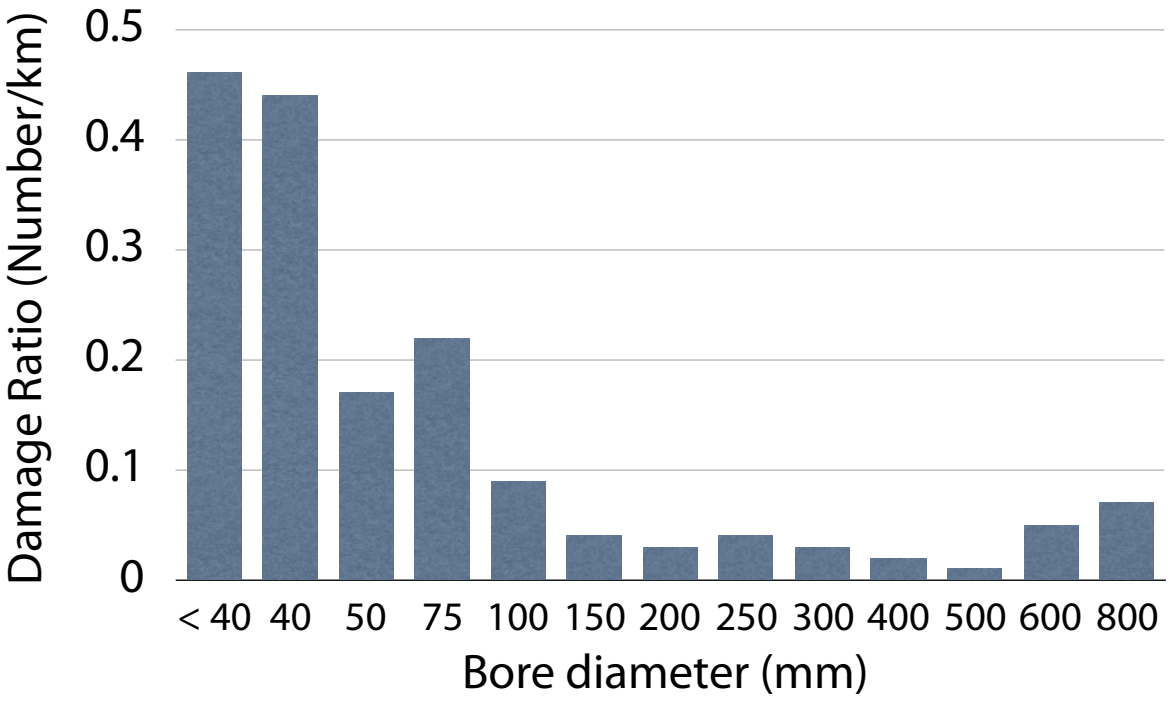
Damage to Water Transmission Pipe

Damage to ϕ2,400



Emergency Recovery of ϕ2,400

Damage Ratio in Each Bore Diameter in City of Sendai



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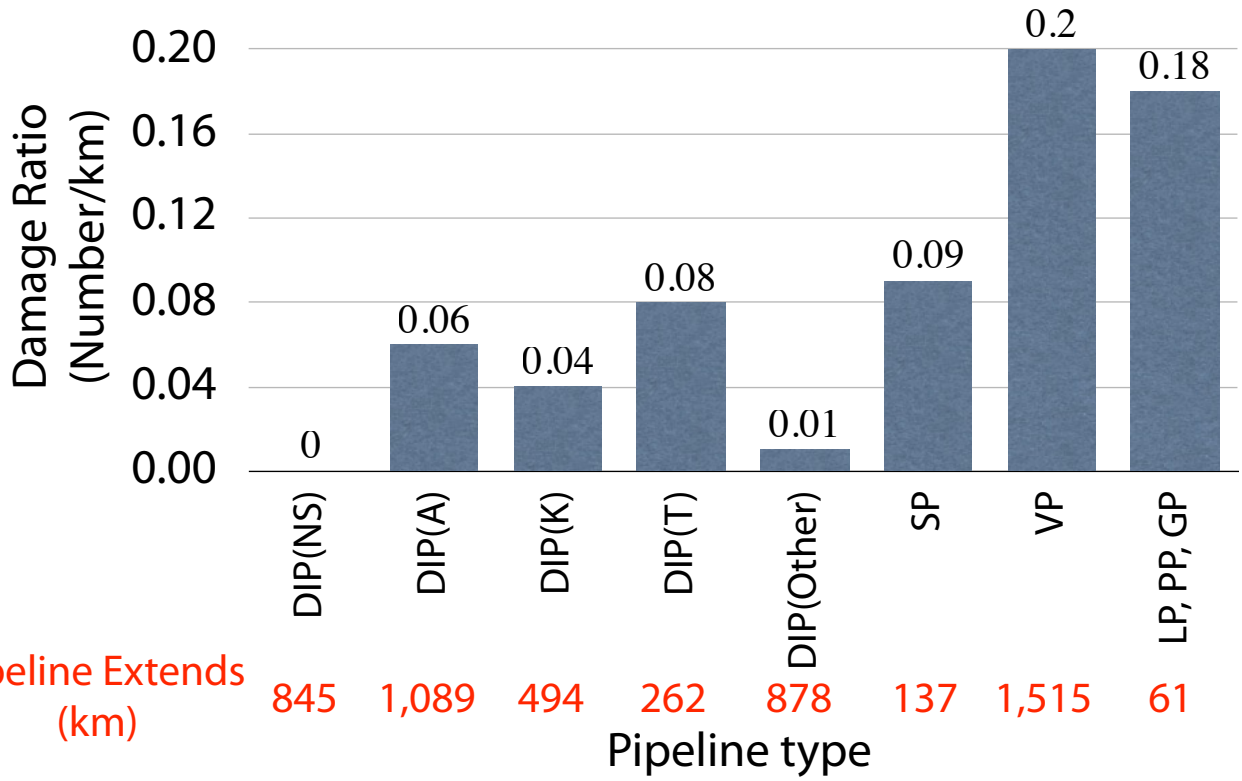
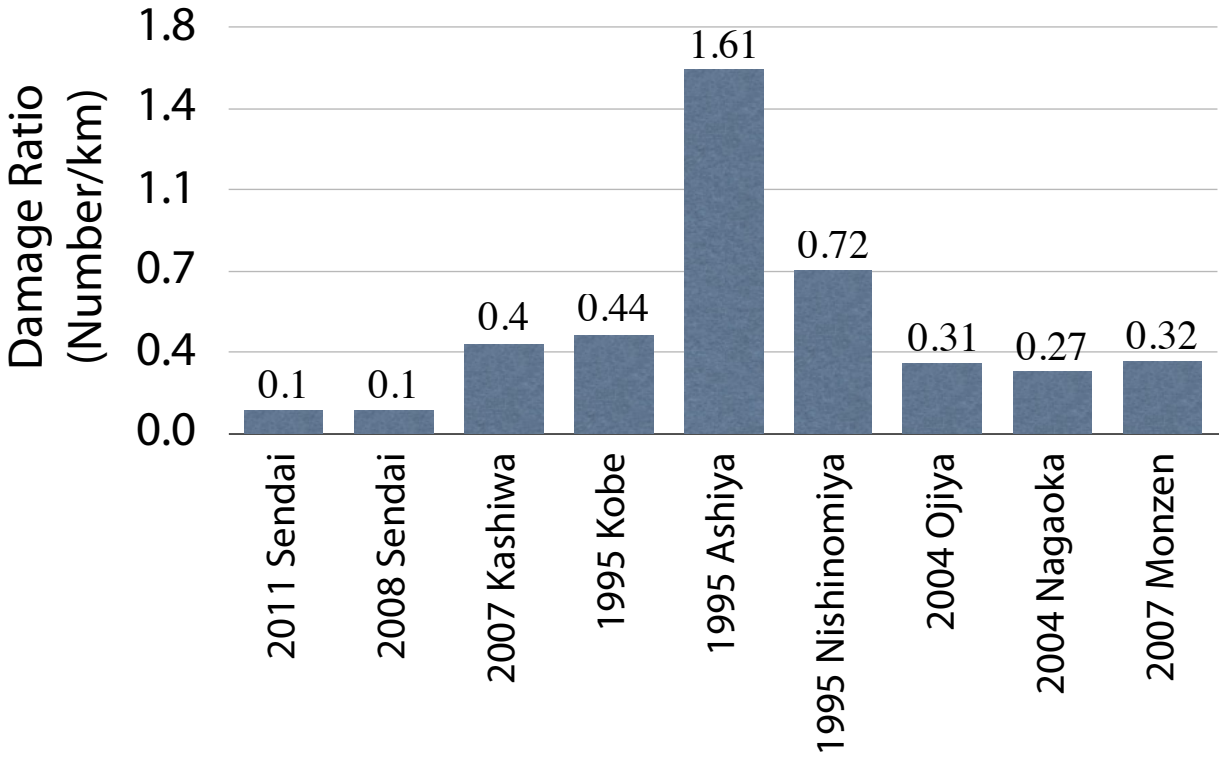
Damage Ratio of Pipeline in City of Sendai



Comparison Results of Damage Ratio in Japanese Experiences



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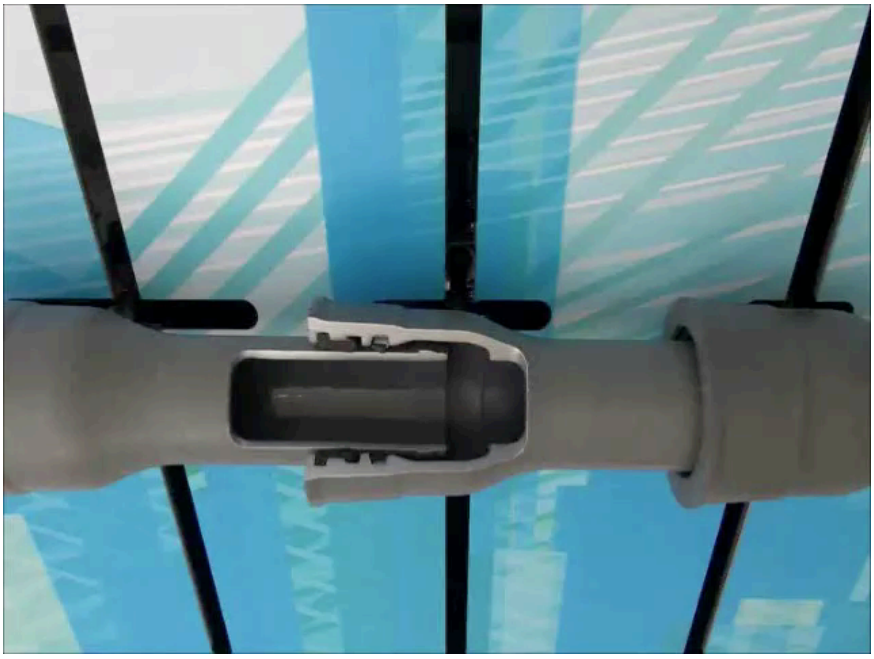
Earthquake-Resistant Ductile Iron Pipe (DRDIP)

Property	Performance
Amount of expansion/contraction	±1% of nominal pipe length
Pull-out resistance	3 DkN
Maximum deflection angle	6 – 8˚

Earthquake Resistant DIP



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Emergency water supply station

Disaster Community Training at KOBE primary school

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Disaster Assistant Cooperation System

US-JP International Research:
Implementation of Earthquake Resistant Ductile Iron Pipe (ERDIP) in U.S.

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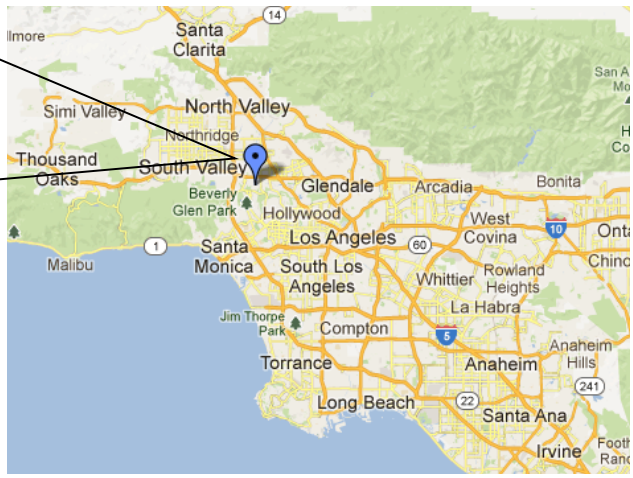
LADWP 1st Pilot Project



(1) Contour Dr. **(Installed on January – March 2013)**

- Pipeline Length: 1800’
- Pipe diameter: 6” (150mm)
- Hillside area (Sloped and curvy roads)
- Landslide risk

LADWP ERDIP Installation

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LADWP Pilot Project on the Wall Street Journal

THE WALL STREET JOURNAL.

DOW JONES · MONDAY, APRIL 15, 2013 · VOL. CCLXI NO. 87 · WSJ.com · $2.00

Los Angeles Tests Water Pipes That Stand Up to Quakes

By Hannah Karp

Los Angeles has a come up with a strategy to prepare for the Big One: earthquake-proof water pipes made only in Japan.

The Los Angeles Department of Water and Power recently finished installing a test patch of about 2,000 feet of a special kind of iron piping in the San Fernando Valley.

The piping, made by Japan's Kubota Corp. and designed to withstand ground deformation, has endured 40 years of earthquakes in Japan—including the 9.0-magnitude Tohoku earthquake that struck in 2011, triggering a tsunami.

Unlike traditional water pipes, these so-called ductile iron pipes are able to withstand quakes because they can bend and flex instead of buckling under pressure. The system is engineered to work like a chain, meaning it doesn't break apart even if its various components are moving.

LADWP supervising engineer Craig Davis learned about the pipes in 2003 and negotiated to import some for the Los Angeles pilot project shortly after the 2011 quake. Mr. Davis said water agencies in San Francisco, Portland and Seattle have contacted him, expressing interest in similar projects. "We're just learning about it—it's really only recently that you could identify this pipe system as earthquake-resistant," said Mr. Davis, who sent his chief work-crew trainer to Japan last year and has two Japanese reps on site supervising the Los Angeles installation.

Engineer Craig Davis is overseeing a test of Japanese-made earthquake-resistant water pipes in Los Angeles.

Initially, the city plans to replace only a fraction of its piping—about 2 miles of the total 7,000 miles—with the quake-proof tubes, limiting installation to the most vulnerable, fault line-adjacent areas. The material is expensive, about 2½ times the price of the standard water pipe used in Los Angeles.

The first test installation cost $106,000; the 6,500 feet of piping for the second installation scheduled to start this fall will cost $900,000. To cut expenses, Los Angeles officials are trying to help Kubota find a manufacturing partner in the U.S.

The Los Angeles Aqueduct, which channels water to Southern California residents from the Sierra Nevada more than 200 miles away, was built a century ago, and the city has worked to replace and retrofit the system's oldest cast-iron pipes in recent years. LADWP said it has installed 2,390 miles of new pipe since 1963 and replaced 107 miles of pipe since 2006.

But work crews have struggled to keep pace with water-main bursts throughout the city. Engineers say bursts may have intensified since rules went into effect limiting outdoor plant watering to certain times during the week, meaning more people are watering at the same time, causing increased pressure.

The Japanese quake-proof piping has endured forces like shaking, landslides and extreme temperature swings because it can expand, contract and bend without leaking or pulling apart, said Thomas O'Rourke, an engineering professor at Cornell University who studies such pipes. The flexible joints are still strong enough when they lock up to allow a heavy load of water to flow through the piping.

While some U.S. manufacturers also produce ductile-iron pipe, those varieties haven't been designed with quakes in mind, nor have they been tested through nearly as many tremblors as in Japan, Mr. O'Rourke said.

Meanwhile, the LADWP is adopting a different kind of plastic-piping technology used in New Zealand to protect Los Angeles's water supply as it crosses the San Andreas fault through a tunnel on its way to the city. Although continuous plastic pipes couldn't be easily integrated into most of the city's cast-iron distribution system, the agency plans to route water through one long tube just as it passes through the Elizabeth Tunnel, which could easily cave in during a major quake. Construction is slated to begin in the fall on the $4 million project.

"This reduces significantly the risk of losing the water supply to Los Angeles, which would be a real threat to the U.S., not just to Southern California," Mr. O'Rourke said.

In 1994, the 6.7-magnitude Northridge earthquake cost Los Angeles more than $40 million in pipe, tank and filtration plant repairs, according to the LADWP. It took seven days to get water flowing to all its customers.

Business Continuity (ISO22301)

- **Business Continuity**: capability of an organization to continue delivery of products or services at acceptable pre-defined levels following disruptive incidents
- **Business Continuity Management**: process identifying potential threats to an organization and potential business impacts the threats may cause, which provides a framework for building organizational resilience with the capacity of an effective response that safeguards the interests …
- **Business Continuity Plan**: documented procedures that guide organizations to respond, recover, resume, and restore to pre-defined level of operation following disruption
- **Business Continuity Management System**: part of overall management system that establishes, implements, operates, monitors, reviews, maintains, and improves business continuity

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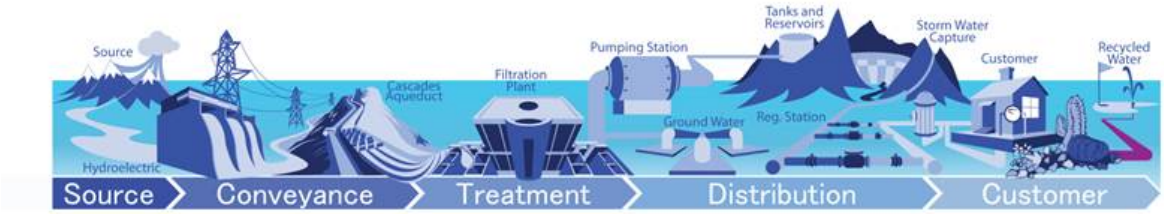
Need for Business Continuity

- **Existing Emergency Management Systems have serious gaps to ensure business can continue to function following disruptive events**
  - ✓ Financial
  - ✓ Business functions
- **Dis-link between existing plans**
  - ✓ Operating procedures
  - ✓ Preparedness, Response and Recovery plans
  - ✓ Hazard mitigation plans, and etc.
- **Recent disasters have identified need for systemic business improvements**
  - ✓ Great East Japan Disaster, Hurricane Sandy & Katrina

Why Business Continuity for Water Sector?

- Water Systems function as businesses
  - ✓ No matter what size
  - ✓ Even municipal utilities
- A **business process** is a collection of linked tasks which find their end in the delivery of a service or product to a client/customer.



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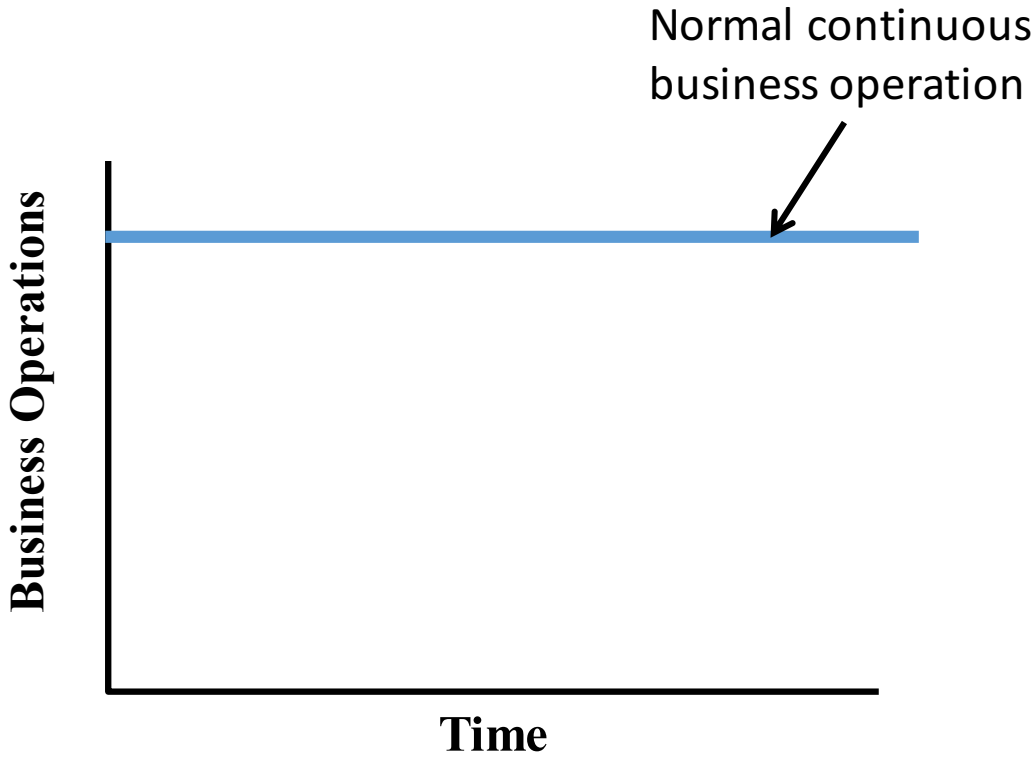
Why Conduct Business Continuity Planning?

- Address gaps in the existing emergency management system (e.g., business functions, administrative facilities, etc.)
- Provide guidance for a business interruption (e.g., power outage)
- Strengthen a utility's ability to continue serving its customers
- Improve resource management and reputation
- Keep employees engaged and employed during event
- Reduce downtime and associated costs
- Improve ability to survive through catastrophic incidents

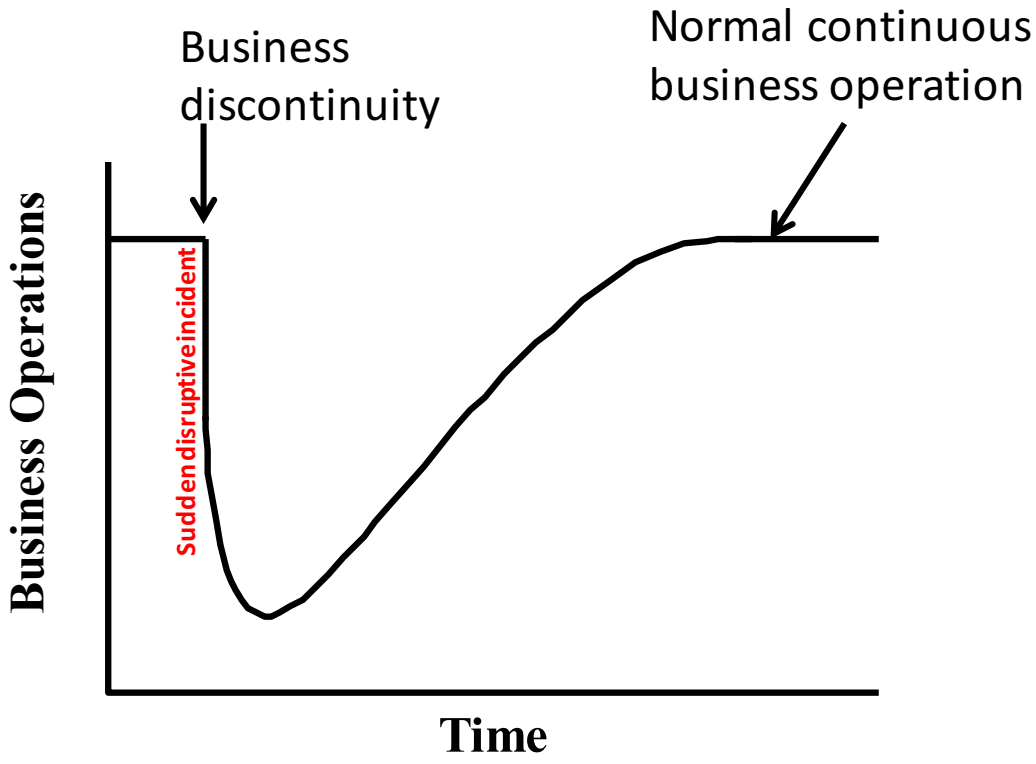
Incidents – natural, man-made

- Fire, flood, hurricane, monsoon, tornado, earthquake, volcanic, landslide, pipe burst(s), etc.
- Plane crashes, vandalism, terrorism, riots, sabotage, loss of personnel, etc.
- Anything that diminishes or destroys normal business processes

Effect of a Significant Incident on Business Operations



Effect of a Significant Incident on Business Operations



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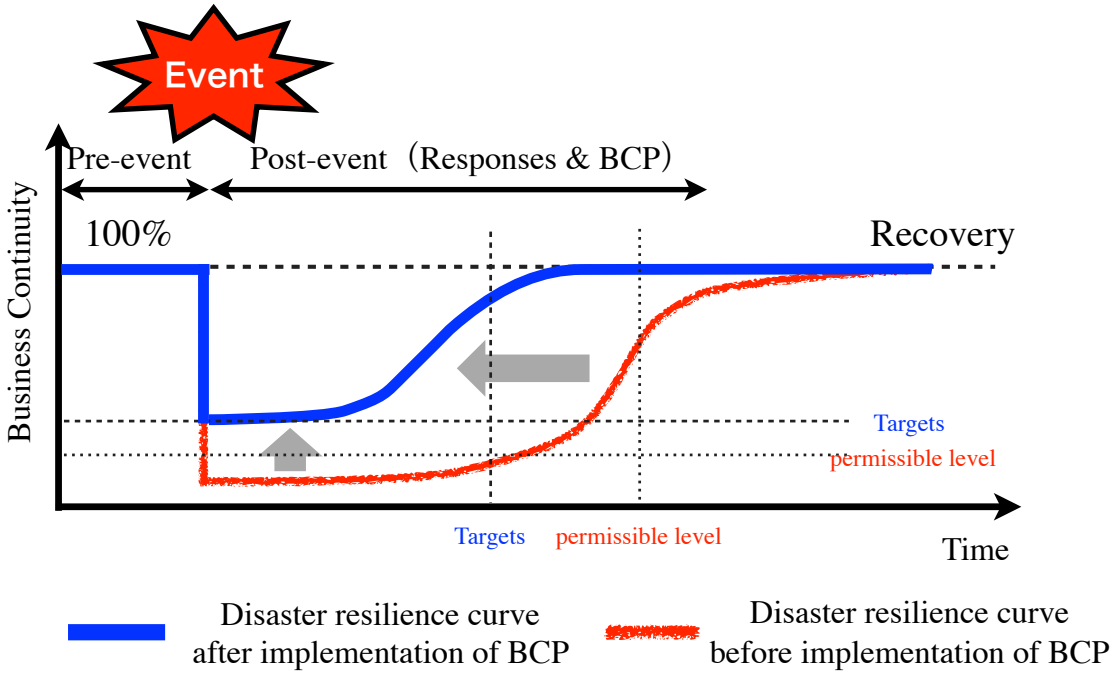
Business Continuity Management

- **Business Continuity Management** (BCM) provides the guidance and control to coordinate the efforts of people and systems to accomplish goals and objectives of mission essential functions using available resources efficiently and effectively.
- In effect, BCM prepares and coordinates all the essential functions of all other water business management activities for employment, or reinstatement, once an incident occurs and a Business Continuity Plan is activated.
- BCM is important to ensure a resilient organization

Concept of Business Continuity Planning



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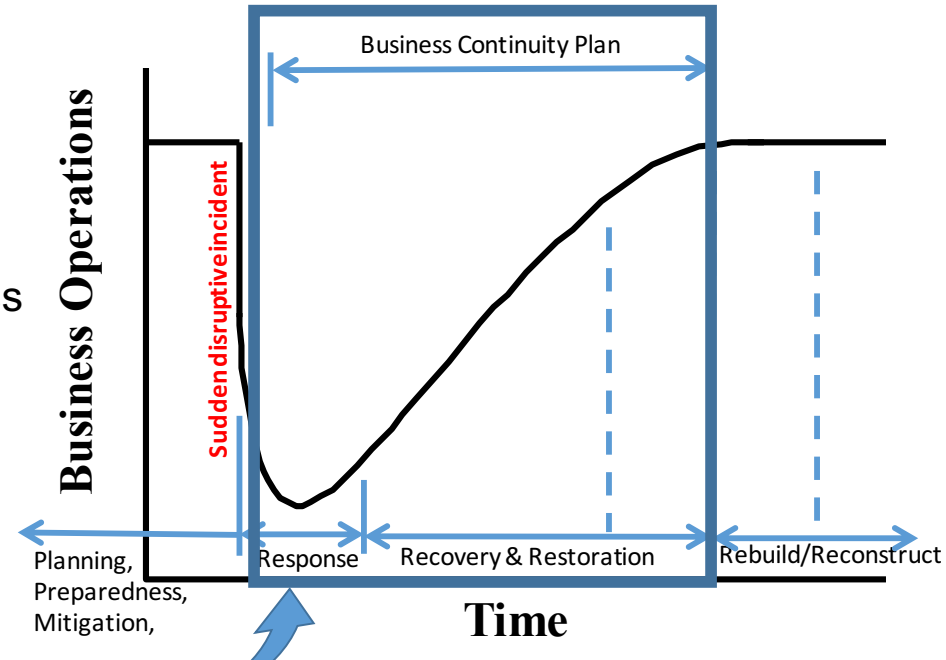
Typical Resilience Curve

Plans

- Pre-event
  - Planning process
  - Preparedness
  - Mitigation
- Post-event
  - Response
  - Recovery
  - Restoration
  - Rebuild
  - Reconstruction



Integrating With Other Plans

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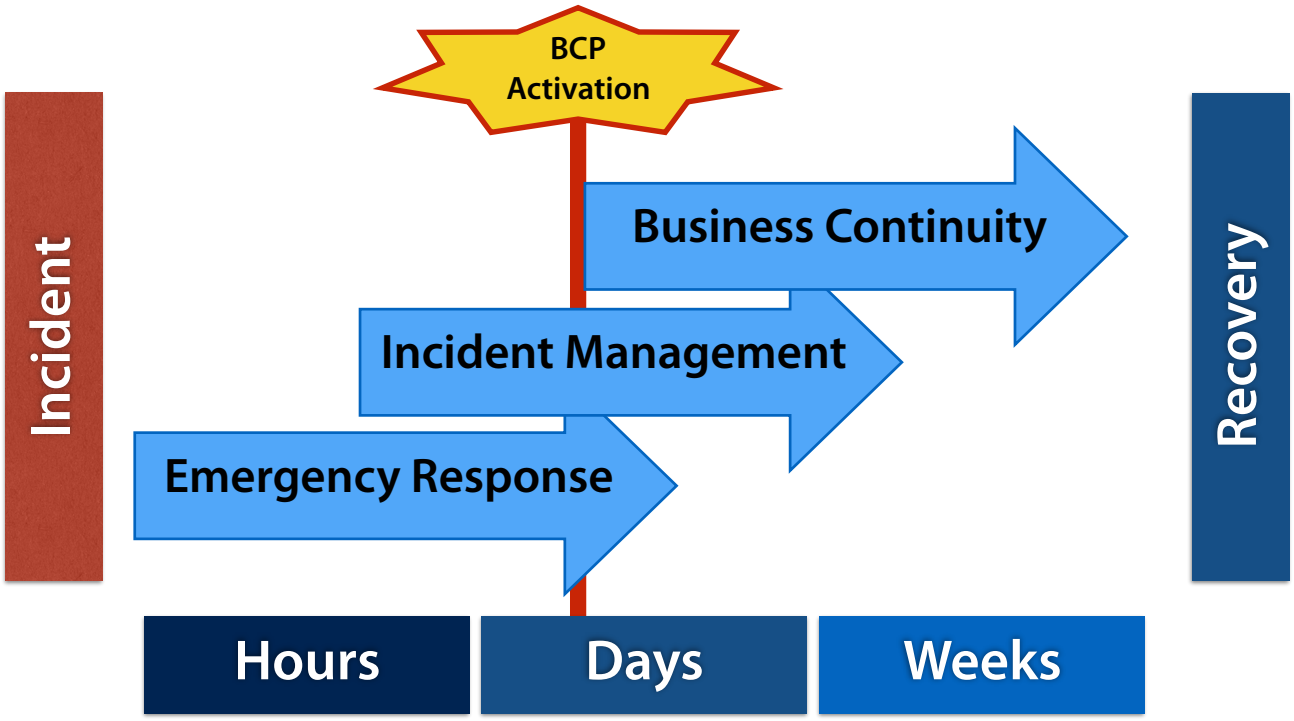
Water Research Foundation Introduction of BCP

- **It is important that business continuity planning be integrated into *a utility's culture* and, as such, consistent with *the utility's mission*.**
- **The utility's mission includes the provision of a reliable supply of high quality water.**
- **Does the BCP:**
  - Define the scope
  - Establish written policy by the water utility Executives
  - Define the Incident
  - Provide basic assumptions
  - Integrate with other plans

Plan Activation Process



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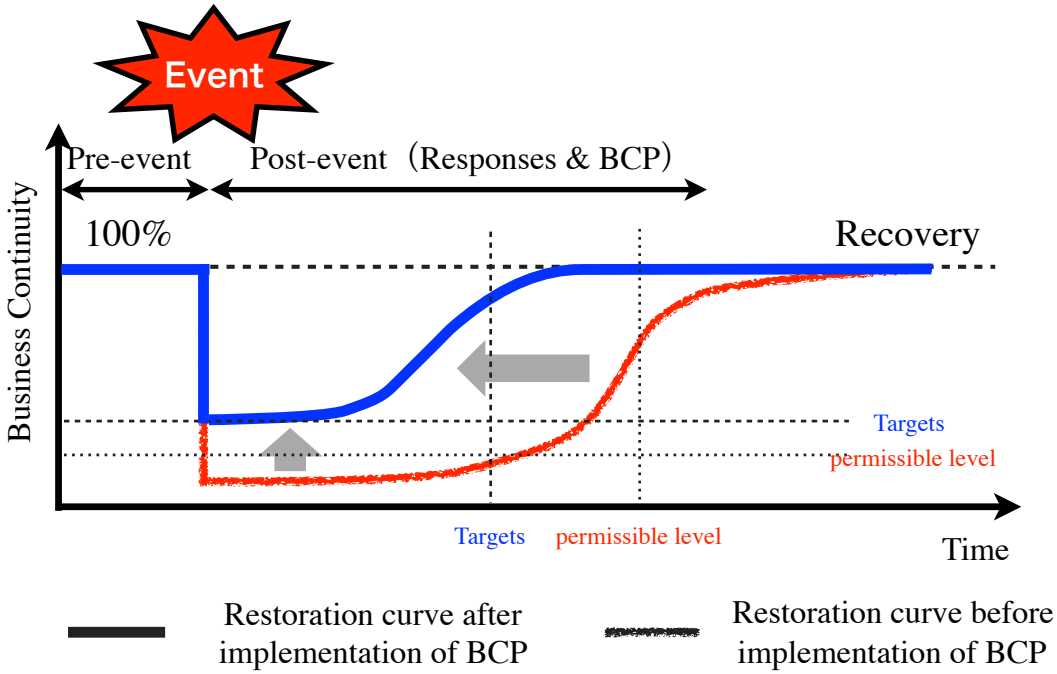
BCM/BCP in Water Sector

- Business Continuity Management is required;
  - Business Continuity Guidelines 3rd (Central Disaster Management Council, Cabinet Office, 2014)
  - New Visions of Water Supply System in Japan (Ministry of Health, Labour and Welfare, 2014)
  - Handbook for emergency response and operation in water sector (Japan Water Works Association, 2008)
  - Business Continuity Planning for Water Utilities (Water Research Foundation, 2014)
  - ISO 22301:2012 Societal security - Business continuity management systems (ISO, 2012)
  - BS25999 Part 1: Code of practice & Part 2: Specification (British Standards Institution, 2006, 2007)

Concept of BCP



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Introduction of BCP by WaterRF, US

- It is important that business continuity planning be integrated into ***a utility's culture*** and, as such, consistent with ***the utility's mission***.
- The utility's mission includes the provision of a reliable supply of high quality water.
- Does the BCP:
  - Define the scope
  - Establish written policy by the water utility Executives
  - Define the Incident
  - Provide basic assumptions
  - Integrate with other plans

Water Utility's Missions

- Confidence with customers and the communities
- Operation to supply safe and portable water steadily
- **Support a civil life and social economic activities**

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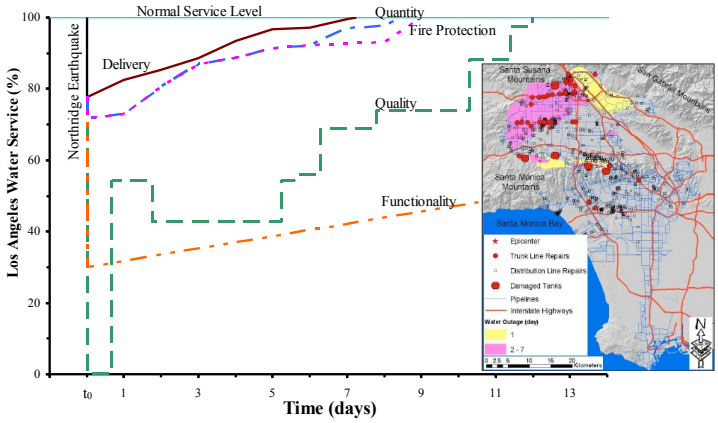
Performance of Business Continuity in Water Services

- Recently, many researchers and water professionals
  - establishment of BCM/BCP in water sector
- Evaluation method of business continuity in water service
- Evaluation of disaster risk reduction

Disaster Resilience Curves in Water Sector

- Water supply ratio
- Available quantity of water
- Opportunity loss
- Water delivery
- Quantity
- Quality
- Fire Protection
- Functionality
- Water accessibility...



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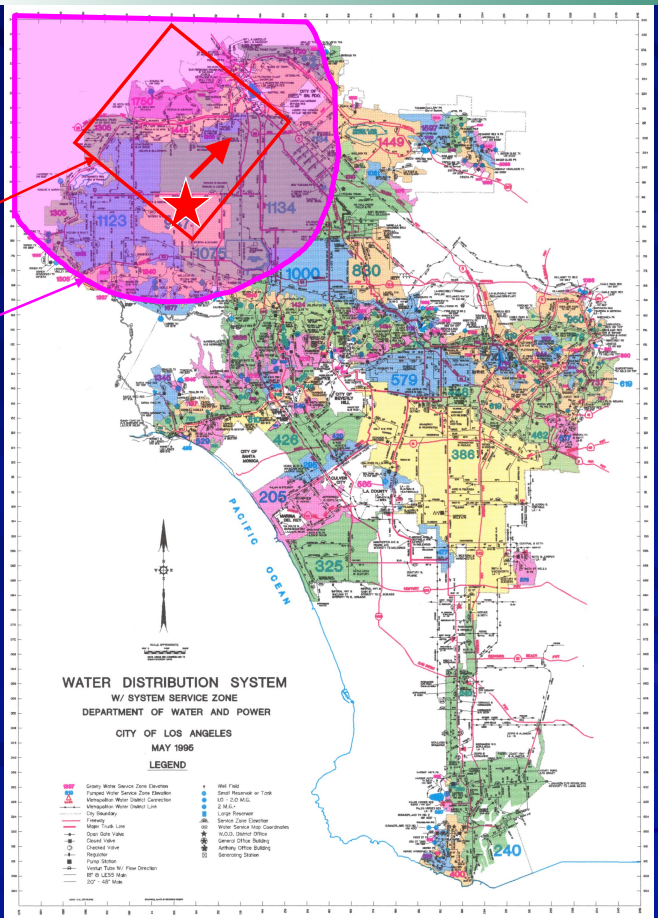
1994 Northridge Earthquake

- January 17, 1994
- Magnitude 6.7 (Mw)
- Thrust Fault (blind/buried)
- Epicenter in Northern Los Angeles
  - ✓ Urban San Fernando Valley
- Millions of people impacted by strong shaking
- 670,000 residents in LA without water
- Another 180,000 people in LA had reduced pressure

Fault rupture area

Primary damage area



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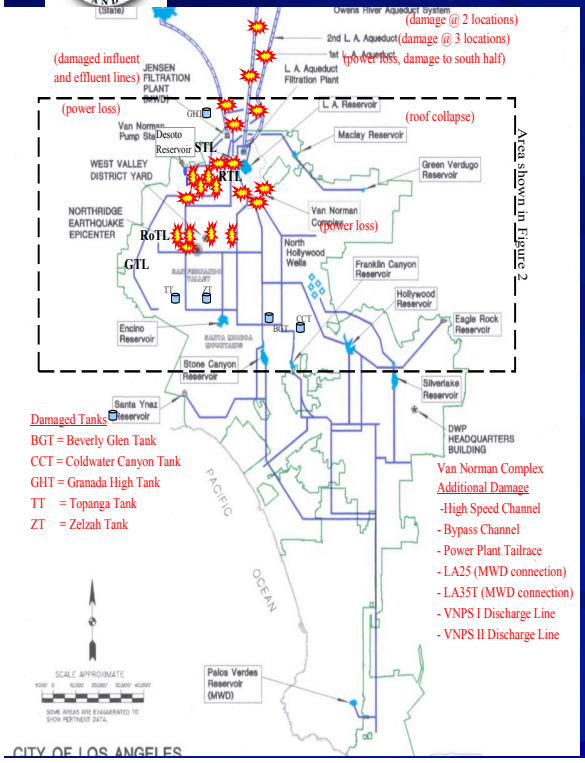
LA Water System Damages



- 14 repairs to raw water pipes
- 60 repairs transmission pipes
- 1013 repairs distribution pipes
- 200 service connection repairs
- 7 damaged reservoirs
- 1/2 treatment plant out of service
- Lost power up to 27 hrs
- No outage at pump and chlorine stations

©Craig A., Davis, 2012

Large Pipe Breaks

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Fire and Pipe Break Balboa Boulevard

- 5 homes burned here
- 120 mobile homes burned
- 470 fires reported

©Craig A., Davis, 2012

Water Services

- Service restoration will be presented in the following categories:

Service Category	Description
Water Delivery	Able to distribute water to customers, but the water delivered may not meet water quality standards (requires water purification notice), pre-disaster volumes (requires water rationing), fire flow requirements (impacting fire fighting capabilities), or pre-disaster functionality (inhibiting system operations).
Quality	Water to customers meets health standards (water purification notices removed). This includes minimum pressure requirements.
Quantity	Water flow to customers meets pre-disaster volumes (water rationing removed).
Fire Protection	Able to provide pressure and flow of suitable magnitude and duration to fight fires. In many water distribution systems the minimum pressure required for fire protection is 20 psi (140 kPa), with flow quantities varying by neighborhood.
Functionality	System restored to meet or exceed pre-disaster functionality and reliability (operational constraints resulting from the disaster have been removed/ resolved) including pressures.

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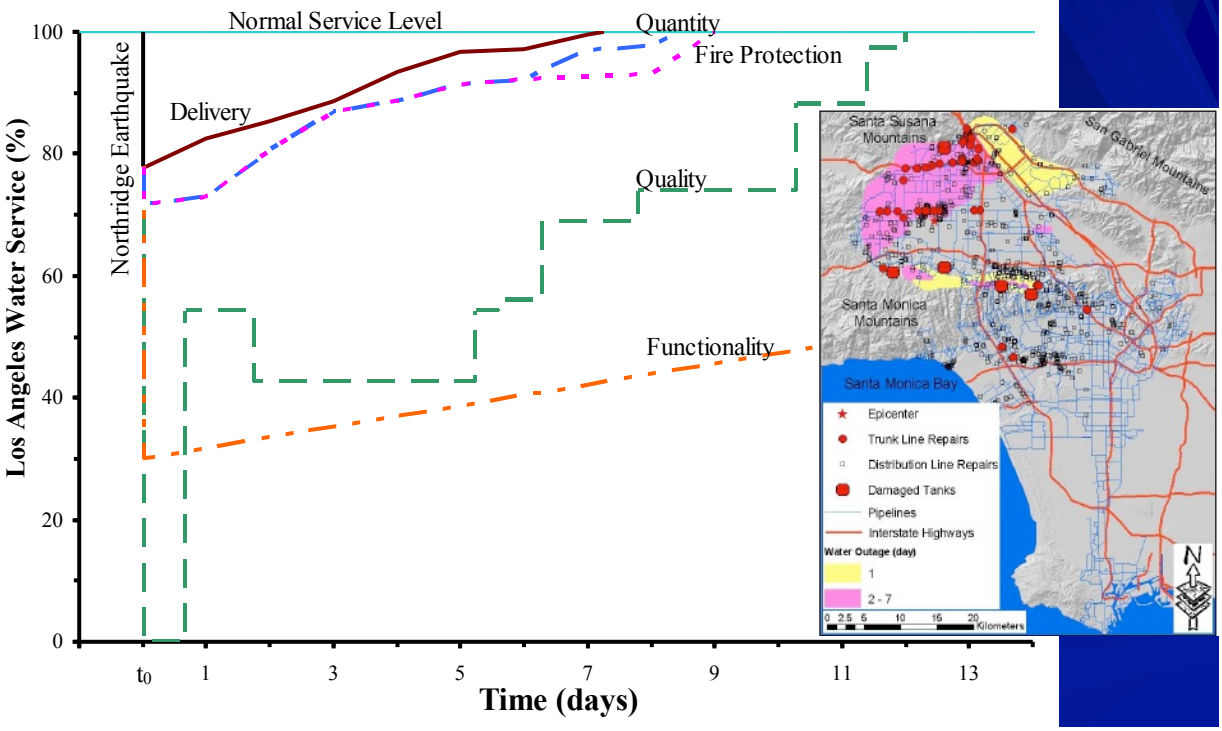
1994 NORTHRIDGE EARTHQUAKE L.A. WATER RESTORATIONS



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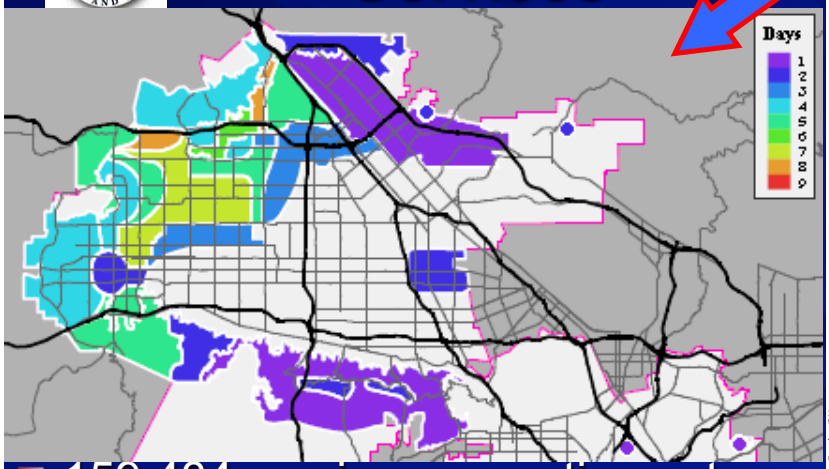
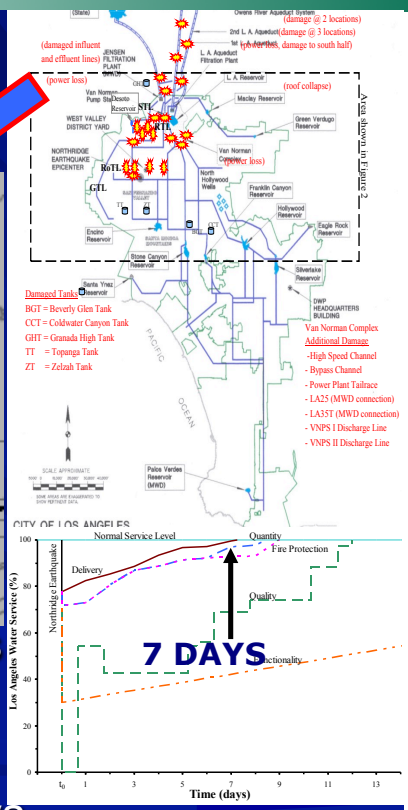
1994 L.A. Delivery Services





- 159,434 service connection outages
- 22% of all services
- ~670,000 residents
- All delivery service restored in 7 days
- Pipe repairs completed several weeks later

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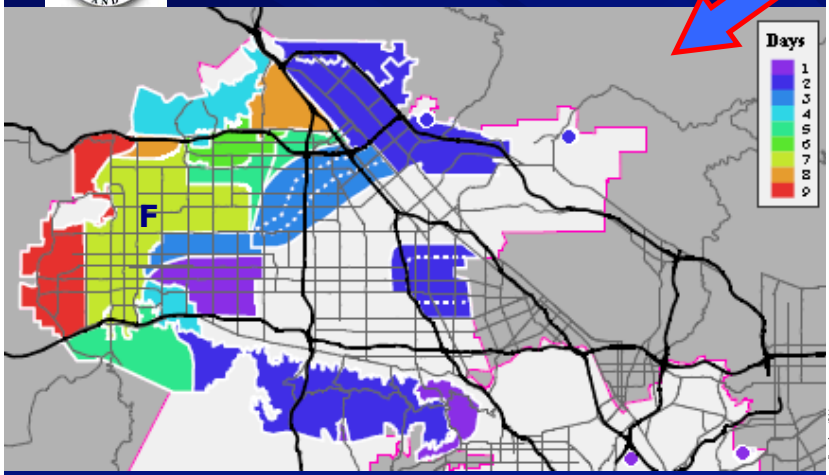
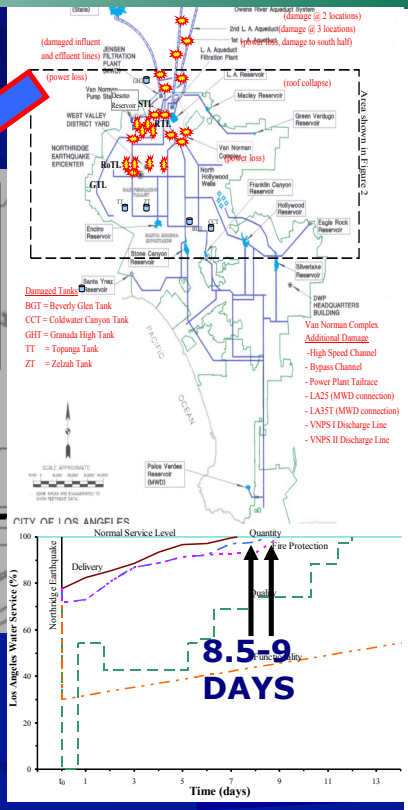
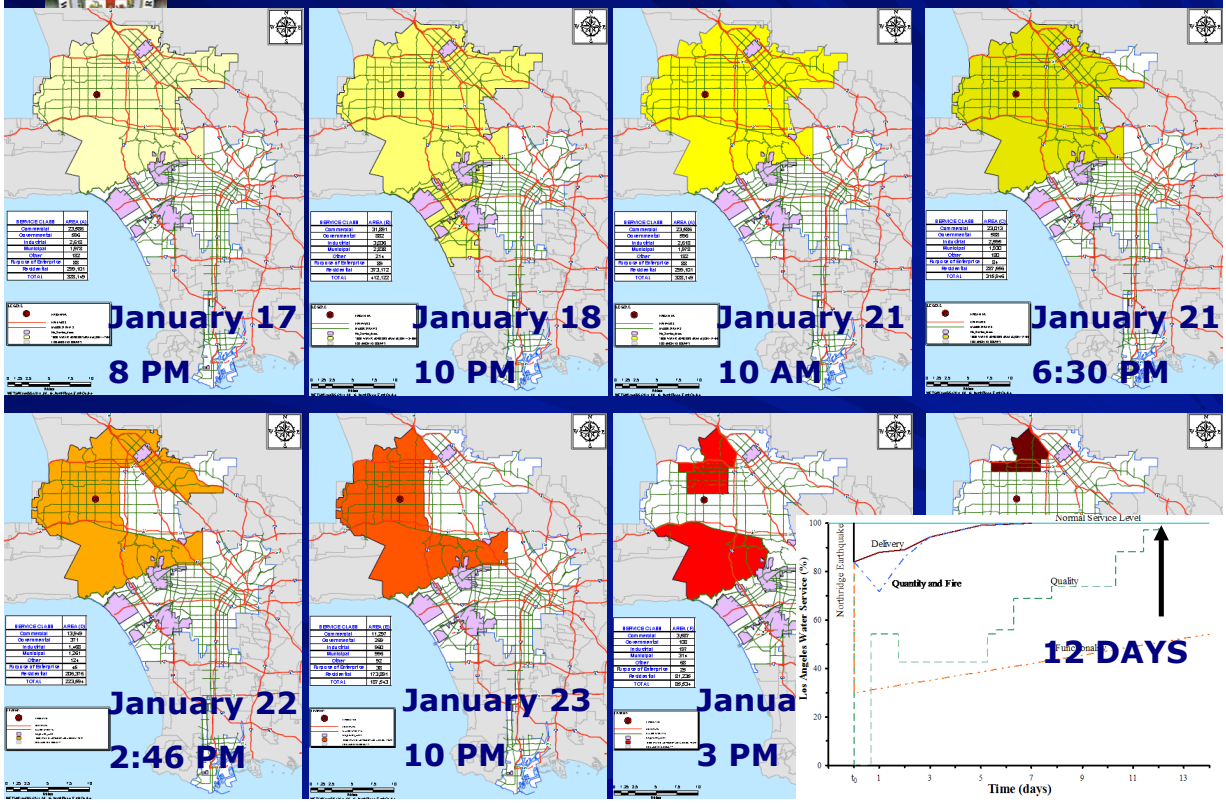
1994 L.A. Quantity and Fire Service





- 203,164 service connection outages
- 28% of all services
- ~850,000 residents
- All quantity restore in 8.5 days
- All fire flow restored in 9 days

1994 L.A. QUALITY RESTORATION



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1994 L.A. Functional Services

- System functionality dropped to about 30% immediately after the earthquake
- Great redundancy and isolation capabilities in system allowed other services to be restored well in advance of total functionality
  - e.g. 8 of 60 transmission repairs completed to restore delivery
- Full functionality restored over 1-year later
- Functionality increased over next 2 decades by making improvements to vulnerabilities exposed by earthquake

©Craig A., Davis, 2012

Customer Impacts
Service outage

- No water service
- Reduced fire protection capability
- Flooded streets restricted access
- Commerce and economics impacted for most industrial and restaurant businesses
- More bottled water used
- LADWP supplied emergency water in sanitized tanker trucks (15 locations)
- Beverage companies supplied bottled water

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Tanks Delivering Water to Customers

©Craig A., Davis, 2012

Water Purification Advisory

- Issued throughout system on Jan. 17
- Concern: Potential for contamination from pipe breaks
- Lifted advisory in areas after water testing
- Longest in epicenter area
- Water purification advisory lasted up to 12 days
  - ✓ longer than service outage

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Customer Impacts Water Purification Advisory

- Boil or disinfect before using
- Customer concern with water quality
- More bottled water used
- Restaurants
  - ✓ Impacted serving and cooking food
  - ✓ Impacted cleaning
- Los Angeles Airport
  - ✓ Commercial airlines threatened to be grounded
- Flush pipes and water heaters in buildings following advisory removal

Conclusions: water

- 1994 Northridge Earthquake affected:
  - ✓ Entire city with boil water advisory
  - ✓ 159,434 service connections without water
  - ✓ 670,000 people + businesses
- All customers had pre-earthquake services restored in 12 days
- Took many more months to return system back to pre-earthquake functionality

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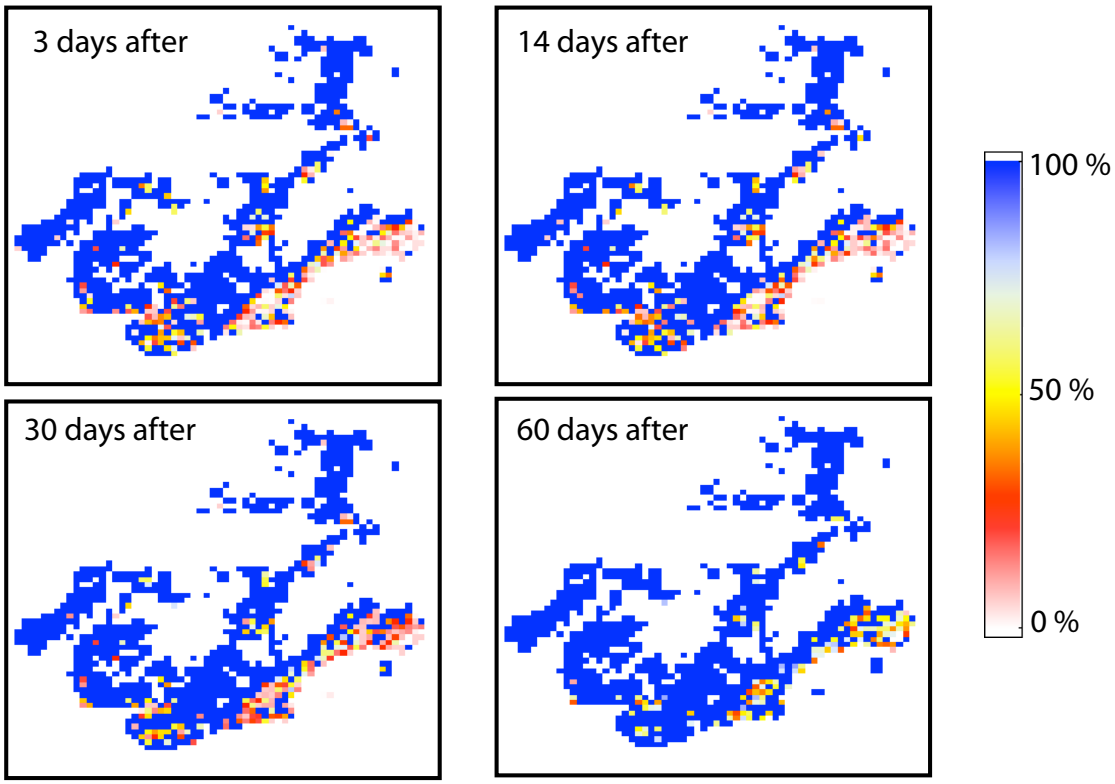
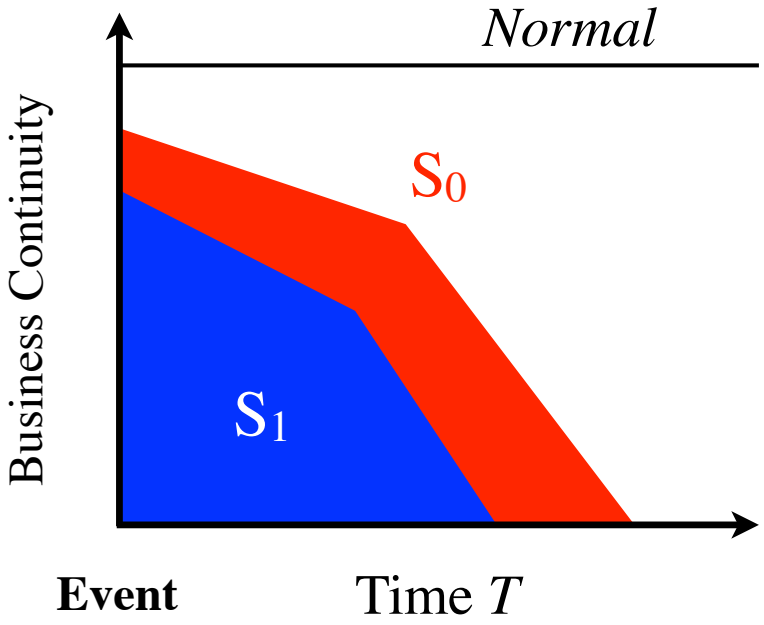
Water System Service Categories Map (Quantity)



Concept of Performance Evaluation



Risk Reduction

$\Delta S = S_0 - S_1$

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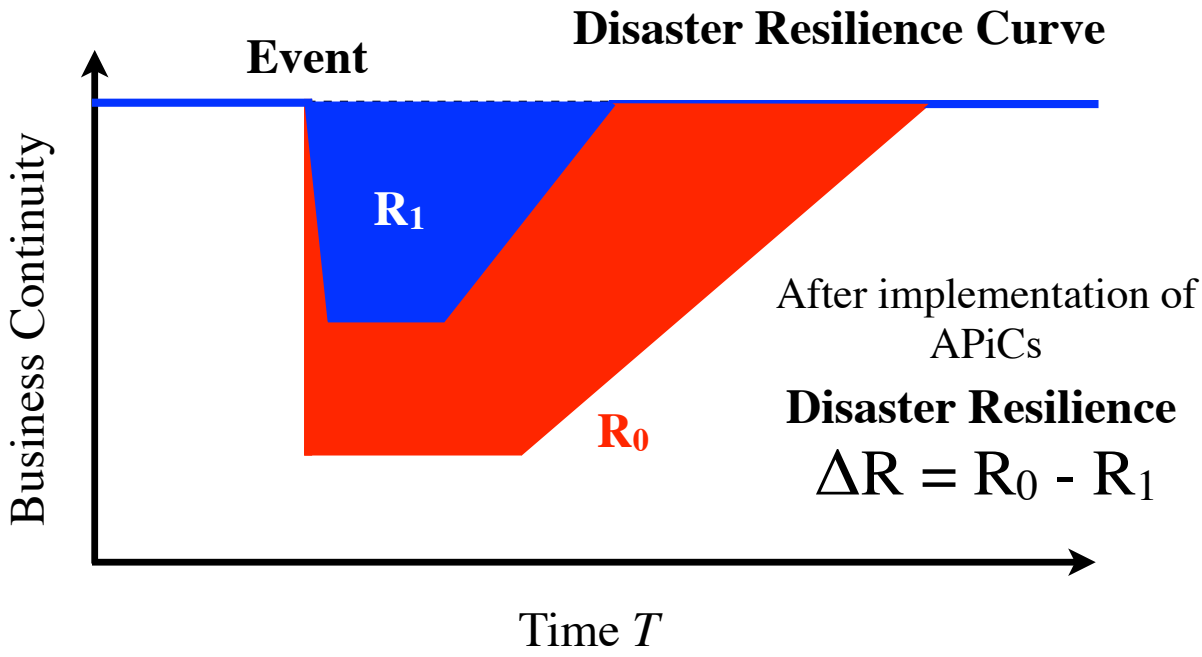
Evaluation of Disaster Risk Reduction Performance

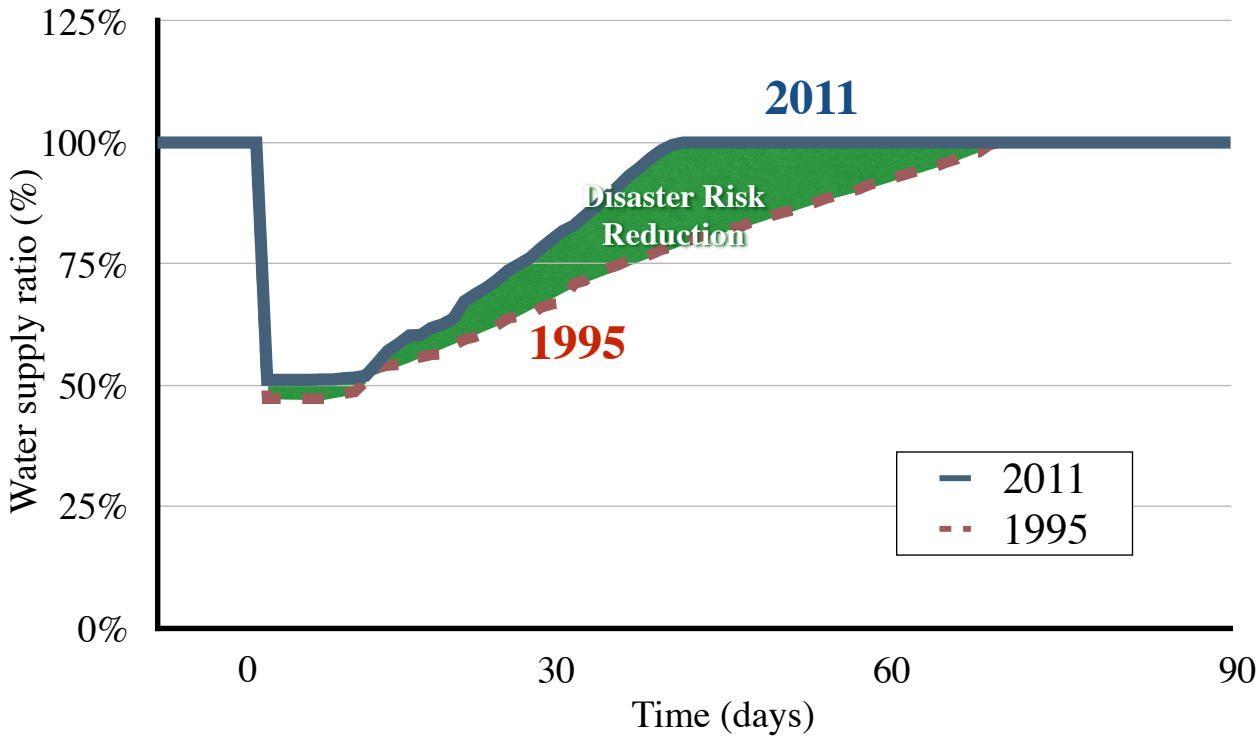


After implementation of APiCs

Disaster Resilience

$\Delta R = R_0 - R_1$

Comparison Results in Business Continuity; Water Supply Ratio in Kobe Case



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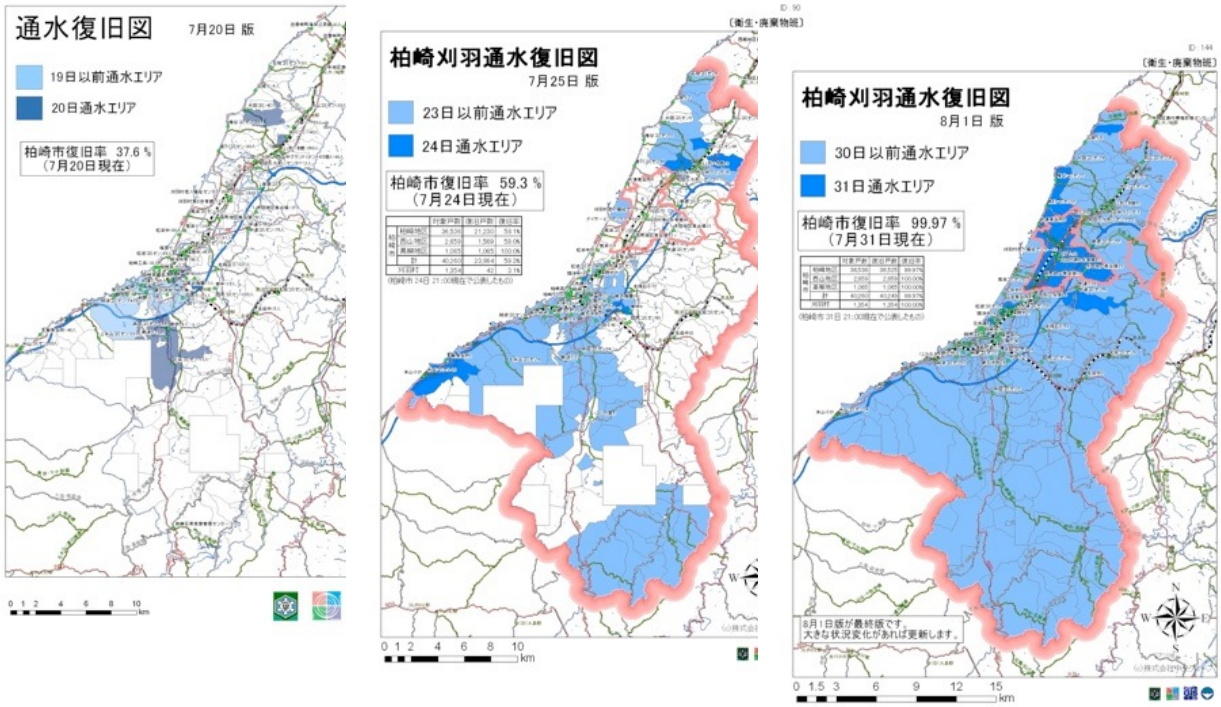
Water System Recovery Map after Earthquake



Communication with Community in Emergency

- **Basic Act on Disaster Control Measures (Cabinet Office, Government of Japan)**
  - Act for prompt and precise circulation of information, public relations for support the appropriate decision of citizens to ensure the security in emergency
- **Action Plan for Disaster Prevention (Local Municipal Governments in Japan)**
  - Provision of disaster information

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Newspaper after 1995 Kobe Earthquake

ライフライン復旧状況

	神戸	西宮	芦屋	尼崎	伊丹	宝塚	川西	猪名川	淡路
水道	9％	10％	×	70％	80％	50％	90％	○	北淡×
ガス	ほぼ×	ほぼ×	×	○	○	中心部	20％	30％	北淡×
電気	一部	ほぼ○	○	○	○	○	○	○	○
毛布	16万	1.4万	2万	不明	6千	7千	9百	0	充足
医療	県が神戸などに医師55人、看護婦85人、薬剤師10人。保険証なしで受診可								
食料	神戸市でパン10万個確保など。淡路は充足								

（注）○は復旧、×は見通し立たず、％の数字は復旧率。

Recovery ratio
(Kobe Newspaper, Jan. 20, 1995)

◆水道復旧見込み　県の22日のまとめによると、復旧の見通しは今後2、3日＝津名郡淡路町▽約1週間＝尼崎市、川西市、津名町▽1月末＝伊丹市、北淡、一宮町▽2月上旬＝神戸、明石、宝塚市▽同下旬＝西宮、芦屋市、神戸市は22日中に復旧率48・6％に達するとした。

Expected restoration period
(Kobe Newspaper, Jan. 23, 1995)

水、住宅、病院

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◆通水（神戸市）新たに校（兵庫区下三条町）▽長田区五番町四丁目バス停付の、同くまの▽新港第八突堤＝補給艦とわだ▽魚崎・次の九万五千世帯で。灘区近海自阪神基地隊＝護衛艦と＝都賀川―石屋川間▽中央かち▽青木フェリー岸壁＝区＝中山手通、三宮町、加枝吉）。

納町、諏訪山町の各一部▽◆宮水を開放（西宮・菊正宗酒造）同市久保町二の補給艦。問い合わせは海自須磨区＝板宿―須磨浦間▽非戸を一般に開放。阪神基地隊☎078・441・1001。

垂水区＝つつじが丘、臨海部▽西区＝押部谷町、玉津町、平野町、西神ニュータウン、学園都市、枝吉、曙町。旧市街地はJR神戸線の南側を中心とする区域。

◆仮設水道（同）新たに陸艦みうら、同さつま▽新港第四突堤＝護衛艦よし次の市内三カ所。平野小学

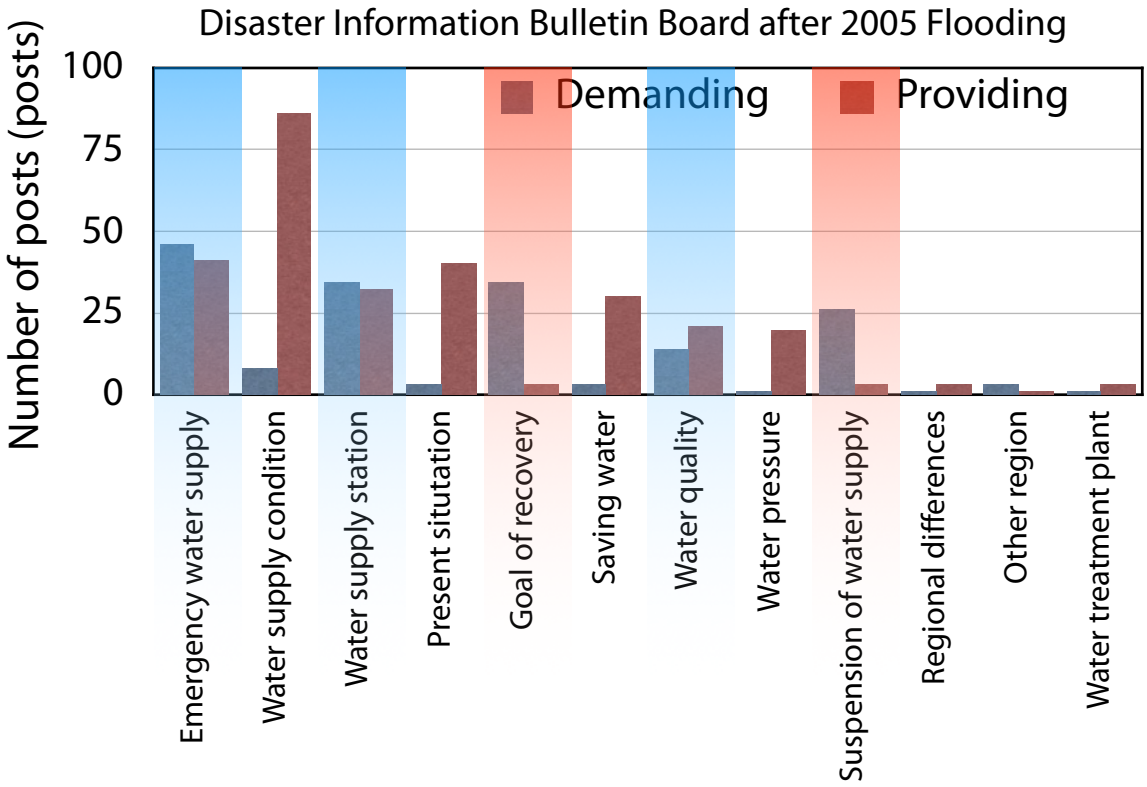
◆飲料水補給（海上自衛隊）七隻の艦艇を使い、神戸港の五カ所で飲料水の提供を開始。当分の間、二十四時間対応。接岸場所は次の通り。新港第一突堤＝揚

◆交通（神戸市など）神戸・ハーバーランド高浜岸壁―大阪天保山間に、二十

◆国民年金保険料（県災害対策本部）納付が困難な地震被災者を対象に、保険料を免除。希望者は住所地の市区町役場に申請を。

Water availability
(Kobe Newspaper, Jan. 20, 1995)

Demanding and Providing of Information on Emergency Water Supply



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Communication with Customers' Controllability

— **Customers' Controllability**

✓ A technical term in Social Psychology

✓ According to proper risk information, a customer becomes able to make a choice of risk for own volition.

— Hirayama (2005) pointed out that information that increases controllability about the risk of drinking water quality reduces customers' concern in water quality.

Objective of This Study

- To reveal emergency information disclosure technique that reduces disaster risk of customer in the restoration period from the viewpoint of customers' controllability

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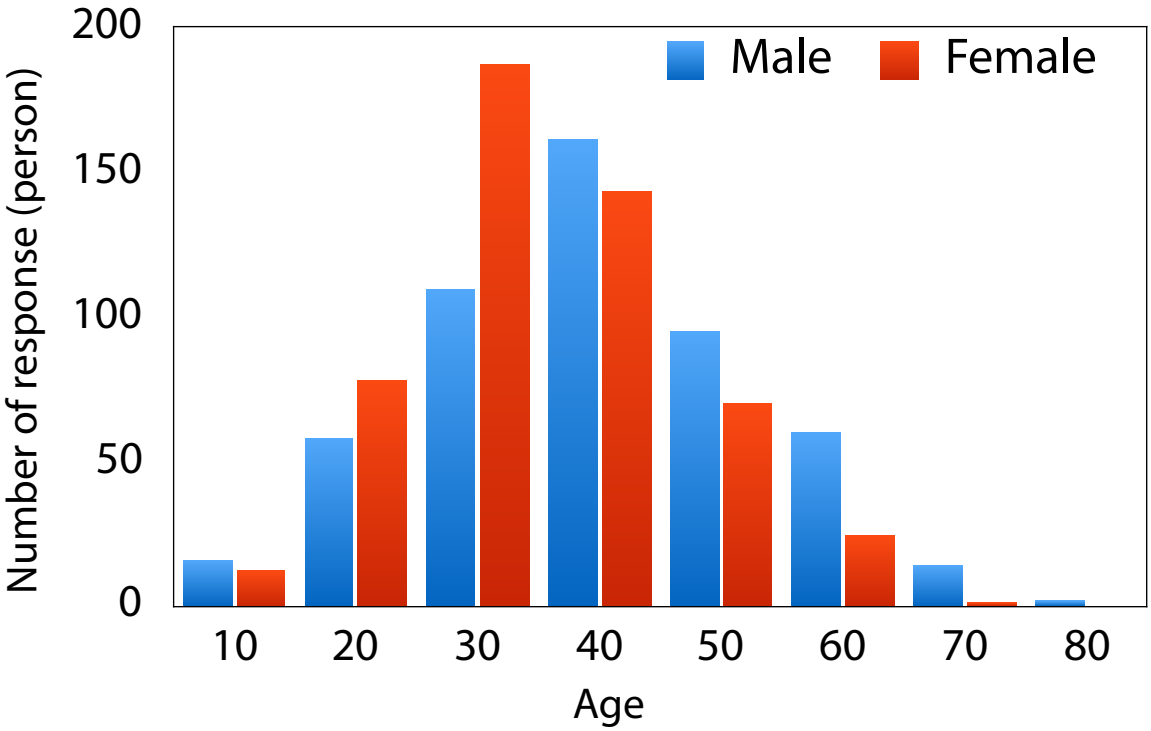
Questionnaire Survey

- Internet-based
- Residents in Japan
- March 21 – 22, 2012, 2 days
- 1,000 responses (male = 50%, female = 50 %)

Response Classification (Age)



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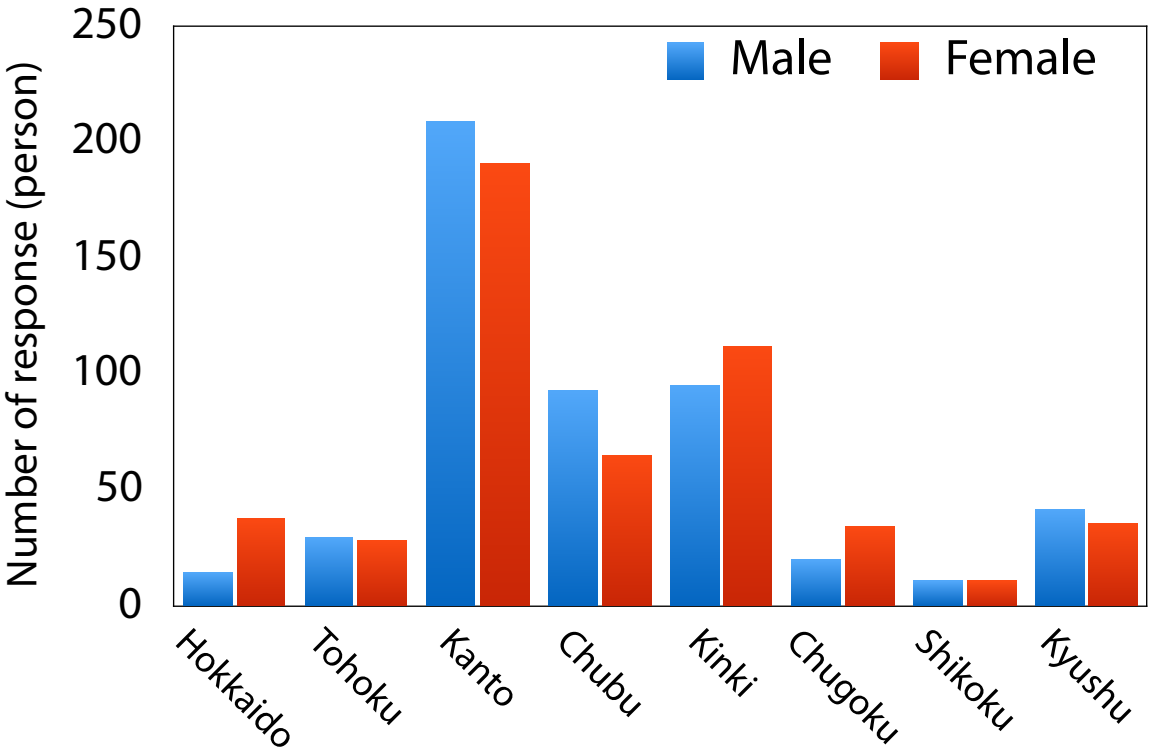
Response Classification (Region)



Questionnaire Items

A. Drinking style for tap water

B. Experience of emergency water supply

C. Perception of Information on water supply system in emergency

(1) Damage to water supply system

(2) Prediction of future situation for recovery and reconstruction

(3) Concrete goal, policy

(4) Strategies and operation for emergency recovery

(5) Report of recovery using GIS and illustration

(6) Periodical information update

D. Crucial information in emergency recovery operation

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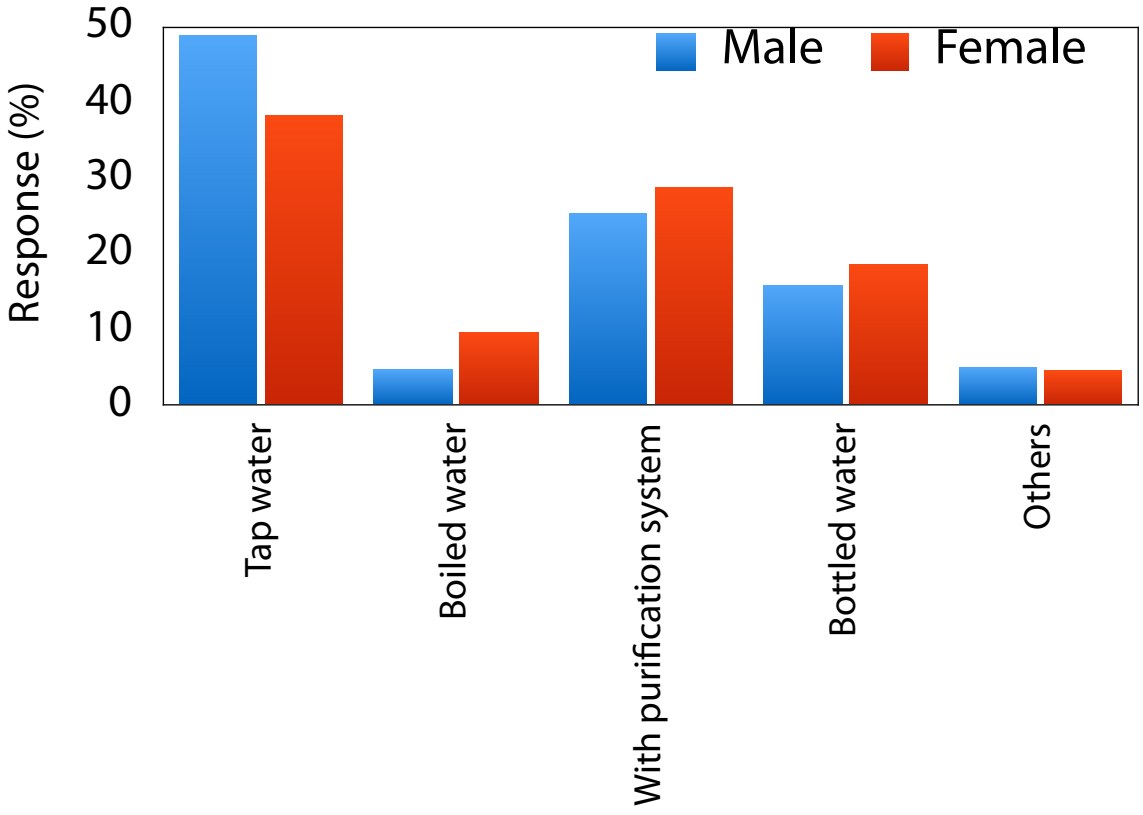
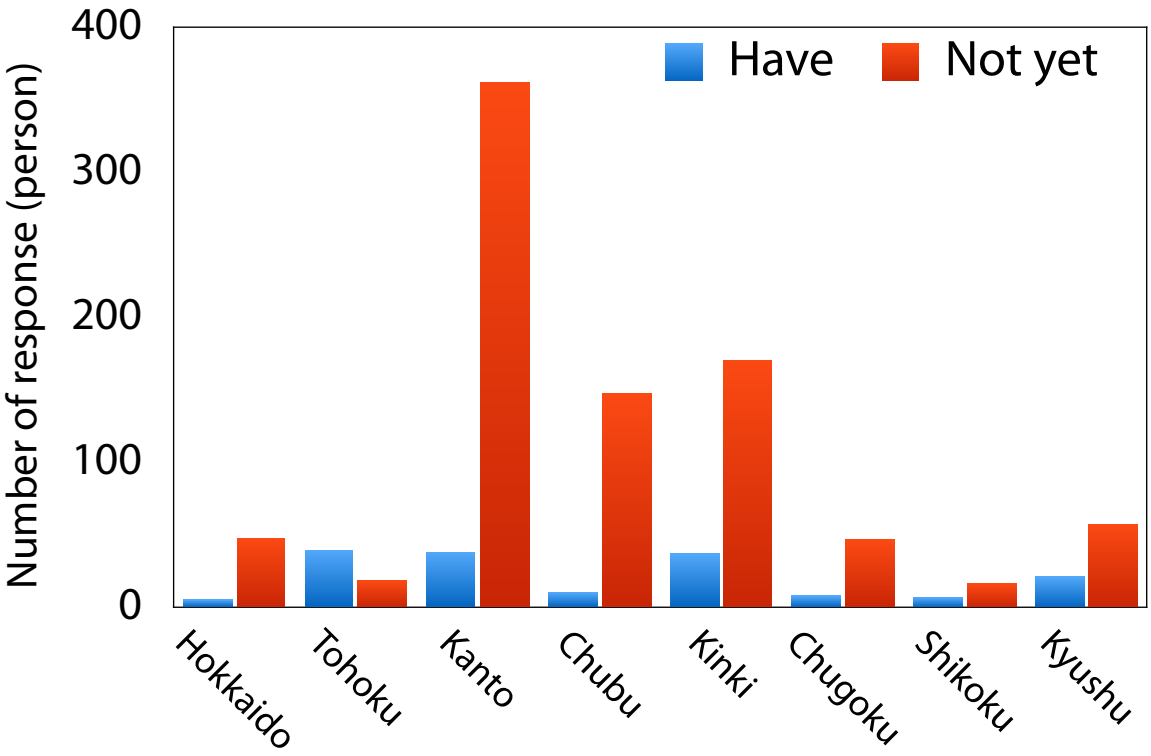
Alternative Drinking Tap Water



Experience of Emergency Water



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Potential Factors in the Information Disclosure

- **Factor analysis**
  - N = 1,000
  - Perception of information on water supply system in emergency
    - ✓ Five point Likert scale
  - Promax rotation
  - **Five factors** were extracted.

Five Factors in the Information Disclosure in Emergency

1. **Reliability** to water utilities
2. **Controllability** of disaster risk
3. Disaster **risk reduction**
4. **Same understanding** and Common Operational Picture
5. **Comprehensiveness of information**

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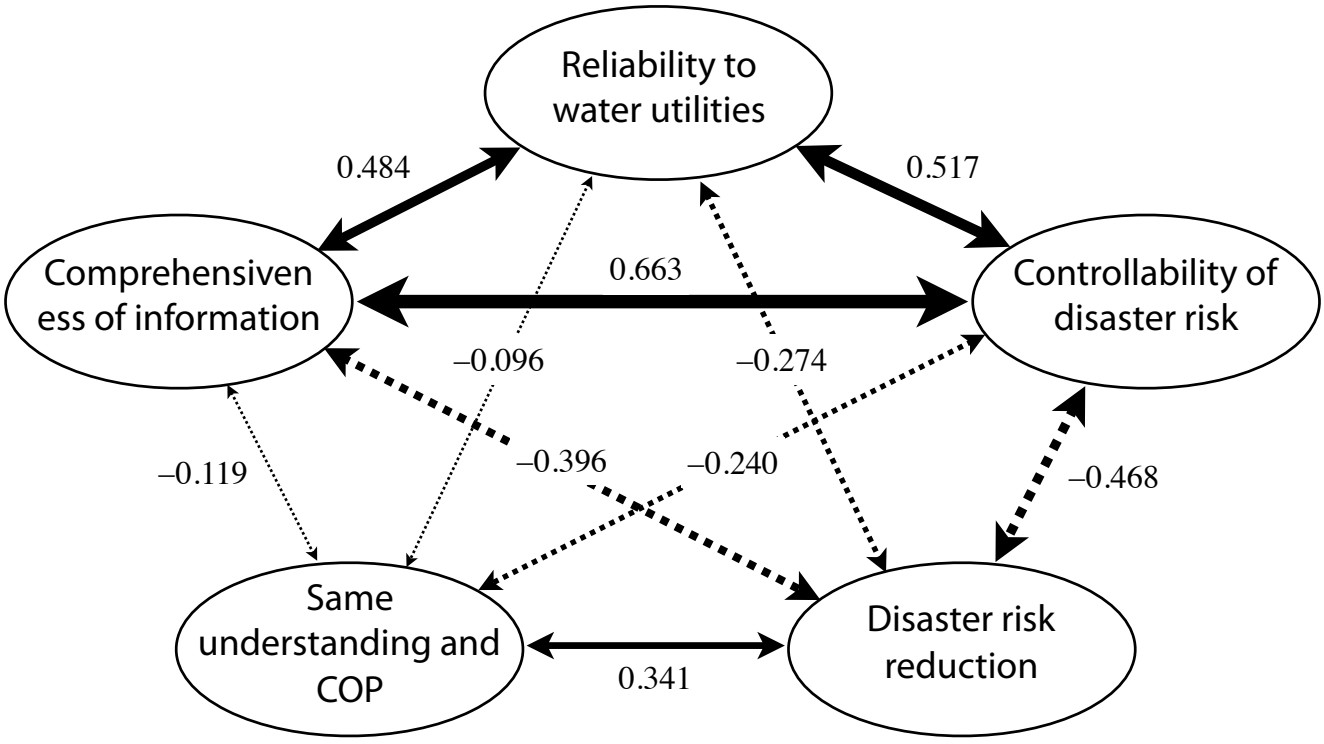
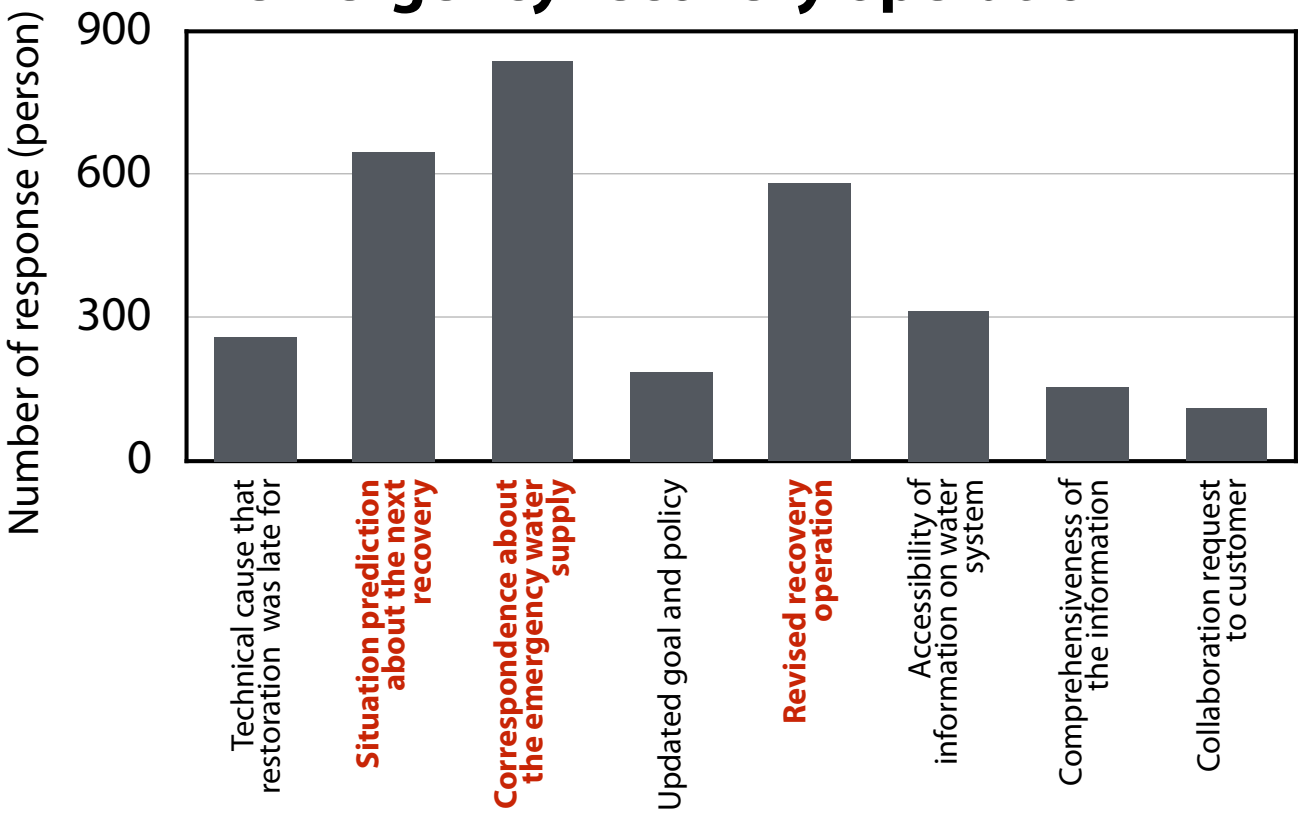
Path Diagram of Five Factors



1% significance level

Crucial information in emergency recovery operation



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Conclusions

- Five Factors in the Information Disclosure in Emergency
  - ✓ Reliability to water utilities
  - ✓ Controllability of disaster risk
  - ✓ Disaster risk reduction
  - ✓ Same understanding and Common Operational Picture
  - ✓ Comprehensiveness of information
- **Information with customers' controllability** result in **reliability to water utilities**

Concluding Remarks

- More Resilient and Reliable Water System
  - Business continuity planning & management
  - Disaster mitigation & preparedness
  - Technologies (Hardware) & Systems (Software)
  - Community-based
  - Utility's culture and mission
  - Water professional mind