Developing a Seismic Resilient Pipe Network Using Performance Based Design Procedures

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Objectives

This presentation describes

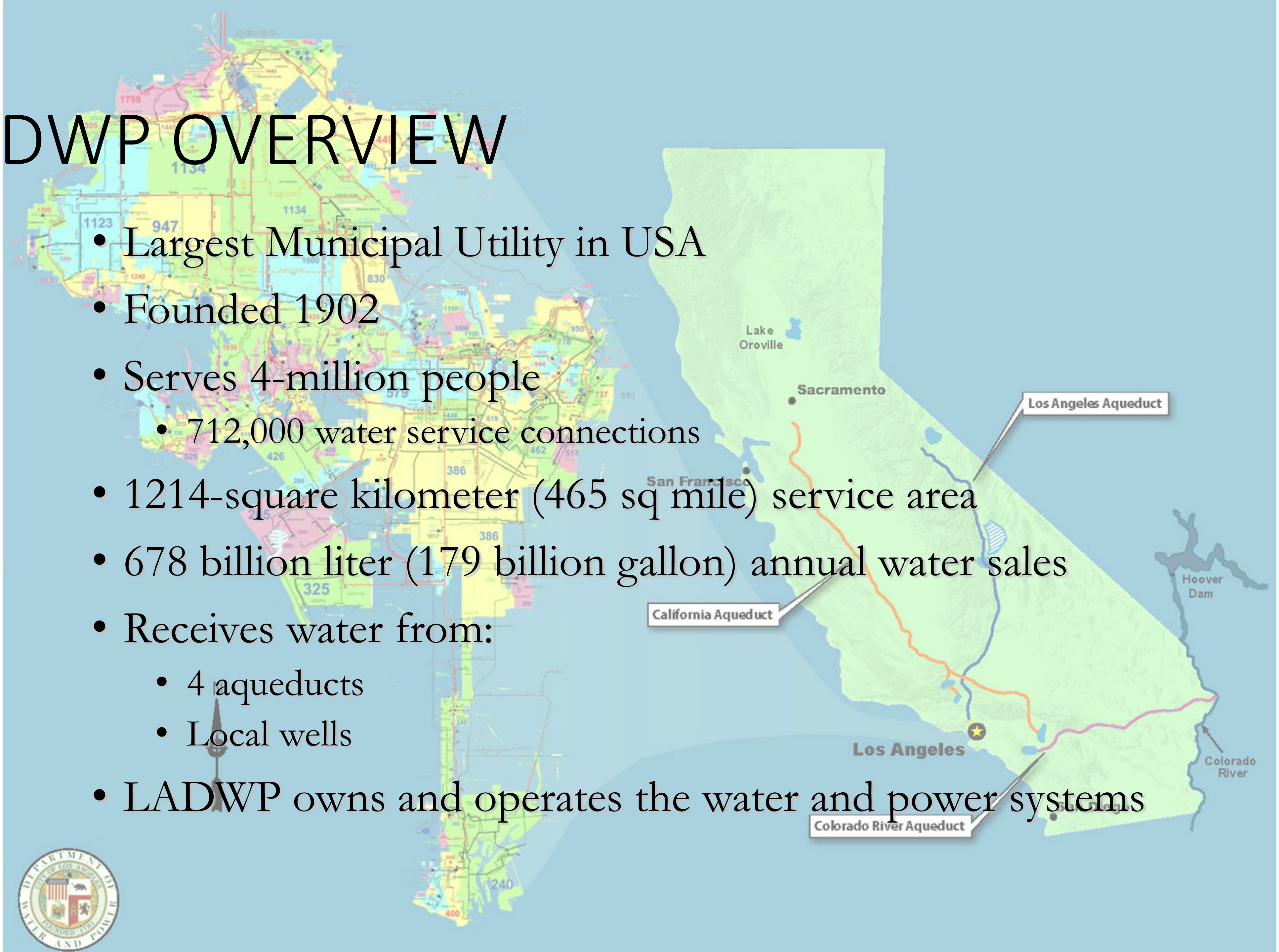
- How the Los Angeles Water System is proposing to have consistent design and construction across the entire service area for all seismic hazards it is exposed to, by implementing a **Performance Based Seismic Design** methodology
- Application of this methodology to create a **Seismic Resilient Pipe Network**

Contents

- Introduction to Water System performance based seismic design
- Performance objectives
- System level performance
- Component level performance
- Seismic resilient pipe network
  - Resilient transmission network
  - Resilient distribution network
  - Implementation

LADWP OVERVIEW

- Largest Municipal Utility in USA
- Founded 1902
- Serves 4-million people
  - 712,000 water service connections
- 1214-square kilometer (465 sq mile) service area
- 678 billion liter (179 billion gallon) annual water sales
- Receives water from:
  - 4 aqueducts
  - Local wells
- LADWP owns and operates the water and power systems



LA Water System Resilience Program

Primarily formulated by two reports

1. LADWP Summary Report
   - Water System Seismic Resilience and Sustainability Program

2. Resilience by Design
   - Mayor Eric Garcetti
   - Dr. Lucy Jones, United States Geological Survey
     Mayor's Science Advisor for Seismic Safety

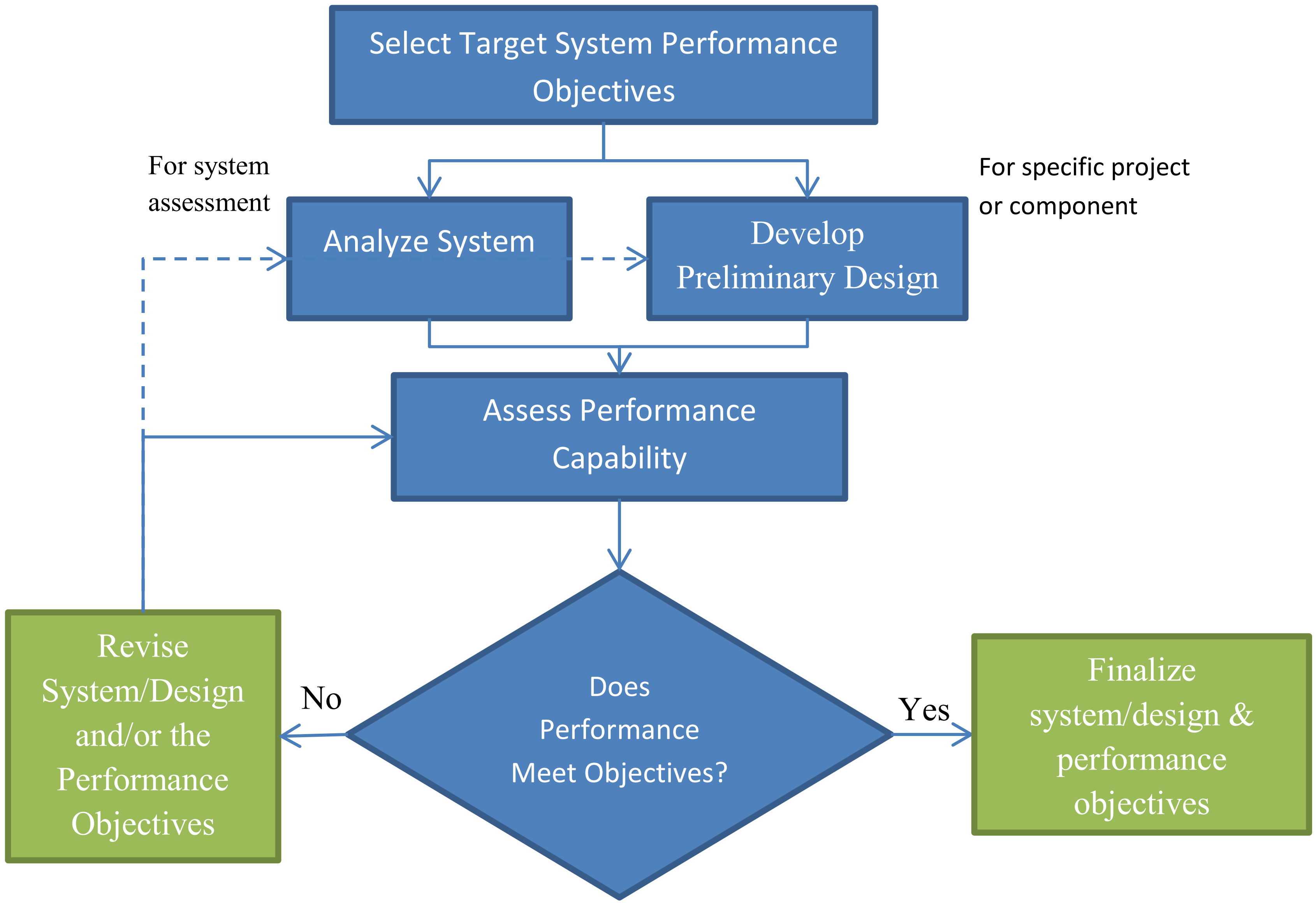
Common Recommendation: **Develop a Seismic Resilient Pipe Network**

A resilient pipe network must be consistent with all other water system components
To do this, an overarching procedure applicable to the entire system is needed

What is Performance Based Seismic Design?

- Process in which the performance of the system and components being designed is evaluated over the entire range of possible loadings rather than for one or more discrete intensities or events.
- System to be designed to match targeted objectives
- Components designed to prepare system to meet the targeted objectives
- Objectives are scaled relative to the probability and size of earthquake events.
  - The larger/less probable events will have more expected service losses and longer time to restore

Performance Based Design Flow Diagram



Draft Target Performance Criteria

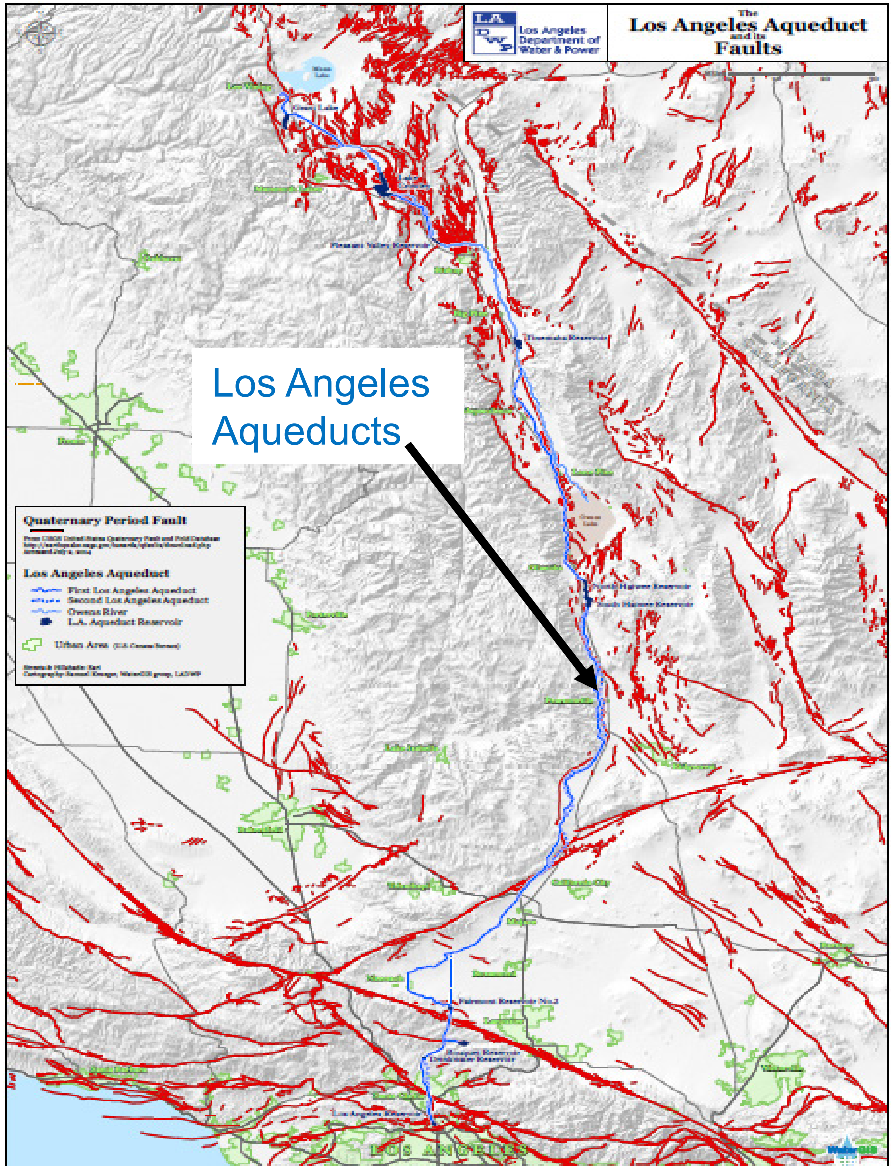
Level	Hazard Return Period Criteria	Target Water System Performance
1	100 years	Limited damage to water system, no casualties, few to no water service losses. All customer services operational within about 3 days.
2	500 years[1]	Life safety and property protection. All customer services operational within about 20 days, except water quantity; rationing may extend up to 30 days.
3	2,500 years[1]	Life safety and property protection. All customer services operational within about 30 days, except water quantity; rationing may extend up to 60 days.
4	>2,500 years up to about 10,000 years; including major to great earthquakes	Life safety and property protection. All customer services operational within about 45 days, except water quantity; rationing may extend up to 12 months.

[1]Highly active faults like the San Andreas Fault have great earthquakes of Mw>7.8 within Level 1 and 2 return periods, for which the performance criteria are proposed to meet Level 4

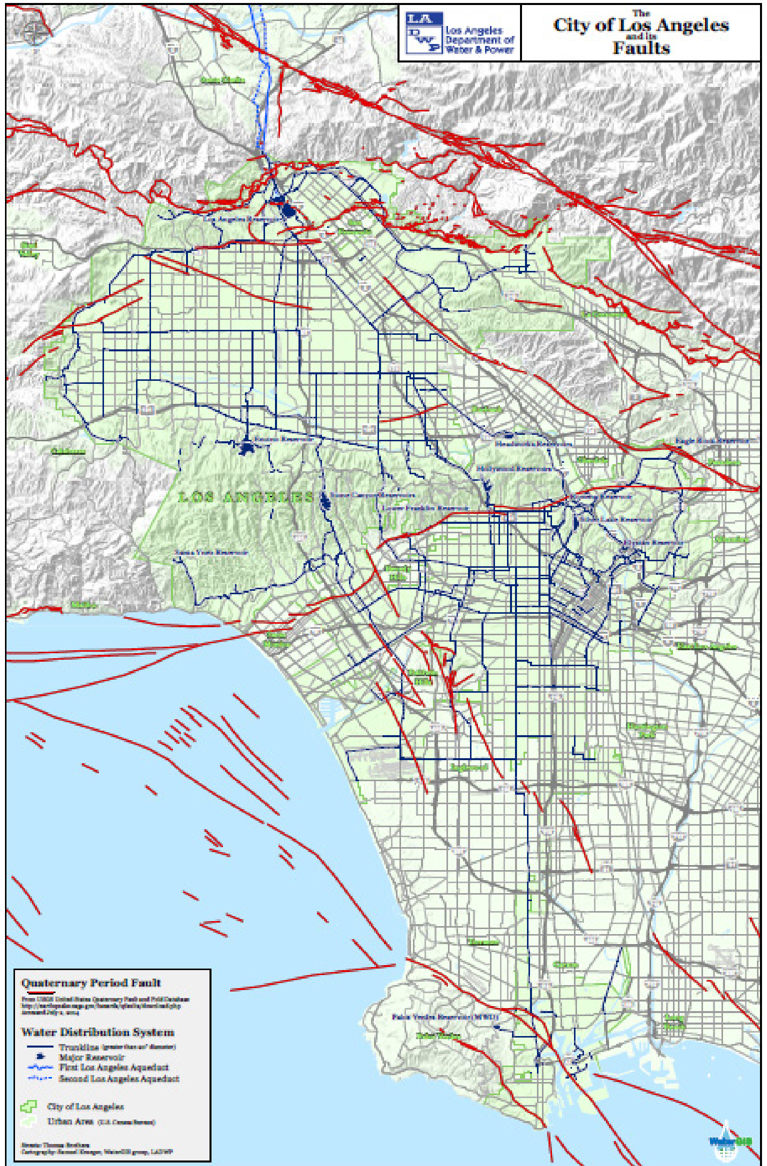
Earthquake Sources

- Faults listed in Appendix A
- Over 40 faults
- 30 impact City
- More than 20 rupture ground surface in LA

Los Angeles Aqueducts



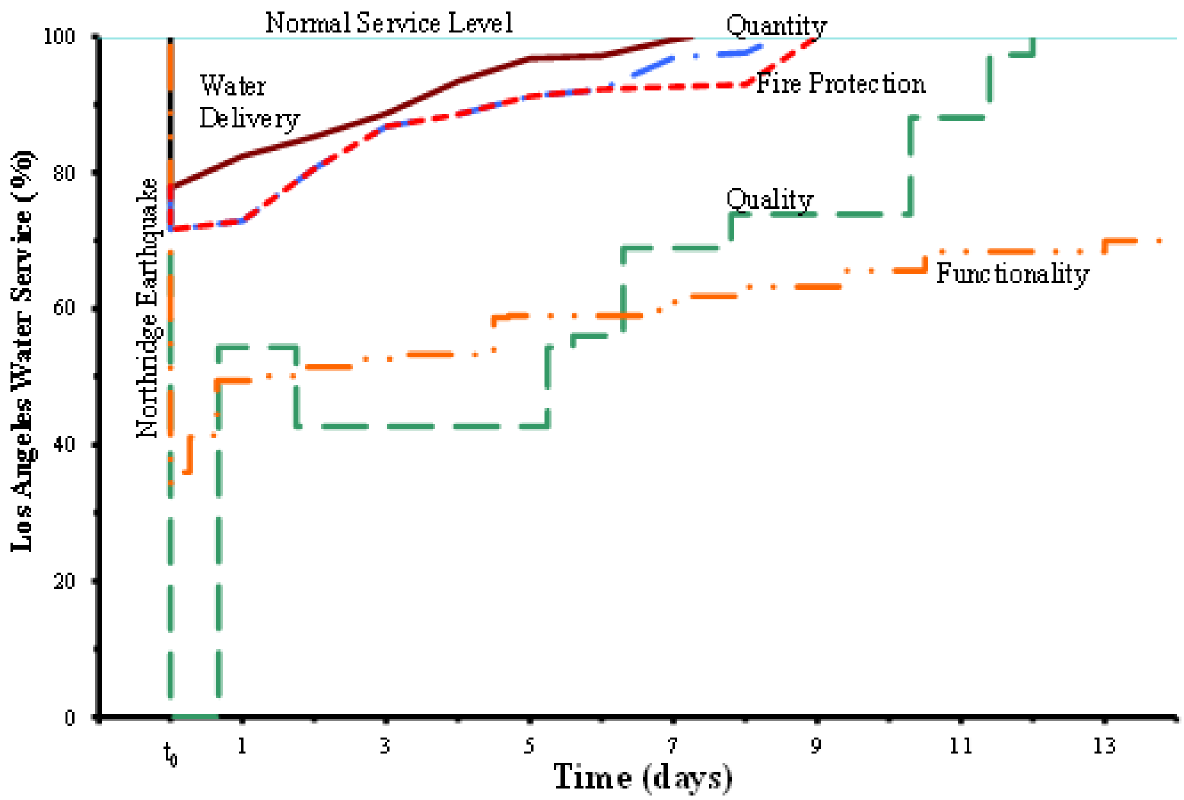
Los Angeles Metro Area

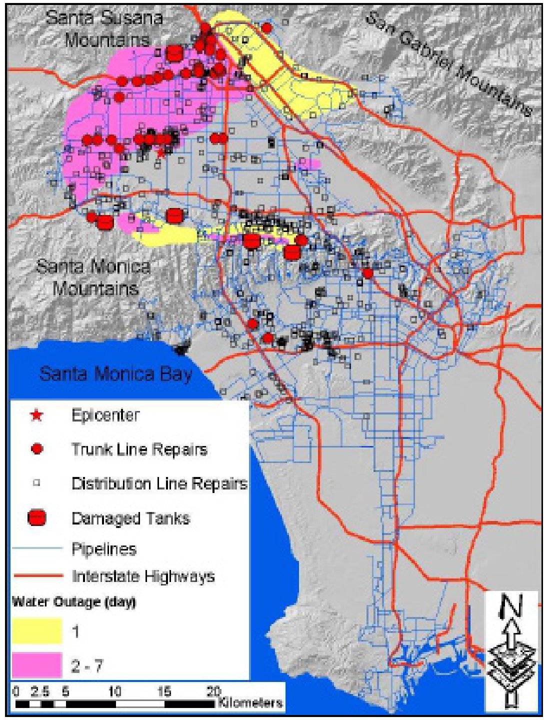


SYSTEM LEVEL PERFORMANCE: Water System Service Categories

Service Categories	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).	Does water come out of tap?
Quality	Water to customers meets health standards (water purification notices removed). This includes minimum pressure requirements.	Is it safe to Drink?
Quantity	Water flow to customers meets pre-event volumes (water rationing removed).	Can you get the amount you need?
Fire Protection	Able to provide pressure and flow of suitable magnitude and duration to fight fires.	Does Fire Dept. get what they need?
Functionality	The system functions are performed at pre-event reliability, including pressure (operational constraints resulting from the disaster have been removed/resolved).	Is the water system in working order?

1994 NORTHRIDGE EARTHQUAKE, L.A.
EXAMPLE WATER RESTORATIONS





Community Resilience

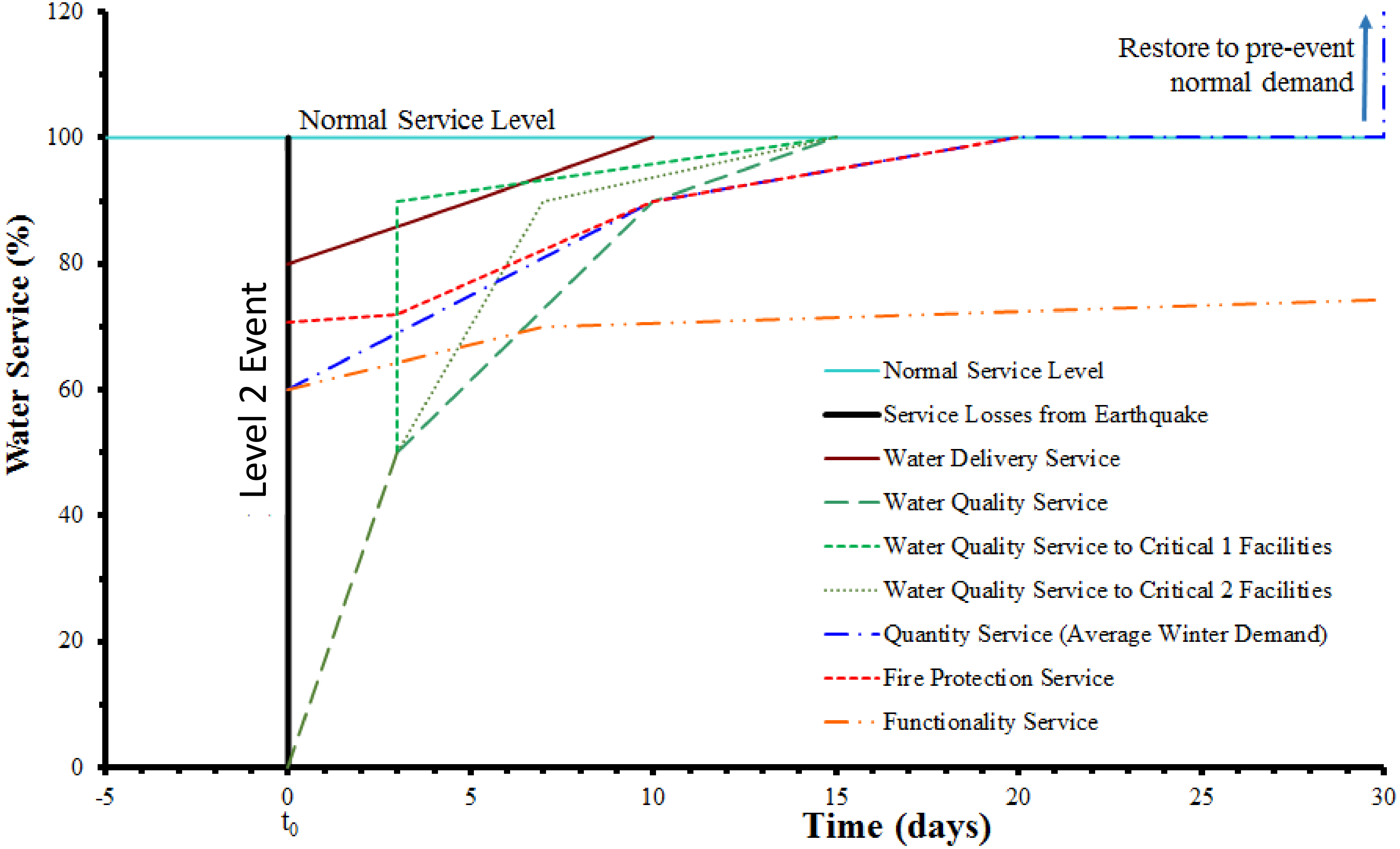
- Service restoration to critical customers, defined as
  - Critical A Customers: public health and safety
    - Examples: Hospitals, Evacuation Centers Fire Department, etc.
  - Critical B Customers: critical community resilience services
    - Examples: schools not used as evacuation centers, lifeline utilities not providing public health services, etc.

Draft Service Goals Level 2

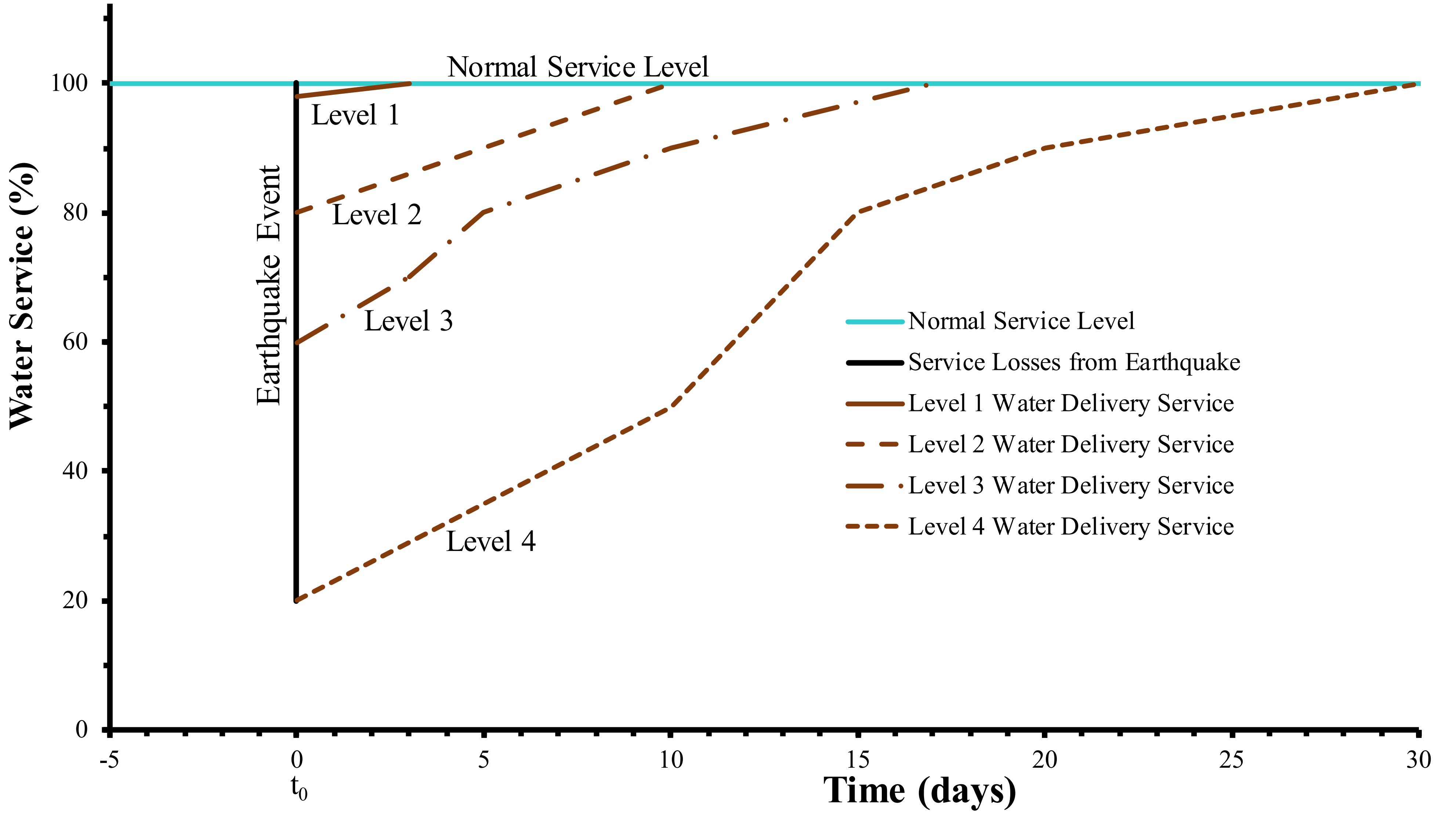
Service Category	Service Description	Target restoration time
Delivery[1]	Limit losses to approximately 20% of customers	0 days
	Restore to 90% of customers	5 days
	Restore to all customers	10 days
Quality[2]	Restore to 50% of customers	3 days
	Restore to 90% of customers	10 days
	Restore to all customers	15 days
	Restore to 90% of all Critical 1 customers[3]	3 days
	Restore to 90% of all Critical 2 customers[3]	7 days
Quantity	Implement city-wide rationing at average winter day demand (AWD)	0 days
	Limit losses below AWD to approximately 40% of customers[1]	0 days
	Restore AWD to 90% of customers	10 days
	Restore AWD to all customers	20 days
	Restore to pre-event normal demand	30 days
Fire Protection	Provide partial[4] services from pipe network within 5-miles distance of any delivery loss	0 days
	Provide partial[4] services from pipe network within 2-miles	3 days
	Restore to 90% of hydrants	10 days
	Restore to all hydrants	20 days
Functionality[5]	Limit system losses to approximately 40% (maintain 60% functionality)	0 days
	Restore system to 70%	7 days
	Restore system to 80%	60 days
	Restore system to 90%	180 days
	Restore system to 100%	360 days
	Improve system vulnerabilities identified	5 years
Emergency Accessibility	Provide 1 gallon per person per day potable water to domestic users within 5 miles from residence[6]	3 days
	Provide 2.5 gallons per person per day potable water to domestic users within 0.3 miles from residence[7]	7 days

[1]System is able to contain flow and minimize continued service losses in 1 day or less (i.e., drainage losses are constrained and do not have significant continued drainage).
[2]Water quality may be effectively lost to all customers out of precaution taken by issuing city-wide tap water purification notice. This has occurred in past earthquakes in LA (e.g., Davis et al., 2012).
[3]Critical customers and facilities are described in Appendix B.
[4]May not meet hydraulic requirements for pressure and volume, but sufficient flow to be used with in-line pumping and hauling.
[5]Functionality can be measured using Davis (2014b) or other similar evaluation methods.
[6]Rough estimate of distance based on expected area of delivery service loss, current water bladder plan, and assumed additional support from other organizations such as FEMA, Red Cross, and other volunteer organizations.
[7]Volume and distance estimates based on recommendations from World Health Organization (2005). Volume includes use for consumption (drinking and food preparation), personal hygiene, and laundry.

Draft Service Goals – Level 2



Draft Delivery Service Restorations



WATER SUBSYSTEMS

Water System is made up of multiple subsystems having their own characteristics

Subsystems	Description	Typical Facilities/Components
Raw Water Supply Systems	Systems providing raw water for local storage or treatment including local catchment, groundwater, rivers, natural and manmade lakes and reservoirs, aqueducts.	Reservoirs, pump stations, wells, pipelines, canals, tunnels, dams, levees, raw water intersystem connections. This may also include pertinent storm water capture facilities.
Treatment Systems	Systems for treating and disinfecting water to make it potable for safe use by customers.	Treatment plants, ultraviolet treatment processes, filtration systems, settling basins, chlorination stations.
Transmission Systems	Systems for conveying raw or treated water. Raw water transmission systems convey water from a local supply or storage source to a treatment point. Treated water transmission systems, often referred to as trunk line systems, convey water from a treatment or potable storage point to a distribution area.	Medium to large diameter pipes (>20”), tunnels, reservoirs and tanks, pumping stations, valves and regulating stations. This also includes treated water intersystem connections.
Distribution Systems	Networks for distributing water to domestic, commercial, business, industrial, and other customers.	All pumping stations, regulating stations, tanks and reservoirs, valves, and piping not defined as part of other subsystems forming a network from connections at the transmission systems to points of service.
Recycled Water Systems	Systems for producing, disinfecting, conveying, and distributing recycled water to customers.	Treatment plants, pumping stations, regulating stations, tanks, valves, and piping.

Each subsystem is critical to providing services

Component Level Design

Each component must be designed and constructed in a manner to provide the targeted system performance

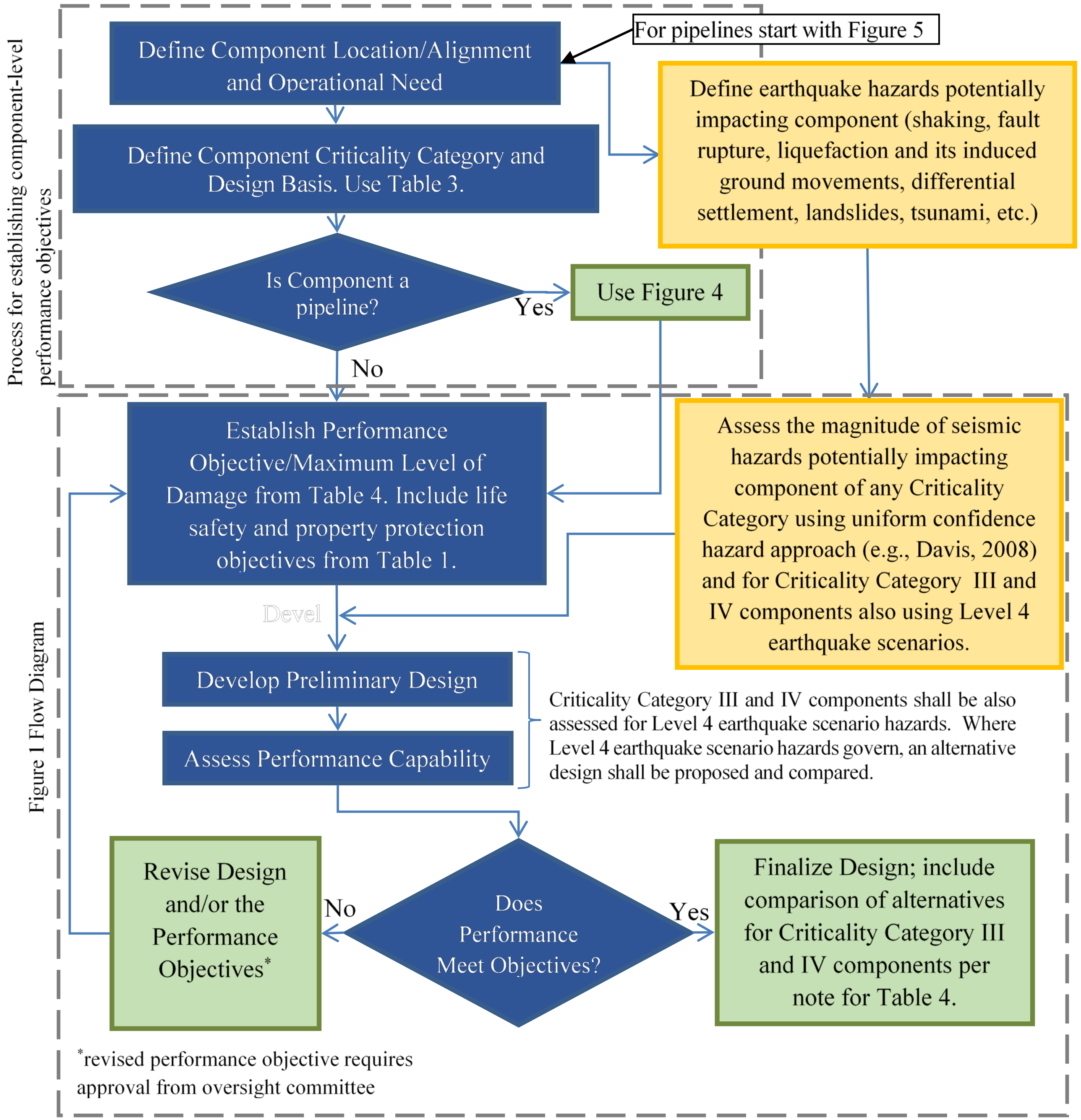


Figure 3

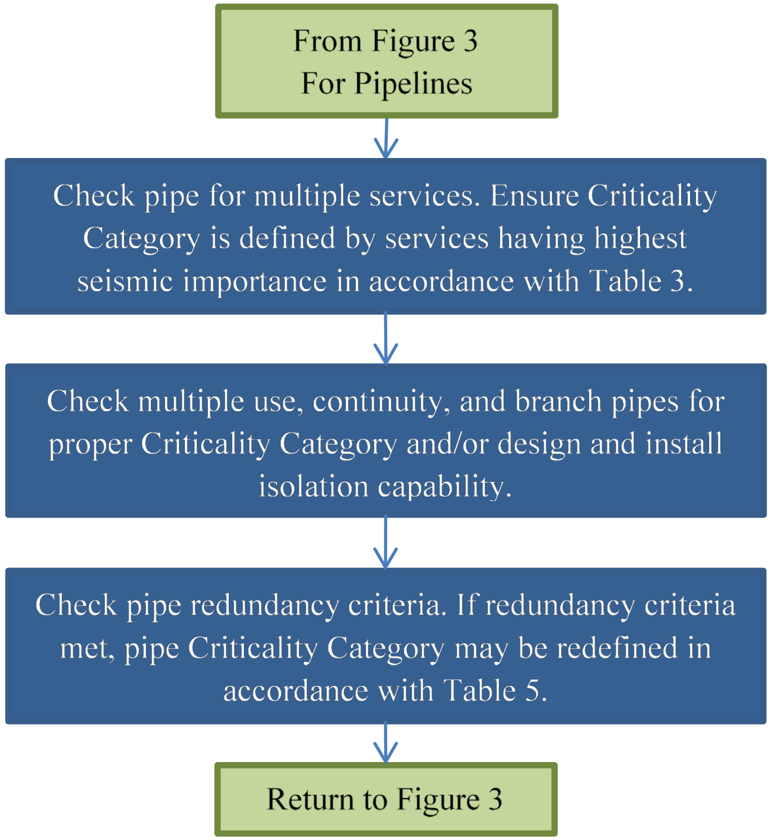


Figure 4

Criticality Categories

- Each component is to have a designated Criticality Category I, II, III, or IV
- The design of each component for defined hazard return period in table below is expected to aggregate to the desired system-level performance

Criticality Category	Description	Design basis hazard return period (years)
I	Components that present very low hazard to human life in the event of failure. Not needed for post-earthquake system performance, response, or recovery.	72
II	Normal and ordinary components not used for water storage, pumping, treatment or disinfection. They provide water for typical residential, commercial, and industrial use within the system and include all components not identified in Criticality Categories I, III, and IV.	475
III	Components, mainly pipelines, providing water to services that represent a substantial hazard or mass disruption to human life in the event of failure. These components may also result in significant social or economic impacts in the event of failure.	975*
IV	Components needed to provide water to essential facilities for post-earthquake response, public health, and safety. This includes components needed for primary post-earthquake firefighting. These components are intended to remain functional during and following an earthquake.	2,475*

*Note: Also check against Level 4 earthquake scenario hazards,

Component Performance Objectives

- Component performance objectives are established through definitions of maximum tolerable damage
- Each designation of minor, moderate, high, and severe damage have corresponding definitions
- Designs for Criticality Category III and IV components are to be checked against Level 4 earthquake scenario hazards.

Increasing Performance

Increasing Event Intensity

		Criticality Category			
		I	II	III	IV
Level 4 Event Scenario*		Severe	High to Severe	High	Moderate to High
Hazard Return Period (yrs)	2,475	High to Severe	High	Moderate to High	Moderate
	975	High	Moderate to High	Moderate	Minor to Moderate
	475	Moderate to High	Moderate	Minor to Moderate	Minor
	72	Moderate	Minor to Moderate	Minor	None

Redundant Pipes

- Criticality Category may be reduced based on increased reliability
- This redundancy factor shall not be applied to any pipes which:
  1. Otherwise are required to have a higher Criticality Category based on life safety or other factors,
  2. Are exposed to common cause failures, such as:
     a. A leak or break in one pipe may lead to damage on other redundant pipes,
     b. Pipes are exposed to the same permanent ground deformation hazards (i.e., pipes cross same fault, landslides, liquefaction zones, etc.).
  3. There are foreseeable plans to remove the designated primary redundant pipe from operation, in which case multiple redundant pipes shall be designated to be the same highest-level Criticality Category for their intended use.

	L_R		
Criticality Category	0	1	2
I	I	I	I
II	II	II	II
III	III	II	II
IV	IV	III	II

Seismic Resilient Pipe Network

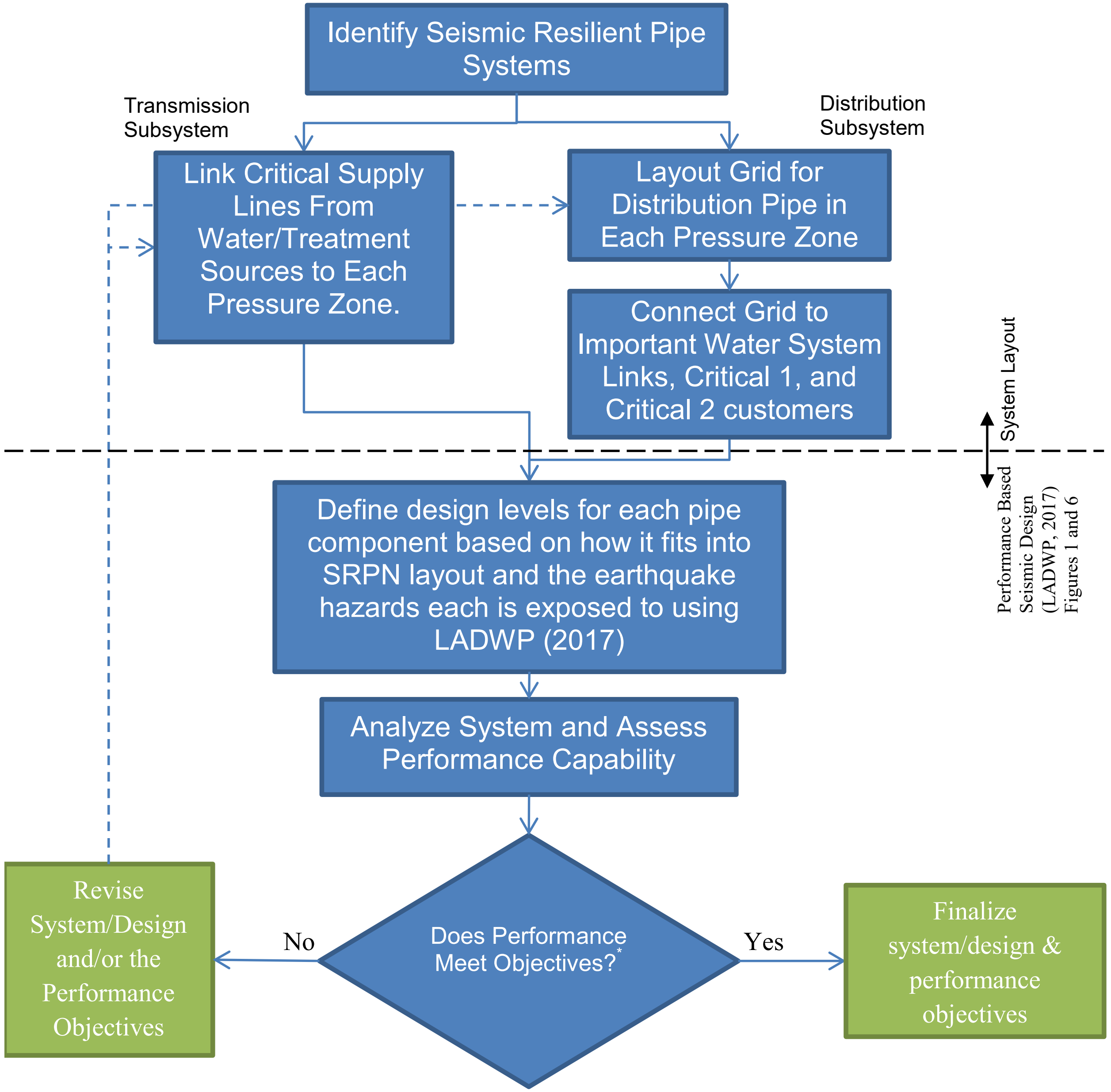
- <u>Definition</u>: A Seismic Resilient Pipe Network is designed and constructed to accommodate damage with ability to continue providing water or limit water outage times tolerable to community recovery efforts
- Seismically Robust Pipes
  - Earthquake Resistant Ductile Iron Pipe
  - High Density Polyethylene (HDPE)
  - Welded Steel with special design
  - Others under development and testing
- Water System Resilient Strategies
  - Prevent damage
  - Post-event pipe repair, limit damage level
  - Redundancy
  - Isolation
- Responsibility to Community Resilience
  - Provide water to critical areas when needed by community for disaster recovery

Relation to Performance Based Seismic Design

- The Seismic Resilient Pipe Network is the implementation of performance based seismic design principals as related to the transmission and distribution pipes
  - Made up of entire 12,000 km of pipe
  - Not just seismic resilient pipes
  - Considers how all pipes perform and their resulting interactions
- Necessary to meet the target performance objectives

- Proposing to use arterial sub-grid of seismically robust pipes which can be easily adapted to increase reliability of post-event services in support of community resilience
- Minimum pipe layout needed to meet performance objectives
- More seismically robust pipe can be used.
- If all pipe were seismically robust then plan would entail prioritizing seismic pipe placement

Process for Implementing Seismic Resilient Pipe Network



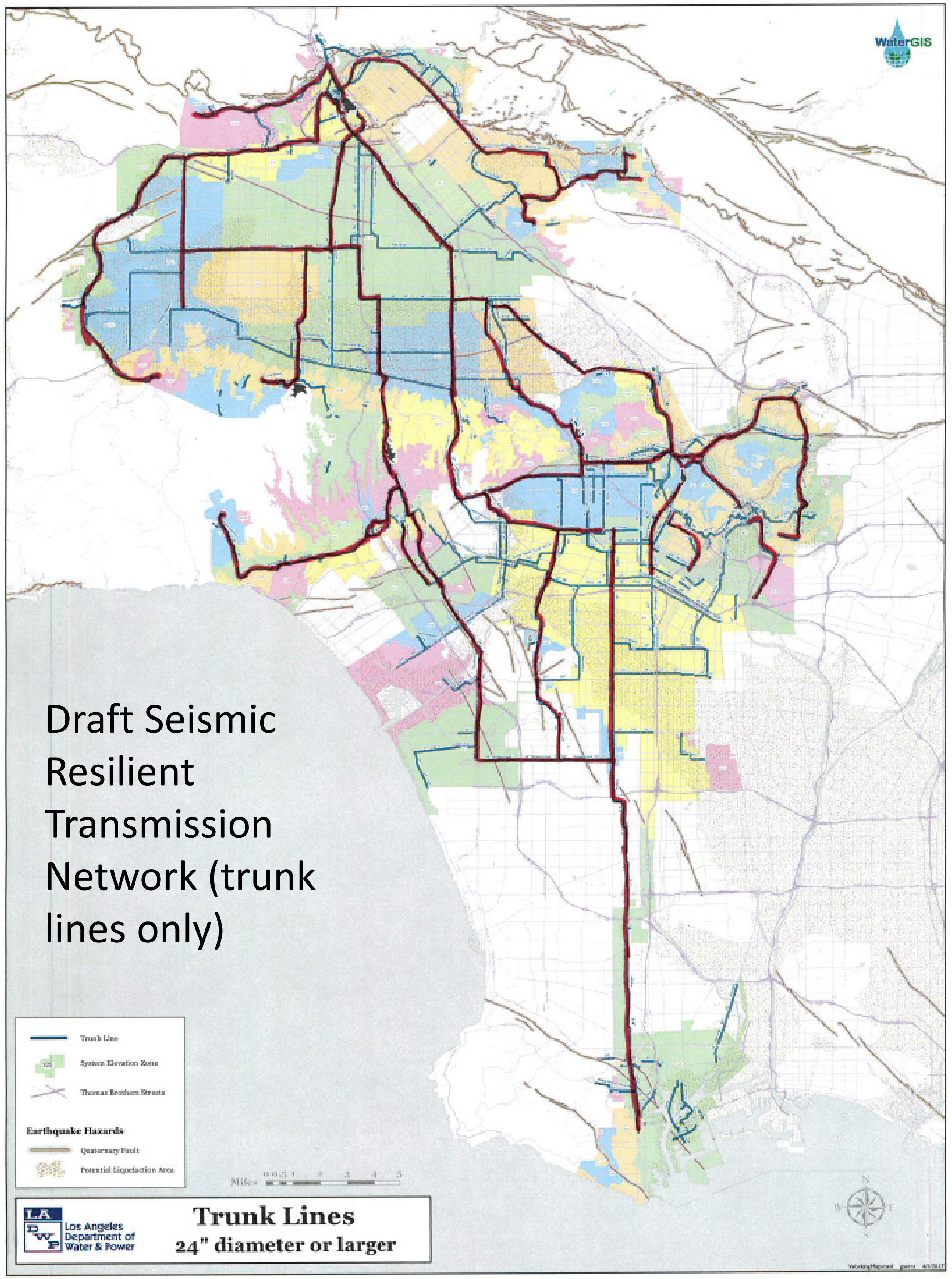
*Performance Objectives are defined in LADWP (2017)

Attributes of a Seismic Resilient Pipe Network

- Robust piping systems capable of resisting the seismic hazards for which they may be exposed, including: shaking, surface fault rupture, liquefaction induced settlement and lateral spreading, landslides, cyclic mobility, and other known earthquake hazards.
- Transmit bulk water to each pressure zone meeting minimum flow requirements established by performance objectives, proposed herein as average winter demand.
- Ability to rapidly isolate seismically reliable pipes
  - from more vulnerable pipes which may leak and drain potions of system following an earthquake.
  - To improve ability to rapidly isolate seismically reliable pipes to increase repair time
- Distribute potable water to critical customers within days after an earthquake, and in accordance with defined target performance objectives.
- Provide water flow to areas in need of fire suppression soon after an earthquake, consistent with the fire following earthquake risk and the Fire Department's equipment capability for relaying water.
- Support post-earthquake emergency water accessibility to customers who may not have potable water.
- Connects important links within the water transmission and distribution subsystems with seismically robust pipes. Critical links include, but are not limited to:
  - Transmission lines, regardless of the trunk line Criticality Category
  - Inter-system pumping connections (to pump between pressure zones)
  - Key water supply sources (tanks, reservoirs, ground water, treatment plants, inter-system connections to other agencies, etc.)
  - Pump and regulating stations
- Connects to Critical A and Critical B customers

Transmission Pipe

- Need **continuous transmission supply chain** of bulk water from supply/treatment to each pressure zone to provide **Average Winter Day Demand**
- Trunk lines and large distribution mains
- Hydraulic analysis needed to ensure performance criteria is met and to optimize the layout



Seismic Resilient Distribution Network

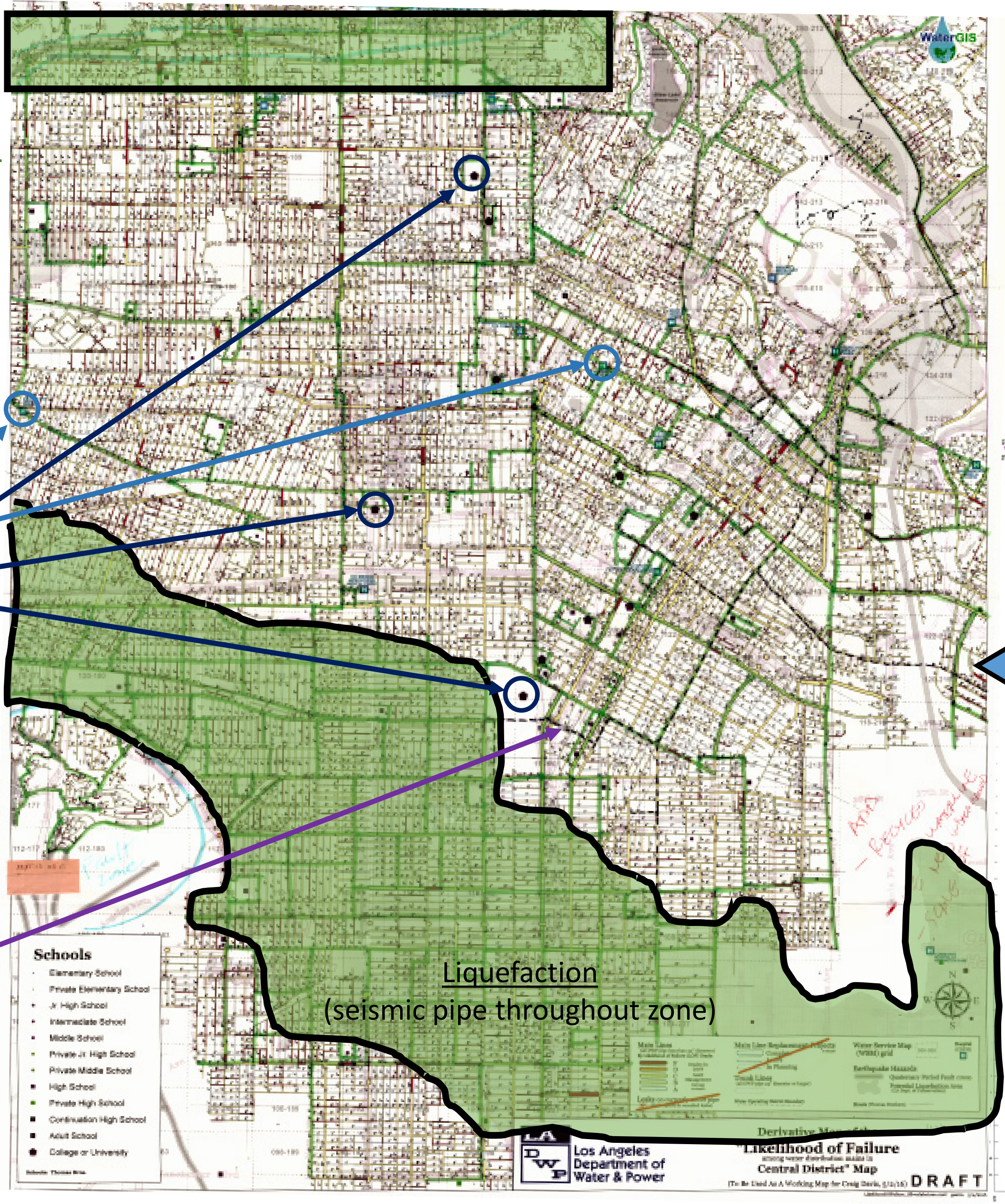
- Robust pipes placed at key locations and alignments to increase probability of continuous water delivery and reduce time to restore areas suffering from total loss of water after an earthquake
- Propose a grid of pipes determined primarily based on:
  - Firefighting needs and/or,
  - Emergency water distribution
- Grid recommended to be defined by:
  - LAFD capability to relay water through hoses (considering a maximum ~2-miles by 2-miles).
  - High risk areas to meet emergency water distribution needs in residential areas requiring long restoration (considering ~0.5-miles by 0.5 miles)
- Connect grid to important system links and critical customers using seismically robust pipes
- In high seismic hazard areas, only use seismically robust pipes
  - Liquefaction zones
  - Fault rupture zones
  - Landslide zones
- Hydraulic analysis needed to ensure performance criteria is met and to optimize the layout

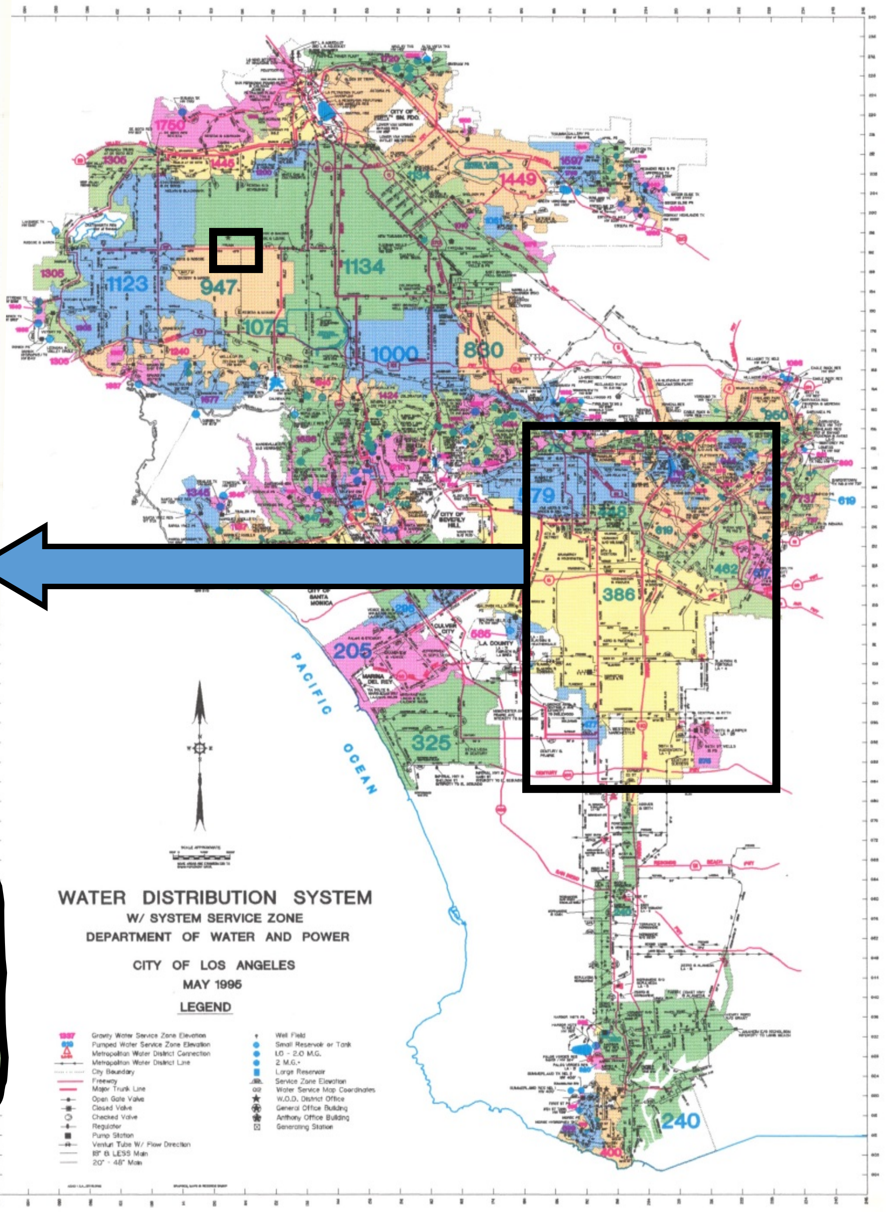
Hollywood Fault
(seismic pipe at all crossings)

Central District
Silver Lake Bypass Service Area

Essential Distribution Mains preliminary Layout (green highlighted)

- Maximum grid (~2x2 miles) for fire fighting access
- Example Critical Customers
  - Hospitals
  - Schools
- Fault Crossing
- Liquefaction zones
- Include recycled water lines (when appropriate)
  - Downtown Water Recycling Project





Implementing

- Pre-identify pipes needing to be seismically robust
- Install seismically robust pipes as part of on-going pipe replacement program
  - Long-term implementation plan (~120 years)
  - Incremental resilience improvements with each project
- Relies on isolation capabilities to restore water
  - Large number of valves needed in distribution system
- Need for permanent ground deformation maps across the city (liquefaction, faulting, landslides, etc.)
- Identify any specific seismic funding which may increase ability to increase rate of seismic pipe installation

Summary

- Performance based seismic design procedures provide a basis for consistent design and construction across the entire Water System
- A seismic resilient pipe network is the application of performance based seismic design for the pipe network
- The proper layout of seismically robust pipe will allow the network to cost-effectively suffer damage while meeting performance criteria supporting community resilience goals
- Developing a seismic resilient pipe network may take many decades to accomplish

Questions?