REPORT

SEISMIC RESILIENCE

FIRST BIENNIAL REPORT

The Metropolitan Water District of Southern California
700 N. Alameda Street, Los Angeles, California 90012

Report No. 1551
February 2018

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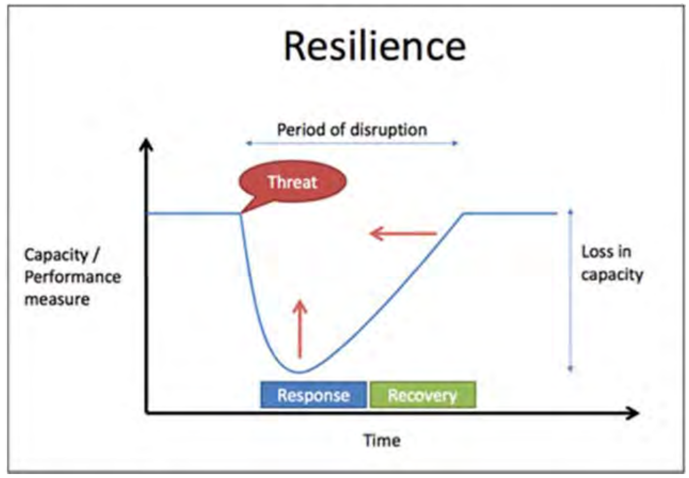
EXECUTIVE SUMMARY

The ability to maintain, or quickly restore, water deliveries after a seismic event.

--Definition of "Seismic Resilience" for a water agency

An interruption in a key lifeline service such as water delivery can be devastating to a community's recovery after an earthquake. As the agency responsible for delivering imported water to over 19 million people in one of the world's most seismically active regions, The Metropolitan Water District of Southern California (Metropolitan) has made substantial efforts to minimize the impact of a major earthquake on the people and businesses within its service area. In 2017, Metropolitan refined and formalized its approach for addressing seismic resilience by fully integrating its planning, engineering, operations, and reporting functions.



This report documents Metropolitan's integrated Seismic Resilience Strategy, reports on key historic achievements, and communicates near-term goals aimed at further enhancing the seismic resilience of Metropolitan's infrastructure and water deliveries.

Seismic Resilience

"Resilience" is broadly defined as the ability of a system to absorb and rebound from shocks. The more resilient a system is, the smaller the impact will be that any given shock will have on the system, and the shorter the duration of recovery will be. Using the broad definition of resilience as a baseline, Metropolitan defines "seismic resilience" as the ability to maintain (or quickly restore) water deliveries following a seismic event. The more prepared a water agency is for earthquakes, and the more effective its emergency response capabilities are, the less impact the event will have on water deliveries to its customers.

Metropolitan's Seismic Resilience Strategy

Metropolitan's Seismic Resilience Strategy is a multi-faceted approach to prepare for and respond to seismic events. It involves close, formal coordination within the Metropolitan organization and with other owners of imported water conveyance systems that cross the Southern San Andreas Fault.

Coordination within Metropolitan and its member agencies focuses on diversifying water resources; enhancing operational flexibility; providing adequate emergency water supplies; and identifying and addressing infrastructure and system vulnerabilities. This coordination also involves development of effective emergency response capabilities.

The coordination with other owners of imported water conveyance systems is through a multi-agency task force. The members of this task force, which includes the California Department of Water Resources

(DWR) and the Los Angeles Department of Water and Power (LADWP) as well as other State and water industry organizations, work together to evaluate the unique seismic vulnerabilities of Southern California's imported water systems.

In addition to the coordination elements, Metropolitan's Seismic Resilience Strategy includes a reporting component to increase transparency and accountability. Each year, Metropolitan staff will update its Board of Directors on recent achievements and near-term goals. Every two years, a written report will be prepared to document these items.

Water is recognized as a critical resource, but having sufficient water available following an earthquake is essential. Seismic resilience has a goal that in most scenarios, water will be available for the vast majority of people and business affected by the event and for essential post-earthquake activities such as fire suppression.

Conclusion

Metropolitan's strategy for seismic resilience has evolved over time and has benefited from the lessons learned from major seismic events around the world. Because of this strategy, significant improvements in the overall seismic resilience of Metropolitan's water system have been made in each of the following key areas: water resource diversity, operational flexibility, emergency water storage capacity, resilience of existing infrastructure, and emergency response capabilities.

Metropolitan has also established a number of near-term goals within each of the planning, engineering, and operations components of seismic resilience that will further enhance this multi-layered approach.

Metropolitan's refined Seismic Resilience Strategy approach will maintain a clear and effective focus on long-term efforts, clearly communicate program achievements and goals to the Board, and provide member agencies with more clarity regarding projected seismic performance of Metropolitan's infrastructure.

SECTION 1 INTRODUCTION

Purpose

The Metropolitan Water District of Southern California (Metropolitan) owns and operates a complex conveyance, treatment, and distribution system that serves a 5,200-square-mile service area within an active seismic region. Over its nearly 90-year history, Metropolitan has been proactive in mitigating seismic risks posed to this expansive infrastructure, as well as improving its ability to maintain (or quickly restore) water deliveries following a major earthquake. This ability to mitigate seismic risks and maintain (or quickly restore) water deliveries following a seismic event is referred to as “seismic resilience.” Metropolitan’s strategy for seismic resilience follows a “defense in depth” multi-layered approach for managing risk: providing a diversified water resource portfolio, system flexibility, emergency water storage, robust emergency response capabilities and performing cyclical assessments of facilities and addressing identified vulnerabilities.

Over the last 20 years, Metropolitan has made significant progress in a number of key areas related to seismic resilience (see Appendix 1):

1. Increasing water supply resilience, flexibility, and emergency storage
2. Addressing the susceptibility of above-ground structures to damage from seismic events
3. Developing effective and robust emergency response capabilities

Recognizing the need for continuous improvement, Metropolitan recently re-assessed the various activities that enhance seismic resilience to refine, expand, and formalize its overall approach. The resulting Seismic Resilience Strategy is a fully integrated approach toward minimizing regional water delivery interruptions and restoring interrupted regional deliveries quickly after an earthquake.

The specific goals of the refined Seismic Resilience Strategy are to:

- Improve the integration of planning, engineering and operations activities focused on seismic resilience through regular collaborative meetings and integrated reporting
- Expand current programs to identify and address any additional seismic vulnerabilities
- Re-visit existing seismic performance objectives in light of advancements in the knowledge of earthquake hazards, earthquake engineering, and mitigation capabilities
- Document Metropolitan’s seismic resilience activities to facilitate knowledge transfer and coordination
- Improve accountability by communicating seismic resilience goals and accomplishments to Metropolitan’s Board of Directors and member agencies on an annual basis
- Enhance member agency planning efforts for emergency response and facility improvements by providing more clarity regarding the projected seismic performance of Metropolitan’s infrastructure

This document describes Metropolitan’s Seismic Resilience Strategy, summarizes key historical achievements, and communicates near-term goals that will further increase the seismic resilience of Metropolitan’s system.

Seismic Resilience Strategy Structure

Metropolitan's Seismic Resilience Strategy (see **Figure 1-1**) is a multi-faceted approach that involves coordination among key functions within Metropolitan as well as formal coordination with other owners of imported water conveyance systems that cross the Southern San Andreas Fault.

Figure 1-1: Seismic Resilience Strategy Structure and High Level Goals

As shown in the figure, the coordination within Metropolitan and its member agencies focuses on the activities of planning, engineering/design, operations/emergency response, and reporting. These efforts are complemented by the efforts of the multi-agency Seismic Resilience Water Supply Task Force (Task Force). This Task Force includes the California Department of Water Resources (DWR) and the Los Angeles Department of Water and Power (LADWP) as well as other State and water industry organizations and focuses on the unique seismic vulnerabilities of Southern California's imported water supplies.

The purpose of Metropolitan's Seismic Resilience Strategy is to enable Metropolitan to restore water deliveries to its member agencies promptly after seismic events by maintaining a diversified supply portfolio, system flexibility, and emergency storage; minimizing damage to infrastructure; and supporting a robust emergency response and recovery capability. This integrated, comprehensive approach will maintain focus on effective long-term efforts, clearly communicate program achievements and goals to the Board, and provide more clarity to member agencies regarding projected regional seismic performance to enhance local facility and emergency response planning efforts.

Report Organization

This report is organized as follows:

- *Section 2 – Background.* Provides context regarding inherent seismic risks within Southern California, a definition of seismic resilience, and a summary of how Metropolitan's seismic resilience strategy developed over time.
- *Section 3 – Planning Component.* Describes planning activities that address seismic resilience through Metropolitan's diverse water supply portfolio and adaptive management approach to managing resources, including establishing emergency storage.
- *Section 4 – Engineering Component.* Describes technical programs that identify and mitigate the seismic vulnerability of Metropolitan's infrastructure and systems.
- *Section 5 – Operations Component.* Describes the emergency response organization, training exercises, and post-event capabilities that serve to minimize the disruption of water deliveries following earthquakes.
- *Section 6 – Reporting Component.* Explains the purpose and timing of the integrated reporting component.
- *Section 7 – Seismic Resilience Water Supply Task Force Component.* Describes the purpose of the collaborative task force, recent progress, and planned activities.
- *Section 8 – Seismic Resilience Performance Objectives and Near-Term Goals.* Summarizes existing objectives of the various components of seismic resilience, describes areas where new objectives are being considered, and provides high-level goals planned to be achieved by December 2019.

List of Abbreviations and Acronyms

BCP	Business Continuity Plan
CIP	Capital Investment Plan
CRA	Colorado River Aqueduct
DATs	Damage Assessment Teams
DSOD	Division of Safety of Dams
DVL	Diamond Valley Lake
DWR	California Department of Water Resources
EAP	Emergency Action Plan
EOC	Emergency Operations Center
ERO	Emergency Response Organization
FEMA	Federal Emergency Management Agency
ICCs	Incident Command Centers
IRP	Integrated Water Resources Plan

IT	Information Technology
ITP	IT Continuity Plan
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
LRP	Local Resources Program
M	Magnitude
MARS	Member Agency Response System
MCE	Maximum Considered Earthquake
Metropolitan	The Metropolitan Water District of Southern California
MOU	Memorandum of Understanding
M_W	Moment Magnitude
MWD	The Metropolitan Water District of Southern California
NIAC	National Infrastructure Advisory Council
NIMs	National Incident Management System
O&M	Operation and Maintenance
OCC	Operations Control Center
PCCP	Prestressed Concrete Cylinder Pipe
PGA	Peak Ground Acceleration
SCE	Southern California Edison
SEMS	Standardized Emergency Management System
ShakeOut	Great Southern California ShakeOut Scenario
SWC	Security Water Center
SWP	State Water Project
Task Force	Seismic Resilience Water Supply Task Force
UBC	Uniform Building Code
UCERF3	Uniform California Rupture Forecast Version 3
USGS	United States Geological Survey
WSAP	Water Supply Allocation Plan
WSDM	Water Surplus Drought Management

SECTION 2 BACKGROUND

Seismic Risk

Within Southern California, there are a number of known active faults with varying levels of activity that are capable of generating significant earthquakes and causing widespread damage to infrastructure. Modern era earthquakes that occurred within or close to Metropolitan's primary service area with a magnitude above 6.3 (M6.3) are listed in Appendix 2. In 2015, the United States Geologic Survey (USGS) released the Uniform California Earthquake Rupture Forecast Version 3 (UCERF3), which provides a forecast for the likelihood of rupture for particular earthquake faults within California. UCERF3's forecast of the likelihood of a M6.7 earthquake or greater in the next 30 years on each active fault in Southern California is shown in **Figure 2-1**. As indicated in the figure, the Southern San Andreas Fault was identified as having the highest likelihood (19%) of a M6.7 earthquake or greater in the next 30 years. UCERF3 further states that the there is a 93% chance of a M6.7 or greater earthquake occurring on one of the faults within Southern California within the next 30 years, and a 36% chance of a M7.5 or greater earthquake occurring within the next 30 years.

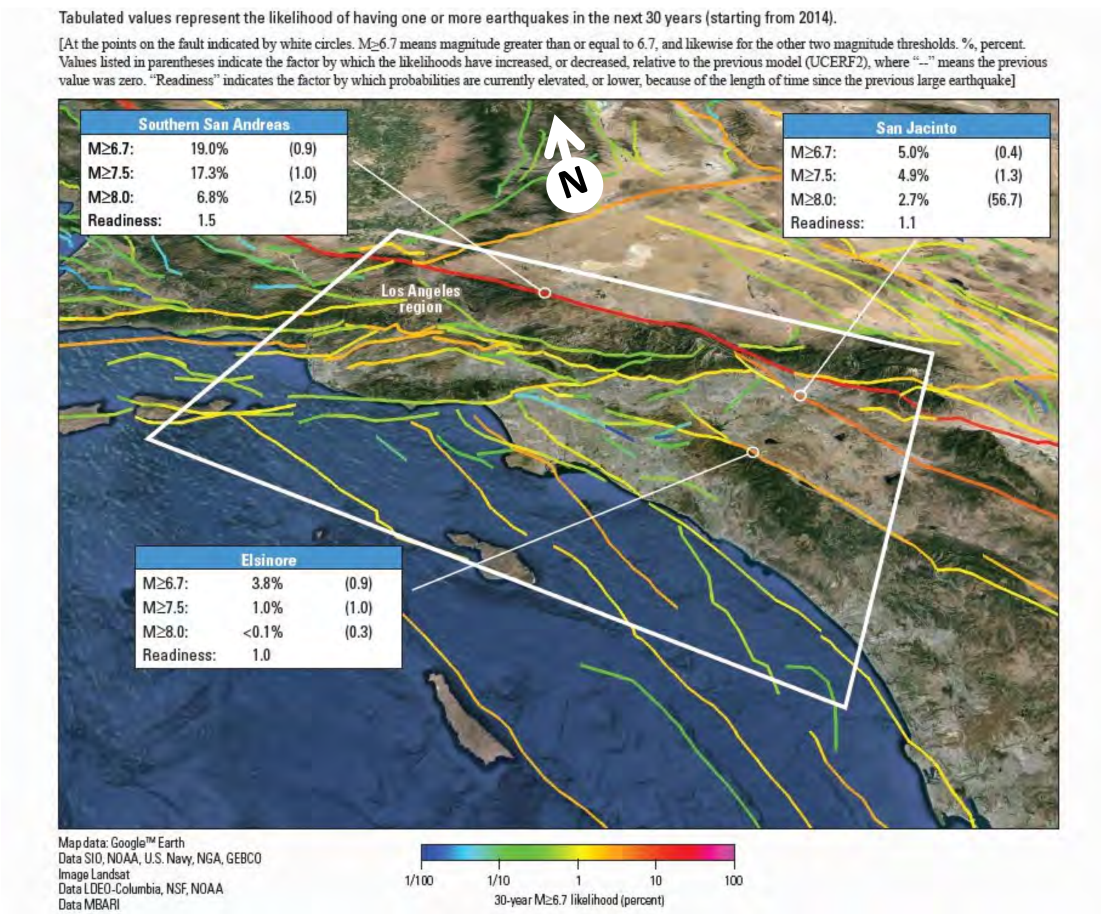


Figure 2-1: Likelihood of M6.7 or greater earthquake in the next 30 years (Source: UCERF3)

As shown in **Figure 2-2**, a significant portion of Metropolitan's infrastructure, including the Colorado River Aqueduct (CRA) and several treated water pipelines, is located near or crosses active faults.

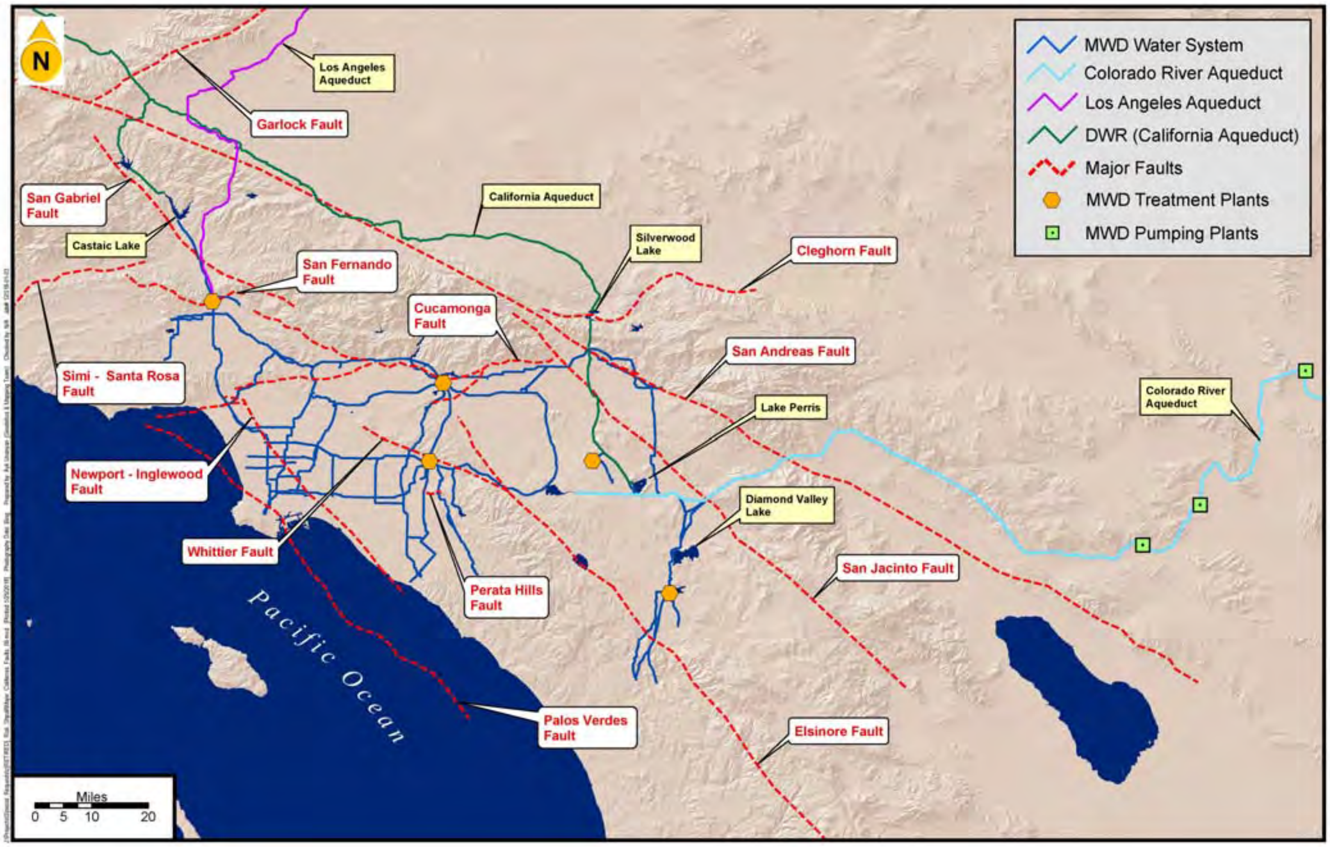


Figure 2-2: Major Earthquake Faults in Southern California

The risk of earthquake damage to Metropolitan's infrastructure from these active faults is manifested through different seismic hazards, including seismically induced ground shaking, seismically induced ground failure, and surface fault displacement.

- <u>Seismically induced ground shaking</u> can damage buildings, structures, aqueducts, pipelines, and tunnels. The intensity and duration of shaking at a particular location is dependent on a number of factors, including the earthquake magnitude, the distance from the earthquake epicenter, and local soil conditions.

Examples of typical effects of seismically induced ground shaking. The photograph on the left shows a damaged building from the 1994 M6.7 Northridge Earthquake. The building has essentially fallen backwards, and what was once a straight wall now appears curved. The photograph on the right shows the collapsed portion of a freeway overpass from the same earthquake.

- Seismically induced ground failure includes liquefaction, landslide, and seismic settlement. Liquefaction occurs when prolonged shaking causes saturated (water-bearing) soils to consolidate and lose their bearing capacity. This can compromise the support of structures that are constructed in these zones, including buildings and pipelines. Prolonged shaking can also lead to displacement of large areas of soil or rock, resulting in hazardous landslides and rock falls. The integrity of buildings and pipelines constructed in landslide zones can be compromised if the supporting ground experiences seismically induced failure; rockfalls can also result in structural damage due to the impacts of large boulders on structures. Seismic settlement is similar to liquefaction, except that the soil is not saturated.

Examples of seismically induced ground failures include liquefaction (left photo) and landslides (right photo) from the 2011 M6.3 Christchurch, New Zealand Earthquake and the 2016 M7.8 Kaikoura, New Zealand Earthquake, respectively.

- Surface fault displacement is usually only observed in large magnitude earthquakes but can result in devastating structural damage. The 1972 Alquist-Priolo Earthquake Fault Zoning Act prohibits construction of buildings in California within 50 feet of a known active fault trace. Therefore, surface fault displacement is generally not an issue for Metropolitan's buildings constructed after the early 1970s. However, several components of Metropolitan's conveyance and distribution infrastructure cross known active faults, including the CRA, various pipelines, and power transmission lines. These facilities are subject to damage from surface fault displacement.

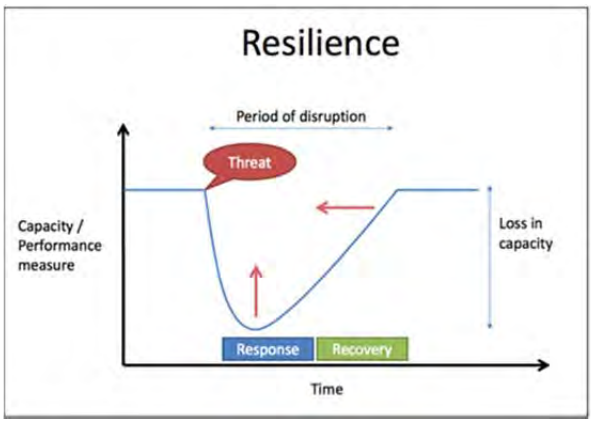
Examples of surface fault displacement. The photograph on the left shows railroad tracks displaced as a result of the 1952 M7.5 Kern County Earthquake. The photograph on the right shows a field that shifted as a result of the 2010 M7.1 earthquake in Canterbury, New Zealand.

Seismic Resilience

General

According to the National Infrastructure Advisory Council (NIAC), infrastructure resilience is "the ability to reduce the magnitude and/or duration of disruptive events." The effectiveness of a resilient infrastructure or enterprise depends upon its ability to "anticipate, absorb, adapt to, and rapidly recover from a potentially disruptive event." [ref. "*Critical Infrastructure Resilience Final Report and Recommendations*," September 8, 2009]**.** This event may be man-made, such as a cyber-attack, or a natural disaster, such as a drought, flood, or earthquake.

"Seismic resilience" (see **Figure 2-3**) narrows the focus of infrastructure resilience to only earthquakes. Using the definition of "infrastructure resilience" presented above, Metropolitan has defined seismic resilience for water agencies as the ability to reduce the magnitude and/or duration of water delivery interruptions resulting from seismic events. Rather than striving to make an entire water system "earthquake-proof," seismic resilience involves setting reasonable performance goals that provide sufficient benefits that justify the corresponding investments required by both an agency and its ratepayers. Metropolitan's seismic resilience performance objectives are summarized in Section 8 of this report.



Source: http://www.iparametrics.com/solutions/infrastructure-resilience.html

Figure 2-3: Resilience -- the ability to reduce the magnitude and/or duration of disruptive events

Applicability to Metropolitan

For over a decade, Metropolitan has had a well-defined approach to system reliability that addressed overall system resilience in five key areas: Water Supply Reliability, System Capacity, Infrastructure Reliability, System Flexibility and Emergency Response.

Seismic resilience is an essential aspect of Metropolitan's overall reliability strategy. Water deliveries are extremely crucial following earthquakes for fire suppression, for the general welfare of local residents, and for the regional economy that relies on imported water. Metropolitan's approach to seismic resilience has evolved over time to become one that is highly effective and recognized within the water industry [ref. "*Water Supply in Regard to Fire Following Earthquake*," Charles Scawthorn, Pacific Earthquake Engineering Research Center, November 2011]**.**

Metropolitan's Historical Approach to Seismic Resilience

"The aqueduct is being built for the future as well as the present, and must stand and give adequate service for an indefinitely long time."

From the "Design" Chapter of "The Great Aqueduct" book by Julian Hinds, 1938.

"It was desirable that faults be crossed at right angles, to minimize damage in the event of movement, and that some flexible type of conduit on or near the surface be used so that if repairs become necessary they will be as simple as may be…"

From "Major Problems of Aqueduct Location" by Julian Hinds, Nov. 24, 1938 Engineering News-Record.

Since its inception, and particularly during the design and construction of the CRA, Metropolitan has recognized the potential vulnerability of water infrastructure to disruptions by earthquakes. This section provides a brief overview of Metropolitan's historical approach to seismic resilience, focusing on major earthquake events in the past and lessons learned from these events.

The 1906 M7.8 San Francisco earthquake struck the coast of Northern California at 5:12 a.m. on April 18. Severe shaking was felt from Eureka on the North Coast to the Salinas Valley. Broken gas lines resulted in fires that lasted for several days due to a lack of fire supply. As a result, about 3,000 people died and over 80% of the city of San Francisco was destroyed.

The 1933 M6.7 Long Beach earthquake took place on March 10 at 5:54 P.M. Damage to buildings was widespread and between 115 and 120 people died. The earthquake highlighted the need for earthquake-resistant design for structures in California.

Post-1906 San Francisco and 1933 Long Beach Earthquakes (1930-1970)

Conveyance and Distribution System: The majority of Metropolitan's conveyance and distribution system was constructed between the 1930s and the 1970s. Historical documents regarding the planning and design of this infrastructure describe a philosophy of "permanence," which may be considered as a forerunner to "resilience." This philosophy not only took into account decades of wear and tear, routine hazards, and large storms, but also provided for seismic resilience.

Despite having no provisions within design codes, Metropolitan took proactive measures to address seismic resilience while designing the CRA. Metropolitan geologists and engineers took into account the ground shaking and deformation that had occurred along the San Andreas Fault system during the 1857 Fort Tejon earthquake and lessons learned from 1906 San Francisco earthquakes, and supplemented their understanding of regional active faults through geologic mapping and analysis of stereo aerial photographs. This led to the aqueduct being designed to cross active faults near the ground surface in inverted siphons and cross fault traces at right angles. The designers also opted for a more flexible siphon design in fault regions than the rigid monolithic concrete construction used elsewhere on the CRA, and provided extra hydraulic grade at three siphons crossing active faults (Appendix 3). These provisions were intended to minimize the adverse effects of seismically induced ground movement and to simplify access for repairs.

Metropolitan's dams are inspected on a regular basis.

Photo of the 120-inch Froriep Vertical Turning Lathe (above) and the 5-inch G&L Horizontal Boring Mill (below) in the La Verne Machine shop.

Water Treatment Plants: Metropolitan's water treatment plants were also designed with features that enhance seismic resilience, beginning with the F. E. Weymouth Water Treatment Plant in 1940, and followed by the Robert B. Diemer Water Treatment Plant in 1963. The plants are modular in design and incorporate redundancy of key components. They are also situated strategically to maximize gravity flow to a majority of the distribution system.

Dams and Reservoirs: Metropolitan began a Safety of Dams program many years before formal reporting was required by the California Division of Safety of Dams (DSOD). Staff regularly inspects Metropolitan's dams for vulnerabilities, documents their findings, and reports these findings to DSOD.

La Verne Shops and Construction Equipment: The La Verne Shops were built in the 1940s to support the construction and maintenance of Metropolitan's initial infrastructure. The shops were expanded in the 1960s as Metropolitan's system grew along with its service area. These specialized shops provide support for routine maintenance activities and are also vital for responding to emergency events impacting Metropolitan and member agency facilities. The stockpiling of key materials and the ability to roll pipe and fabricate or repair specialty equipment greatly enhances seismic resilience. Many of Metropolitan's pumps, piping, valves, and related equipment are too large to be routinely stocked by vendors.

Post-1971 San Fernando Earthquake (1971-1990)

The San Fernando earthquake struck the greater Los Angeles region in the early morning of February 9, 1971. The M6.5 earthquake caused severe property damage over $500 million and the loss of life directly attributable to the earthquake reached 58.

There were over 145 post-earthquake ignitions, typically caused by severed gas lines. Metropolitan experienced widespread damage at the Jensen plant, including a severe break to a 72" influent conduit and damage to the new finished water reservoir (shown below).

Earthquake Committee: Following the San Fernando Earthquake in 1971, Metropolitan formed an Earthquake Committee to investigate damaged structures at the Joseph Jensen Water Treatment Plant and to recommend enhanced seismic design criteria and site improvements to mitigate the seismic risk from potential future events.

The recommended modifications, such as the addition of stone columns to prevent liquefaction, are believed to have contributed to improved seismic performance of the Jensen plant in the 1994 Northridge Earthquake (see Section 4 of this report).

The Earthquake Committee also evaluated other facilities and recommended additional improvements that resulted in the upgrade of several key structures throughout Metropolitan's system. The Committee's efforts evolved over time into the current formal approach, with its emphasis on improving the seismic resilience of structures.

Emergency Response Plan: This period also saw Metropolitan adopt its Emergency Response Plan and establish a formal Emergency Response Organization (ERO). These steps led to regular emergency response training for staff, and eventually to staging formal emergency response exercises. As part of this effort, Metropolitan coordinated with its member agencies to establish the Member Agency Response System (MARS). Engineering Damage Assessment Teams (DATs) were also created to rapidly assess damage and help prioritize and initiate repair efforts.

La Verne Shops and Construction Equipment: The La Verne Shops were further expanded in the 1980s to support a major rehabilitation of the main pumps on the Colorado River Aqueduct. The additional fabrication capacity increased Metropolitan's ability to respond to emergency events.

Local Projects Program: To decrease reliance upon imported water, Metropolitan established the Local Projects Program in 1982 to provide financial incentives to member agencies for the development of recycled water projects throughout the region. A more diversified water portfolio helps the region's overall water supply reliability, which improves seismic resilience for the entire service area.

Post-1989 Loma Prieta and 1994 Northridge Earthquake (1990-2010)

During this period, Metropolitan greatly enhanced seismic resilience by performing seismic risk assessments, updating seismic design criteria, strengthening dozens of at-risk structures, encouraging development of local water resources, increasing emergency storage supplies, and enhancing emergency response capabilities.

The M6.9 Loma Prieta earthquake occurred in Northern California on October 17, 1989, at 5:04 p.m. . The shock was centered approximately 10 miles (16 km) northeast of Santa Cruz on a section of the San Andreas Fault System.

The earthquake was responsible for 63 deaths and over 3,750 injuries. The Loma Prieta segment of the San Andreas Fault System had been relatively inactive since the 1906 San Francisco earthquake until two moderate foreshocks occurred in June 1988 and again in August 1989.

As a result of this event, there were more 916 documented water system pipe breaks. This resulted in the loss of water pressure in the Marina District of San Francisco and difficulty in fighting fires.

<u>Seismic Design Criteria:</u> During the Inland Feeder Project, criteria were developed for new pipelines that cross seismic faults. The refined fault-crossing strategy includes using steel pipelines with welded joints; crossing fault-zones at right angles, and burying the pipes at relatively shallow depth to enable easy access for repair; and locating the pipelines where they can drain into channels or streams if damaged at fault crossings. Metropolitan also began considering the benefits of exceeding minimum code requirements for essential structures.

<u>Seismic Upgrade Program:</u> Dozens of pre-1990 structures were upgraded during this period. The benefit of upgrading seismically vulnerable facilities was demonstrated during the Northridge Earthquake in 1994. Structures that were upgraded at the Jensen plant, which was near the earthquake's epicenter, experienced only minor damage. The only significant damage consisted of rupture of an inlet 84-inch steel pipeline. The Jensen plant was off-line for less than 72 hours while the broken pipeline was repaired, and limited water deliveries were maintained during the repairs. Appendix 4 summarizes damage to Metropolitan infrastructure from the 1971 San Fernando and 1994 Northridge earthquakes.

<u>Local Resources Program:</u> In 1995, Metropolitan established the Local Resources Program (LRP). The LRP combined the Local Projects Program, which provided financial incentives for recycled water projects, with the Groundwater Recovery Program, which provided financial incentives to encourage the development of local groundwater recovery projects. The present LRP has been highly successful in reducing the region's dependence upon imported water.

<u>Diamond Valley Lake (DVL):</u> DVL was completed in 1999 to increase operational flexibility and reliability by providing seasonal storage, drought protection, and dedicated emergency supplies. Seismic resilience was a major factor in both the siting and design of the reservoir. DVL was specifically constructed south and west of the San Andreas Fault, and it was designed to withstand a major event on that fault in order to mitigate for the potential interruption of Southern California's imported water supplies. This 810,000 acre-

foot reservoir, combined with other storage programs, provides a 6-month emergency water supply for Metropolitan's service area.

The M6.7 Northridge earthquake occurred on January 17, 1994, at 4:31 a.m. and had a duration of approximately 10-20 seconds.

The death toll was 57, with more than 8,700 injured. Property damage was estimated to be between $13 and $50 billion. LADWP reported a total of 1,405 pipe repairs and that water pressure had dropped to zero in some areas.

Metropolitan experienced damage at the Jensen Plant including a rupture of an 84" diameter pipeline. Crews worked around the clock and restored service within 72 hours. The ability to roll pipe in the La Verne shops expedited these emergency repairs.

Although Metropolitan's response was very good, a task force was formed to develop recommendations for further improvement (Ref. Report 1087, "Northridge Earthquake Assessment Report").

Special Seismic Risk Assessments: During this period, Metropolitan broadened the scope of seismic risk assessments, from focusing on isolated structures to assessing entire facilities, such as the Diemer plant, and overall systems, such as the CRA. These efforts included seismic vulnerability assessments, facility reliability assessments, and system flexibility studies. These special seismic risk assessments led to several capital projects to structurally upgrade facilities, provided input into Metropolitan's emergency response planning to reduce the time to restore service, and identified options to improve system flexibility to help maintain water deliveries during planned and unplanned outages.

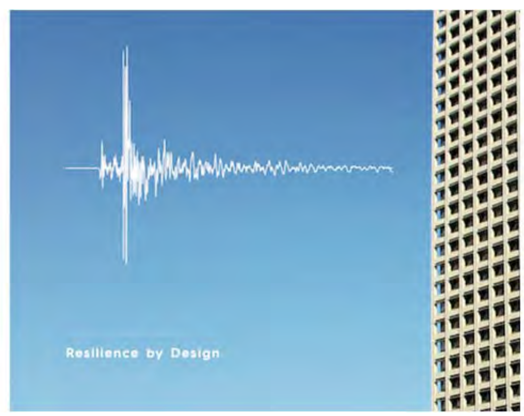
Emergency Response Planning: Following the Northridge Earthquake, Metropolitan revised its Emergency Response Plan and associated programs and established a Member Agency Coordinator function. Metropolitan also began conducting training exercises in coordination with member agencies and other external agencies and three functional exercises based on postulated seismic events were conducted during this period. In addition, the EOC was relocated from the Sunset Headquarters Building to Eagle Rock, and Incident Command Centers (ICCs) were established at each of the water treatment plants. Recognizing that seismic events can impact business functions as well as infrastructure, staff developed a formal Business Resumption Plan. Over time, this evolved into the present Business Continuity Plan (BCP) and IT Continuity Plan (ITP).

Emergency Response Construction Capabilities: In 2008**,** Metropolitan enhanced its ability to respond to emergency events by initiating a long-term project to refurbish and upgrade the La Verne Shops. Metropolitan can roll pipe and conduct simultaneous repairs on two large-diameter pipelines. Retaining in-house fabrication functions is important, as there are few firms in the western U.S. with similar capabilities. In recent years, private firms with machine shop and fabrication capabilities have tended to increase the amount of work outsourced to offshore facilities, instead of retaining it locally. These firms have little ability to respond expeditiously to emergency needs.

Post-2010 Chile, 2011 Christchurch and 2011 Great East Japan Earthquakes (2010-Present)

<u>Seismic Resilience Strategy Defined:</u> The recent earthquakes in Chile, New Zealand, and Japan demonstrated the importance of seismic resilience, and have resulted in extensive discussions among industry experts and public agencies on strategies to achieve greater levels of seismic resilience beyond the conventional measures of prevention and protection. This was particularly true for the 2011 Christchurch, New Zealand Earthquake, although it was the smallest of the three. The reason was the widespread damage that occurred in the downtown section of Christchurch, despite the fact that the infrastructure was designed and constructed in accordance with modern building codes. While the majority of buildings did not fall, and most people were able to exit safely, many of the downtown structures were unsuitable for occupation and had to be demolished. In addition, many of the buried utilities were damaged and had to be abandoned in place. The combined loss of structures and utilities resulted in a long-term reduction to the population within the city.

A M6.3 earthquake occurred in Christchurch, New Zealand on 22 February 2011 at 12:51 p.m. The earthquake was centered 6 miles south-east of the center of Christchurch, which at the time was New Zealand's second-most populous city. The earthquake caused widespread damage across Christchurch, killing 185 people in the nation's fifth-deadliest disaster.



In December 2014, Los Angeles Mayor Eric Garcetti released Resilience by Design which provided recommendations to addresses Los Angeles' greatest earthquake vulnerabilities, including taking steps to secure imported water supplies.

Concurrent with the infrastructure industry's focus on resilience, Metropolitan re-assessed its existing programs and developed a more integrated, comprehensive approach to seismic resilience. One improvement was to incorporate the concept of performance-based design during seismic evaluations. In addition to the evaluation of structures based on design-level earthquakes to prevent damage, performance-based design evaluates the effects of more extreme events to anticipate structural damage. Another improvement was to embrace the significant technological advancements that can improve seismic resilience, including computer modeling techniques, seismic resistant products, and recent industry research. These improvements have allowed Metropolitan to develop an enhanced strategy for seismic resilience moving forward.

During this period, Metropolitan also formed a collaborative Task Force to address the unique vulnerabilities of the major aqueducts that cross the San Andreas Fault. In 2017, Metropolitan fully integrated the various seismic resilience efforts currently underway throughout the organization. The resulting Seismic Resilience Strategy is described in detail in Sections 3 through 7 of this report.

Metropolitan's Comprehensive, Integrated Seismic Resilience Strategy

The enhanced Seismic Resilience Strategy has the following objectives for Metropolitan and for the entire southern California region:

- Provide a diversified water supply portfolio, system flexibility, and emergency storage
- Prevent damage to water delivery infrastructure in probable seismic events and limit damage in extreme events
- Minimize water delivery interruptions through a dedicated emergency response and recovery organization

This strategy is built upon improved collaboration within Metropolitan and formal collaboration with LADWP and DWR, which also import water to Southern California.

Figure 2-4: Detailed Breakdown of Metropolitan's Seismic Resilience Strategy

As shown in **Figure 2-4**, Metropolitan's enhanced Seismic Resilience Strategy includes four components within Metropolitan and a fifth component that involves formal coordination between Metropolitan, LADWP, and DWR.

1. The **Planning component** develops diversified water resources, system flexibility, and emergency water storage through Metropolitan's Integrated Water Resources Plan (IRP) and System Overview Studies. The goal of Metropolitan's IRP is to develop a diverse water supply portfolio that will be able to maintain a reliable water supply under any conditions, including a major seismic event.
2. The **Engineering component** addresses design concepts, vulnerability studies, and seismic resilience projects executed under Metropolitan's Capital Investment Plan (CIP). The Engineering component includes evaluating the seismic resilience of structures, monitoring dams, special seismic assessments, and enhancing pipeline seismic resilience. These efforts are all aimed at improving the seismic resilience of the treatment plants and distribution system through facility upgrades and operational flexibility improvements.
3. The **Operations component** involves Metropolitan's emergency response organization, training exercises, and construction capabilities. Their objectives are to effectively prepare for and respond to emergency events so that impacts to water deliveries are minimized and interrupted deliveries are restored quickly.
4. The **Reporting component** involves documenting the Seismic Resilience Strategy, tracking progress of seismic resilience activities, and annual reporting of near-term goals and recent accomplishments to Metropolitan's Board. This component is aimed at facilitating knowledge transfer, increasing accountability, and improving the transparency of seismic resilience goals and achievements to the Board and member agencies. The reporting component also supports the planning efforts of member agencies by communicating potential outage durations of Metropolitan facilities during emergency events.
5. The **Seismic Resilience Water Supply Task Force component** involves Metropolitan's formal collaboration with DWR, LADWP, the State of California, and other water industry organizations to address the unique seismic vulnerabilities of Southern California's imported water supplies. The two primary objectives of this task force are to 1) enable the agencies to coordinate emergency response efforts, and 2) identify practical mitigation options for reducing the magnitude and duration of disruptions to the region's imported water supplies following a large earthquake on the San Andreas Fault.

SECTION 3 PLANNING COMPONENT

As a supplemental supplier to the Southern California water community, Metropolitan faces many challenges in meeting the region's needs for water supply reliability and quality. One of the challenges is the ability to maintain water deliveries within the region following a major seismic event. In general, Metropolitan's planning efforts focus on meeting demands during dry and critical periods. However, during the original planning for Diamond Valley Lake (DVL), Metropolitan considered a scenario and a plan to meet demands if imported supplies were interrupted due to a seismic event, including development of a significant increase in storage dedicated to meeting emergencies.

Historically, Metropolitan has provided 50 to 60 percent of the water used in its service area from the Colorado River (via the Colorado River Aqueduct) and from the Sacramento-San Joaquin River Watershed (via the State Water Project). In addition to relying on imported supplies, Metropolitan and its member agencies have developed other sources, including groundwater, surface water, recycled water, desalination of seawater, and an aggressive water conservation and water use efficiency program. These investments, and Metropolitan's ongoing efforts in several different areas, coalesce toward the goal of long-term regional water supply reliability.

Metropolitan's Integrated Water Resources Plan (IRP) is the foundation for planning and developing a diverse water supply and emergency storage. The fundamental goal of the IRP is for Southern California to develop a water supply portfolio that will be able to maintain a reliable water supply. Maintaining this reliability includes investments prior to major seismic events, when there could be extended outages of imported water conveyance systems. To meet this fundamental IRP goal of a diversified water portfolio, Metropolitan believes in investing in the reliability of imported supplies, incentivizing its member agencies to develop increased water conservation, recycling, storage, and other resource-management programs. A significant part of imported water supply reliability is preparing for recovery periods following seismic events. With the commencement of the IRP process in 1993, Metropolitan formalized this process as a long-term strategy and official policy.

Metropolitan's success in improving water supply reliability by diversifying its water resource portfolio, and by the application of adaptive resource management approaches has also increased seismic resilience. At a system level, the Planning component of seismic resilience has several facets:

- Diversified water supply portfolio
- System flexibility
- Emergency storage

Diversified Water Supply Portfolio

Metropolitan has undertaken a number of planning initiatives over the years in order to maintain a diversified water portfolio. These initiatives include the IRP, periodic IRP updates, the Water Surplus and Drought Management (WSDM) Plan, and the Water Supply Allocation Plan (WSAP). Collectively, these initiatives provide policy framework guidelines and resource targets for Metropolitan to ensure regional water supply reliability, along with additional resilience for seismic events. In addition to Metropolitan's efforts to coordinate regional supply planning through its inclusive IRP process, Metropolitan's member agencies also conduct their own planning analyses and may develop projects independently of Metropolitan.

2015 IRP Update

The 2015 IRP Update was a refinement of Southern California's water management strategy, with seismic resilience continuing to be a key component. The 2015 IRP Update called for increasing the targets for conservation and local supply development and an emphasis on the importance of protecting and maintaining existing local supplies. The more that conservation and local supplies can contribute to the baseline each year, the more imported water Metropolitan can divert into storage to prepare for droughts of unknown duration or potential seismic events. Further developing a diverse water supply portfolio also contributes to increased seismic resilience.

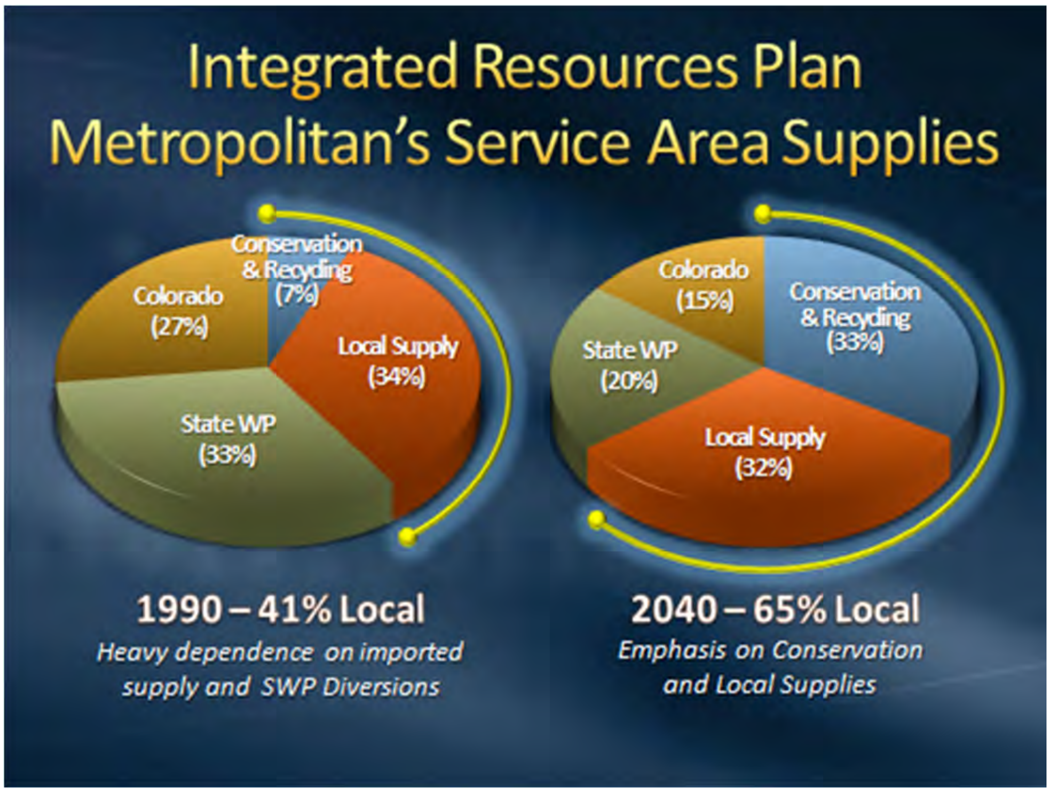


Figure 3-1: Integrated Resource Plan, Metropolitan's Service Area Supplies

Metropolitan's Service Area Supplies under the IRP

In 1990, about 41 percent of regional water demands were met with local resources and conservation. By 2040, about two-thirds will be met by local resources and increased conservation and recycling, as shown in **Figure 3-1**. Metropolitan's strategy is to maintain rather than increase traditional levels of imported supplies. The long-term portfolio approach looks to local solutions to sustain the region's continued growth. Increased flexibility to draw upon a wide range of sources from an ever more diverse water supply portfolio results in greater resilience to the potential impacts of seismic events on Southern California's water supply infrastructure.

Water Surplus and Drought Management (WSDM) Plan

Diversifying the region's water supplies and developing adequate and healthy water storage reserves have proven to be the backstop for water supply reliability. These actions have also contributed to improved seismic resilience for the region. Stored water reserves provide certainty for meeting the needs of the region's vast service area when traditional sources of supply are challenged by drought, climate change, seismic events, and other risks. It is critical that these storage resources be developed, managed and enhanced.

Metropolitan's WSDM Plan, which defines a regional water management strategy for Metropolitan and its member agencies, has focused on using storage to manage water supplies and enhance reliability since 1999. The WSDM Plan includes the following guiding principle: Metropolitan will encourage storage of water during periods of surplus and work jointly with its member agencies to minimize the impacts of water shortages on the region's retail consumers and economy during periods of shortage.

Water Supply Allocation Plan

When continued drought, earthquakes, or other natural disasters lead to shortages of supplies, Metropolitan distributes a limited amount of water through its Water Supply Allocation Plan (WSAP). First developed in 2008, Metropolitan's WSAP takes a basic premise --to fairly distribute a limited amount of water supply-- and applies it through a detailed methodology to reflect a range of local conditions and needs of the region's retail water consumers. In particular, under severe drought conditions or a potential seismic event that impacts imported conveyance systems, it may be necessary and prudent to call for greater reductions in the use of limited water supplies and to reduce reliance on storage reserves. The WSAP has 10 levels of water supply allocations, each corresponding to a five percent reduction of supply. A Level 2 allocation, for example, represents a reduction of approximately 10 percent in overall water supply available to each member agency. The level of WSAP reduction implemented would correlate to the severity of the seismic event.

System Flexibility

Metropolitan develops its facilities to meet demands; however, in the course of developing a reliable system to meet demands, some flexibility has been incorporated into the system. This flexibility helps Metropolitan accommodate changes in water supply, demands, and water quality. System flexibility also helps mitigate the impacts of planned and unplanned outages. Metropolitan's system flexibility has two key components:

- Operational flexibility: the ability to respond to changes in regional supply, water quality, or member agency demands
- Delivery flexibility: the ability to maintain partial to full deliveries during planned and unplanned single-facility outages

Metropolitan has found that for planned and unplanned outages of Metropolitan facilities, system flexibility at the regional and local levels is key to minimizing the effects of these outages. Water supply reliability and water demand-driven projects increase Metropolitan's system flexibility, which in turn can also increase seismic resilience. For example, the construction of DVL and the Inland Feeder provided significantly increased water supply reliability through the potential for dramatically increased storage of imported supplies within the service area. These projects increased water supply reliability and system flexibility, and also greatly improved seismic resilience as the storage was purposely located on the coastal side of major faults that are crossed by the SWP, CRA, and Los Angeles Aqueduct (LAA). A significant amount of storage in DVL is dedicated to emergency storage. This water is not used except in emergency conditions such as following a major seismic event. Additionally, the Diemer and Jensen plants (and associated feeders) were constructed as water demand-driven projects that also significantly improved delivery flexibility and seismic resilience within Metropolitan's distribution system.

Emergency Storage

Over the past two decades, Metropolitan has developed a large regional storage portfolio that includes both dry year and emergency storage capacity (summarized in Appendix 5). Storage generally takes two forms: surface reservoirs and groundwater basin storage. In late 2011, heading into the most recent drought cycle, Metropolitan had developed over 5.5 million acre-feet of storage capacity and had successfully stored over 2.7 million acre-feet.

Additionally, Metropolitan has long discussed and executed plans to maintain a reliable supply of water in the face of any type of water supply condition, including following major seismic events that could impact imported water conveyance systems. The development of its diverse resource mix has enhanced the flexibility of Metropolitan's conveyance and distribution system. Metropolitan established criteria for determining emergency storage requirements in the October 1991 Final Environmental Impact Report for the Eastside Reservoir, which is now DVL. These criteria were again discussed in the 1996 IRP. Both of these documents were approved by Metropolitan's Board. Additionally, Metropolitan's emergency storage requirements were summarized in a 2008 Board Report entitled "Water Surplus and Drought Management Plan on water supply and demand as of October 30, 2008."

Emergency storage requirements are based on the potential of a major earthquake causing damage to one or more of the aqueducts that convey Southern California's imported supplies (SWP, CRA, and LAA) into the region. The adopted criteria assume that damage from such an event could render the aqueducts out of service for six months. As a result, Metropolitan has based its planning on a 100 percent reduction in these imported supplies for a period of six months.

Metropolitan's WSDM Plan shortage stages guide Metropolitan's management of available supplies and resources during an emergency to minimize impacts of the catastrophe. This emergency plan outlines that under catastrophic loss of water supply the following actions will be taken:

1. Interruptible water deliveries would be suspended
2. Firm supplies to member agencies would be restricted by a mandatory cutback of 25 percent from normal year retail demand levels
3. Water stored in surface reservoirs and groundwater basins under Metropolitan's program would be made available

4. Full local groundwater production, recycled water, and local surface emergency storage reserve production would be sustained
5. Metropolitan would draw on its emergency storage as well as other available storage

Under the emergency criteria, retail demands would be met through existing surface storage, local production, and storage in surface reservoirs owned and operated by Metropolitan and by DWR. The total amount of storage available for emergency needs in Metropolitan's storage facilities, including DVL, Lake Mathews, and Lake Skinner, is currently 292,100 acre-feet (February 2018). The amount of emergency storage available to Metropolitan in DWR's reservoirs, including Lake Perris, Castaic Lake, Silverwood Lake, and Pyramid Lake, is an additional 334,300 acre-feet (February 2018).

SUMMARY

Through its IRP, Metropolitan has established a fundamental goal that Southern California will have a reliable water supply system for present and future generations, even if imported water supplies are disrupted due to a major seismic event. This reliability is achieved through Metropolitan's development of local water supplies, emphasis on water conservation, and establishment of emergency storage on the coastal side of major earthquake faults that are crossed by the SWP, CRA, and LAA. These reliability actions enable Southern California to continue water deliveries during the period when imported supply aqueducts are out of service due to damage from a major seismic event. In addition, Metropolitan's planning efforts to diversify the water supply and increase overall system flexibility over time have also contributed to providing resilience against potential in-basin earthquakes.

Metropolitan will continue to evaluate its water resource planning programs in terms of how they may further enhance seismic resilience and coordinate these efforts with the Engineering and Operations functions that are described in Sections 4 and 5 of this report.

SECTION 4 ENGINEERING COMPONENT

Metropolitan manages a number of strategies and component studies that evaluate facilities and systems against earthquake hazards. Mitigation options are then developed and executed when practical. These strategies include evaluating the seismic resilience of structures; special seismic assessments that address multiple facilities and systems; and other specialized efforts that address the seismic resilience of dams and reservoirs and the mitigation of geotechnical hazards.

Seismic Resilience of Structures

The purpose of evaluating the seismic resilience of structures is to prevent seismic damage to water delivery infrastructure from probable events and to limit damage due to extreme events in order to minimize water delivery interruptions. For occupied structures, the goal is to protect life safety and critical functions. Metropolitan applies a systematic approach to evaluate older structures that were constructed in accordance with earlier codes, and where necessary, to upgrade structures with seismic deficiencies. The criteria applied to the seismic evaluations incorporate current code provisions and up-to-date industry standards. In general, structures are upgraded to maintain seismic performance levels that are comparable to the levels of a new facility. Additional details are provided in Appendix 6, "Seismic Design Frequently Asked Questions."

Over the past two decades, this effort was primarily aimed at improving the seismic resilience of above-ground facilities and structures constructed prior to 1990. For example, the original pump houses at the five CRA pumping plants were determined to be vulnerable to significant damage in a design-level earthquake. A design-level earthquake is a probable event that is defined by the Building Code as the basis for seismic design of structures. To address this vulnerability, which could have impacted deliveries from the CRA over an extended period, new buttress walls were constructed in 1996.

Construction of new buttress walls at Hinds Pumping Plant

Procedure for Seismic Evaluation of Structures

A seismic risk-reduction program identifies seismic deficiencies of structures and quantifies the associated risks through an effective evaluation process, enabling limited resources to be allocated strategically to projects that address key vulnerabilities and to maximize improvements in seismic resilience of the water delivery system.

Metropolitan's procedure for the seismic evaluation of structures includes the following steps:

1. **Preliminary evaluation of all high-risk structures**

   The preliminary evaluation of existing structures is a high-level assessment to quickly determine if a structure is seismically deficient. Typically, this evaluation involves drawing review, visual inspection, and simplified calculations. If a potential seismic deficiency is identified, the structure is categorized as seismically deficient and the preliminary evaluation is complete.

2. **Prioritization of structures with seismic deficiencies**

   Structures identified as seismically deficient are then prioritized in preparation for a detailed evaluation. Structures built after 1990 were designed and constructed in accordance with the 1988 or later versions of the Uniform Building Code (UBC), which provides reasonable assurance of withstanding a design-level earthquake without catastrophic structural failure. Therefore, structures built before the early 1990's are given priority for the detailed evaluations, with consideration of life safety and the importance of the facility in water deliveries.

3. **Detailed evaluation to develop retrofit options**

   Structures identified with at least one potential seismic deficiency via the preliminary evaluation are thoroughly assessed to confirm any deficiencies. Feasible retrofit options are developed during this step to mitigate the identified deficiencies, and more advanced procedures such as finite element modeling and comprehensive structural calculations may also be applied. The analysis methodology, its results, findings, and recommendations are then summarized in a report that includes rough order-of-magnitude construction costs.

4. **Final retrofit design to strengthen deficient structures**

   The recommendations from the detailed evaluation form the basis for requesting approval from the Board of Directors to proceed with a seismic upgrade project. A project team consisting of design engineers and a project manager considers all feasible retrofit options developed during the detailed evaluation and recommends one option for the final retrofit design. In this process, the project team considers adequacy for seismic resistance, cost, constructability, operational impacts, and environmental impacts to select the preferred option. The selected option is then developed into bidding documents that include detailed design drawings and specifications for the retrofit work.

5. **Periodic reevaluation of strengthened structures**

   The seismic design provisions in building codes are constantly evolving, which reflects lessons learned from recent earthquakes and new findings in regional seismicity. Metropolitan periodically re-evaluates its facilities to ensure that system reliability is not compromised due to newly discovered vulnerabilities. Factors that may trigger a re-evaluation of a previously upgraded structure include:

   - Substantial increase of seismic hazard level at the site
   - New discovery of site seismicity
   - New discovery of potential seismic deficiencies in the structure
   - Significant deterioration of existing materials in the structure

Progress to date

A comprehensive inventory list of Metropolitan's above-ground structures is used to track the progress of the evaluation and seismic upgrades of structures. To date, Metropolitan has completed preliminary evaluations of all 311 pre-1990 above-ground structures (see **Figure 4-1**). Upgrades of many critical structures have also been completed, including the five pumping plants along the Colorado River Aqueduct, the Jensen Administration Building, and the Lake Mathews Outlet Tower.

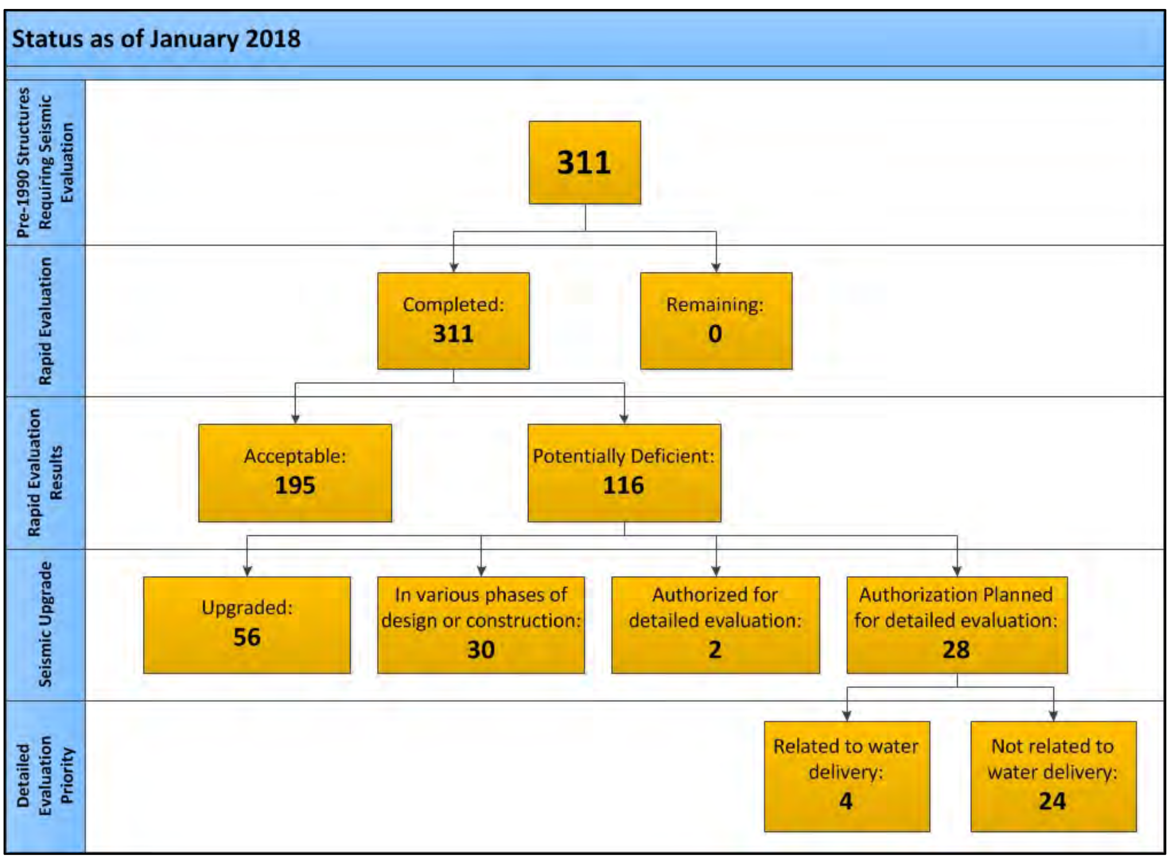


Figure 4-1: Status of Seismic Assessments and Upgrades of Pre-1990 Structures

As shown in the figure, of the 116 structures identified as potentially deficient, 56 have been upgraded and 32 are authorized for study, design or construction. The remaining 28 structures will proceed through Metropolitan's CIP evaluation process to obtain authorization for the detailed evaluations. Since 1998, Metropolitan has invested over $200M in seismic upgrades of its key structures.

Expanded Approach for Achieving Seismic Resilience of Structures

In 2017, the strategy for achieving the seismic resilience of structures was modified to further enhance the seismic resilience of the delivery system. The refined strategy moved beyond assessing only Pre-1990 above-ground structures to include the following:

- Fully and partially buried structures
- Seismic anchorage and bracing of non-structural components such as equipment, pipes, and ducts.
- Structures constructed between 1990 and 2000 (prior to the adoption of UBC1997)

For the first two items, it was recognized that fully and partially buried structures, while less vulnerable to seismic hazards than above-ground structures, are nevertheless important to maintaining system reliability. Similarly, the seismic resilience of non-structural components, such as equipment and piping, is also important for minimizing operational downtime after an earthquake.

The third item, relating to UBC1997, is included in the expanded effort since seismic design codes have been modified such that some structures designed and constructed after 1990 also warrant an assessment. Recorded ground motions in the 1994 Northridge Earthquake, for example, revealed that the design seismic force specified in building codes at the time were underestimated for sites located close to faults. This near-fault effect was incorporated into the subsequent code (UBC 1997). As a result, certain structures designed between 1990-2000 prior to the adoption of UBC 1997 may be vulnerable to a major earthquake.

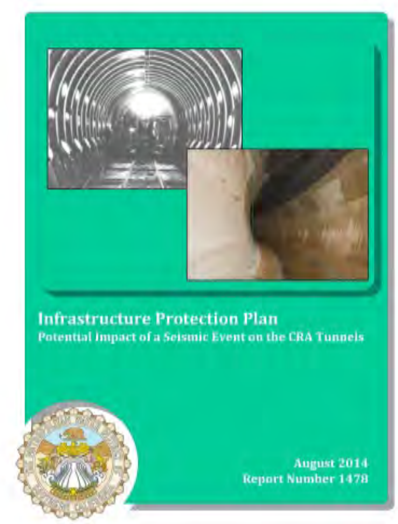
Moving forward, the near-term focus is to complete the detailed evaluations and seismic retrofit projects that have been authorized to date. Long-term goals include:

- Continue assessment of seismic design criteria to incorporate updated seismic resilience strategy
- Document a systematic approach to improve seismic resilience of non-structural components
- Conduct preliminary evaluations for critical fully or partially buried structures
- Conduct preliminary evaluation of post-1990 structures.

Special Seismic Assessments

Special seismic assessments are performed to complement the original seismic resilience of structures evaluations. These special assessments include seismic vulnerability evaluations, general reliability assessments, and system flexibility studies.

Seismic Vulnerability Evaluations. Seismic vulnerability evaluations identify potential impacts of credible earthquake scenarios on individual facilities and the system as a whole. For these studies, staff review current and readily available seismic hazard data from public, academic, state, and federal sources, as well as input from geotechnical consultants, to screen each facility or system (e.g., the CRA) for its level of exposure to seismic hazards (i.e., surface displacement, ground shaking, liquefaction, and landslides) during a major seismic event. Based on the potential level of exposure and the resulting damage to Metropolitan facilities, the time to restore service are estimated. These studies then evaluate the impact of the damage on Metropolitan's water delivery capability and identify areas with limited backup capability to provide water while the facility is out of service. Improvements that could reduce the loss of service, and/or reduce the time to restore service, are then identified and prioritized.



The 2014 Potential Impact of a Seismic Event on the CRA Tunnels validated historic assumptions regarding potential outage durations for the CRA tunnels.

Findings from these evaluations can lead to capital improvements to strengthen facilities, improve system flexibility, and/or provide input into Metropolitan's emergency response planning to improve the seismic resilience of the distribution system.

To date, Metropolitan has completed over ten seismic vulnerability studies. A few examples are listed below, while a complete list with a brief summary of each study is included in Appendix 7.

- *Seismic Risk Assessment of Local Water Production Facilities in the Service Area of Metropolitan Water District of Southern California,* January 14, 1991, Dames & Moore
- *Probable Maximum Loss Analysis for Metropolitan Water District of Southern California*, September 1998, EQE International
- 2009 Report No. 1335: *Effects of Southern California Seismic Events on Metropolitan Water District Deliveries*
- 2014 Report No. 1490: *Colorado River Aqueduct Seismic Vulnerability Investigations – Summary Report*
- 2017 Report No. 1533: *Seismic Risk Assessment – Conveyance and Distribution System Tunnels*

General Reliability Assessments. The vulnerability of Metropolitan's facilities to damage from major seismic events is also evaluated through general reliability assessments. The objective of these assessments is to examine the vulnerability of facilities to unplanned service interruptions from the following hazards and events:

Seismic activity	Fire
Hydraulic surge	Corrosion
Vehicle impact	Wind-blown projectiles
Equipment malfunction	Third-party construction
Erosion/Scour/Flooding	Vandalism

The assessments are based on compiling data collected from several sources and evaluating the information to identify vulnerabilities that may damage a facility and impact water deliveries. The sources of information include prior reliability studies conducted for the facility; the facility's piping and instrumentation diagrams, electrical single-line drawings and plant layout drawings; interviews with Water System Operations and Engineering Services staff; reviews of corrective maintenance reports, reviews of CIP projects; and field inspections of the facilities.

The general reliability assessments focus on the following when relating to seismic activities:

- Assessing the ability of individual equipment and piping within the facilities to withstand an earthquake
- Reviewing potential soil stability issues that might affect earthquake vulnerability with Metropolitan's geotechnical staff
- Reviewing the ability of existing critical structures (i.e., tanks, treatment basins and pump house buildings) to withstand a seismic event

After identifying potential vulnerabilities to specific hazards and events, staff categorize the vulnerabilities based on the potential service impacts and identify options to mitigate the vulnerability and improve reliability. Mitigation steps include conducting capital projects to rehabilitate, replace, or upgrade equipment and facilities; performing operation and maintenance (O&M) activities for minor equipment modifications; creating procedures for designing, operating or maintaining the facility; and refining Metropolitan's emergency response plan. These options are prioritized based on their potential impact on the operation of the facility and are considered for evaluation and action. The cost and benefit of options that involve capital projects are evaluated through the normal CIP evaluation process.

Metropolitan has completed a total of eight general reliability assessments to date, including assessments of the CRA, all five water treatment plants, the conveyance system, and portions of the distribution system. A few examples are listed below, while a complete list with a brief summary of each study is presented in Appendix 7. As the understanding of earthquake probability and seismic forces continues to increase, these studies will be periodically updated.

- 2006 Report No. 1227: *Distribution System Reliability Assessment*
- 2006 Report No. 1255: *Weymouth Water Treatment Plant Reliability Assessment*
- 2006 Report No. 1297: *Colorado River Aqueduct Reliability Assessment*

System Flexibility Studies. System flexibility studies identify:

1. The impacts of regional facility outages on water deliveries to member agencies
2. Areas with limited flexibility to serve water, which may impact deliveries during an outage
3. Options to improve system flexibility (e.g., interconnections with other agencies, local resource development, or isolation valves).

These studies postulate outages to Metropolitan and DWR facilities, assign a reasonable duration to the outage based on past experience, and then evaluate the impact of the assumed outage on water deliveries through the following steps:

1. Identify service connections affected by an outage
2. Evaluate Metropolitan options to deliver water to the affected service connections

3. Evaluate member agency backup options (e.g., wells, treatment plants, surface storage, interconnections with other agencies) to deliver water to affected service connections
4. Quantify the impact of each outage in terms of loss of retail service to affected service connections, and identify service connections and/or regions with limited or no backup capability
5. Identify options to mitigate the impact of the outage and improve system flexibility to respond to planned and unplanned outages

The results of these studies support member agencies' efforts to improve local system reliability in the event of a planned or unplanned outage of a Metropolitan facility; support joint efforts of Metropolitan and its member agencies in evaluating the reliability benefits of potential projects; and support Metropolitan's efforts to identify options to improve operational flexibility.

Two significant system flexibility studies have been completed to date:

- **System Reliability Study (2006).** This study evaluated the flexibility of Metropolitan's overall distribution system. The study examined the impact of single failures in the system to the ability to deliver water to member agencies and identified existing backup options to deliver water during the outage. Specific types of failures considered in the study included individual facility failures (e.g., the CRA, a treatment plant, a reservoir) and failures in each isolatable segment of the distribution system (e.g., pipelines). Over 250 different postulated events were considered, and the impact on delivery to each service connection was evaluated for each event. The study considered the capabilities both within Metropolitan's system as well as the member agencies' to mitigate impacts of an outage. The study did not, however, consider multiple failures that might be associated with an earthquake, due to the almost unlimited number of combinations of failures that would have to be considered. Metropolitan and member agency discussions regarding this study and local and regional obligations led to a clarification about Administrative Code 4503 "Suspension of Deliveries" that is included in Appendix 8.
- **Mills Water Supply Reliability Study (Report No. 1337).** One of the findings of the 2007 Integrated Area Study was that the supply of raw water to the Mills plant had a lesser degree of redundancy than Metropolitan's other water treatment plants. The Mills Water Supply Reliability Study was undertaken to evaluate conditions that could interrupt the normal raw water supply to the Mills plant, such as earthquakes, and develop options to improve the redundancy and flexibility of supply to the plant.

Seismic Resilience of Dams and Reservoirs

The seismic stability of Metropolitan's dams is safeguarded by a robust and proactive comprehensive dam safety strategy managed by the Safety of Dams Team. The core responsibilities of the Safety of Dams Team are to perform inspections, interpret and analyze collected surveillance and monitoring data, evaluate dam structures and appurtenant works, report the findings, and serve as Metropolitan's liaison with the California Department of Water Resources, Division of Safety of Dams (DSOD).

Metropolitan owns and operates 20 facilities that are under the jurisdiction of DSOD, as listed in Table 4-1. There are a total of 24 individual dams/reservoirs, as some of these facilities have multiple dams.

Table 4-1: Current Metropolitan Jurisdictional Dam and Reservoir Facilities

Dam/Reservoir Name	Dam Type
Cajalco Creek Detention Basin	Flood Control
Copper Basin Reservoir	Surface Water Reservoir
Diamond Valley Forebay	Hydraulic Structure
Diamond Valley Lake	Surface Water Reservoir
Diemer Mixing & Settling Basin No. 8	Hydraulic Structure
Diemer Ozone Contactor Basins	Hydraulic Structure
Diemer Treated Water Reservoir	Hydraulic Structure
Garvey Reservoir	Surface Water Reservoir
Gene Wash Reservoir	Surface Water Reservoir
Goodhart Canyon Detention Basin	Flood Control
Lake Mathews	Surface Water Reservoir
Lake Skinner	Surface Water Reservoir
Live Oak Reservoir	Surface Water Reservoir
Mills Reclamation Basin No. 14	Hydraulic Structure
Mills Treated Water Reservoir No. 1	Hydraulic Structure
Mills Treated Water Reservoir No. 2	Hydraulic Structure
Orange County Reservoir	Surface Water Reservoir
Palos Verdes Reservoir	Surface Water Reservoir
Skinner Treated Water Reservoir	Hydraulic Structure
Weymouth Treated Water Reservoir	Hydraulic Structure

Metropolitan's Comprehensive Dam Safety Management Program

Metropolitan's comprehensive dam safety strategy is comprised of six key elements:

1. Regular detailed inspections
2. Surveillance monitoring and performance reporting
3. Cyclical facility assessments
4. Emergency preparedness
5. Inundation map preparation
6. Execution of capital projects

Regular Detailed Inspections

Regular detailed inspections are essential to preserve the integrity of a dam and are necessary for early problem detection and remediation. All Metropolitan dams are regularly inspected by Metropolitan staff at specific intervals using a formal, multilayered process:

- Daily or weekly observations
- Monthly inspections of dam and reservoir facilities with the highest DSOD designated hazard classification, with at least semi-annual inspections of all other facilities
- Detailed mandatory annual inspections conducted in the presence of DSOD staff

Upon completion of the annual DSOD inspections, DSOD prepares and provides a summary inspection report that summarizes their findings and may identify recommended remedial work, which is cataloged as action items that are corrected promptly.

Surveillance Monitoring and Performance Reporting

All Metropolitan dams and reservoirs incorporate instrumentation that measures specific performance parameters such as dam or structural movement, water levels, and seepage, as well as other parameters such as shaking due to earthquakes. Collected data are retained as part of the required annual DSOD inspection report.

In terms of seismic resilience, data from surveillance monitoring and performance reporting contribute to the Cyclic Facility Assessments described below by identifying changes in specific parameters, such as dam or reservoir movement or increased seepage, that may indicate a condition that could affect the ability of the dam or reservoir to withstand an earthquake.

Cyclical Facility Assessments

Cyclic facility assessments were initiated at Metropolitan in 2004 and are generally repeated about every 10 years. These assessments use the most up-to-date data and evaluation criteria to identify potential vulnerabilities in dam embankments, dam structures, foundations, outlet facilities and spillways and develop mitigation options, if necessary. If a potential vulnerability or deficiency is identified, a rehabilitation or remediation project may be included in Metropolitan's CIP.

An example of a facility assessment that evolved into a project under Metropolitan's CIP is the Lake Mathews Outlet Tower. The outlet tower, which is critical for water deliveries to a large portion of Metropolitan's service area, was constructed in 1938 and modified in 1961 to increase its height by 30 feet. A facility assessment conducted in 1994 determined that the modified tower was vulnerable to significant damage from ground shaking. A project was authorized to evaluate and address this vulnerability, resulting in a new seismically resilient Outlet Tower being constructed in 2005.

New and Old Outlet Towers at Lake Mathews (2008)

Emergency Preparedness

Metropolitan has a comprehensive Emergency Action Plan (EAP) for each of its dam and reservoir facilities. The EAP identifies potential emergency conditions that could occur at a dam or reservoir facility and describes procedures to be implemented to minimize loss of life and property damage. EAPs serve to provide guidance to responders, local agencies, and stakeholders in evaluating potential hazards, determining the severity of the emergency, and establishing communication protocols. Required content of dam EAPs are provided in the Federal Emergency Management Agency's (FEMA) Federal Guidelines for Dam Safety, Emergency Action Planning for Dams (FEMA 64, July 2013).

Inundation Map Preparation

Inundation maps illustrate worst-case flooding that would result in the complete draining of a full reservoir. Inundation maps show lateral and longitudinal extent of flooding, flood wave arrival times, maximum flood wave depths, total flooding duration, and peak flood flow rates. Inundation maps are a required component of dam and reservoir EAPs and are used by local emergency response agencies for emergency planning purposes.

Metropolitan's current cycle of inundation mapping updates is planned to be completed by 2018 for all dam and reservoir facilities.

Execution of Capital Projects

Dam and reservoir facility vulnerabilities or deficiencies that are identified during detailed inspections or from cyclical assessments are proposed for rehabilitation or remediation through Metropolitan's CIP. Past examples of facility rehabilitation or remediation projects include the Lake Mathews Outlet Facilities, described earlier, and the Seismic Upgrade of the Diemer Finished Water Reservoir.

Currently, several dam and reservoir related capital projects are in progress, including the final design of the outlet valve replacements at Copper Basin and Gene Wash Reservoirs and the construction of the Palos Verdes Reservoir floating cover replacement and tower seismic upgrades. Planned future projects include floating cover replacements and facility upgrades for the Mills Finished Water Reservoir Nos. 1 and 2 and Garvey Reservoir.

Pipeline Seismic Resilience

Metropolitan's pipelines are exposed to a number of geohazards of varying risk, including fault zone crossings, permanent ground deformation from causes such as liquefaction or landslides, and ground shaking during seismic events. While Metropolitan's pipelines have always been constructed in conformance with standards of practice at the time of design, there haven't been code requirements to address seismic risk. In addition, until recently, there have not been mitigation options for large diameter pipelines.

The photograph on the left shows a pipe joint pullout due to liquefaction from 1995 in Kobe, Japan. (photo courtesy of D. Ballantyne, *Understanding the Seismic Vulnerability of Water Systems*, Regional Water Providers Consortium Board, October 2013)

The photograph on the right shows pipe damage at a fault crossing (photo courtesy of D. Ballantyne, *Understanding the Seismic Vulnerability of Water Systems*, Regional Water Providers Consortium Board, October 2013)

There are currently several seismic resistant pipeline options, such as earthquake resistant ductile iron pipelines with special seismic resistant joints (see **Figure 4-2**), that are becoming available in diameters suitable for use by Metropolitan.

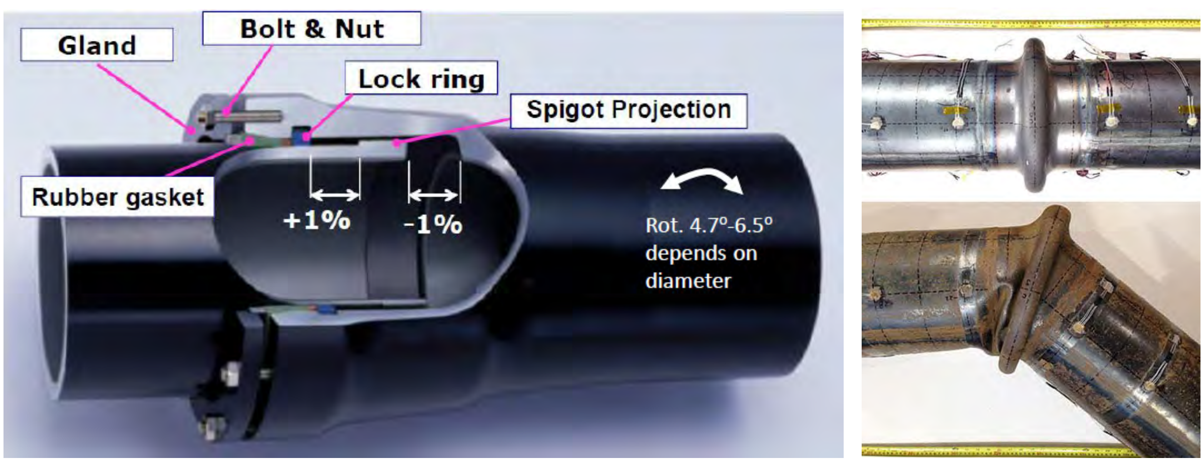


Figure 4-2: Example of Seismic Resistant Pipe (courtesy of Kubota Corp. and JFE)

As mentioned previously, Metropolitan is now formalizing a strategy to achieve significant improvements in seismic resistance of the distribution system over time. This approach takes advantage of up-to-date seismicity data, modern computer modeling techniques, recently developed seismic resistant products, extensive industry research, and updated codes.

The seismic resilience strategy for pipelines has three components:

1. Part 1 – Conducting vulnerability assessments of the existing distribution system
2. Part 2 – Identifying potential mitigation measures for existing pipelines
3. Part 3 – Establishing design and performance criteria for new pipelines and rehabilitation projects

Parts 1 and 2 are described below in more detail. Part 3 for new pipelines will be developed in conjunction with several new large-diameter pipeline projects that are planned over the next 5 to 10 years.

Part 1 –Vulnerability Assessment of Existing Pipelines: Due to the relatively good performance of large-diameter pipelines within Metropolitan's distribution system during previous earthquakes, Metropolitan is focusing on the most vulnerable existing pipelines to establish the need and priority of future mitigation work as well as integrating seismic mitigation into planned rehabilitation programs for aging pipelines. This approach is currently being followed for the PCCP Rehabilitation Program. It is anticipated that there will be relatively few cases where it would be considered cost-effective to upgrade a pipeline solely to enhance seismic resilience.

Vulnerability assessments of pipelines within the distribution system follow the same multi-step approach used for traditional risk assessments. The initial steps entail gathering available geologic, seismologic, and geodetic data, and then identifying seismic hazards along a pipeline route, such as fault zone crossings, liquefaction zones, and landslide hazards. Three simulated earthquake scenarios are considered in the evaluation: a frequent seismic event, moderate event, and a severe event. The hazard assessment provides a bounded solution that includes the expected probable and maximum probable damage for each earthquake scenario.

The resulting damage to the pipeline due to the three design seismic scenarios provides an insight into the corresponding consequences of disruption. These consequences include life-safety impacts, delivery impacts, and societal/environmental impacts.

Preliminary screening is then performed to identify the most vulnerable pipelines that warrant further analysis. Depending on the nature of the seismic hazard, Metropolitan may perform a preliminary assessment using a simplified analysis based on probable ground strain and pipeline material properties. However, in some cases, a more detailed finite element model is required to fully determine the behavior of the pipe and the surrounding support strata under seismic shaking. This comprehensive analysis includes soil-structure interaction, rupture modeling, and permanent pipeline deformation.

For any pipelines that do not meet the performance objectives, mitigation measures are considered. The order and timing of projects to mitigate risks as part of the overall rehabilitation strategy are evaluated and prioritized for inclusion in Metropolitan's CIP.

Part 2 – Mitigation Measures for Existing Pipelines: Where mitigation is recommended to minimize the consequences of service disruption, the general design goals are to design pipe segments and joints that can withstand projected vertical and horizontal movement. In most cases, a simplified analysis will provide sufficient insight into seismic performance; however, in some cases, it may be necessary to analyze the pipeline and connecting structures using a more comprehensive computer model.

Existing continuous welded steel pipe with adequate wall thickness and joint welds typically perform well under significant ground shaking. Where mitigation of existing pipelines is required to achieve acceptable seismic performance, Metropolitan may use specialized earthquake resistant joints as an option. Where these joints cannot achieve acceptable seismic performance, other options may include stiffening of the joints and pipe section; and enlarged vault sections to isolate the pipe from maximum ground deformation. Metropolitan may also evaluate alternate alignment options to relocate existing pipes, if feasible, to avoid areas of known fault crossings or expected permanent ground deformation that may result in significant disruption. Where these options are not feasible and seismic risk is not within acceptable limits, Metropolitan may consider installation of isolation valves or addition of a vault with a removable pipe spool to allow quick insertion of a bulkhead to facilitate shutdown and repair of the damaged section of pipe

Part 3 – Design Guidelines for New Pipelines: The guidelines for new pipelines will be similar in concept to existing pipelines and will be developed in conjunction with several new large-diameter pipeline projects that are planned over the next 5 to 10 years.

SECTION 5 OPERATIONS COMPONENT

Metropolitan is prepared to respond to all types of emergencies through its Emergency Management and Business Continuity Operating Policy A-06. Key elements of this policy include IT Disaster Recovery, Business Continuity and Emergency Response functions. This section focuses on the Emergency Response functions due to specific steps in this area that pertain to seismic resilience.

Emergency Response Organization

Metropolitan maintains a dedicated Emergency Operations Center (EOC) that can be activated at any time to manage Metropolitan's response to a large disaster, including seismic events. The EOC is equipped with multiple modes of communication and coordinates directly with Metropolitan's Operations Control Center (OCC) and Security Watch Center (SWC), as well as with numerous external agencies. For example, the EOC would coordinate with DWR and LADWP, as well as other related agencies, in the event of one or more aqueducts being damaged by an earthquake on the San Andreas Fault, as further explained in the next section.

Metropolitan also has Incident Command Centers (ICCs) located at various facilities. These ICCs can also be activated at any time to manage localized emergencies, and will coordinate directly with the EOC during a major disaster. Metropolitan also has Damage Assessment Teams (DATs) that that can be called upon by the ICCs to conduct investigations at incident sites. The DATs consist of engineers who can assess damage and initiate engineering responses, including recommendations for short-term repairs or work-arounds and potential designs for permanent, long-term repairs.

The Emergency Response Organization (ERO), illustrated in **Figure 5-1**, is comprised of over 200 pre-designated employees who work in the EOC, the ICCs, or in the field during emergencies. ERO staff has completed specialized training that meets State and Federal requirements.

Metropolitan's emergency response structure follows the National Incident Management System (NIMS) and the State of California's Standardized Emergency Management System (SEMS).

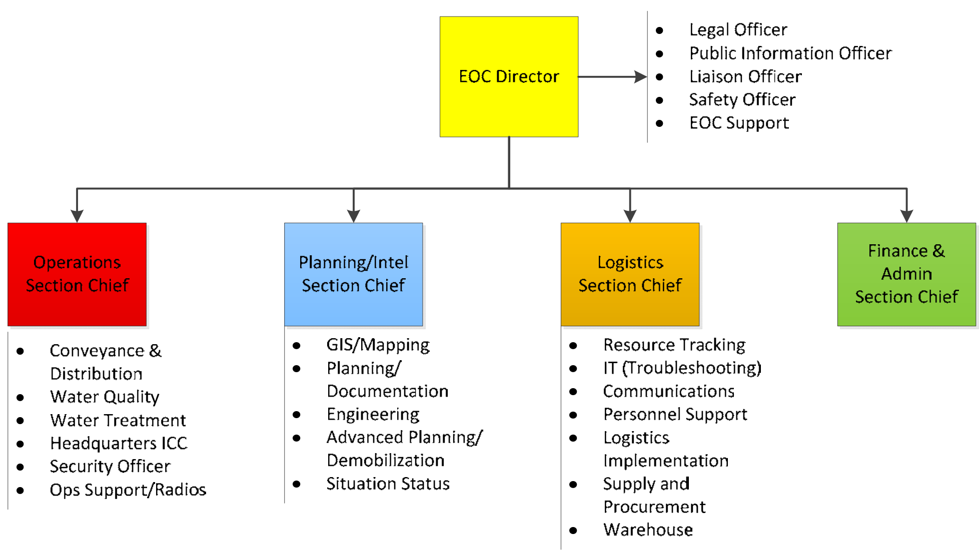


Figure 5-1: Metropolitan's Emergency Response Organization

Photographs from recent emergency exercises at the EOC

Emergency Response Training Exercises

In addition to training emergency response staff on NIMS procedures, Metropolitan regularly conducts emergency response training exercises which have often been based upon a postulated seismic event. Examples include:

- “Resilient Grid“ Functional Exercise, 19 Oct 2017
- “Can you hear me now?” Full Scale Communications Exercise, 08 Apr 2017
- “Desert Shake” Functional Exercise – 04 Nov 2015 (Metropolitan and seven other agencies)
- “Oh Susana!” Functional Exercise – 05 Nov, 2013 (Metropolitan and four other agencies)
- “Golden Guardian” Functional Exercise – 20 Jun 2012
- “California Rolling” Mini Functional Exercise – 08 Oct 2008
- “Hollywood Havoc” Functional Exercise – 04 April 2007
- “Mayhem at Mathews” Tabletop Exercise – 15 Mar 2006 (Metropolitan and four other agencies)

In 2017, Metropolitan completed a five-year exercise plan that allowed all of its member agencies to participate in at least one of Metropolitan’s annual emergency exercises during that period. Metropolitan also conducts approximately 50 tabletop and functional exercises each year. This includes three large-scale emergency exercises per year for the EOC and for each of the 12 ICCs. There are also monthly communication drills (includes Member Agency Response System (MARS) two-way radio, internal Metropolitan radio system, WebEOC updates, mass notification system, and satellite phones) with member agencies, ICCs, Treatment Plant Control Centers, and DWR facilities. These regular exercises, as well as monthly radio and communications tests with member agencies and other outside agencies, help Metropolitan to continually improve its readiness.

Emergency Response Construction Capabilities

Metropolitan maintains the capability to perform rapid repair of damaged facilities such as large pipelines for up to two simultaneous repairs. The machine, fabrication, coating, and valve shops at the La Verne

Shops are used extensively to support system-wide maintenance; to provide emergency services within Metropolitan, for member agencies, and for DWR; and to perform fee-for-service work that supports member agencies and the State Water Project. The fabrication shop can roll pipe on a 24-hour-per-day basis. In 2015, Metropolitan expanded the La Verne Shops to enable the fabrication of two pipe sections up to 12 feet (3.7 meters) in diameter simultaneously, and has been developing standardized pipeline repair drawings and shoring drawings to expedite repair operations.

Metropolitan also maintains stockpiles and materials on hand, and has its own construction equipment and crews ready to mobilize if necessary. Pre-selected urgent repair contractors can also provide additional construction support in case of an emergency. Maintaining these manufacturing and construction capabilities supports Metropolitan's efforts to efficiently operate and maintain its infrastructure and to quickly repair components or systems that may be damaged.

Pipe being rolled at Metropolitan's La Verne Shops

Metropolitan construction crews

42" x 30" adapter flange being drilled at Metropolitan's La Verne Shops

Stocks of steel plate allow Metropolitan to roll pipe of various diameters and wall thicknesses

SECTION 6 REPORTING COMPONENT

The reporting component of Metropolitan's seismic resilience strategy focuses on the following areas:

1. Record Keeping: Tracking progress and maintaining a record of expenditures
2. Annual Updates: Providing annual updates to Metropolitan's Board of Directors
3. Formal Reporting: Preparing a formal Seismic Resilience Biennial Report

Record Keeping

The Record Keeping component involves tracking progress on key seismic activities and maintaining a detailed record of all investments and expenditures related to seismic upgrade projects.

Key seismic resilience activities include the planning, engineering, operations, and Task Force component near-term goals identified in Section 8. Specific activities include:

- Special planning studies related to seismic resilience
- Seismic evaluations of structures, facilities, and regions
- Designs for seismically upgrading structures/systems and related construction activities
- Emergency response training exercises
- Development of new seismic performance objectives
- Joint efforts with external agencies through the Task Force

For each of these activities, progress will be tracked and reported on at regular intervals. In addition, the cumulative cost of capital investments in seismic upgrade projects will be tracked and reported on annually.

Annual Updates

Staff will update Metropolitan's Board of Directors on an annual basis. The annual update will focus on current seismic resilience issues, recent Metropolitan and Task Force accomplishments, and near-term goals.

Formal Reporting

The biennial report will summarize seismic resilience objectives, goals, and accomplishments; consolidate key reference material; and provide a high-level summary of the various activities related to seismic resilience throughout Metropolitan. Specific areas of emphasis will include:

- Knowledge Transfer: The biennial report will provide a convenient, comprehensive source for seismic resilience information. The report will contain key information for all seismic resilience efforts throughout Metropolitan, and will include a list of all formal Metropolitan reports on seismic issues. Individuals can use this information to familiarize themselves with Metropolitan's seismic resilience history, issues, and goals, which will make them more effective in supporting seismic resilience efforts.

- Accountability: Through annual reporting to the Board, seismic resilience programs will maintain a higher degree of visibility, focus and momentum on projects and studies that will help Metropolitan meet target goals.
- Transparency: The sharing of seismic resilience studies, projects, and performance objectives will benefit the facility planning efforts of member agencies. Seismic risk, mitigation, and projected duration of outages are complex issues that deserve adequate discussions between Metropolitan and member agencies to facilitate decisions and investments that best serve the public.

This summary report will be updated every two years.

SECTION 7 SEISMIC RESILIENCE WATER SUPPLY TASK FORCE

The City of Los Angeles has recently increased its focus on seismic risks and public safety. In December 2014, the city released the report, "Resilience by Design," which highlighted Los Angeles' earthquake vulnerabilities and laid out strategies to protect lives; improve the capacity of the city to respond to earthquakes; prepare the city to recover quickly from earthquakes; and protect the economy of Los Angeles and all of Southern California.

A concern noted in "Resilience by Design" is the importance of water infrastructure and the unique dependence of the region upon imported water supplies, all of which cross the San Andreas Fault. The report included a recommendation to fortify the imported water aqueducts by creating a Seismic Resilience Water Supply Task Force (Task Force) with the LADWP, Metropolitan, and DWR.

In August 2015, the three agencies formed the Task Force for the purpose of collaborating on studies and mitigation measures to improve the seismic resilience of imported water supplies to Southern California. The Task Force is comprised of managers and staff from the planning, engineering, and operations functional groups of each agency, and includes executive management on a steering committee. The Task Force also coordinates with other agencies and utilities.

The Task Force created a structure (**Figure 7-1**) that includes functional sub-teams that will focus on aqueduct assessments and mitigation, emergency response, and public relations in the near-term. The Task Force also recognized the benefit of long-term collaboration regarding 'non-aqueduct' assessments and mitigation, and agreed to discuss such issues as they arise.

The initial Task Force goals include:

- Establishing a common understanding about individual agency aqueduct seismic vulnerability assessments, projected damage scenarios, and planning assumptions
- Revisiting historical assumptions regarding potential aqueduct outages due to seismic events
- Discussing opportunities for improving the seismic resiliency of Southern California's imported water supplies through multi-agency cooperation

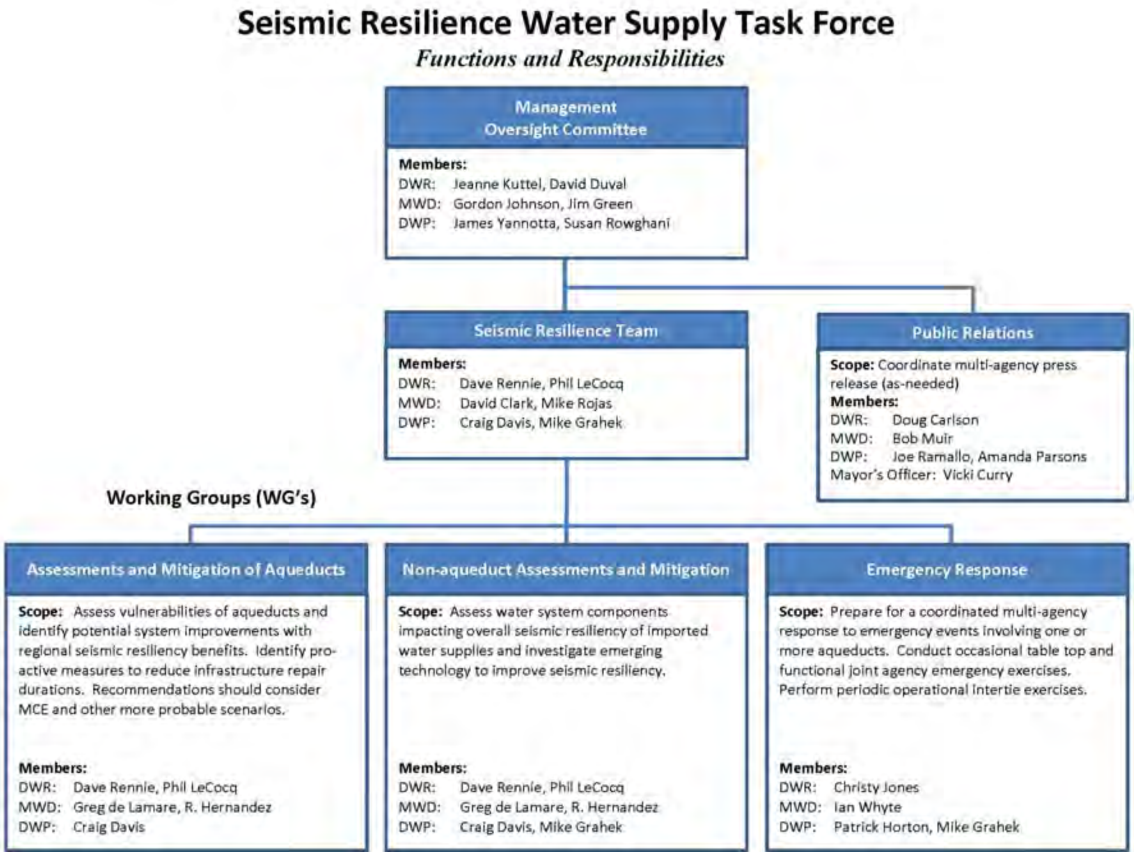


Figure 7-1: Seismic Resilience Water Supply Task Force

One of the initial activities for the Task Force was to conduct a workshop that would allow the three agencies to establish a common understanding about each agency's seismic vulnerabilities; revisit historical planning assumptions; and identify action items that would lead to increased seismic resilience moving forward. The workshop is summarized below.

2016 Aqueduct Workshop

On March 30, 2016, the Task Force held an Aqueduct Workshop at Metropolitan's Headquarters Building in Los Angeles. The purpose of this workshop was to discuss potential damage to Southern California's imported water aqueducts from a major seismic event on the San Andreas Fault. The discussion focused specifically on the Great Southern California ShakeOut Scenario (ShakeOut) of a M7.8 earthquake, developed by the U.S. Geological Survey (USGS) and many partners. The workshop format allowed for a candid exchange of information and ideas between staff from the three agencies, along with LADWP's Seismic Resilience and Sustainability Program's Expert Panel that included experts from industry and academia.

Participants were asked to consider preparations for, and response to, the ShakeOut Scenario from a regional perspective. Specifically, participants were asked, "If all aqueducts were owned and operated by a single agency, then what steps should be taken now to mitigate potential damage, and what would the priority of repairs be following a major seismic event to most rapidly restore imported water deliveries to the region?" This focus on actions that would best serve the region led to productive discussions and practical recommendations for the three agencies to improve the resilience of imported water supplies.

The assembled team concluded that for a M7.8 ShakeOut Scenario event on the southern portion of the San Andreas Fault, the recovery times would exceed historic planning assumptions:

- Restoration of full aqueduct capacities could take more than six months
- Restoration of partial aqueduct flows could take at least two months

The March 30, 2016 Task Force Workshop at Metropolitan's Headquarters Building

When considering this specific scenario from a regional perspective, the participants concluded that residents within Metropolitan's service area would be best served if the three agencies:

- Implement recently identified mitigation projects on the Colorado River Aqueduct and Los Angeles Aqueduct
- Prioritize known vulnerabilities on the Colorado River Aqueduct, Los Angeles Aqueduct, and the State Water Project
- Execute an agreement to allow for a coordinated response to emergency events
- Share resources when responding to emergency events
- Focus initial repair efforts on the State Water Project's West Branch and the Colorado River Aqueduct*

(*This is based on a ShakeOut-type event; it is recognized DWR will also have a priority to serve other customers on the East Branch)

LADWP's Seismic Resilience and Sustainability Program's Expert Panel noted the significance of the nation's largest municipal utility, largest water wholesaler, and largest state-owned water agency joining together to address a major hazard for the first time, and encouraged the Task Force to continue working together long into the future. The assembled team agreed that Southern California could become better prepared for seismic events and that the Task Force should continue to facilitate coordinated vulnerability assessments, evaluate mitigation options, and develop agreements that allow coordinated emergency responses to major seismic events. It was clear that common issues could be studied more efficiently together and there was a consensus for the Task Force to continue to maintain the momentum achieved through this workshop. Although the regional challenge of achieving a greater level of seismic resiliency is significant, the consensus was that it would be achievable through the continued, dedicated efforts of the Task Force.

Future Task Force Activities

To continue the momentum built during the collaborative workshop, the Task Force agreed to conduct conference calls every two months and to initiate a repeating 5-year cycle of planning, executing, and reporting on collaborative goals, activities and accomplishments. This approach is aimed at providing effective management of long-range actions and ensuring task force stability.

The first cycle has included preparation of a detailed report that summarized the 2016 Workshop and identified goals for the period between April 2017 and March 2022. The second cycle will report on progress achieved between 2017 and 2022, and will identify goals for the period between 2022 to 2027.

The high-level goals for 2018 to 2019 are included in Section 8 of this report.

SECTION 8 SEISMIC RESILIENCE PERFORMANCE OBJECTIVES AND NEAR-TERM GOALS

This section summarizes Metropolitan's established performance objectives for the various components of seismic resilience, along with corresponding near-term goals. The goals listed are those that are anticipated to be completed in calendar years 2018 and 2019.

Established Performance Objectives and Near-Term Goals:

- System Level
- Facility Level
- Emergency Response
- Task Force

Other Near-term Goals:

- Establish Additional Performance Objectives
- Develop a Standard Approach for Evaluating Non-Structural Elements
- Enhance Member Agency Planning Efforts
- Seek Funding for Identified Projects
- Support California WaterFix

Established Performance Objectives and Near-Term Goals

Seismic resilience performance objectives are summarized in this section along with the corresponding near-term goals.

System Level

System-level seismic resilience performance objectives and near-term goals focus on two areas: System Flexibility and Regional Supply Interruption/Emergency Storage.

System Flexibility

There are two primary components of system flexibility that contribute to seismic resilience:

1. Operational flexibility - the ability to accommodate short-term changes in regional supply, water quality, or member agency demands, and
2. Delivery flexibility - the ability to maintain deliveries to member agencies during single regional facility planned or unplanned outages.

Metropolitan will continue to develop a demand-driven, flexible regional system aimed at meeting demands, while reducing the impacts of regional infrastructure outages. Regional delivery flexibility improvements will be achieved through demand-driven projects.

System Flexibility Goal	
2019 Goal:	Conduct Rialto Pipeline Alternative Supply Needs study
This study will identify potential near-term and long-term options to meet municipal and industrial (M&I) demands supplied exclusively from the Rialto Pipeline system in the event of a disruption of supplies from the California Aqueduct, East Branch.	

Emergency Storage

Performance Objectives: Metropolitan's objectives for emergency storage include maintaining a six-month supply of water to account for interruption of imported water supplies (assuming a 25% reduction at the retail level).

Emergency Storage Goals	
2019 Goal:	Complete a re-evaluation of Metropolitan's emergency storage needs
This study will re-evaluate Metropolitan's emergency storage requirement based on updated assumptions on potential outage durations for the State Water Project and the Los Angeles Aqueduct. The latest projections for the worst case scenario are that Metropolitan's Colorado River Aqueduct can be repaired within 6 months, LADWP's Los Angeles Aqueduct within about 18 months, the West Branch of the SWP within 6-12 months and the East Branch of the SWP within 12-24 months.	
2019 Goal:	Complete a comprehensive evaluation of Metropolitan's storage programs
This comprehensive evaluation will review all existing storage programs within Metropolitan	

Facility Level

Facility-level seismic resilience performance objectives and near-term goals are categorized based on functionality of facilities: essential facilities related to water delivery; supporting facilities with permanent staff, such as administration buildings; and supporting facilities without permanent staff, such as warehouse facilities.

Essential Facilities (related to water delivery)

Performance Objectives: Performance objectives for essential facilities include maintaining operation with minimum interruption after design-level events and controlling structural damage to facilitate recovery after extreme events.

<table>
<tr><th colspan="2">Essential Facility Goals</th></tr>
<tr><td>Goal 1:</td><td>Complete construction of approved seismic upgrade projects</td></tr>
<tr><td colspan="2">• Carbon Creek Pressure Control Structure (2018)
• Ten Control Structures along the Allen McColloch Pipeline (2018)
• Diemer Administration (Control) Building (2019)
• Five CRA Pumping Plant Switch Houses (2019)</td></tr>
<tr><td>Goal 2:</td><td>Conduct studies, and complete design of approved upgrade projects</td></tr>
<tr><td colspan="2">• Define the scope and approach for assessing potential seismic-induced damage to Metropolitan’s water conveyance and distribution pipelines (2018)
- The purpose of the damage assessment is to estimate the number and severity of pipeline breaks and leaks during major earthquakes, and identify pipelines with the greatest risk for seismic damage. The results of the study will provide input into Metropolitan’s emergency response planning activities, and will help prioritize future pipeline seismic resilience enhancements.
• Design of seismic upgrade for Weymouth West Wash Water Tank (2018)
• Design of seismic upgrade for Diemer West Filter Building (2018)
• Complete evaluation of options, design, and award of construction contract to strengthen the CRA Whitewater Tunnel No. 2 (2019)
- This work will include strengthening shallow tunnel sections near the portals, improving tunnel access at the west portal, prequalifying tunnel repair contractors, stockpiling steel sets, and pre-designing tunnel repair elements.
• Investigate options to improve emergency raw water bypass capabilities at Skinner, Weymouth, Jensen and Mills Water Treatment plants (2019)
• Vulnerability study of CRA electric transmission and distribution systems (2019)
• Design of seismic upgrade for the original portion of the Water Quality Lab in La Verne and the Weymouth Administration Building (2019)</td></tr>
</table>

Supporting Facilities with Permanent Staff

Performance Objectives: Performance objectives for support facilities with permanently assigned staff include controlling structural damage to prevent casualties and severe injuries under design-level events and maintaining structural stability to prevent catastrophic collapse under extreme events.

Supporting Facilities (with permanent staff) Goals	
Goal 1:	Expedite construction of approved seismic upgrade projects
• Headquarters Building seismic upgrades (award construction contract in 2018)	
Goal 2:	Complete approved studies and seismic upgrade designs
• Seismic upgrade to Field Engineering Building at La Verne (2019)	

Supporting Facilities without Permanent Staff

Objectives: Performance objectives for support facilities without permanently assigned staff include controlling structural damage to facilitate recovery after design-level events and maintaining structural stability to prevent catastrophic collapse under extreme events.

Goals: Metropolitan's near-term goal for improving the seismic resilience of support facilities without permanently assigned staff is to continue exploring opportunities of integrating seismic upgrade work of these relatively minor structures with future capital projects at the facility. At this time, no specific goals have been identified in this area.

Emergency Response

Objectives: Metropolitan's objective is to maintain an effective emergency response organization and support facilities to ensure Metropolitan is prepared to respond to significant earthquakes. Regular training is conducted to ensure staff is prepared for actual events. Metropolitan maintains shop and construction crew capabilities to complete the repair of two simultaneous large diameter pipeline breaks within seven days. This capability is augmented by Metropolitan's ability to re-deploy its contractors and to call upon other agreements to repair four additional large diameter pipe breaks simultaneously within seven days (as well as repair other facility damages). These capabilities ensure Metropolitan is prepared to respond to significant earthquakes.

Emergency Response Goals	
Goal 1:	Prepare and conduct emergency exercises
• Conduct a joint agency workshop to prepare a draft Joint Agency Response Plan (2018) • Conduct high-level training for DWR, LADWP, and MWD staff on the Joint Agency Response Plan (2019) • Run a functional exercise on the Joint Agency Response Plan (2019)	
Goal 2:	Execute a MOU to allow for a coordinated emergency response
• Prepare draft MOU and submit for review (2018) • Secure LADWP, Metropolitan, and DWR approval for the MOU (2019)	

Task Force

Task Force Goals	
2018 Goals:	Collaborative LADWP, Metropolitan, and DWR Goals
• Discuss the applicability of lessons learned from seismic events in Japan, Chile, New Zealand, and Mexico • Compare each agency's approach to conducting seismic assessments • Meet with Southern California Edison (SCE) and Southern California Gas Co. to discuss the potential vulnerabilities of aqueduct power systems • Conduct workshop to explore potential aqueduct interties	
2019 Goals:	Collaborative LADWP, Metropolitan, and DWR Goals
• Establish a leadership structure for a coordinated response to major events • Finalize a three-agency database of available emergency response resources • Conduct a three-agency table top emergency exercise • Develop a ShakeOut Scenario Response and Restoration Plan • Conduct a second three-agency functional emergency exercise that includes energy utilities	

Other Near-Term Goals

Additional seismic resilience goals Metropolitan plans on achieving during 2018 and 2019 include:

1. **Develop a Standard Approach for Evaluating Non-Structural Elements (2019)**

   The Seismic Upgrade Program was expanded from its focus on pre-1990 above-ground structures to include post-1990 structures, partially buried structures, and non-structural components in essential facilities. The existing approach to evaluating pre-1990 structures is also applicable to the post-1990 and partially buried structures. However, a standard approach needs to be developed for evaluating the non-structural components within existing facilities, which involves equipment anchorages and bracing for piping, ducts, and cable trays.

2. **Establish Additional Performance Objectives (2019)**

   Metropolitan intends to establish seismic resilience performance objectives in the following areas:

   a) New pipelines

   b) Retrofit of existing Metropolitan pipelines, typically concurrent with rehabilitation projects

   c) New and existing tunnels

   Metropolitan is now in the process of developing a more comprehensive strategy for incorporating seismic mitigation into the design of its pipelines and tunnels. Although it is possible to clearly define performance objectives for above-ground structures, this process is more complicated for pipelines and tunnels for two reasons: 1) The performance of a pipeline or tunnel subjected to seismic forces is less well-defined than with structures, and 2) The performance needs of specific pipelines, pipeline segments, or tunnels vary widely due to Metropolitan's supply flexibility and the varied reliance on imported water by member agencies. Metropolitan will explore these issues in greater detail as it moves ahead with major capital programs, including the PCCP Rehabilitation Program. It is expected that by December 2019, Metropolitan will have established an approach for addressing seismic vulnerabilities during pipeline and tunnel rehabilitation projects, and for new pipeline and tunnel design efforts.

3. **Investigate the Potential for Developing a Model to Prioritize Pipeline Rehabilitation (2019)**

   The prioritization model will seek to optimize the sequence of pipeline repairs to achieve the greatest risk reduction for every dollar invested. The prioritization model would take into account multiple risk factors including seismic risk exposure, pipeline condition, consequence of failure in terms of damage to key facilities (e.g., hospital), difficulty of repairs, system flexibility, and cost of repairs.

4. **Enhance Member Agency Planning Efforts (2019)**

   Development of the following documents will support member agency planning efforts regarding new facilities and emergency response programs:

   a) Summary of seismic performance objectives by facility class; examples of recent seismic upgrade projects; and identification of open items

   b) Summary of projected outage durations for Metropolitan facilities under “Operational”, “Design”, and “MCE” earthquake scenarios

5. **Seek Approval for Detailed Seismic Studies (Ongoing)**

   Under the ongoing Seismic Upgrade Program, Metropolitan will assess the options for seismic upgrades to 28 structures identified as seismically deficient. These projects will be considered for inclusion in Metropolitan’s Capital Investment Plan.

6. **Support California Water Fix (Ongoing)**

   Metropolitan will continue supporting the California WaterFix to increase seismic resilience of the Bay-Delta portion of the State Water Project.

Appendix 1

Key Seismic Resilience Achievements

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Metropolitan has made significant improvements in the overall seismic resilience of its water system over the past few decades. These achievements include:

1971	Earthquake Committee formed to assess damage and recommend improvements
1976	Metropolitan's Emergency Response Plan formally adopted
1983	Member Agency Response System (MARS) established
1993	Incident Command Centers (ICCs) established at each treatment plant and a formal engineering response chart adopted for the Damage Assessment Teams (DATs)
1995	Formal Business Resumption Plan developed
1996	Seismic upgrade of CRA Pump Houses completed
1999	Construction of Diamond Valley Lake completed
2004	South slope stability improvements completed at Diemer
2005	Construction of new Lake Mathews Tower completed
2010	Jensen Administration Building seismic upgrade completed
2010	Construction of the Inland Feeder completed
2011	Seismic upgrade of Mills Electrical Buildings 1 & 2 completed
2013	Seismic upgrade of Diemer Finish Water Reservoir completed
2013	Diemer East Wash Water Tank seismic upgrade completed
2014	Seismic upgrade of Weymouth Filter Buildings 1 and 2 completed
2014	CRA seismic assessment confirmed historical assumptions for duration of worst-case outage of the CRA
2015	Seismic upgrade of Jensen Washwater Tanks 1 & 2 completed
2015	Seismic upgrade of Weymouth East Wash Water Tank completed
2015	Task Force formed to enhance seismic resilience of imported water supplies
2017	Seismic upgrade of Diemer East Filter Building completed

Note: Metropolitan has invested over $250M in seismic upgrade projects since 1998.

The California Department of Water Resources has also taken steps to improve the seismic resilience of Southern California's imported water systems, including:

1997	Construction of new Outlet Tower at Silverwood Lake completed
2018	Lake Perris Dam improvements completed

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Appendix 2

Modern Era Earthquakes over M6.3 Within or Near Metropolitan's Primary Service Area

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Southern California has experienced at least six earthquakes within or near Metropolitan's service area and with magnitudes greater than M6.3 during the past hundred years.

Date	Event Location	Fault	Magnitude
April 21, 1918	San Jacinto	San Jacinto	6.7
Mar. 10, 1933	Long Beach	Newport-Inglewood	6.4
Feb. 9, 1971	San Fernando	Sierra Madre	6.5
June 28, 1992	Landers	San Andreas	7.3
Jan. 17, 1994	Northridge	Northridge Thrust	6.7
Oct, 16, 1999	Hector Mine	Lavic Lake Fault	7.1

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Appendix 3

Provision for CRA Uplift

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MWD
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

COLORADO RIVER AQUEDUCT

TECTONIC ALLOWANCE ORIGINAL INTENTION INVESTIGATION

1 March 2016

Purpose and Objective

Historic documents have mentioned that the designers of the Colorado River Aqueduct (CRA) incorporated "measures in their engineering designs to minimize the impacts on the flow through the CRA due to future vertical displacements across the key fault traces mapped at that time. The measures included an additional 0.8 m (2.5 ft) of drop beyond that required by siphon losses at… three fault crossings" (Report 1484). "In each siphon [Big Morongo and San Andreas] approximately 2.5 feet of additional grade was allowed to provide for adjustment in slope if future movement should occur" (Contract Number 149).

Figure 1
Overview Map

Figure 1 shows the location of each of the siphons in question.

The question was raised regarding the specifics of how this was accomplished. This document will describe investigation into whether this allowance was incorporated, the mechanism by which this allowance was included, summarize historical records suggesting such an allowance, and recommend field investigations which can confirm this analysis.

Observances of Tectonic Allowance

Record drawings for the Colorado River Aqueduct were explored to identify any occurrences or explanation for design Hydraulic Grade Line (HGL) at the Big Morongo Siphon, San Andreas Siphon and Casa Loma Siphon. The first observance of the allowance is found in the hydraulic profiles prepared as a part of the original record drawings of the Colorado River Aqueduct in 1935. Selected copies are included at the end of this document.

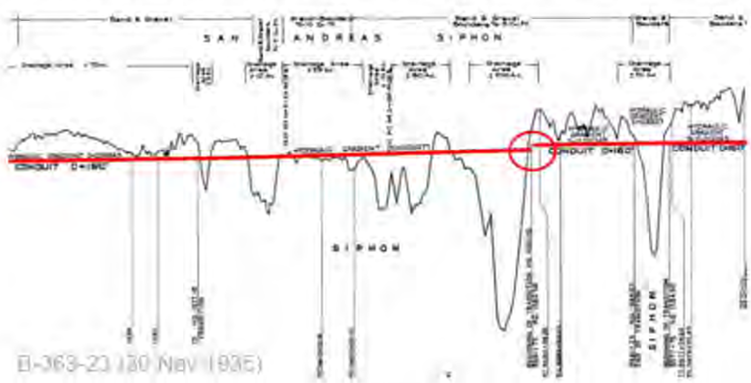

Figure 1
Original 1935 San Andreas Siphon Plan and Profile

A discontinuity is observed in the HGL, dropping by a notated 2.5 feet at the beginning of the Big Morongo Siphon, San Andreas Siphon, and Casa Loma Siphon. The HGL is highlighted in red on Figure 1, with the 2.5-foot drop circled.

A second observance of the allowance is found in the record drawings associated with the late 1950's construction of the second barrel for the CRA siphons (Specification Numbers 504 and 509). As before, selected copies are included at the end of this document. The plan and profiles found in the second barrel siphon record drawings show two parameters corresponding to hydraulic grade at the downstream transition structures, as follows:

- "HG. El.", assumed to be an acronym for Hydraulic Grade Elevation, and assumed to refer to the pressure head at design flow
- "WS El.", assumed to be an acronym for Water Surface Elevation, and assumed to refer to the water surface under free-surface flow conditions at design flow

In the siphon, the HGL is observed to be above the soffit of the pipeline, indicating the pipeline is designed to be under pressurized flow. Upon entering the transition structure, the HGL is below the top of the transition structure walls as free surface flow is designed for.

As shown on Figure 2, the Water Surface Elevation line in the outlet transition structure is depicted 2.5 feet below the Hydraulic Grade Elevation line, as circled in red. For other transition structures, the Hydraulic Grade Elevation line meets the Water Surface Elevation line, as shown on Figure 3 for Thousand Palms Siphon.

Figure 2
Big Morongo Siphon Second Barrel Plan and Profile

A second barrel was not constructed at Casa Loma Siphon according to the original plans, so no corresponding record drawing was identified.

Staff from the Hydraulics team confirmed via calculation that the headloss depicted by the HGL is consistent with the major and minor losses shown in the record drawings for the design flows.

A third observation of the allowance is found in the hydraulic profiles. While not called out numerically as on the previous two sources, the hydraulic profiles depict a slope offset at the Big Morongo and San Andreas Siphons of a much greater magnitude than those observed for other siphons. This is depicted in two figures on the following page.

It is understood that the design philosophy for each siphon was to size the losses across each siphon to maintain the free surface flow HGL across the siphon. This can be graphically observed in Figure 4 as shown by the red dashed line highlighting the HGL matching the canal or conduit slope upstream and downstream of the siphon.

At Big Morongo and San Andreas siphons, an offset of 2.5 feet is observed between the slope upstream of the siphon and the slope downstream of the siphon. Figure 5 highlights this in blue for Big Morongo Siphon.

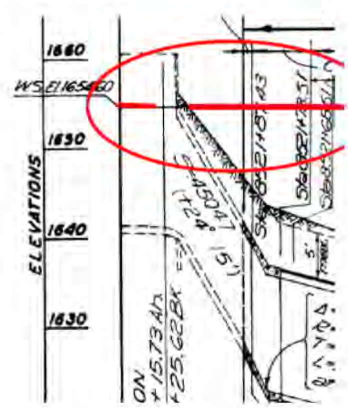

Figure 3
Thousand Palms Siphon Second Barrel Plan and Profile

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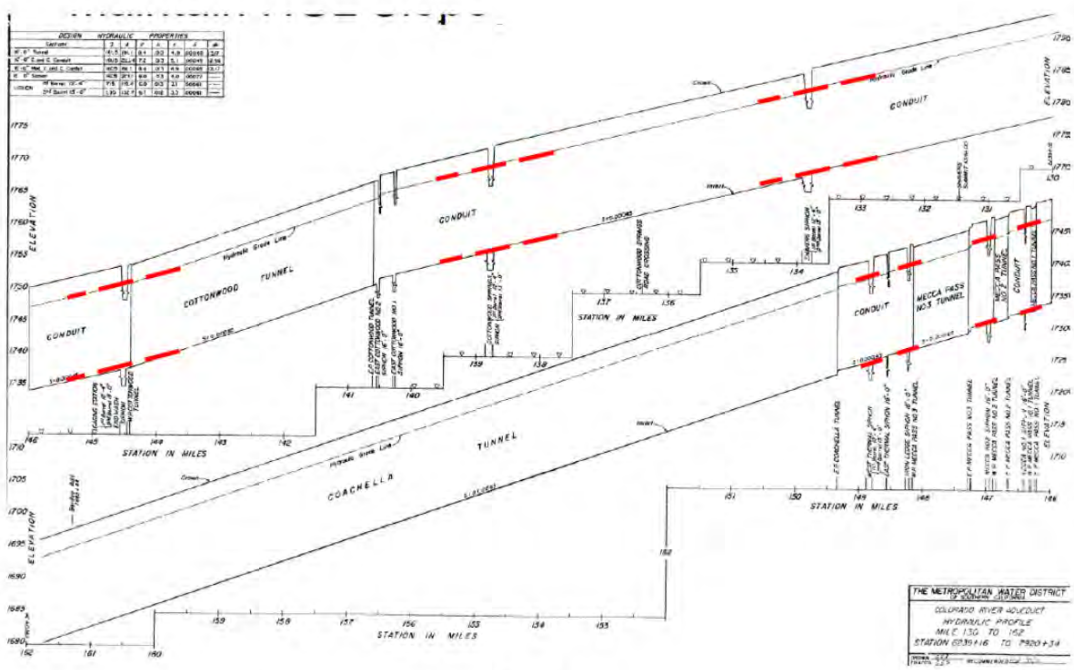

Figure 4
Siphon HGL Slope Consistent with Aqueduct Slope

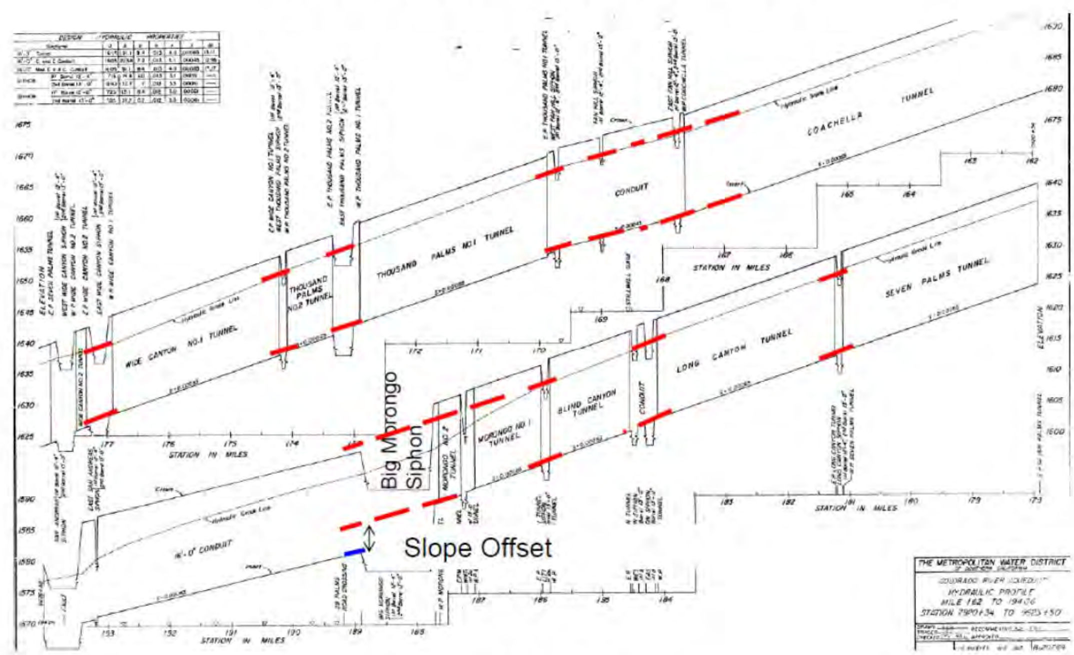

Figure 5
Siphon HGL Slope at Big Morongo Siphon

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This last set of observances of the 2.5-foot allowance may provide a suggestion of the designer's thoughts on the effect of the allowance. The Hydraulic Grade Line observed on the profiles gradually drops relative to the invert elevation though the Morongo Number 1 Tunnel and the Morongo Number 2 Tunnel, and in the conduit immediately upstream of the San Andreas Siphon. While dimensions nor elevations are called out on this profile, the depth at the outlet to the Morongo Number 2 Tunnel can be measured on the drawing as 8.9 feet, and the depth at the entrance to the San Andreas Siphon can be measured on the drawing as 7.8 feet.

Previous Surveys

Based on the contract document, construction on Big Morongo Siphon and San Andreas Siphon was started on 5 Feb 1935 and concluded on 16 Sep 1936, with work activities completed by May 1936.

In February and March 1935, a construction staking survey was conducted. Included in the survey notes are an adjustment to the slopes consistent with the markups included in the contract documents (Contract 149). This timing is consistent with the start of construction.

In August 1937, after construction of the CRA, the as-built survey was conducted to set brass caps on the transition structure as permanent benchmarks. Benchmarks established include:

- a manhole at Station 9316+46
- the outlet transition structure for Big Morongo Siphon at Station 9353+15
- the outlet transition structure for East San Andreas Siphon at Station 9581+25 (referred to as "Outlet Siphon" in survey notes)
- the inlet transition structure for San Andreas Siphon at Station 9591+75
- a manhole at Station 9595+00
- the outlet transition structure for San Andreas Siphon at Station 9625+75
- the outlet transition structure for West San Andreas Siphon at Station 9651+75 (referred to as "small siphon" in survey notes)

These are recorded in Field Book 2740. No mention is made within the survey notes of any measurement of invert elevations of the pipeline or transition structure, so any inferences made to the invert elevation require the assumption that the transition structure dimensions are consistent with the planned dimensions appearing on the construction plans (19.17 feet for the Big Morongo Siphon outlet transition structure 18.96 feet for the Big Morongo Siphon inlet transition structure and both San Andreas Siphon transition structures).

In 1998, the Casa Loma Siphon first barrel was surveyed as a part of an as-built survey prepared for construction of concrete encasement between Stations 11073+45 and 11073+93 related to work on the Inland Feeder. The survey notes mention replacement of the pipeline, but do not appear to include any survey of invert elevations.

In 2008, the San Jacinto Diversion Structure, which originated as the inlet transition structure to the Casa Loma Siphon first barrel, was surveyed as a part of establishing NAVD 1988 elevations in the area. While the survey notes do not include invert elevations, they do include the weir elevation, which can be used to estimate the invert elevation based on the record drawings.

In 2014, a settlement study was conducted by Survey at San Andreas Siphon and Big Morongo Siphon to determine the difference in elevation between the inlet and outlet transition structures. The survey only measured the relative difference between the benchmarks set on the inlet and outlet transition structures of each siphon in the August 1937 survey. The difference in elevation between the inlet and outlet structure benchmarks is presented in the table below, suggesting no changes in relative ground movement in the intervening eight decades.

Table 1 1934 and 2014 Survey Comparison

Siphon	May 2014 Survey (feet)	August 1935 Survey (feet)	Difference (feet)
Big Morongo	7.90	7.90	0.00
San Andreas	6.64	6.68	-0.04

Source: Survey Field Book 2740 and Survey Note 1001-29 042

As with the previous surveys, no measurement was made of the invert elevations, so it is not possible to verify that the slope of the canal includes the 2.5-foot slope offset upstream of the siphon directly from survey measurements.

However, using the derived measurements developed as a part of IMDC (ultimately from the design drawings), the slope offset can be calculated. If the difference in elevation between the invert elevations at the inlet and outlet transition structures is 2.5 feet greater than that calculated based on the design slope for the siphon, then the survey data would confirm the tectonic allowance is included in the slope offset. Based on the notes included in the contract document and the slopes appearing on the hydraulic profiles, a slope of 0.00077 was used for design of the lengths of the CRA siphons. The table below presents the calculation, including several other siphons for comparison.

Table 2 Slope Offset Calculation

Siphon Name	Transition Structure Invert Elevation: Upstream (ft-msl '88)	Transition Structure Invert Elevation: Downstream (ft-msl '88)	Drop per Survey (feet)	Drop per Slope (feet)	Slope Offset (feet)
Cottonwood Spring Siphon	1,759.21	1,758.60	0.61	0.46	0.15
End Wash Siphon	1,740.23	1,740.12	0.11	0.45	-0.34
Iron Ledge Siphon	1,729.36	1,728.93	0.43	0.23	0.20
East Thermal Siphon	1,728.27	1,727.90	0.37	0.14	0.23
West Fan Hill Siphon	1,657.67	1,657.03	0.64	0.42	0.22
Thousand Palms Siphon	1,645.53	1,643.93	1.60	1.46	0.14
Whitehouse Canyon Siphon	1,593.82	1,593.27	0.55	0.40	0.15
Big Morongo Siphon	1,591.85	1,584.31	7.54	4.94	2.60
East San Andreas Siphon	1,574.16	1,573.69	0.47	0.27	0.20
San Andreas Siphon	1,573.22	1,566.84	6.38	2.62	3.76

Notes:
(1) Design slope of 0.00077 does not appear on most siphons on most hydraulic profiles, but was checked on the individual plan and profiles for all of the siphons listed in this table

As shown in Table 2, most of the siphons exhibit a deviation in surveyed slope from the design slope of between 0.1 and 0.2 feet. Big Morongo Siphon and San Andreas Siphon slope offsets of more than 2.5 feet each, showing that the slope across each of these siphons is greater than that required to meet the design slope for the siphon of 0.00077. It should be noted that the slope offset for San Andreas Siphon is calculated as 3.76 feet, 1.26 feet greater than the 2.5 feet suggested by the allowance. This may suggest the suggested mechanism for accomplishing the allowance is incorrect, or there may be other factors at play here.

While survey data has not explicitly measured the invert elevations at any point following the construction of these siphons, this calculation is based on the assumption that the siphon transition structures were constructed consistent with the construction plans. If the internal height of the transition structures is in doubt, survey of the invert elevations of the transition structures could be of value.

Field Observations

Given the lack of level sensors along the CRA, Water Supply Operations (WSO) staff have conducted several field investigations of depths along the CRA during periods of constant flow. These field investigations generally consist of one or two staff recording single measurements of depth at several manholes and transition structures between Hinds Pumping Plant and San Jacinto Tunnel.

Under the design flow of 1,605 cfs, the normal depth is designed as 12.96 feet in the most frequently used cut and cover conduit cross-sections, and 13.17 feet in the most frequently used tunnel sections. Figure 1 presents results from the field investigation conducted on 20 March 2013, with flow conditions near design flows.

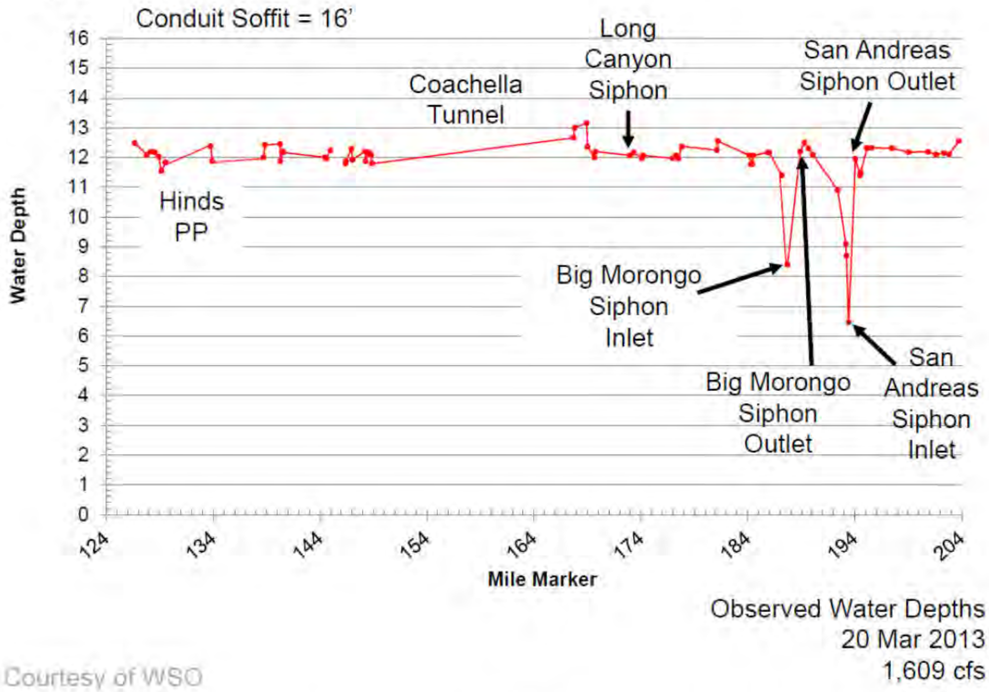

Figure 1
Observed Water Depths at Design Flow

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The depth at the San Andreas Siphon and Big Morongo Siphon transition structures consistently stand out with observed water depth lower than the other siphons, dropping to less than 7 feet and less than 9 feet, respectively. These depths are fairly consistent with the depths of 7.8 feet and 8.9 feet observed in the design hydraulic profile discussed at the end of Section 0.

Mechanism

Some possible ideas that could have been incorporated include sizing the diameter of these siphons larger (reducing the headloss across the siphon) or including some type of weir structure.

It is surmised that the mechanism used for incorporating the additional head was to build the inlet transition structure 2.5 feet above the elevation at which the structure would have been constructed without the slope offset. Given that the pressurized pipeline within the siphon can change slope without impacting the hydraulics beyond minor losses, the slope of one of the stretches of pipeline could be raised to achieve a 2.5-foot elevation increase. The contract document suggests this -"The slope given in the hydraulic properties [0.00077] does not include the additional grade allowed to provide for adjustment if future earth movement should take place." (Contract 149)

An exaggerated demonstration of this mechanism is shown in Figure 1. The existing profile of the aqueduct, including the 2.5 foot allowance, is shown in black. A red line, lower at the upstream end of the siphon has been added to shown the 2.5-foot lower starting invert without the allowance. The blue line shows what the initial slope in the siphon would have been in the first pipeline segment without the allowance.

Figure 1
Surmised Design Mechanism

Further, exploring the different versions of the drawings prepared prior to construction suggests the addition of the grade as a slope change. Eight different record drawings are present in EDMS between August and December 1934 (the notice for bids was released 5 December 1934.) These partially correspond to four different construction methodologies and material choices prepared prior to the bid notice (jointed cast-in-place concrete, pre-cast concrete, above ground steel pipe, and buried steel pipe). Ultimately, jointed cast-in-place concrete was selected at the time of the bid notice. The upstream invert elevations of the transition structure in some of the drawings prepared in November 1934 have been raised by 2.5 feet from the August 1934 drawings, with differing slopes (however, each of the differing construction methodologies uses different slopes), with the height of the transition structures maintained between the different drawings. It should also be noted that the 2.5 foot allowance is observed on drawings dating back to 1933, so the allowance was likely planned for prior to 1934.

Assuming the head constraints on the design of the CRA would have been established first at the downstream end (either at the tunnels or of the elevation of Lake Mathews), this would suggest that if the allowance had not been included at each siphon, the CRA upstream of all three upstream siphons could have been designed 7.5 feet lower in elevation, with the lift at Hinds Pumping Plant reduced by 7.5 feet.

Conclusions

In review of record drawings and contract documents associated with the CRA, a tectonic allowance of 2.5 feet of HGL has been included in the design of Big Morongo Siphon, San Andreas Siphon, and the Casa Loma Siphon. Based on the above investigation into this allowance, it is believed that the mechanism for accomplishing the allowance is a slope offset in the invert elevation slope, accomplished by an increased slope in the pressurized pipeline segments within these siphons.

Based on available records, invert elevations have never been surveyed at Big Morongo Siphon, San Andreas Siphon, and the first barrel of the Casa Loma Siphon. Having invert elevation survey data will not prove the mechanism any further than currently shown on record drawings. However, if the internal height of the transition structures is in doubt, survey of the invert elevations of the transition structures could be of value.

In addition, internal inspection of the cast-in-place concrete pipeline and associated joints, as well as internal survey to determine any localized movement, may be desired for non-hydraulic reasons.

Differential survey between the inlet and outlet transition structures would likely be of little value beyond that already provided in 2014. Two additional levels of survey could be conducted—a survey of just the invert elevations of the transition structures, requiring minimal de-watering, and a survey and inspection of the entirety of the siphons, requiring full dewatering.

Estimates of effort for survey of the invert elevations in just the transition structures would be 24 staff hours plus minimal dewatering, and effort for the full siphon survey of the entire length of the two siphons would be 200 staff hours, plus staff for full dewatering.

References and List of Record Drawings

The following table lists record drawings and documents used in preparation of this analysis.

Table 3 Record Drawings and Documents Consulted

Record or ID Number	Record Drawing Type	Siphon	Revision Date
B-363-26	Plan and Profile	Big Morongo	22 Nov 1934
B-363-23	Plan and Profile	San Andreas	30 Nov 1935
B-363-12	Plan and Profile	Casa Loma Siphon	15 June 1934
B-11975	Plan and Profile	Big Morongo	30 Oct 1997
B-11979	Plan and Profile	San Andreas	1 Nov 1956
B-20749	Hydraulic Profile	Multiple, including Big Morongo and San Andreas	1 Aug 1965
B-20748	Hydraulic Profile	Multiple	1 Aug 1965
HR-149	Contract	Big Morongo and San Andreas	5 Feb 1937
FB 2740	Survey Field Book	Big Morongo and San Andreas	12 July 1938
1001 29 042	Survey Notes	Big Morongo and San Andreas	19 May 2014
2037 01 037	Survey Notes	Casa Loma Siphon Number 1	24 August 1998
2039 02 008	Survey Notes	San Jacinto Diversion Structure	5 May 2008
B-1660	Transitions & Sections	San Andreas	21 Nov 1934
B-1663	Transitions & Sections	Big Morongo	22 Nov 1934

Notes:
(1) Since the second barrel was never installed at Casa Loma Siphon, it does not have a

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Appendix 4

Summary of Damage to Metropolitan Infrastructure from Past Earthquakes

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Metropolitan experienced a significant amount of damage to its infrastructure during both the 1971 San Fernando and 1994 Northridge earthquakes. Both of these seismic events primarily impacted the Jensen Water Treatment Plant. Engineering prepared summary reports for both events. The information below represents a convenient summary of what may be found in "Report of Structural Damage to Joseph Jensen Filtration Plant, Earthquake of February 9, 1971" (Report No. 891C), "Historical Documentation of the Jensen Plant Earthquake Disaster of February 9, 1971" (Report No. 909), and "Damage and Repair Report for Joseph Jensen Filtration Plant, Northridge Earthquake of January 17, 1994 (October 1994).

1971 SAN FERNANDO EARTHQUAKE

The San Fernando earthquake struck the greater Los Angeles region in the early morning of February 9, 1971. The thrust earthquake, which had a moment magnitude between 6.5 and 6.7, caused severe damage in the northern San Fernando Valley, with extensive surface faulting to the south of the epicenter. The epicenter was approximately 6.8 miles from the Jensen Plant.

Metropolitan experienced widespread damage at the Jensen Plant. This included a severe break to a 72" Influent Conduit and damage to various structures including the Administration Building, Finished Water Reservoir, Access Tunnel, Mixing and Settling Basins, and Filters.

Following is a summary of the damage to these facilities.

INFLUENT CONDUIT

- Transverse cracks up to ½-in on concrete encasement
- Three joints in the ¼-inch thick steel cylinder separated
- Joint failed and opened up to ¾-inch at the soffit
- Fracture continued thru the top half of the joint
- Much spalling of the mortar lining about 8-inches on each side of the joint
- About 113-feet south of the 72-inch outlet, 75% of the joint failed
- Joint opened up about ¾-inch near the invert and the lining was damaged for about thirty inches each side of the joint
- Entire joint was pulled apart
- Mortar lining was damaged for about 24-inches on each side of the joint
- Considerable spalling and cracking of the lining was evident around the 72-inch outlet
- Lining suffered spalling and cracking approximately 15-feet downstream of the tunnel portal
- Several additional cracks, up to 1/16-inch wide, were observed in the lining
- Two 84-inch and 72-inch welded steel pipelines suffered only minor damage and consisted of cracking of the lining
- Minor cracking at the junction of the 72-inch pipelines and the 12-foot, 6-inch square reinforced concrete box conduit

- The 12-foot wide by 12-foot high reinforced concrete box extending northerly from the main control building had three transverse cracks in the walls and slabs located between Station 5+60 and 6+00;
- Cracks varied in width from 1/32-inch to 1/16 inch;
- 5 Transverse expansion joints in this portion of the influent conduit had separations varying from ½ -inch to 2-inches horizontally, and from ¼-inch to 1-inch vertically.

EFFLUENT CONDUIT

- Severe damage toward the southerly end;
- Differential displacement;
- Complete fracture or shearing.

MAIN CONTROL BUILDING

- Considerable horizontal and vertical displacement throughout; led to multiple non-structural damaged areas throughout building
- Building moved approximately 5-inches to the south and approximately 6-3/4-inches to the east
- There was settlement of 2-inches on the south side of the building causing a slight southeasterly tilt.

BALBOA INLET TUNNEL

- Concrete tunnel lining badly spalled and cracked at a distance approximately 100 feet near the Olive View Fault crossing;

CONNECTING CONDUITS

- Significant damage occurred at expansion joints, intersection of east-west and north-south galleries, and by punching of an embedded pipe into a wall
- Several portions of the structure between expansion joints moved as separated structures, on the three axes of movement, and also moved with twisting (torsional) action on each of the three planes
- In some cases, the joint filler and sealant was compressed and squeezed out of the joint
- Individual working of the structurally separated portions of the structure caused them to pound against each other, thereby resulting in spalling of concrete adjacent to the edges of the expansion joints
- Considerable cracking and some spalling occurred at the intersection of the east-west and north-south 25-foot wide influent conduit and pipe gallery, all were repairable
- Cracks in slabs and walls occurred at the intersection of pipe galleries Nos. 1 and 2 in the north-south influent conduit and pipe gallery, but all were repairable

- The southern end of the east-west pipe that was cast into the west wall of the north-south influent conduit pipe gallery pounded and caused the wall to shatter
- Large amount of movement took place in the overhead piping at the intersection of the east-west and north-south influent conduit pipe galleries
- Movement was in several directions, with pipe having been displaced.

MIXING AND SETTLING BASINS

- Significant damage occurred at expansion joints, and the intersection of the east-west and north-south galleries
- Several portions of the structure between expansion joints moved as separate structures on the three axes of movement
- Some cases, the joint filler and sealant was compressed and squeezed out of the joint;
- The individual working of the structurally separated portions of the structure caused them to pound against each other, thereby resulting in spalling of concrete adjacent to the edges of the expansion joint
- Cracking and some spalling occurred at the intersection of the east-west and north-south influent conduit and pipe gallery
- Cracks in slabs and walls occurred at the intersection of pipe galleries Nos. 1 and 2 in the north-south influent conduit and pipe gallery

FILTERS

- Some vertical and lateral displacement occurred between adjacent beds at some expansion joint locations
- Compressive loads forced expansion joint material out of some joints
- Minor spalling occurred adjacent to some expansion joints
- An apparent lateral thrust from the west caused the wash troughs to pull partly out of the insets
- Wash troughs acting as struts transferred the thrust to the gullet wall, which had not been completely poured, causing the wall to split at the east line of reinforcing bars
- Cracking and spalling in other filter beds occurred at the wash troughs but were minor in nature
- Minor spalling occurred where 16-inch spray header line passes through the wall filter beds
- The west end of the conduit was damaged
- Connection between the used washwater conduit and the 48-inch diameter conduit pulled apart
- Top walkway grid slab cracked diagonally across the northeast corner of filter bed
- Filter control building No. 2 separated from the walkway at the top of the filter beds expansion joint
- Separation varied from ½-inch to 1 ¼-inch at the expansion joint between Filter Control Building No. 2 and the valve and meter structure

- Valve and meter structure settled 1” lower than Filter Control Building No. 2
- Lining on north side of the return washwater line had a spalled area.

CHEMICAL BUILDING

- Severe lateral and vertical motion
- Column anchor bolts either stretched or pulled out of the footing concrete at all six columns
- Column in south wall buckled
- Column at northeast corner bowed out of line
- Diagonal bracing system in exterior walls failed
- Diagonals failed in tension or damaged in compression
- Upper concrete floors and roof were pierced by the diagonal bracing and columns
- Considerable cracking or spalling of slab concrete
- Building frame racked out of plumb, being tilted toward the east
- Metal door and window frames in north wall were racked out of square
- Several siding panels on the north wall broke loose from the framing
- Siding fasteners snapped off or pulled out
- All anchor bolts for the four chemical tanks failed by being sheared, bent or pulled out
- Tanks were not damaged by second floor slab; although marks on tank indicate that 6 to 8 inches of vertical movement took place
- Columns supporting exterior stairway were bent.

BRIDGE AND BOX CULVERT FOR RAILROAD SPUR TRACK

- Vertical crack at the juncture between the north abutment and the wing wall on the west side
- Wall and abutment became offset.

WASHWATER TANK

- Vertical movement of the tank
- Movement caused anchor bolts to either pull out or fail in tension
- Tank slammed down upon the ring wall, resulting in buckling in the upper courses of the tank skin
- Damage to stairway.

FINISHED WATER RESERVOIR

- North Wall:
  - Did not rupture but had 3 continuous horizontal cracks
  - Cracks varied in width from hairline to 1/32 inch and were spaced
  - There were many random vertical and diagonal hairline or large cracks.

- South Wall:
  - Easterly half of the south wall had several vertical and diagonal random cracks
  - Wall between column lines ‘B’ and ‘C’ was severely shattered
  - Some earth backfill entered the reservoir thru the wall and roof rupture
  - Random vertical and diagonal wall cracks occurred in the westerly half of the south wall
  - Fracturing and spalling occurred at other locations along the south wall on both the interior and exterior surfaces
  - Lateral offset at crack, particularly where it crossed the wall corbels.
- East Wall:
  - Portion of east wall, north of outlet received extensive damage
  - Bowed inward between the floor and roof slabs
  - Series of continuous horizontal cracks
  - Extensive lengths of spalls and cracks with some fractures occurred at the base of the wall
  - Large vertical crack occurred in the east wall
  - Overflow weir wall was also damaged and laterally offset at a vertical construction joint in the same area
  - East wall, south of the outlet structure, showed some offset and spalling at the floor line
  - Random and vertical cracks occurred at about mid-height
  - East wall of the finished water reservoir was severely fractured and spalled.
- West Wall:
  - Fractured and shattered above the floor slab line;
  - Horizontal displacement of the bottom of this wall occurred at the fracture;
  - Wall shattered for its full height between column 24 and 25.
- Roof
  - Failure plane occurred in the roof slab between column lines B and C
  - Extensive damage to the roof slab occurred adjacent to the drop panel connections;
  - Fracture at the drop panel line was apparent only in the north half of the reservoir
  - Continuous east-west failure occurred in line with the south edge of the roof slab drop panels
  - Roof slab south of this line had a vertical offset approximately 12 inches lower than the roof slab on the north side
  - From column line “0”, east to column line “V”, spalling was evident only at the west faces of the drop panels
  - Roof slab fractured between column lines “B” and “C”
  - Continuous east-west lines of failure occurred between column lines 3 and 4, 7 and 8, and 24 and 25. These breaks or spalls exposed the reinforcement for the full length of the reservoir roof slab.

- The width of spalling at the construction joint between column lines 24 and 25 varied between 4 feet and 6 feet. During the quake, this joint opened up, allowing for considerable quantities of gravel backfill to fall through from above.
- The roof slab was also severely spalled, shattered and offset vertically at the west edge of the drop panel line adjacent to the east wall
- Spalling also occurred at the west face of the drop panels at line "B" from column line 22, to a point midway between column lines 24 and 25.

RESERVOIR FLOOR

- While floor slab damage was general throughout the structure it was most apparent in the southeast quadrant
- Spalled strip running east-west between column 2 and 3, from a point midway between lines B and C to the east wall
- Spalled strip at the center of the structure, between lines 13 and 14. These spalled strips averaged about 2 feet wide and many of them had vertical offsets upward from the general floor level.
- There were additional spalled construction joints in the north-south direction; however, none of these were as long as the two east-west spalls previously described
- Spalling occurred at the drainage gutters for almost the entire length in both the north-south and east-west directions
- Continuous spalls occurred throughout and between various lines
- Floor cracking occurred midway between lines 14 and 15 in the east-west direction; the south exterior wall drop panels at M-1, N-1 and U-1 spalled in the east-west direction;
- Floor slab cracks located were located as follows:
  - North-south between lines Y and Z; from midway between lines 5 and 6 to a point midway between lines 17 and 18
  - North-south between lines between Z and AA, from a point midway between lines 2 and 3 to a point midway between lines 19 and 20; diagonally across the southeast corner of drop panel W-18
  - North-south between lines P and Q; from a point midway between lines 13 and 14; to column line 15
  - East-west between lines 14 and 15, from a point midway between lines D and E, to a point midway between lines E and F.

BAFFLE WALLS AND COLUMNS

- Damage to the baffle walls consisted of two principal types; cracking or fracturing of the vertical beams and dislodgement and fracturing of the corrugated asbestos cement panels, only one vertical concrete beam collapsed
- The other beams remained standing but were tilted out of plumb
- Many of the other vertical beams were fractured or cracked near the base or in the region slightly above the base
- There were a number of spalls in the cast-in-place concrete projections forming the panel slots on the sides of the circular roof columns
- A large number of the corrugated asbestos cement panels were damaged or completely destroyed. Some of them fell to the floor and were shattered, while others that remained in place were damaged less severely.
- Approximately 73 baffle walls vertical beams sustained cracks, fractures, spilling, etc.
- Damage to the reservoir roof columns varied widely, from hairline cracks to complete fractures
- The damage to any individual column appeared generally to be the same at the top as at the bottom
- The majority of columns were spalled, or otherwise damaged on the east and west sides
- There were two notable exceptions: The first row of columns south of the north wall and the first row of columns north of the south. In these two rows, major damage occurred on the north and south sides
- In all cases, damage to the circular columns appeared to be primarily due to flexure and not to vertical load
- A number of the columns, notably those in the first row east of the west wall, were visibly out of plumb
- The tops of these columns were displaced east. Damage to drop panels and column capitals were generally limited to minor spalls and some cracks, except for several bottom capitals located in the northeasterly quadrant of the reservoir that were fractured or shattered.

RESERVOIR OUTLET STRUCTURE

- Severe and extensive damage;
- Fractures throughout the entire structure.

RESERVOIR INLET STRUCTURE

- Moderate damage;
- Spalled concrete exposing reinforcement.

1994 NORTHRIDGE EARTHQUAKE

In 1994, the Northridge earthquake occurred on January 17, at 4:30 a.m. It had a duration of approximately 10–20 seconds. The blind thrust earthquake had a moment magnitude (M_w) of 6.7. The death toll was 57, with more than 8,700 injured. In addition, property damage was estimated to be between $13 and $50 billion, making it one of the costliest natural disasters in U.S. history. LADWP reported a total of 1,405 pipe repairs and that water pressure had dropped to zero in some areas. The epicenter was approximately 7.3 miles from the Jensen Plant.

Metropolitan had damage at the Jensen Plant and adjacent facilities. Following is a summary of the damage to these facilities:

MAJOR DAMAGE

- Jensen Plant Balboa Influent Conduit
  - 84-in influent pipeline severed approximately 3-in horizontally and 1-in vertically near venturi structure
- East Valley Feeder
  - Pipeline breaks occurred between Odessa and Rinaldi Streets (976+86.70) and Woodley Avenue and Rinaldi Street (957+66.50)
  - Sectionalizing valve damage caused damage to all electrical equipment
  - Street asphalt damage as result of pipe breaks/leaks
- West Valley Feeder No. 1
  - Crack at cut-off wall at Station 1219+10
  - Sectionalizing valve structure damaged, causing damage to all electrical equipment
- Main Electrical Center
- Service Connection CLWA-1T
  - Service connection structure settled and drifted laterally
  - Misalignment of valve assemblies
- Service Connection LA-25
  - Extensive damage at ten pipe joints in the 97-in diameter pipeline and 60-in diameter overflow pipeline; pipe joints spread 1/8” to 3/4”
  - Reinforced box conduit suffered a break and 2” separation; a 6-1/2” separation occurred at the joint where the double box conduit meets the discharge structure
  - Turnout structure moved 6 to 8 inches east
  - Double box conduit moved 3 inches to the east

- Service Connection LA-35T
  - Damage to valve structure and pipe bridge due to differential displacement
- Newhall Tunnel
  - Buckling of steel liner
  - Concrete construction joints opened and closed resulting in sand and water infiltration
  - Bulge on steel liner split at circumferential joint resulting in oil and water infiltration

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Appendix 5

Metropolitan Water Storage Capacity

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Over the past two decades, Metropolitan has developed a large regional storage portfolio that includes both dry year and emergency storage capacity. Storage generally takes two forms: surface reservoirs and groundwater basin storage. Heading into the most recent drought cycle, Metropolitan had developed over 5.5 million acre-feet of storage capacity and had successfully stored over 2.7 million acre-feet. This is a more than 13 times the storage capacity compared to the 1980s, with record quantities of water in reserve. This increase in storage capacity is shown in Figure 5-1.

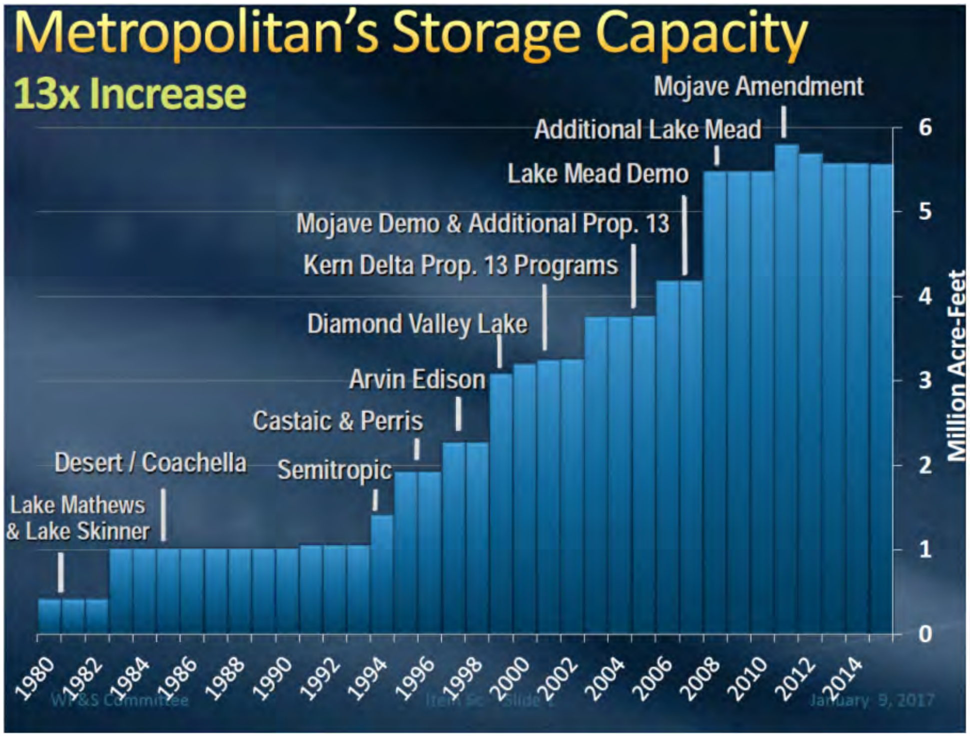

Figure 5-1. Summary of Metropolitan's Storage Capacity Over Time

Some examples of storage resources that have been developed since 1990 include:

- Surface Water Reservoirs:
  - Diamond Valley Lake (810,000 acre-feet)
  - SWP Article 56 Carryover Storage (up to 200,000 acre-feet)
  - Flexible Storage in Castaic Lake and Lake Perris (219,000 acre-feet)
  - Intentionally Created Surplus in Lake Mead (1.5 million acre-feet)
- Groundwater Storage:
  - Member Agency Conjunctive Use Programs (210,000 acre-feet)
  - Semitropic Storage Program (350,000 acre-feet)
  - Arvin-Edison Storage Program (350,000 acre-feet)
  - San Bernardino Municipal Water District Storage Program (50,000 acre-feet)
  - Kern Delta Water District Storage Program (250,000 acre-feet)
  - Mojave Storage Program (390,000 acre-feet)

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Appendix 6

Seismic Design Frequently Asked Questions

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Seismic Design FAQs

September 2017

What are the effects of earthquakes?

- Ground shaking
- Ground rupture
- Liquefaction
- Landslides and avalanches
- Tsunamis

What causes earthquakes?

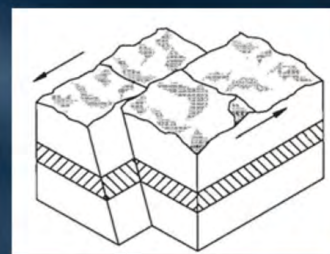
- Slips or rupture of faults
- Movements of tectonic plates
- Volcanic or magmatic activity
- Sudden changes in earth's crust

What is a fault?

- Faults are fractures or discontinuities in large masses of rock, where the rocks on either side have undergone relative displacement
- Faults are planar surfaces, not lines
- Faults can be vertical, horizontal, or at some angle in between
- Faults can be divided into three basic types
  - Strike-slip
  - Thrust
  - Normal
- Strike-slip and thrust most common in So. Cal.

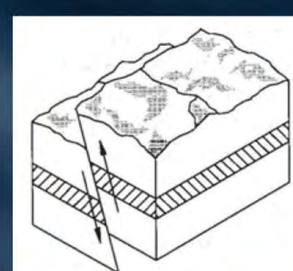
Strike-Slip Faults

- Faults are primarily vertical or near-vertical
- Movement occurs primarily laterally - one side slides by the other
- Primary examples are the San Andreas and San Jacinto Faults

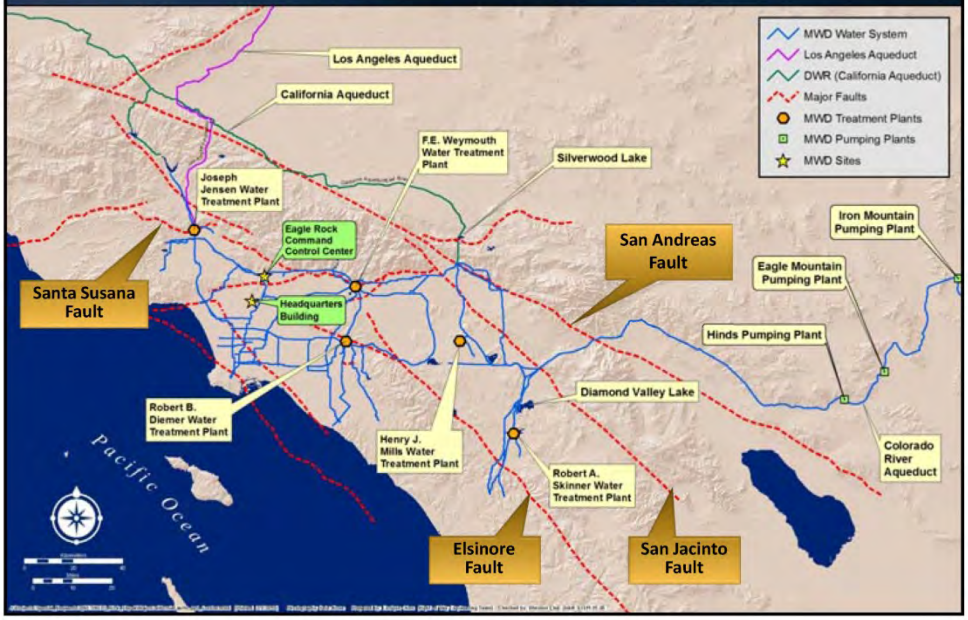


Thrust Faults

- Faults occur at an angle to the surface
- Movement occurs primarily vertically - one side slides up over the other
- Primary examples are the Santa Susana and Bunker Hill Faults



Major Earthquake Faults in So. Cal.



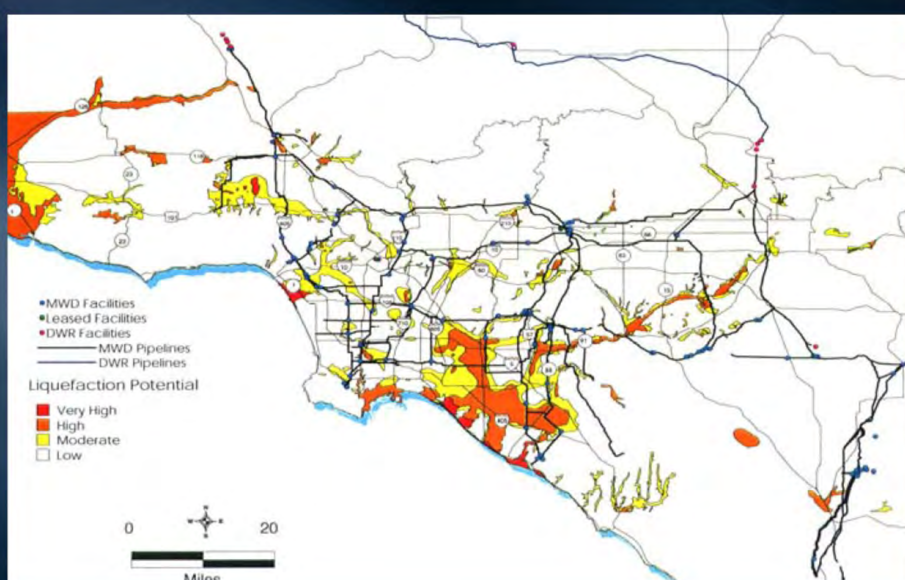
San Andreas Fault

- Fault with the highest probability of generating a major earthquake in So. Cal.
- Potential impact on MWD operation
  - CRA
  - Hinds and Eagle Mountain Pumping Plants
  - Rialto and Inland Feeders
  - East Branch of State Water Project
  - DWR's Santa Ana Pipeline

Liquefaction

- What is liquefaction?
  - A process by which water-saturated soils temporarily lose strength and act like liquid
- Factors needed for liquefaction
  - Loose or low density sandy soils
  - Shallow ground water
  - Strong ground shaking

Liquefaction Susceptible Zones in So. Cal.



How to measure earthquakes?

- Earthquake Magnitude
  - Describes size of earthquake
  - Unique value for each earthquake
  - Quantitative value based upon amount of released energy
- Earthquake Intensity
  - Describes effect of earthquake
  - Multiple number of values for every earthquake
  - Qualitative description or quantitative measurement of ground or structural response to earthquake

Definitions

- Maximum Credible Earthquake
  - Largest earthquake that is physically capable of occurring on a fault
- Peak Ground Acceleration (PGA)
  - Maximum acceleration measured at ground surface during the course of earthquake motion
- %g
  - Acceleration expressed as a percentage of the force of gravity
- Maximum Considered Earthquake Ground Motion
  - Smaller of the probabilistic ground motion (2% probability of exceedance in 50 years), and the deterministic ground motion (Maximum Credible Earthquake occurring on the controlling fault)

Earthquake Magnitude

- One unique value for each earthquake depending upon amount of energy released
- Earlier version – Richter or Local Magnitude
- Current version – Moment Magnitude
- Logarithmic-based measurement scale
- A magnitude 6 earthquake releases 32 times more energy than a magnitude 5 and 1,024 times more energy than a magnitude 4 earthquake (based on Moment Magnitude)
- Reported to the nearest 0.1, e.g., M7.1

What affects earthquake magnitude?

- Fault rupture length - Longer rupture length releases more energy
- Length of fault – Longer faults have the potential to release more energy than shorter faults
- San Andreas is longest fault in So. Cal. and has the largest potential to generate a Magnitude 8+ earthquake.

Earthquake Intensity

- Multiple values for each earthquake depending on location relative to earthquake epicenter
- Described qualitatively using a system such as the Modified Mercalli Scale (roman numerals between I: not felt and XII: total damage) based upon visual perception of earthquake severity in terms of effects on humans and structures
- Reported quantitatively using seismographs to measure ground motion

What affects earthquake intensity?

- Magnitude of earthquake - increased magnitudes tend to increase intensity
- Distance from earthquake – increased distance from an earthquake tends to lessen intensity
- Fault type – thrust faults tend to increase intensity of vertical ground motions
- Site soil conditions – rock sites tend to lessen intensity compared to soil sites
- All factors interact to yield unique site-specific intensity

Comparison of Magnitude Scale and Intensity Scale

Richter Scale	Modified Mercalli Intensity Scale	Perception of Earthquake Intensity*
2	I-II	Detected only by instruments
3	III	Felt indoors
4	IV-V	Felt by most people; slight damage
5	VI-VII	Felt by all; damage minor to moderate
6	VII-VIII	Everyone runs outdoors; damage moderate to major
7	IX-X	Major damage
8+	X-XII	Major to total damage

***Measured at epicenter**

How are earthquake magnitude and intensity used in design?

- Earthquake magnitudes are not specifically used in design
- Designs are based upon resisting predicted earthquake intensities (quantified by peak ground accelerations stated to nearest 0.01 or %g)
- Earthquake magnitudes and several other factors are used to estimate earthquake intensities for design

Deterministic Seismic Hazard Assessment

- Determines the largest Peak Ground Acceleration that can occur on a site for a single magnitude earthquake at a single distance from the site, regardless of the likelihood that an earthquake event with the selected magnitude and distance will occur.
- Induced Peak Ground Accelerations at a site are evaluated assuming that the specific Maximum Credible Earthquake occurs on each of the nearby faults at the closest approach to that site.
- The fault that generates the largest Peak Ground Acceleration at a site is called the "controlling fault."
- The Peak Ground Acceleration generated by the controlling fault is the controlling ground motion.

Probabilistic Seismic Hazard Assessment

- Considers all possible magnitude earthquakes (up to the Maximum Credible Earthquake) on all faults identified within 100km at all possible distances from a site, and the likelihood of the occurrence of each combination.
- Each identified fault is evaluated separately with regard to activity rates, the relative number of earthquakes at different magnitudes, expected earthquake magnitude range, and its location relative to the site.
- The individual fault contributions are combined to develop total probabilities for any specified Peak Ground Acceleration at a site. As a result, Peak Ground Accelerations for a site can be determined with a specified probability of exceedance.

Current Building Code Seismic Design Requirements

- Maximum Considered Earthquake (MCE) Ground Motion
  - Probabilistic: Ground motion with 2% probability of exceedance in 50 years
  - Deterministic: Ground motion generated by Maximum Credible Earthquake occurring on the controlling fault(s)
  - Smaller ground motion determined by these two methods governs design
  - Deterministic approach usually governs in So. Cal.
- A Regular Facility is designed for 2/3 of MCE Ground Motion to achieve Life Safety performance
- An Essential Facility is design for a higher performance
  - Building codes establish the minimum seismic design criteria, and building owners can choose to design for a higher performance
- Building codes do not apply to facilities under Cal. Division of Safety of Dams (DSOD) jurisdiction

Examples of Regular and Essential Facilities

Facilities	Description	Examples
Regular	Normal occupancy	•Commercial buildings •Residential buildings •Manufacturing facilities
Essential	High occupancy/Special occupancy	•Schools •Hospitals •Jails, detention facilities •Public utility facilities •Hazardous material storage facilities • Fire and police stations • Emergency shelters • Aviation facilities

Based on IBC 2009, ASCE 7-05

Examples of Design Peak Ground Acceleration in Recent Codes

Codes	Year in Effect in Cal.	Design Peak Ground Acceleration (PGA)+		
		Weymouth	USHQ	Skinner
UBC 1994	1995	0.4g	0.4g	0.4g
1994 Northridge Earthquake - Resulted in codification of the near-source effect*				
UBC 1997	1998	0.52g	0.4g	0.4g
Seismic hazard map updated to reflect the adoption of Maximum Considered Earthquake Ground Motion as the basis of structural design				
IBC 2009	2010	0.71g	0.59g	0.4g

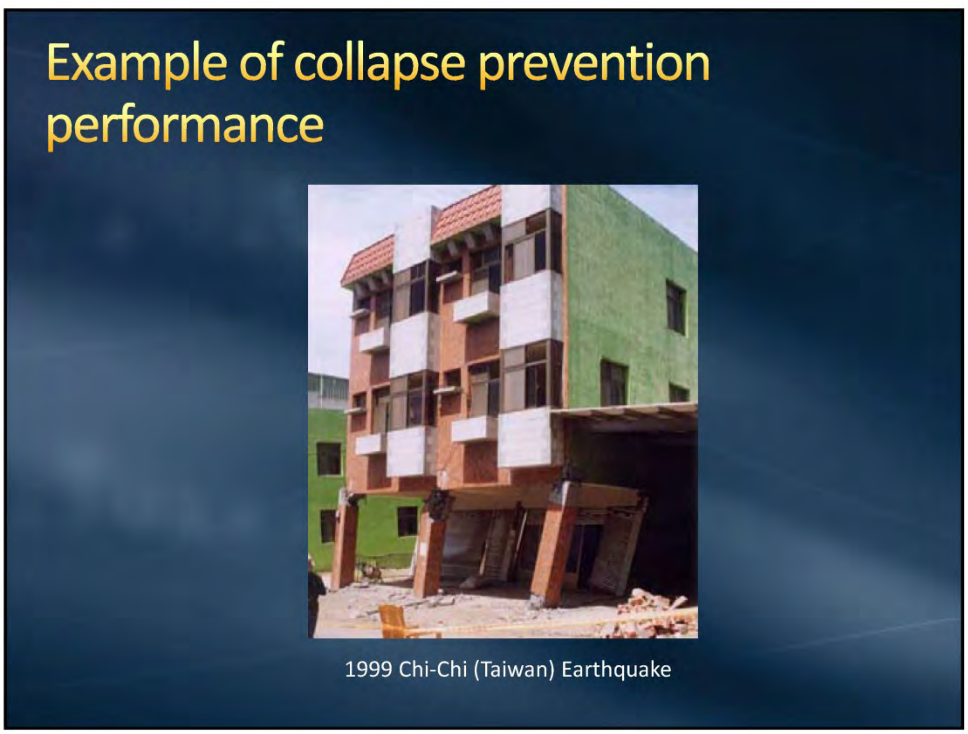
+The listed PGA values are based on generic seismic hazard maps included in the codes. A site-specific analysis may result in different values.
*Other factors such as frequency contents and shaking duration will result in adverse effect on structures that cannot be captured by PGA along. The effect is more pronounced when the site is close to earthquake epicenter, and accounted for by amplifying PGA.

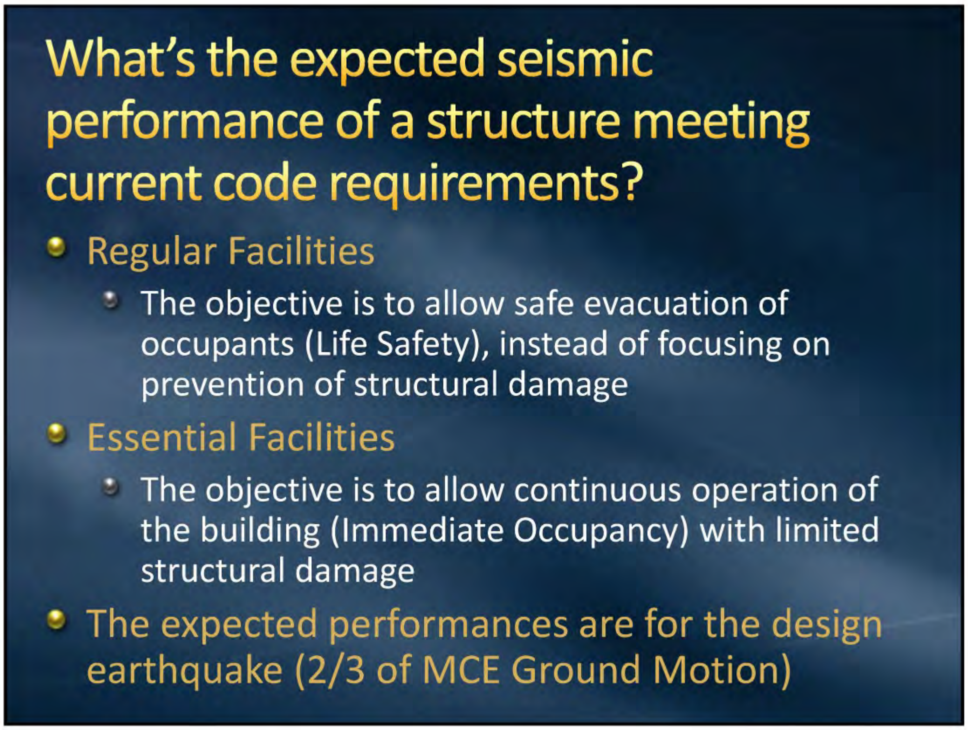
How to define seismic performance of structures?

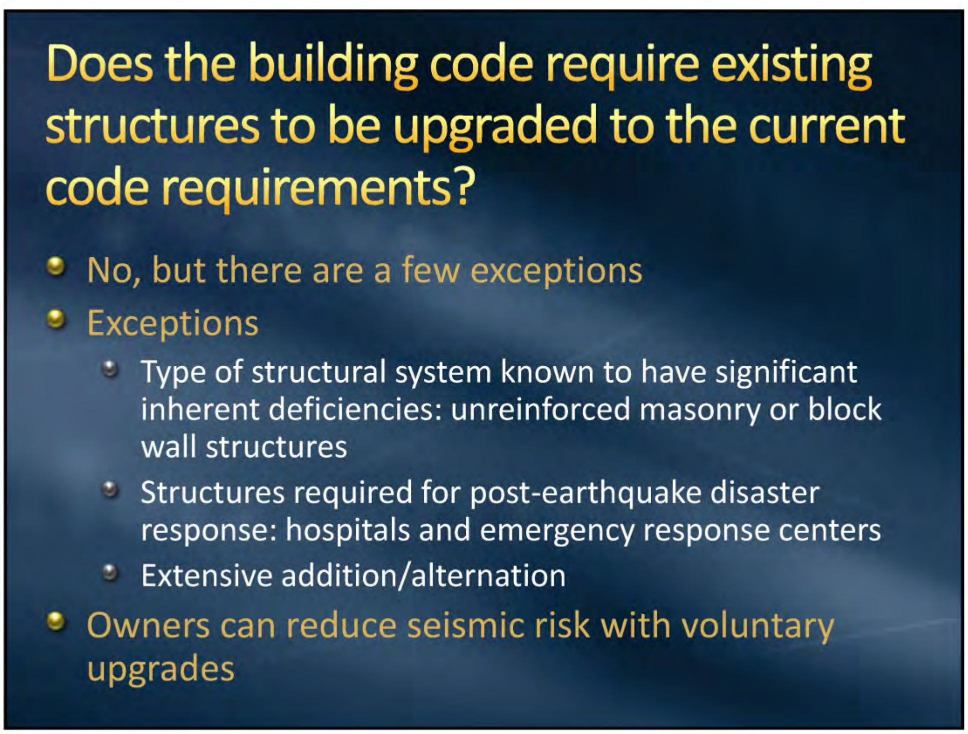
Structural Performance Level*	Expected Performance	Post-Earthquake Assessment
Immediate Occupancy	• Limited structural damage • Safe to occupy immediately after earthquake with minor repair	Green
Life Safety	• Significant structural damage; no imminent risk of collapse • Occupants would safely evacuate from the building • Not safe to occupy w/o major repair. Repair may be economically impractical.	Yellow or Red
Collapse Prevention	• Extensive structural damage and on verge of partial or total collapse • Building is likely damaged beyond repair both technically and economically	Red

*As defined in ASCE 41-06 Seismic Rehabilitation of Existing Buildings


Example of life safety performance
1999 Chi-Chi (Taiwan) Earthquake


Example of collapse prevention performance
1999 Chi-Chi (Taiwan) Earthquake


What's the expected seismic performance of a structure meeting current code requirements?
Regular Facilities
The objective is to allow safe evacuation of occupants (Life Safety), instead of focusing on prevention of structural damage
Essential Facilities
The objective is to allow continuous operation of the building (Immediate Occupancy) with limited structural damage
The expected performances are for the design earthquake (2/3 of MCE Ground Motion)


Does the building code require existing structures to be upgraded to the current code requirements?
No, but there are a few exceptions
Exceptions
Type of structural system known to have significant inherent deficiencies: unreinforced masonry or block wall structures
Structures required for post-earthquake disaster response: hospitals and emergency response centers
Extensive addition/alternation
Owners can reduce seismic risk with voluntary upgrades

What's the acceptable seismic performance level for an existing structure, as it may not meet the current code requirements?

- Depending on post-earthquake functions of the building, the owner may choose the desired performance level
  - Immediate Occupancy
  - Life Safety
  - Collapse Prevention
- Non-building structures (reservoirs, tanks…) are designed based on consensus standards and guidelines (e.g. ASCE, ASME, AWWA…)
  - Operational
  - Prevention of uncontrolled release of contents

What seismic performance are specified in MWD's seismic design criteria?

Building Type Structures				
Importance Designation	**Essential Facilities**		**Regular Facilities**	
	New	**Existing**	**New**	**Existing**
Building Code and Industry Standards	CBC ASCE 7	CBC ASCE 41	CBC ASCE 7	CBC ASCE 41
Design Intent Per Code/ Standard Language	Provide a larger margin against collapse in MCE and remain operational in Design Earthquake (2/3 MCE)	Enhanced performance against life safety in Design Earthquake	Collapse prevention in MCE and prevent life threatening damage in Design Earthquake	To achieve life safety in Design Earthquake
Metropolitan Seismic Design Objective	To remain operational following a major seismic event	Intended to maintain occupancy immediately following a major seismic event	May experience significant damage, but would prevent life threatening injury or casualty following a major seismic event	May experience significant damage, but would prevent life threatening injury or casualty following a major seismic event

What seismic performance are specified in MWD's seismic design criteria? (Cont.)

Water Containing Structures				
Importance Designation	Essential Facilities (Related to Water Delivery)		Regular Facilities (Not Related to Water Delivery)	
	New	**Existing**	**New**	**Existing**
Building Code and Industry Standards	CBC ASCE 7 ACI350 AWWA D100 API 650	CBC ASCE 41 ACI350 AWWA D100 API 650	CBC ASCE 7 ACI350 AWWA D100 API 650	CBC ASCE 41 ACI350 AWWA D100 API 650
Design Intent Per Code/ Standard Language	Provide a larger margin against failure in MCE and require a higher level of liquid tightness to maintain serviceability in Design Earthquake (2/3 MCE)	Not differentiated.	Prevent catastrophic failure in MCE and prevent uncontrolled release of liquid in Design Earthquake	Not differentiated.
Metropolitan Seismic Design Objective	To remain operational following a major seismic event	To remain operational or can be restored quickly following a major seismic event	May experience significant leak and require dewatering to repair, but would prevent uncontrolled release of liquid following a major seismic event	May experience significant leak and require dewatering to repair, but would prevent uncontrolled release of liquid following a major seismic event

Appendix 7

Summary of Previous Metropolitan Seismically Induced Damage Studies

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The impact of earthquakes on Southern California and on Metropolitan's system has been the subject of several previous internal and external assessments:

Seismic Risk Assessment of Local Water Production Facilities in the Service Area of Metropolitan Water District of Southern California, **January 14, 1991, Dames & Moore.** This is a comprehensive report on the effects of a major earthquake on the Southern San Andreas Fault. The report has various models for estimating damage and concludes that there could be hundreds of local water pipelines damaged, loss of power, etc. Metropolitan feeders that are vulnerable to damage were identified, and the report estimates that Metropolitan service will be lost for 6 months or less. The report also predicts significant damage to ground water wells.

***Probable Maximum Loss Analysis for Metropolitan Water District of Southern California*. September 1998, EQE International.** This report was prepared to assess the potential monetary loss associated with several earthquake scenarios. This report highlighted the potential for widespread damage resulting from an earthquake. The study did not address the impact on deliveries or system recovery.

Assessment of Frequency of Recovery Plan and Extreme Events within the Metropolitan Water District Service Area, **December 2001, Geomatrix Consultants.** This report was prepared to aid in the evaluation of hazards under the System Reliability Plan (see next report). This report evaluated the probability of earthquakes of two levels of severity within Metropolitan's service area. The first was a moderate (strong) earthquake similar to the Northridge earthquake (M6.7) and the second was an extreme event, on the order of M7.5. The report provided information on the probability of these earthquakes both within each of Metropolitan's operating regions and within the service area as a whole. The scope of the report did not include evaluating the impact on service or time for recovery.

Distribution System Reliability Assessment, (Report No. 1227), **December 2006, Metropolitan Facility Planning staff.** This report evaluated the reliability of the distribution system. In addition, a separate section of the report dealt with the vulnerability of Metropolitan's facilities to various initiating events. The report addressed the probability of failures in the system due to various random causes including earthquakes. It utilized information from the Geomatrix study to estimate the probability of seismically induced failures. Estimates for the recovery time from the various events were provided.

Facility Reliability Assessments, **2006, Metropolitan Facility Planning staff.** Reliability assessments were conducted by Metropolitan of the five treatment plants and the Colorado River Aqueduct. These assessments evaluated the susceptibility of individual facilities to a series of hazards such as fire, flooding, and earthquakes. Earthquakes were identified as one of the highest risk hazards because of the potential to cause numerous simultaneous failures. The reliability assessments identified structures that had not been updated to the latest seismic criteria. As part of the Seismic Upgrade Program, these structures have been evaluated. Where necessary, capital projects were initiated to upgrade the facilities to the most recent building codes. Completed Facility Reliability Assessments are listed below:

- *Diemer Water Treatment Plant Reliability Assessment, (Report No. 1225),* 2006
- *Skinner Water Treatment Plant Reliability Assessment, (Report No. 1246),* 2006
- *Weymouth Water Treatment Plant Reliability Assessment, (Report No. 1255),* 2006

- *Mills Water Treatment Plant Reliability Assessment, Report No. 1269,* 2006
- *Jensen Water Treatment Plant Reliability Assessment, Report No. 1280,* 2006
- *Colorado River Aqueduct Reliability Assessment, Report No. 1297,* 2006

***System Reliability Study,* 2007, Metropolitan Facility Planning staff.** This study evaluated the reliability of the entire system. This study examined the impact of single failures within the system on the ability to deliver water to member agencies and identified existing backup options. The failures considered included individual facilities as a unit (e.g., a treatment plant or a reservoir). For pipelines, the study considered a failure in each isolatable segment of the line. The impact on deliveries to each service connection was identified and over 250 different events were studied. The study considered capabilities within Metropolitan's system, as well as the member agencies', to mitigate the failures. This study did not consider multiple failures that might be associated with an earthquake due to the almost unlimited number of combinations of failures that would have to be considered.

Golden Guardian 2008. In November 2008, under the auspices of the USGS, Caltech and Earthquake Research Associates, a major disaster drill was conducted in Southern California. The drill was based on a magnitude 7.8 earthquake on the San Andreas Fault (Golden Guardian Exercise). The preliminary studies conducted as part of the exercise indicated that major damage is expected. The impact on water systems was one of the areas of focus for the drill and the related studies. The studies concluded that in areas impacted heavily, water service could be lost for six months.

***Potential Effects of Southern California Seismic Events on Metropolitan Water Deliveries (Report No. 1335)*, January 2009, Metropolitan Facility Planning staff.** This report provided a perspective on the magnitude of damage that could result from moderate and extreme earthquakes, the corresponding potential impacts on Metropolitan water deliveries, and estimated time frames for restoring service. The report also offered recommendations for reducing the potential impacts of certain significant seismic events.

***Mills Water Supply Reliability Study (Report No. 1337),* Metropolitan Facility Planning staff.** The Mills study was prepared in response to findings of the Integrated Area Study, which identified risks to the raw water supply to the Mills plant. The study evaluated alternatives to improve the reliability and redundancy of the raw water supply to Mills. A capital project has been initiated to implement one of the options.

***Potential Impact of a Seismic Event on the CRA Tunnels (Report No.* 1478), August 2014, Metropolitan Facility Planning staff.** This is the first report of a comprehensive study of the seismic vulnerability of the CRA. Five companion reports (Metropolitan Report Numbers 1470, 1484, 1485, 1490 1558) are described below. This study evaluated the vulnerability of CRA tunnels to damage from a major seismic event, provided a perspective of the level, extent and type of seismic damage that could be imposed on CRA tunnels, and estimated the time frame to restore service. The results of the study showed that most of the CRA tunnels are expected to perform well following a large seismic event. Of all the CRA tunnels, only the area near the west portal of the San Jacinto tunnel would be subject to liquefaction, but this area would be easily accessible. The area above the west portal of the San Jacinto tunnel could also be subject to seismically induced landslides, but a project was completed in 1998 to mitigate the potential damage from a landslide at the portal. For the remainder of the tunnels, the potential to experience heavy damage from landslide or rockfalls is negligible. Despite traversing a highly seismic area, there are only three instances of the CRA tunnels crossing a known active fault: Whitewater Tunnel No. 2, Thousand Palms Tunnel No. 2, and Wide Canyon Tunnel No. 2. Of these three tunnels, Whitewater Tunnel No. 2 would likely experience the most significant displacement from a fault rupture.

For ground shaking, while a number of the tunnels could experience high levels of shaking based on estimated Peak Ground Acceleration (PGA), most of these tunnels are deep and constructed in hard rock, which is beneficial for their performance during an earthquake. However, approximately 4.2 miles of tunnel were identified as having a high potential of experiencing heavy damage from the Maximum Considered Earthquake (MCE). These are areas that have shallow cover (e.g. near portals) and experience high PGA values. It should be noted that the entire 4.2 miles would not be expected to be damaged from a single earthquake, but rather there would be isolated areas of damage with those identified tunnel sections. A CIP has been submitted to further investigate the vulnerability of these tunnel sections and to identify options to mitigate the risk.

The Whitewater Tunnel No. 2 was identified as having the greatest cumulative seismic risk. The tunnel is crossed by the Garnett Hills segment of the San Andreas Fault which, from the San Gorgonio Pass Seismic Event Vulnerability Study (Report No. 1484; 2014), could experience up to a 12 foot horizontal and 3 foot vertical offset from a rupture of the San Andreas Fault approximating the MCE. The tunnel could also experience very high levels of shaking from the MCE, and was constructed in compacted sands and gravels, which could negatively impact the performance against the shaking.

For the purpose of estimating repair times, a worst-case damage scenario was developed for the Whitewater Tunnel No. 2, and a tunnel repair workshop was conducted to get a realistic understanding of repair methods and repair times (reference Report No. 1485).

***Colorado River Aqueduct – San Gorgonio Pass Seismic Event Vulnerability Study (Report No. 1484),* July 2014, GeoPentech.** This study evaluated the potential for horizontal and vertical deformation following a large seismic event within the San Gorgonio Pass area. To assist in the study, a team of geoscientists experienced in assessing the potential for fault displacements along the southern San Andreas Fault System in the area of the San Gorgonio Pass was assembled under GeoPentech, Inc. The study incorporated the most recent information available regarding the seismicity of the area including: geology, geodesy, seismicity, paleoseismology, and tectonics.

The information gathered during the course of the study was used to develop a 3-dimensional deformation model of the San Gorgonio Pass area using Coulomb 3.3 (San Gorgonio Pass Model). The model was developed to estimate the surface fault displacement and deformation that would occur along and near the CRA within the San Gorgonio Pass as a result of future seismic events. The results of the San Gorgonio Pass Model were compared to current geologic and geomorphic data, which showed a reasonable reflection of the natural conditions of the area, validating the results of the model.

The MCE for the southern San Andreas Fault would be a rupture originating near the Salton Sea around Bombay Beach and extending through the San Gorgonio Pass up to between Wrightwood and Three

Points. Based on available geologic data, the most likely event on the San Andreas Fault to rupture in on the Garnett Hills Fault, which is a strand of the San Andreas Fault system located in the San Gorgonio Pass. Results from the San Gorgonio Pass Model indicate that an earthquake approximating the MCE for the Southern San Andreas Fault System could result in a horizontal offset of approximately 12 feet and a vertical deformation of approximately 3 feet at the Garnett Hills Fault crossing of the CRA. The vertical deformation would extend over the CRA for approximately 60 miles.

The seismic event would result in uplift along the longitudinal profile of the CRA with three separate peaks, with the last peak occurring at or near the Whitewater Tunnel No. 2 and resulting in a cumulative upward deformation of approximately 3 feet. This upward deformation of the CRA would reduce the flow carrying capacity of the aqueduct. An accompanying probabilistic rupture hazard analysis of the San Gorgonio Pass (Report No. 1470) showed that the above deformation occurring at the CRA crossing has a return period of approximately 750 years.

***The Colorado River Aqueduct San Gorgonio Pass Seismic Event Vulnerability Study – Hydraulic Analysis, (Report No. 1558),* September 2014, Metropolitan Facility Planning and Hydraulics staff.** This study documents a detailed hydraulics analysis that evaluated the impact of a seismically induced vertical uplift of the CRA alignment over a length of approximately 60 miles, based on the uplift profile from the San Gorgonio Pass Seismic Event Vulnerability Study (Report No. 1484). The analysis showed that despite the uplift, Metropolitan would be able to continue flowing approximately 1300 cubic feet per second, approximately 80 percent of design flow, through the aqueduct after initial rapid repairs are completed. The analysis assumed free surface flow with a 3-foot minimum freeboard, the same as the current aqueduct design. Minor pressurization of the system could allow for some additional flow if required. The analysis also assumed that repairs to the CRA following the earthquake maintained the design cross sections and friction of the non-damaged CRA sections, and that no repairs were done to reestablish the grade.

***Probabilistic Rupture Hazard Analysis of CRA at San Gorgonio Pass (Report No. 1470),* October 2014, Metropolitan staff.** This report is a supplemental report to Report No. 1484, "Colorado River Aqueduct – San Gorgonio Pass Seismic Event Vulnerability Study." The report documents the results of a probabilistic rupture hazard analysis of the CRA where it crosses the Garnett Hills segment of the Southern San Andreas Fault in the San Gorgonio Pass. The analysis showed that the projected 3-foot vertical and 12-foot horizontal surface deformation at the CRA crossing in the San Gorgonio Pass has a return period of approximately 750 years.

***Colorado River Aqueduct Seismic Vulnerability Investigations – Summary Report (Report No. 1490)*, December 2014, Metropolitan Facility Planning staff.** This report briefly summarizes the results of the CRA seismic vulnerability studies (Reports 1478, 1484, 1485 and 1558).

***Seismic Risk Assessment – Conveyance and Distribution System Tunnels (Report No. 1533),* March 2016, GeoPentech and Metropolitan Facility Planning staff.** This study evaluated the seismic risk of the 41 tunnels within Metropolitan's Conveyance and Distribution System to heavy damage during a future maximum considered earthquake (MCE) event that would adversely impact water deliveries to member agencies while the tunnel is out of service for repairs. The study was completed through a two part process. Part 1 screened each of the 41 tunnels and identified tunnels that were vulnerable to one or more seismic hazard, and could result in a loss of service to the member agencies (i.e., no backup capability) if flow through the tunnel is disrupted. Tunnels that met both criteria in Part 1 were deemed a potential seismic risk to Metropolitan's water delivery reliability and were pushed through to Part 2 of the process. Part 2 further evaluated each of the potential high-risk tunnels identified in Part 1 and numerically ranked each tunnels degree of seismic risk in order to identify which tunnel(s) may pose the greatest risk to Metropolitan's water delivery capability.

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Appendix 8

Administrative Code Section 4503 "Suspension of Deliveries" and 9/21/06 IAS Clarification

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§ 4503. Suspension of Deliveries.

(a) Whenever repairs or maintenance of the District's system, in the opinion of the Chief Executive Officer of the District, shall require suspension of delivery of water at any point or points, such delivery may be suspended without liability on the part of the District; provided, that except in cases of emergency, as determined by the Chief Executive Officer, notice of such suspension of service shall be given to the affected member public agency in advance of such suspension. Metropolitan will make a concerted effort to notify and work with member public agencies regarding all scheduled interruptions. The District will schedule non-emergency interruptions for the low demand months of the year, typically October through April, in coordination with the member public agencies.

(b) Each member agency shall have sufficient resources such as local reservoir storage, groundwater production capacity, system interconnections or alternate supply source to sustain a seven-day interruption in Metropolitan deliveries based on annual average demands. If a member public agency has been provided with a sixty (60) day notice of when an interruption in service is to occur, the member public agency shall be responsible for and reimburse direct costs, excluding labor costs, incurred by Metropolitan in the event that a scheduled non-emergency interruption of up to seven days is postponed or cancelled at the request of the member public agency as a result of insufficient local resources, and the District agrees to such cancellation or postponement. Direct costs shall be determined by Metropolitan's Chief Executive Officer, in consultation with the affected member agency. These direct costs shall be applied to the member public agency's water invoice following cancellation or postponement of the shutdown.

(c) Except in cases of emergency, the District, working with the member agencies, will produce a shutdown schedule each September for the annual shutdown season from October through April. The District will also develop a three-year shutdown schedule, which will give notice of the proposed shutdowns greater than seven days at least one-year in advance.

(d) Replenishment Service certifications will be adjusted for the reduction of credits that are accrued due to shutdowns that are greater than seven days. No adjustments will be made for shutdowns seven days or less unless the member agency provides a service to the District by serving another member agency in-lieu of District deliveries during a shutdown even if the shutdown is seven days or less.

Section 322.4 based on Res. 7260 – May 12, 1970, amending Res. 3896 – August 18, 1950; amended by M.I. 33642 – March 10, 1981. Section 322.4 repealed and Section 4503 adopted by M.I. 36464 – January 13, 1987, effective April 1, 1987; amended by M.I. 42278 - February 11, 1997; paragraph amended by M. I. 44812 - March 12, 2002; paragraph amended by M. I. 45943 – October 12, 2004; paragraphs assigned (a), (b), (c), & (d) designations and amended by M. I. 45988 – November 9, 2004.

2007 Integrated Area Study (IAS) Clarification

1. Original intent
    a. Communicated that MWD's system is interruptible
    b. Protected MWD from liability claims for required shutdowns
    c. Illustrated commitment to minimizing impacts
        i. Advanced notice & coordination
        ii. Non-emergency outages only during low flow months
    d. Required member agencies to make provisions for outages
        i. 7-day supply of average annual demands
        ii. No enforcement – no penalty

2. Updated text & interpretation
    a. Recognized changing conditions
        i. Increased member agency dependence upon MWD
        ii. Many agencies in non-compliance
        iii. Increased difficulty in storing treated water
    b. Revised requirement for member agency outage provisions
        i. Capability to sustain 7-day interruption (not limited to supply)
        ii. Penalty added for cancellation or postponement of outage

3. IAS clarification
    a. MWD planned outages are required to maintain long-term reliability
    b. Unplanned MWD outages may also occur
    c. Intent of 4503 was to encourage agency provisions for planned and unplanned outages
    d. Compliance not enforced (beyond interference with planned outages)
    e. Member agencies responsible for decisions regarding provisions for unplanned outages
    f. Regional flexibility improvements achieved through demand-driven LRP & IAS projects