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Informing effective and equitable environmental policy

The Resilience Value of Recycled Water for Los Angeles

HOW DOES PURE WATER LA (OPERATION NEXT) PREPARE THE CITY FOR AN UNCERTAIN FUTURE?

BY NICHOLAS CHOW, GREGORY PIERCE, BENJAMIN BASS, NAOMI GOLDENSON, ADAM BARSCH, DAVID KONG, ALEX HALL, AND J.R. DESHAZO

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REPORT

UCLA **Luskin Center for Innovation**

Informing effective and equitable environmental policy

The Luskin Center for Innovation conducts actionable research that unites UCLA scholars with civic leaders to solve environmental challenges and improve lives. Our research priorities include the human right to water, community-driven climate action, heat equity, clean energy and zero-emission transportation. We envision a future where everyone has healthy, affordable, and resilient places to live, work, learn, and play.

AUTHORSHIP

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GLOSSARY OF KEY TERMS

Abbreviation	Meaning
AC Model	Avoided Cost Model
AF	Acre-Foot or Acre-Feet
AFY	Acre-Feet per Year
CFS	Cubic Feet per Second
City	The City of Los Angeles
CRA	Colorado River Aqueduct
DWR	Department of Water Resources
EEI Model	Economic and Employment Impact Model
FTE	Full-Time Equivalents
HWRP	Hyperion Water Reclamation Plant
I-O	Input-Output
KAF	Thousand Acre-Feet
LAA	Los Angeles Aqueduct
LAASM	Los Angeles Aqueduct Simulation Model
LADWP	Los Angeles Department of Water and Power
MAF	Million Acre-Feet
Mw	Moment Magnitude
MWD	Metropolitan Water District of Southern California
NAICS	North American Industry Classification System
ORA	Operation NEXT Resilience Analysis
SRFT	Seismic Resilience Task Force
SWP-E	State Water Project East Branch

SWP-W	State Water Project West Branch
SWRCB	(California) State Water Resources Control Board
UCERF3	Uniform California Earthquake Rupture Forecast Version 3
USDM	United States Drought Monitor
WIF	Water Importance Factor

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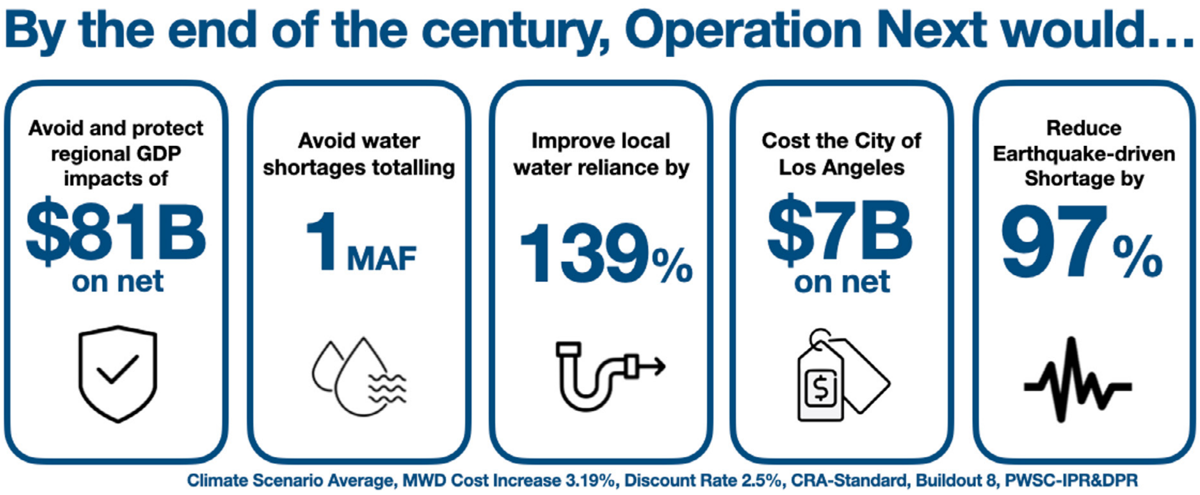
EXECUTIVE SUMMARY

By the end of the century, California will face increasingly variable precipitation and temperature patterns, straining drinking water utilities' supplies. Compounding these challenges are infrastructure resilience risks in densely populated urban areas, such as the City of Los Angeles (City). To enhance urban water management, the Los Angeles Department of Water and Power has committed to invest a minimum of $6 billion in a pioneering water supply initiative called Pure Water Los Angeles (formerly known as Operation NEXT). This project would treat wastewater to create a new local and reliable drinking water supply of over 250,000 acre-feet annually. Cities across the western U.S. and in similar climatic regions globally are likewise considering investing in creating new, sustainable water supplies to help mitigate the risk of shortages during droughts and earthquakes as well as unlock opportunities for greater regional coordination and groundwater storage. This analysis can thus inform broader planning efforts both in the U.S. and beyond.

This report identifies the broad long-term benefits of investing in such critical infrastructure and evaluates its impact on the City and the wider economy. The Operation NEXT Resilience Analysis Model we created and key metrics identified below are crucial to inform decision-makers and strategic planning, and provide a robust foundation to evaluate the benefits and risks of investing in Operation NEXT. The below figure provides the summary results.

FIGURE ES-1

Geographic map of the western United States showing Los Angeles's water import aqueducts and their respective watersheds



By the end of the century, Operation Next would…

Avoid and protect regional GDP impacts of $81B on net

Avoid water shortages totalling 1 MAF

Improve local water reliance by 139%

Cost the City of Los Angeles $7B on net

Reduce Earthquake-driven Shortage by 97%

Climate Scenario Average, MWD Cost Increase 3.19%, Discount Rate 2.5%, CRA-Standard, Buildout 8, PWSC-IPR&DPR

The Operation NEXT Resilience Analysis model incorporates three core components: climate downscaling and flow availability translation, water supply decision-making and cost, and economic and employment impact. Using these components, we assessed 10 distinct climate futures, applying over 40 water supply decision-making and cost assumptions with implications across more than 50 industries. The model's flexibility allows us to explore millions of scenarios, from which we have selected approximately 100,000 for detailed analysis.

Through our analysis, we found that Operation NEXT would be a strategic investment that not only addresses immediate water supply challenges but also offers long-term economic and water security benefits. Because climate uncertainty will be the largest driver of water shortage in the City, the project must be designed to be adaptable. Operation NEXT would:

1. Significantly bolster local water supply resilience;
2. Improve resilience to uncertain water imports;
3. Significantly reduce earthquake-driven water shortages; and
4. Offer substantial regional economic benefits.

Operation NEXT would significantly bolster local water supply resilience. It would create a new, local stable water source which can be used to balance water budgets, better utilize existing assets, and be stored as a safeguard for hazards like earthquakes and droughts. The analysis demonstrates that investing can avoid severe water shortages estimated to total between 680,000 and 1,172,000 acre-feet by the end of the century by providing a direct supply of water and groundwater storage.

Operation Next would improve resilience to uncertain water imports. This new local water source would reduce import reliance between 27.5% and 32.2% and enhance resilience against external cost shifts. Investment in Operation NEXT does not achieve the Green New Deal's 70% locally provided water supply goal on its own, but it is a leap forward, more than doubling the potential for future local water reliance from 23.5% to 51.0% on average.

Operation NEXT would significantly reduce earthquake-driven water shortages. Investment in Operation NEXT would reduce the risk of water shortage during and immediately after an earthquake from 47.8% to 3.1% by providing water directly during these events and indirectly by increasing groundwater storage.

Operation NEXT would offer substantial regional economic benefits. Across the key results, the net regional economic impact of investing in Operation NEXT is projected to be between $44.5 and $80.6 billion USD ($2020). These financial benefits far outstrip the net costs to the City, which range between $5.2-$7.5 billion USD ($2020). At minimum, there is an almost six-fold return on investment regionally for a sizable investment locally.

0. INTRODUCTION

In 2019, the City of Los Angeles (City) announced the development of the Operation NEXT Water Supply Program (Operation NEXT or Program) (City of Los Angeles, 2019), an advanced water recycling project aimed at expanding the use of purified recycled water. The current approach for Operation NEXT (now Pure Water Los Angeles) encompasses several distinct water infrastructure components. One is the construction and operation of an advanced water treatment purification facility at the Hyperion Wastewater Treatment Plant, the largest wastewater treatment facility west of the Mississippi. This project, in partnership with Los Angeles Sanitation & Environment comprises the Hyperion 2035 Program (Hyperion 2035) (LADWP, 2024; LASAN, 2024). Once constructed, potable recycled water flows from this facility will further diversify the City's water supply portfolio, adding up to 257,636 acre-feet of supply each year once it is fully operational. A second component of Operation NEXT is a conveyance system that will transport this purified recycled water to groundwater basins or further treatment facilities, where it will be stored or blended with other water supplies. Currently, the construction and operation of Operation NEXT is still being estimated, and costs range between $6.4 billion and $24.0 billion USD as of 2020.

Further Diversifying the City's Portfolio. Developing Operation NEXT is valuable to the City as it provides a new local water supply with a number of benefits. Firstly, this new water stream will further diversify the City's supply portfolio and provide flexibility and redundancy. This adaptability not only enhances local water supply reliability, but also minimizes the impact of potential future economic shocks and increases. One uncertain but anticipated cost comes from the City's main purchased imported water provider, the Metropolitan Water District (MWD) as it makes investments to adapt to climate change (MWD, 2024). Secondly, as climate change may increase the frequency, severity, and duration of droughts in the three watersheds that supply the City, Operation NEXT will provide additional supplies in those circumstances, thereby reducing the City's need to compete for alternatives.

Enhancing Our Water System's Resilience. Infrastructure lifeline system resilience is typically considered to be a system's resistance to perturbations, recovery after a shock, and adaptability to new conditions. To achieve these ambitious goals, the City has been explicit in its planning efforts to enhance and develop local water supply sources (LADWP, 2015). Planning for Operation NEXT is considering supply partnerships with other water agencies, expanded groundwater recharge to support indirect potable reuse (Guzman & Pierce, 2024), and potentially even direct potable reuse following the state release of final regulations in December 2023 (Title 22, 2024).This diversification of supplies with locally produced recycled water would also benefit the City in providing additional supply redundancy when facing climate and seismic hazards. Shifting climate in the western United States is predicted to result in more intense periods of both rainfall and drought, but water supply from Operation NEXT is likely to mitigate the impact of these swings by: 1) being less impacted than the watersheds that feed the City's imports, and 2) improving groundwater availability for use during droughts. For earthquakes, experts note that there is building tension along the major regional seismic zone and that a major earthquake is increasingly likely to occur at the San Andreas Fault, east of the

City. While the timing and magnitude of seismic events are unpredictable, we anticipate that supplies from Operation NEXT would be available on the western side of a seismic rupture at the San Andreas Fault and thus they could potentially support the City in the event of a major earthquake.

Evaluating the Financial and Economic Impacts. An important question is whether the financial investments of Operation NEXT would produce net benefits for the City in the future. When answering this question, it is a mistake to simply compare the costs of Operation NEXT with the costs of purchased imported water that it would offset. Such a simple cost comparison ignores the resiliency value that Operation NEXT could provide during potential periods of reduced water inflows due to significant droughts and earthquakes. During such periods, the City would have two broad adaptive strategies. Firstly, the City may pay higher water supply costs as it brings emergency water supplies online. Secondly, during these periods of water curtailment, businesses may reduce production of goods and services that use water, leading to job losses. Therefore, the value of Operation NEXT is enhanced by the City's ability to avoid higher emergency water supply costs, lost economic activity, and job loss during these geohazards.

A Roadmap to Our Analysis. Our analysis assumes that Operation NEXT will begin piloting in 2035 and become fully operational by 2050. We assess the resiliency benefits that it might yield over the subsequent 55 years of operation, projecting to 2100. Our objective is to compare the costs of the business-as-usual water supply without Operation NEXT to the cost-benefit of water supply strategies that involve building Operation NEXT. To accomplish this objective, we undertake several intermediate steps:

1. **Identifying potential variances to the City's imported water supply.** In Section 1 of this report, we describe the location of three main water conveyance systems that supply the City: the California Aqueduct, the Los Angeles Aqueduct (LAA), and the Colorado River Aqueduct (CRA). We then describe how droughts may influence their respective watersheds and how each aqueduct transects the San Andreas seismic fault zone.
2. **Defining the droughts and earthquakes for which the City should be planning.** In Section 2, we more precisely characterize the size, magnitude, and frequency of geohazards that have historically affected imported water conveyance infrastructure. We also carefully analyze the literature focused on future droughts and seismic risks. Though we are able to characterize potential droughts and seismic events that may impact the City's imported water supplies, no one can tell with certainty how many droughts and earthquakes, each of differing severity and duration, will occur. The models we employ in this report forecast the cost of droughts and earthquakes that policymakers could use to evaluate Operation NEXT benefits up to the end of the century.
3. **Evaluating potential water supply scenarios impacted by climate change.** To answer this question in Section 3, we first forecast the amount of water that the City expects to consume following moderate conservation projections. In the case of responding to hazards, we assume for the purposes of this exercise that the City would aim to meet only essential water demands, which we take to be consumption needs for indoor water use. We are then able to estimate the difference between essential consumption and

available supplies. Our final step in this section is to estimate both the quantity and costs of emergency water supplies that the City could utilize in each of the hypothetical scenarios.

4. **Estimating the costs and economic impacts attributable to Operation NEXT**. In Section 4 of this report, we apply the modeled water supply portfolio choices to the Avoided Cost model to assess water supply availability in future scenarios which vary the extent to which the City invests in Operation Next. Further, we apply the City's costs and the quantified supplies from Section 3 to the Economic and Employment Impact model to understand the effect of the scenario's assumptions and outcomes on different aspects of the economy, such as jobs and gross domestic product (GDP).
5. **Valuing uncertainty in natural hazards and institutional decision-making.** Section 5 concludes with sensitivity analyses examining the variability in key assumptions within the Avoided Cost and Economic and Employment Impact models. These assumptions are grouped into five categories: 1) climate hazards (e.g., droughts), 2) population growth, 3) exogenous institutional decisions (e.g., cost changes or institutional agreements), 4) endogenous institutional decisions (e.g., engineering or financing), and 5) cost overruns, which are common in large infrastructure projects.

1. INSTITUTIONAL AND HISTORICAL CONTEXT OF IMPORTED WATER SUPPLIES

The three key import channels which supply the City are the State Water Project's California Aqueduct (SWP), the Los Angeles Aqueduct (LAA), and the Colorado River Aqueduct (CRA) (Figure 1). Imported supplies from these three systems can account for up to 90% of the water utilized by the City in a given year and thus are critically important to characterize. More so than for many other water systems, an integrated review of operational, legal, and institutional constraints is necessary to understand these supplies because their availability is not solely hydrologically driven but is instead a complex interplay between hydrology, policy, interinstitutional decision making, and legal constraints from both within and beyond California's borders. Importantly, a historical lens must be applied in developing an understanding of these systems for modeling as present constraints are strongly influenced by historical sentiments, prior institutional decisions, and long-held legal rulings.

Despite sometimes scarce and variable supplies throughout their history, these aqueducts have persisted in supplying the region. The SWP, LAA, and CRA are supplied by distinct watersheds: the Sacramento River Watershed, the Owens River Watershed, and the Colorado River Watershed, respectively. All three of these watersheds are already being impacted by climate change, but future projections anticipate hydrologic patterns that are even more variable and severe than they have been historically.

FIGURE 1

Geographic map of the western United States showing Los Angeles's water import aqueducts and their respective watersheds

In the context of all three import channels, the hazards of severe precipitation—both high and low—present unique challenges. High rainfall may appear to bring water supply benefits, but the magnitude of extreme events may overwhelm parts of our water systems, preventing them from operating optimally. At best, these events squander the opportunity for additional supplies. At worst, they damage valuable water infrastructure. The alternative of a dry extreme may have the primary consequence of diminishing surface and groundwater flow, but oftentimes it can initiate cascading policy constraints beyond water systems, resulting in disproportionately declining supply availability across the region.

In addition to the complex climate impacts cited above, another major threat to these aqueducts is the risk of seismic rupture due to shifting faults. Each of the three aqueducts is crossed by numerous faults, but notably all cross the San Andreas Fault—the major transform fault system in California that has been responsible for several historically devastating earthquakes. The San Andreas Fault runs from the Salton Sea in Southern California through both the Cities of Los Angeles and San Francisco to the Santa Rosa area in the north (Figure 2). On the southern segment of the San Andreas Fault (from the Salton Sea to Fort Tejon), seismologists note that building stress at the fault suggests that a 7.0 or higher magnitude earthquake is overdue to occur (Jones et al., 2008) and an event of this magnitude would likely threaten the water import infrastructure that crosses it (Seismic Resilience Water Supply Task Force, 2017).

FIGURE 2

Geographic map of the western United States showing Los Angeles's water import aqueducts and their respective watersheds

Future drought and seismic hazards will hinder water provision to the City, either through diminishing natural water resource availability or by damaging and hindering the infrastructure's ability to import supplies. How each of these hazards affects the import channels is distinct since each aqueduct system faces unique operational and institutional constraints. This section describes each aqueduct's characteristics, historical hazards, and operational and institutional constraints to provide context for key modeling assumptions.

1.1. The State Water Project

The SWP is a system of reservoirs, aqueducts, power plants, and pumping plants extending from the Bay Delta in Northern California to Los Angeles County—more than 700 miles and two-thirds the length of California (Figure 1). It draws water from the Sierra Nevada mountains, the Sacramento River basin, the San Joaquin River basin, and the Clifton Court Forebay to serve northern California, the Bay Area, the San Joaquin Valley, the Central Coast, and Southern California. Physically, the channel is concretized and there are portions that are both open-air and covered. In Southern California, the SWP bifurcates into east and west branches. The SWP is managed by the California Department of Water Resources (DWR), which scales the amount of flow to users dependent on environmental conditions in Northern California. The SWP serves 29 different users, known as contractors, and each receives a distinct allocation of water supplies annually.

The City is not a contractor, but MWD is, and it is the major supplier of imported (SWP and CRA) water to the City. In this way, MWD acts as an intermediary, providing useful water management services and adding institutional considerations in systems modeling. MWD has pipeline, reservoir, treatment, and storage assets that receive supplies from both the east and west branches of the SWP. While the branches both face the DWR-imposed supply allocations, the physical assets face distinct hazards due to seismic fault crossings and physical flow capacities. Beyond these, the most common perturbations to SWP flow are policy-driven strategies to protect ecologic, economic, and social interests in Northern California.

1.2. The Los Angeles Aqueduct

The City is unique in managing and owning an independent imported water source. The LAA system refers to a series of channels and reservoirs extending from Mono Lake to the LAA Filtration Plant. Water is collected in the eastern Sierra Nevada mountains and then transmitted to the City via two distinct aqueducts known as the Los Angeles Aqueducts 1 and 2. These two channels are commonly referred to together as the LAA as they jointly provide flows to the City of up to 475,402 AFY. Despite a higher theoretical capacity of 507 KAF (700 CFS total: 400 CFS from LAA1 and 300 CFS from LAA2), the LAA system is highly constrained and in recent years has carried closer to 195 KAF per year (15-year mean average across 2003–2018).

The major constraints in the system are rainfall and snowpack in the Sierra Nevada mountains watershed, but also institutional constraints faced by the City regarding exports from the region. The City is the only entity drawing water from the LAA, but there are still legal barriers that complicate its management. Historically, the diversion of water from the Owens River to the

City has impacted the region's fish habitat, lake levels, and air quality. This has led to a series of lawsuits which have resulted in several agreements that now ensure baseline flow to the Owens Valley's water bodies (California Superior Court, 2005; Louis, 2017).

1.3. The Colorado River Aqueduct

The CRA is a 242-mile-long system composed of a series of open canals and reservoirs that pump and transmit water from Lake Havasu to the Whitsett Intake pumping plant to Southern California. The aqueduct itself has a carrying capacity of 1.2 MAF, though not all of this is allocated to MWD. Under its current contracts, MWD only has rights to 550,000 AF per year of Colorado River water while the rest is allocated to other consumers. As with the SWP, the City has no direct contract to waters through this import channel but instead purchases imported supplies through MWD's typical 550 KAF annual allocation.

While the supplies on the Colorado River are protected under the Colorado Compact set out by the federal U.S. Bureau of Reclamation, the allocations legally set are based on imprecise early 20th-century climatic conditions. These conditions formed the foundation for the original Compact, and subsequently Colorado River supplies may be over-subscribed. With the potential that these flows could be diminished in the future—either through climate shifts and/or legally— the Compact is in the process of revision or renegotiation, with several proposed alternatives suggesting relatively small cuts to CRA flows to MWD (USBR, 2023b, 2023a). Ultimately, however, the availability of the CRA's flows to MWD (and by extension, the City) are uncertain. MWD has already begun to increase its CRA water supplies, both through unused rights by other rights holders and from water saved through various conservation programs. An example of this comes from the 2011–2017 California drought, when other aqueduct flows were diminished to below 5% of their annual averages while the CRA exceeded its average by almost 100%. These agreements provide resilience and robustness to MWD's import portfolio, but the additional flows are not guaranteed.

2. CHARACTERIZING HAZARDS TO LOS ANGELES'S WATER SUPPLY SYSTEMS

2.1. Understanding California's Earthquake Context

Earthquakes are one of the most dangerous natural hazards for humans due not only to the immediate loss of life but also their lasting damage to infrastructure and the subsequent societal impacts and reduction in quality of life. Consider the loss of vital services like food, water, fire, health, and waste management systems. Scholars and planners are aware that Southern California is latticed with both minor and major earthquake faults, and this is reflected in many aspects of its policy, infrastructure, and emergency-planning strategies (Jones et al., 2008). Despite these efforts, damages are nearly unavoidable because of the unpredictability of these seismic events, both temporally and in magnitude. Designing our systems to be resilient to every possible event is impractical, so instead experts utilize characteristic examples from the historical record to communicate about, plan for, and model feasible earthquakes in the future.

California's history is punctuated by large earthquakes along the San Andreas Fault, the most infamous being the 1906 7.9 Mw[1] in San Francisco. This quake took a horrific toll on the city, perhaps most indelibly remembered by the fire, which burned for three days and consumed more than 500 city blocks. In total, over 80% of the city was destroyed and 3,000 people lost their lives (Wald et al., 1993). Even today, the memory of this tremendous human loss persists in the minds and policies of California's planning experts as they guide standards in building design and emergency water supplies for fire suppression. Following these actions, when San Fernando was later hit by a 6.6 Mw earthquake in 1971, it faced significantly less damage. However, 58 people still lost their lives, and the gravity of earthquake hazards became enshrined in California's hazard planning. More recently in the state's history, the 1994 (Northridge, 6.7 Mw) and 2019 (Ridgecrest, 7.1 Mw) earthquakes were highly impactful, but with proportionally less loss of life despite significant economic damages.

Understanding the relative strength of past earthquakes contextualizes future planning and provides a foundation for forecasting potential damages—not just to buildings, but of relevance to this work, water systems. Earthquakes damage structures in two ways: through ground motion and shaking or through permanent horizontal or vertical offset. Though the structural integrity of the region's water import infrastructure will likely be significantly affected by ground shaking, it is more likely to be affected by permanent land offset. Vertical offset (uplift) can alter the hydraulic gradient and flow schema of aqueducts, especially in areas of unpressurized, open channel flow. Horizontal offset, if severe enough, can sever channels, resulting in lost flows and even contamination. The amount of offset seen at different points across the fault is reliant on the intensity of the earthquake and can be variable depending on the origin of the rupture along the fault. Understanding the extent of potential offset to the aqueducts is crucial in determining the need for their resilience and unique repair times. Collaborative efforts engaging the LADWP, the Department of Water Resources (DWR), and MWD have described this process for the ShakeOut scenario (Davis, 2009; Seismic Resilience Water Supply Task Force, 2017).

The Great California ShakeOut (Jones et al., 2008) is an ongoing project that develops realistic seismic planning and drill scenarios for Southern California. It relies on expertise from several teams, including those at the USGS, the Southern California Earthquake Centre, the California Office for Emergency Services, and the Federal Emergency Management Agency. Through expert interviews and academic review, this project recognizes that the Great ShakeOut's 7.8 Mw San Andreas Fault Rupture scenario is the most widely used. To be consistent with this approach, we follow this industry standard in our scenario planning.

2.2. Operationalizing Earthquakes for Modeling

In the City, the most utilized earthquake planning scenario comes from the 2008 Great Southern California ShakeOut Study (ShakeOut), which presents a 7.8Mw (moment magnitude) earthquake as a plausible scenario for evaluation (Jones et al., 2008). ShakeOut describes a large earthquake event originating at the south end of the San Andreas Fault propagating northward. The report suggests a mean recurrence interval of 150 years for this earthquake event, though it recognizes that the true present likelihood of an event is higher due to the recent absence of a major event in the region. The ShakeOut earthquake scenario has been applied broadly across the City's departments as well as with regional planning commissions—notably the Seismic Resilience Water Supply Task Force (SRTF) led by MWD. Although Southern California has numerous faults (e.g., San Jacinto, Santa Susana, and the Garlock faults) that could threaten critical water import infrastructure, our analysis has chosen to follow the lead of experts in utilizing the San Andreas Fault as the focus of this research because of the magnitude of its potential impact.

While the ShakeOut is the most used earthquake propagation model for Southern California, it is by no means the only one. Another tool that describes seismogenic movement on the San Andreas Fault is the United States Geological Survey's Uniform California Earthquake Rupture Forecast V3 (UCERF3) model (Field et al., 2013). The UCERF3 model produces a quantitative dataset that enables a nuanced probabilistic approach dependent on the expected location and magnitude of the earthquake event. It summarizes a distribution of probabilities over its modeling range and provides 30-year mean probabilities of participation in an earthquake event at various magnitudes above 6.7 Mw. It is worth noting that the ShakeOut report and the UCERF3 model conflict in their predictions, and neither is definitively correct; seismic prediction is still an imprecise field with room for multiple scientific approaches. To address this discrepancy, we discussed the conflicting outcomes of these two research endeavors with experts including Scott Brandenberg, Craig Davis, Ken Hudnut, Lucy Jones, Jonathan Stewart, and Paolo Zimmaro (personal communications, 2019) and came to three key conclusions that guide the baseline scenario analysis of this exercise:

1. Firstly, we concluded that the ShakeOut scenario (south to north rupture) is more likely than the computational results of the UCERF3 (north to south rupture), and that this discrepancy is likely due to conflicting computational modeling from smaller nearby faults. **This conclusion results in our baseline hypothetical scenario considering a fault rupture event extending northward from the Salton Sea.**

2. Secondly, while fault ruptures may terminate at the San Gorgonio Pass due to complex, unpredictable mountainous geology, limited rupture is unlikely given the tremendous stored energy in the San Andreas Fault system. **This conclusion results in our baseline hypothetical scenario considering a fault rupture that extends beyond the San Gorgonio Pass up to Parkfield.**
3. Thirdly, that a single 7.8 Mw event could impact all of the examined major import channels of Southern California. Importantly, it would likely also impact water management assets within the City. **This conclusion results in our baseline hypothetical scenario considering a fault rupture that impacts all import channels but which considers a feasible demand impact within the City.**

Synthesizing the academic literature with the above information, our analysis identifies three realistic earthquake scenarios (Table 1) that could affect water supply infrastructure to the City. The most significant scenario is expected to be an event that impairs flow across all import channels. This was selected as our primary analysis scenario (E1).

TABLE 1

Probability estimation of earthquakes under each scenario available to the model

Scenario	Import Aqueduct Affected	Length (m)	Average Seismogenic Depth (m)	Magnitude (Mw)
E1	SWPE, SWPW, LAA, CRA	548,765	12.97	7.91
E2	CRA	111,486	11.74	7.16
E3	SWPE, SWPW, LAA	69,262	11.11	6.92

SWP-E: State Water Project East Branch

SWP-W: State Water Project West Branch

LAA: Los Angeles Aqueduct

CRA: Colorado River Aqueduct

To describe the magnitude of the earthquake events in each scenario, we rely on the well-described relationship between the area along the moving fault plane and the magnitude established by Wells & Coppersmith (1994). Using the current industry standard of the Mw scale, the intensity of an earthquake is a function of the length and depth of the fault rupture (area of the moving fault scarp or face). In this report, we utilize GIS mapping to determine the length of relevant fault ruptures for different scenarios of our analysis. Similarly, we utilize quantifications already completed within the UCERF3 dataset to determine the fault depth. Using these values as joint inputs, we rely on the Wells and Coppersmith (1994) method of calculating magnitude. A full explanation of this calculator is available in Appendix A1.

The likelihood of an earthquake event across the San Andreas Fault is useful in our analysis for understanding risk; however, this is difficult to determine precisely. Geologic data suggests that, on average, large events along the fault have a roughly 150-year return period (Jones et al., 2008). This translates to a 0.667% annual probability of a large event across the entire length of the fault. However, this simplified probability belies the complexity of each fault section's characteristics, the influences of neighboring sections and faults, and the time dependence of earthquake activity—that is, sections that have seen less seismic activity recently are more likely to see activity in the future.

In each of the scenarios, the extent to which water supplies will be impacted is dependent on assumptions regarding which aqueducts would be affected and for how long. Existing reports from the SRTF (2016) and Davis (2009) estimate the time to repair each aqueduct given an earthquake event modeled from the ShakeOut report. Given the SRTF's more recent evaluation date, we prioritized using those data in our model construction (Table 2). For the primary analysis of this report, we evaluate and present the E1 scenario, which considers an earthquake event that ruptures all import channels.

TABLE 2

Predicted offset and estimated repair times for the major imported water aqueduct servicing the City of Los Angeles

Water Import Aqueduct	Location of Major San Andreas Fault Intersection	Horizontal Offset (m) (Graves et al., 2011)	Repair Times (months) (SRTF, 2016)	Repair Times (months) (Davis, 2009)
Los Angeles Aqueduct	Elizabeth Tunnel*	2.5	18	7.91
Colorado River Aqueduct	San Gorgonio Pass	3.7	2-6	7.16
State Water Project- East Branch	Several	5.1	12-24	6.92
State Water Project- West Branch	Buena Vista Lakebed	**	6-12	2

* Elizabeth tunnel is a subterranean water conveyance channel owned and operated by LADWP

**Not explicitly assessed in Graves et al. (2011)

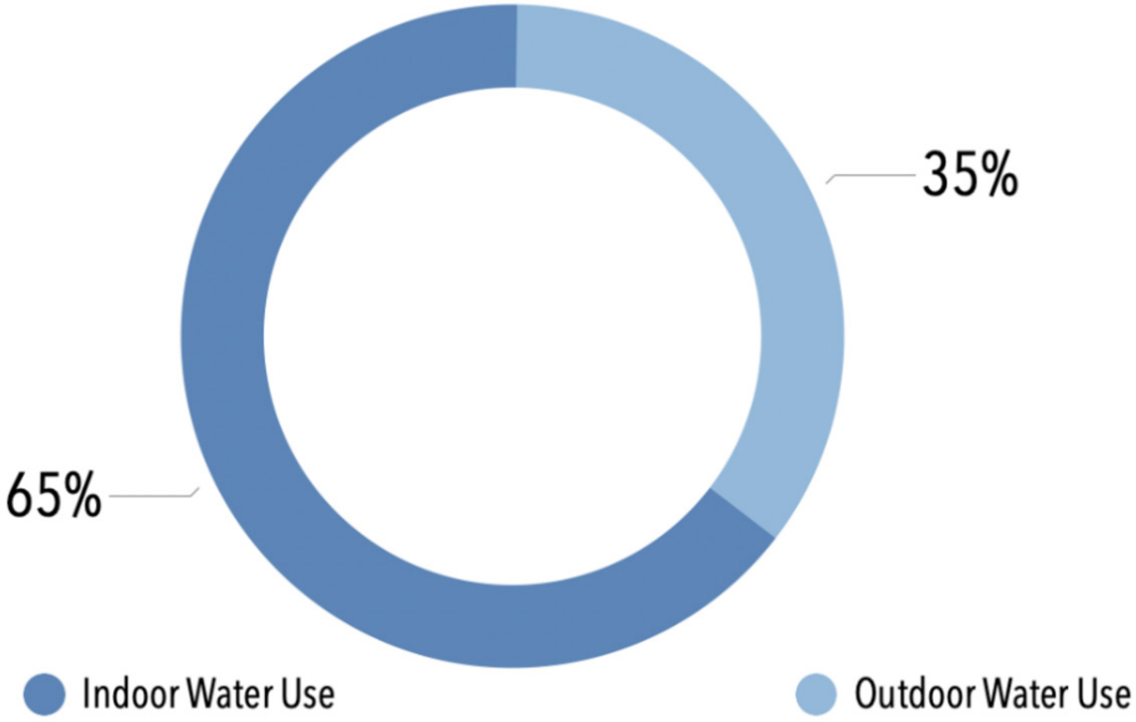
While the width of the aqueduct and its predicted offset are not utilized in the model's quantitative evaluation, the information is shared here to demonstrate the magnitude of the challenge in repair relative to the existing assets. The offset alone does not wholly account for the difficulty in repair because rupture location and geology are also key—consider the disproportionately long repair times of the LAA at the Elizabeth Tunnel due to its distance underground.

The explicit scope of this research project was intended to evaluate the impact of earthquakes to import infrastructure, but stakeholder interviews raised the possibility of significant in-City impacts following such an event. We identified that a >7 Mw earthquake propagating northward from the Salton Sea would likely create ground motion within the City significant enough to damage water distribution networks as well as homes. Hypothetically, with homes damaged and the networks unable to even provide for undamaged homes, we anticipate and apply significant reduction in household demand in the model.

Conversely, as seen in historical earthquake aftermath, we anticipate an increased need for water for fire suppression. The magnitude of each of these conflicting influences on the City's demands is unclear, and without a detailed model it is difficult to discern these further. For this exercise, we take a simplified approach of setting a demand target that the City would aim to achieve. Given the extreme nature of this event, the analysis assumes that the City would aim to meet the essential needs of its population, and we equate this essential use to indoor use (Figure 3). Using this approach, we estimate that the City will attempt to meet 64.8% of its demands in any given year facing hypothetical shortages.

FIGURE 3

The City of Los Angeles's average annual water use distinguishing indoor and outdoor demand (LADWP, 2015), where indoor demand is considered essential for this analysis



2.3. Understanding California's Drought Context

Drought can be broadly defined as below average water resource availability, and it can have differing impacts by region, industry, and end use. While water shortages characterize a drought, infrastructure and legal designations insulate many users from their direct impacts. These differences in classifying drought periods are important particularly for policy and operational decisions and are sometimes seen distinguished into the following categories:

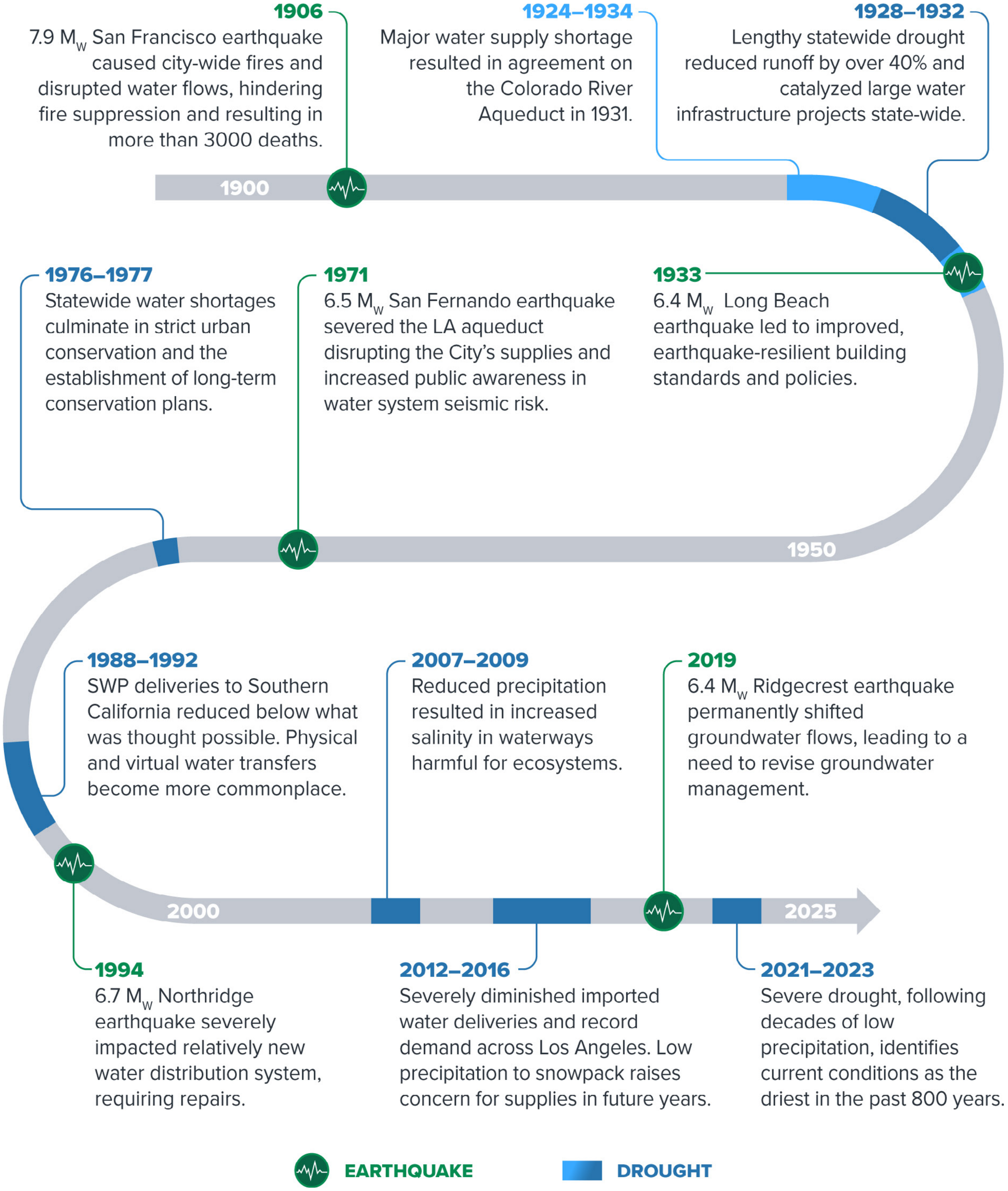
- Meteorological drought, a period of below average precipitation
- Hydrological drought, a period of below average runoff
- Agricultural drought, a period of below average water availability for irrigation
- Socioeconomic drought, a period during which water demand exceeds supply

Due to this analysis's focus on potential variances in surface water supplies, we will henceforth be referencing drought from the hydrologic perspective. To better understand drought classification in California, it is imperative to understand historic droughts in the state and how those shape contemporary water infrastructure. Over the last century, the United States Geological Survey (USGS) reports six major past droughts for California, with each of them varying in intensity and duration. These droughts, their classifications, and their impacts are summarized in Figure 4. The figure lists the statewide average annual runoff during each of the six major droughts, otherwise 71 Million Acre-Feet (MAF) on average, and the corresponding hydrologic consequences and actions.

California's most recent droughts (2011–2016; 2021–2023), have been recognized as some of the most severe on record (Griffin & Anchukaitis, 2014; USGS, 2014; Williams et al., 2022). Water shortages and restrictions have exposed weaknesses in state water management policies and spurred a need for innovations and enhancements in water management at all levels. Although these droughts precipitated steady improvements to the water infrastructure, studies like those of Pagan et al. (2016) suggest that our supply mechanisms could be further improved to meet the growing hydrologic variability expected with California's shifting climate.

FIGURE 4

California's major historic earthquakes and drought periods have shaped modern-day water management



1906
7.9 M_w San Francisco earthquake caused city-wide fires and disrupted water flows, hindering fire suppression and resulting in more than 3000 deaths.

1924–1934
Major water supply shortage resulted in agreement on the Colorado River Aqueduct in 1931.

1928–1932
Lengthy statewide drought reduced runoff by over 40% and catalyzed large water infrastructure projects state-wide.

1933
6.4 M_w Long Beach earthquake led to improved, earthquake-resilient building standards and policies.

1971
6.5 M_w San Fernando earthquake severed the LA aqueduct disrupting the City's supplies and increased public awareness in water system seismic risk.

1976–1977
Statewide water shortages culminate in strict urban conservation and the establishment of long-term conservation plans.

1988–1992
SWP deliveries to Southern California reduced below what was thought possible. Physical and virtual water transfers become more commonplace.

1994
6.7 M_w Northridge earthquake severely impacted relatively new water distribution system, requiring repairs.

2007–2009
Reduced precipitation resulted in increased salinity in waterways harmful for ecosystems.

2012–2016
Severely diminished imported water deliveries and record demand across Los Angeles. Low precipitation to snowpack raises concern for supplies in future years.

2019
6.4 M_w Ridgecrest earthquake permanently shifted groundwater flows, leading to a need to revise groundwater management.

2021–2023
Severe drought, following decades of low precipitation, identifies current conditions as the driest in the past 800 years.

2.4. Operationalizing Drought for Modeling

To determine LAA water supply and SWP deliveries to MWD, statistical models were developed that relate natural flow to water supply. The statistical models were developed using a multiple linear regression, where each independent variable represents total natural flow for a water year. The number of years or independent variables for a given system was optimized based on the number of years of natural flow that provide the best prediction of water supply. To evaluate the statistical model, leave-one-year-out cross-validation was performed, where all years except one were used to train the statistical model, and then the model's prediction of water supply was compared against the observed water supply for the year left out. This was repeated for all years with observed water supply data. The natural flow data used to train the statistical models was obtained based on the hydrologic model's representation of historical streamflow (B. Bass, Goldenson, et al., 2023; B. Bass, Rahimi, et al., 2023). An overview of the process is shown in Figure 5 on the next page.

FIGURE 5

Overview of climate modeling approach

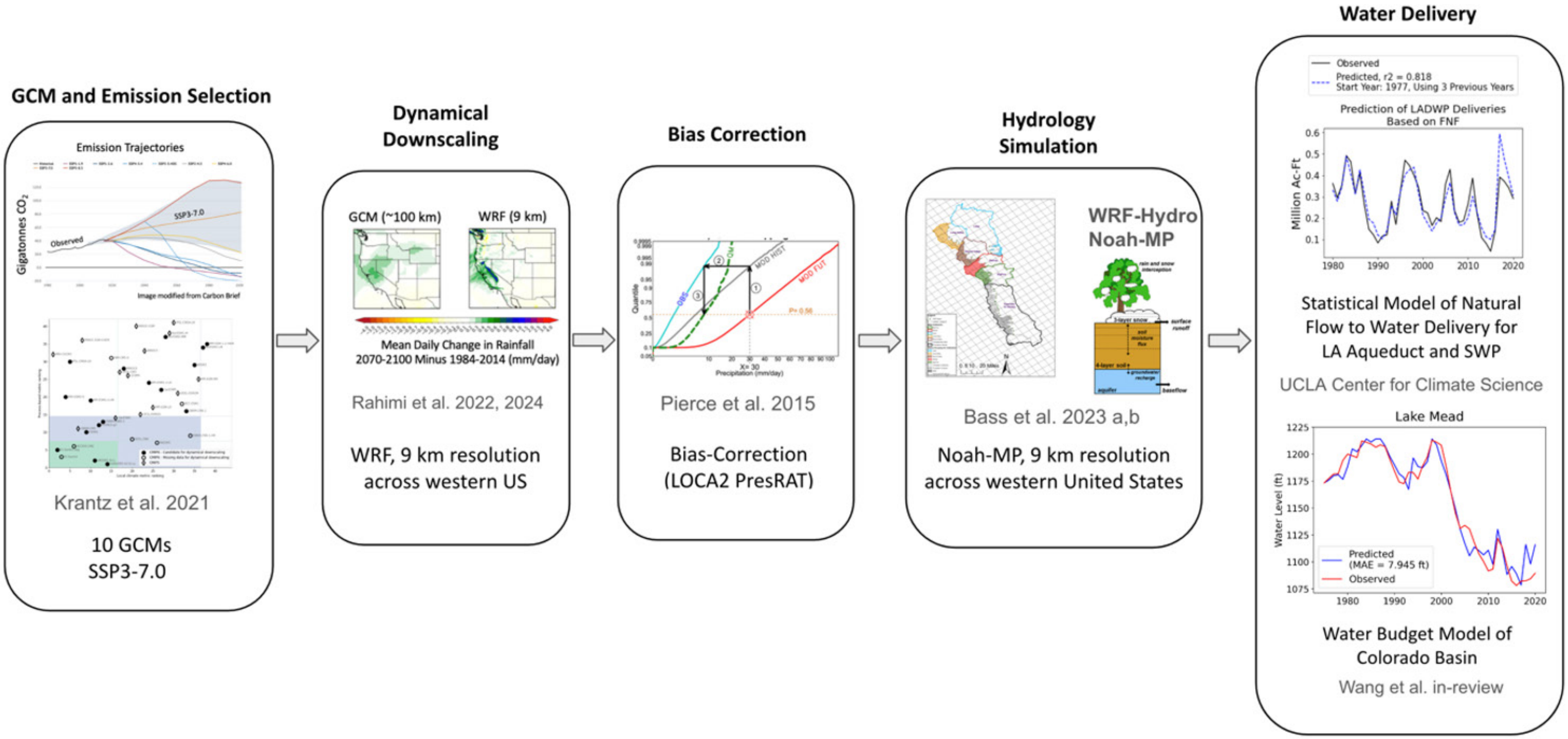


Figure 5 provides an overview of the process used to obtain water supply projections to the Los Angeles region. Natural runoff and subsequent water supply projections were obtained from 1984 to 2099 based on 10 unique CMIP6 Global Climate Models (GCMs) under the SSP3-7.0 scenario. These 10 GCMs were selected primarily based on their ability to accurately represent the hydroclimate of the Western U.S. and on their having the required variables for dynamical downscaling (Krantz et al., 2021). The 10 GCMs were dynamically downscaled using the Weather Research Forecasting (WRF) model (Rahimi et al., 2024) and subsequently bias-corrected using PresRat (D. W. Pierce et al., 2015). Then, the bias-corrected atmospheric data was used as a forcing mechanism for a calibrated hydrology model streamflow (B. Bass, Goldenson, et al., 2023; B. Bass, Rahimi, et al., 2023) to obtain natural flow. Finally, this natural flow was used in water supply models to obtain the water supply from the LAA, SWP, and CRA.

TABLE 3

List of Global Climate Model outputs used as inputs for the climate modeling research component

#	Global Climate Model	Member
1	ACCESS-CM2	r5i1p1f1
2	CanESM5	r1i1p2f1
3	CESM2	r11i1p1f1
4	CNRM-ESM2-1	r1i1p1f2
5	EC-Earth3	r1i1p1f1
6	EC-Earth3-Veg	r1i1p1f1
7	MIROC6	r1i1p1f1
8	MPI-ESM1-2-HR	r7i1p1f1
9	NorESM2-MM	r1i1p1f1
10	TaiESM1	r1i1p1f1

Since we observed an increasing error over the years evaluated for each statistical water supply model for the LAA and SWP, we used historical water supply delivery values that were adjusted to represent existing policy/diversion conditions. Aside from the reduction in error, it is preferable to use delivery data based on existing policy to evaluate how water deliveries may change in the future based on existing policy (as compared to previous policies employed in the historical period). These data were obtained via internal correspondence with LADWP for the LAA and from the State Water Delivery Capability Report from the Department of Water Resources for the SWP (Islam, 2022). Based on leave-one-year-out cross-validation, the final statistical model for each study area demonstrated an accurate representation of water deliveries for the LAA and the SWP, with a coefficient of determination (r2) of 0.818 and 0.815, respectively. The statistical models use four and eight years of natural flow data for the LAA and SWP, respectively, to predict a given year's water supply.

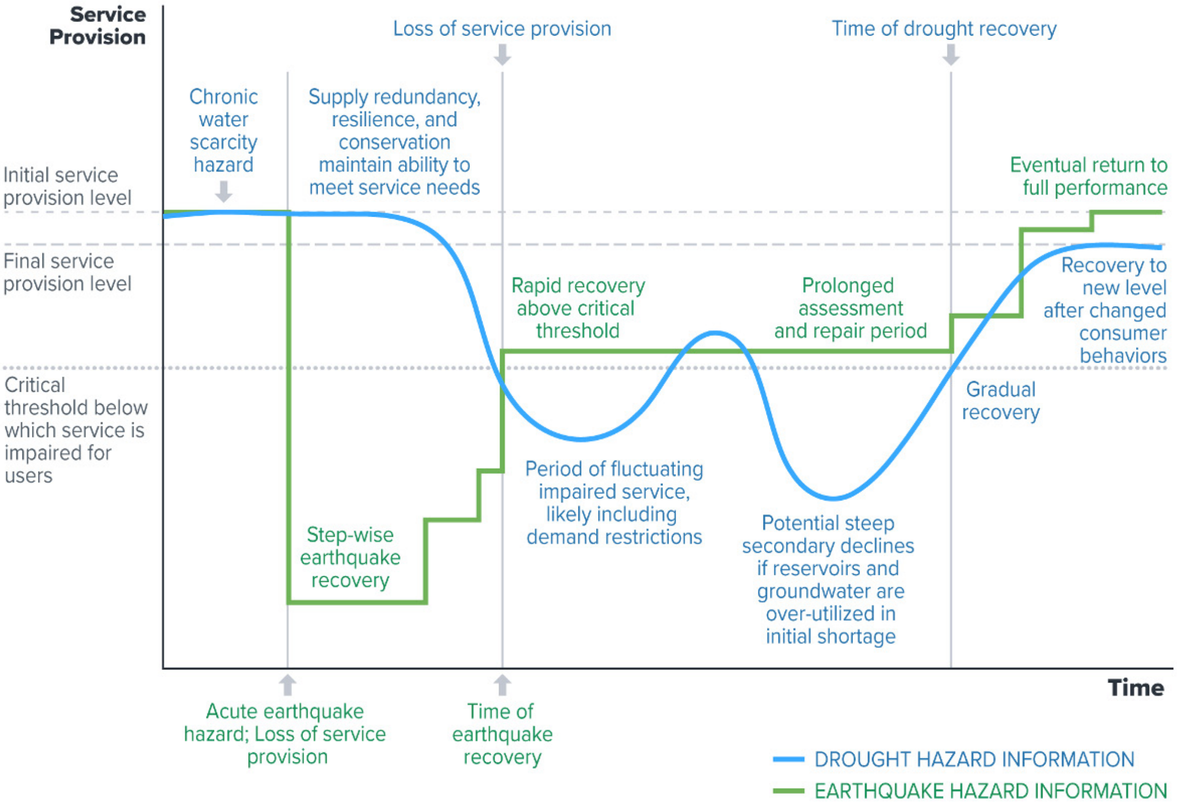
Unlike the LAA and SWP, deliveries from the CRA were determined using a water budget model that calculates the change in storage and thus water levels in lakes Powell and Mead. Water levels in Lake Mead then determine deliveries from the CRA to the MWD based on existing policies in the Colorado Basin (Stern et al., 2022). The main driver of the water budget model is the Upper Colorado River Basin regulated flow, which we represent with an r2 of 0.96 based on its natural flow. Recently, the Colorado Basin experienced its first federally declared water shortage, which was triggered by low water levels in Lake Mead (Stern et al., 2022). This subsequently led to a draft environmental impact statement (EIS) outlining policy recommendations that would modify water deliveries from Lake Mead (USBR, 2023b, 2023a) [2]. As an exercise to understand the implications of such an unprecedented change, we use our water budget model to provide an estimate of the impact of these potential future alternative policies. Similar to how we represent reductions in water deliveries associated with existing policy conditions, we achieve this by reducing downstream deliveries from Lake Mead when specified water levels are reached. Wang et al. (in review) outlines the Colorado Basin water budget model, which evaluates how lakes Powell and Mead respond to future climate conditions under different policies. This paper is currently under review at Nature Communications.

3. DEVELOPING A MODEL TO EVALUATE OPERATION NEXT'S RESILIENCE BENEFITS COMPARED TO COST

The resilience of an infrastructure system reflects its ability to experience shocks and continue operations such that users are minimally impacted. Typically, resilience is considered across three metrics, each of which is difficult to quantify: resistance (robustness), recovery, and adaptation (IPCC, 2012; Lewin et al., 2023; Ouyang & Wang, 2015). Resistance is a system's ability to withstand shocks and realize no or minimal impact to the system's outputs (IPCC, 2012; Poulin & Kane, 2021) (Figure 6). Recovery refers to the ability of the system to return to an acceptable level of operation following hazards and shocks. Lastly, adaptation is the ability of the post-shock system to change its operations to better suit the new equilibrium. Our research team was tasked with understanding how Operation NEXT bolsters resilience to both acute and chronic hazards. This section describes how models were constructed for our evaluation.

FIGURE 6

A guiding framework and conceptualization of infrastructure resilience used in analysis development



Based on the above principles, we first examine how Operation NEXT is anticipated to impact resilience through resistance, recovery, and adaptation. Firstly, the value of Operation NEXT comes as a result of the new, drinking-quality water supplies made available through advanced water treatment. Relative to a future without Operation NEXT, these new supplies make it easier for the City to meet its water demands each year and thus lessen shocks to the system in the face of hazards. Even in years where the City does not face water supply challenges, the water produced by Operation NEXT further enables dynamic water storage and regional partnerships.

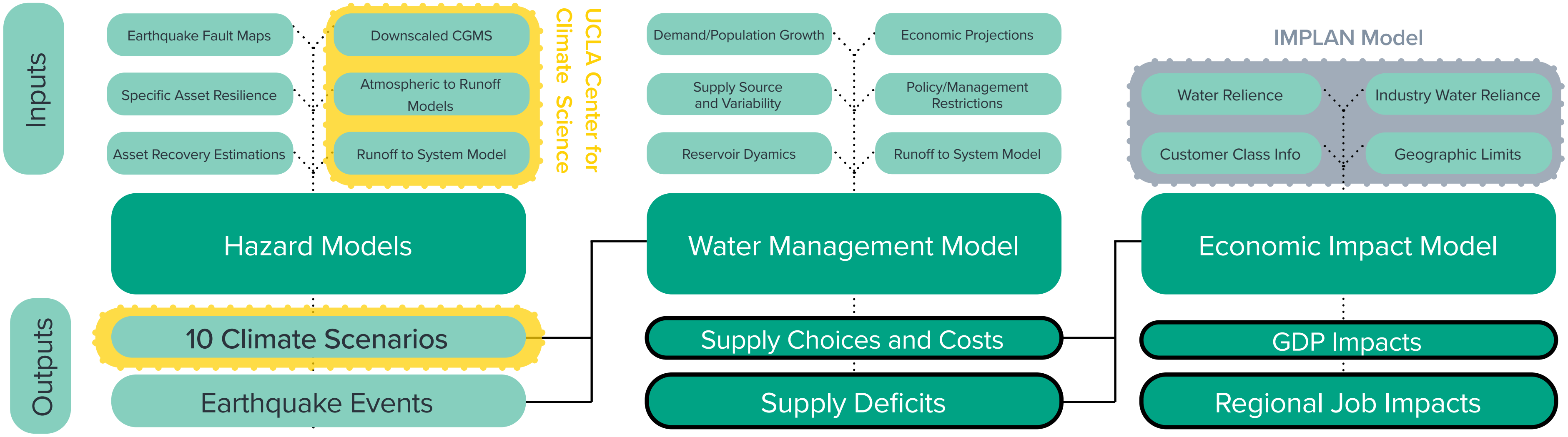
Secondly, Operation NEXT is expected to build resilience value through enhancing recovery by providing an additional local water supply source. Considering how hazards like earthquakes may impact water supplies, having Operation NEXT's supplies available locally to the City promises to help meet demands if the City's other water supply management networks are disrupted. In addition, the City's recovery will likely be aided by Operation NEXT's flows, which may vary less than hydrology and precipitation.

Lastly and perhaps most importantly, Operation NEXT is anticipated to enable greater adaptation by diversifying the City's water supply portfolio. The additional flexibility to draw from different supply sources means that the City's water infrastructure can adjust to accommodate different conditions while still meeting the City's demand. These demands are both physical, reflecting changes in population and consumption, and political, reflecting the City's pLAn targets of achieving 70% local water provision for the City by 2035 (City of Los Angeles, 2015).

For the exercise of identifying the resilience value of Operation NEXT with respect to hazards affecting importing channels, we purposely focus on threats external to the City from 2045–2100. Methodologically, to evaluate the value of Operation NEXT, we consider two future scenarios with and without Operation NEXT present. Overall, we have developed the analysis to quantify value in commonly useful metrics like avoided water shortage, local-imported water division, cost to the City, and regional gross domestic product impacts. To create these common metrics, we examine and compare parallel futures both with and without Operation NEXT, focusing on water supply as well as economic impacts. Broadly, the approach used here separates the tasks of quantifying water and economic impacts across two models, the Avoided Cost (AC) model and the Employment and Economic Impact (EEI) model. Jointly, they form the basis for this analysis and are referred to as the Operation NEXT Resilience Analysis (ORA) model (Figure 7).

FIGURE 7

Overview of the project’s flow, including the climate, resilience, and economic models’ inputs and outputs



The AC model quantifies the mix of water supplies needed to meet demand in future years and estimates a cost of providing that supply. When water supplies are reduced in the face of hypothetical hazards, this model also estimates the extent of hypothetical shortage that results. Outputs from the AC model include overall supply costs faced by LADWP and the volumetric extent of supplies and demands.

The EI model utilizes water shortage and supply cost information from the AC model to evaluate potential industry-specific shortages and the subsequent economic impacts on regional GDP and jobs. Together, these models describe Operation NEXT's potential benefits to LADWP and the regional economy. In the following sections, we describe how each of the models was constructed.

3.1. Avoided Cost Model

The AC model is foundationally a mass balance model that has been adapted to the City's water supply network, decision-making practices, and cost dynamics. Simplistically, the model uses three steps to arrive at its final evaluation outputs: 1) identify hypothetical unmet demands (Figure 8), 2) prioritize supplies and fill hypothetical shortages (Figure 9), and 3) evaluate the total cost of the selected supplies (Figure 10). To complete these steps, the key inputs are the City's demands, supplies, costs, and hazard scenarios.

Realistically, projecting the City's demand is a complex task involving population, housing, industrial projections, and estimates based on regional and local economic policy, but much of this is beyond the scope of our hydro-economic exercise. Instead, to estimate demand, we look to the City's Urban Water Management Plan (UWMP), which projects estimates based on the Southern California Association of Governments (SCAG) population, as well as the City's own conservation targets. This aggregate estimate can vary greatly as droughts produce entrenched changes in population behavior (demand hardening) — as seen in the difference between UWMP 2015 and UWMP 2020 results — or as conservation approaches, targets, and measurement accuracy improve. Currently, the AC model uses UWMP 2020 demand estimates and has the capacity to evaluate three different demand projections that increase, remain steady, or decline.

The supplies considered in the AC model are grouped into 13 categories. Each is prioritized based on a ranking selected by LADWP's engineers. The model works by identifying demanded supplies each year and then assigning supplies based on their ranked prioritization, starting with Rank 1. After all available supplies of Rank 1 are assigned, supplies from Rank 2 are assigned until fully utilized. This process continues until all demands are met, or until supplies are exhausted and the model sees a deficit. Emergency supplies (categories 9-11) are enabled only in years where the AC model identifies hazard conditions (either an earthquake or a drought). Some supplies are anticipated to be used simultaneously and so are assigned the same rank (11); in these cases, supplies are utilized from multiple sources in proportion to their current storage rather than on a ranked or absolute value basis. The final supply considered is a last-resort supply that comes at great cost and low volume: hauled water trucks within the City. Further demands do not have any assigned replacement water supplies. Note that all costs in the AC model are reported in discounted 2020 dollars (year of initial analysis) unless otherwise specified.

TABLE 4

The ranked prioritization of water supplies used in the Avoided Cost model with initial values, as well as the range used in the baseline scenario analysis

Water Supplies Considered by the Model	Rank	Starting Cost Estimate (2020$/AF)	Volumetric Range* (AFY; 2020-2100)		
			Initial	Low**	High**
Conservation	1	$410	133,133	133,133	188,920
Required Groundwater Pumping	2	$574	119,123	119,123	119,123
Required MWD Purchases	3	$1,078	45,000	45,000	45,000
Los Angeles Aqueduct	4	$1,228	249,333	93,462	457,402
Operation NEXT Recycled Water	5	***	-	-	257,636
Groundwater	6	$574	-	-	-
Banked Groundwater	7	$574	-	-	60,000
Metropolitan Water District (MWD) Supplies	8	$755-$1,165	125,684	45,000	308,819
LADWP Local Emergency Supply-Groundwater	9	$574	-	-	-
LADWP Local Emergency Supply-Local Reservoirs	10	$983	-	-	22,583
MWD Emergency Supply-West****	11	$1,165	-	-	75,109
MWD Emergency Supply- Remaining Storage*****	11	$1,165	-	-	122,817
Emergency Backstop Water Supplies	12	$208,146	-	-	2,240

*Range depicting highest and lowest values over time period, though not necessarily 2020 or 2100 values

**Showing values for representative scenarios—climate (media based on available volumes), Operation NEXT (maximum buildout)

***Operation NEXT supply costs include capital and ongoing expenses and are calculated across term instead of per AF

****This designation includes only the major water storage facilities west of the San Andreas Fault: Diamond Valley Lake, Lake Perris, and Castaic Lake

***** This designation includes all availability reported by Metropolitan, excluding the major water storage facilities west of the San Andreas Fault: Diamond Valley Lake, Lake Perris, and Castaic Lake

Even across these categories of prioritized water supplies, further distinctions provide insights into how the City's water supply portfolio might shift before the end of the century. The following graphs represent a range of analysis types among water availability (Phase 1), water utilization (Phase 2), and water costs (Phase 3), all of which have different units. To minimize repetition and aid comparisons of similar graphs, the table below presents a single legend that applies to all graphs.

TABLE 5

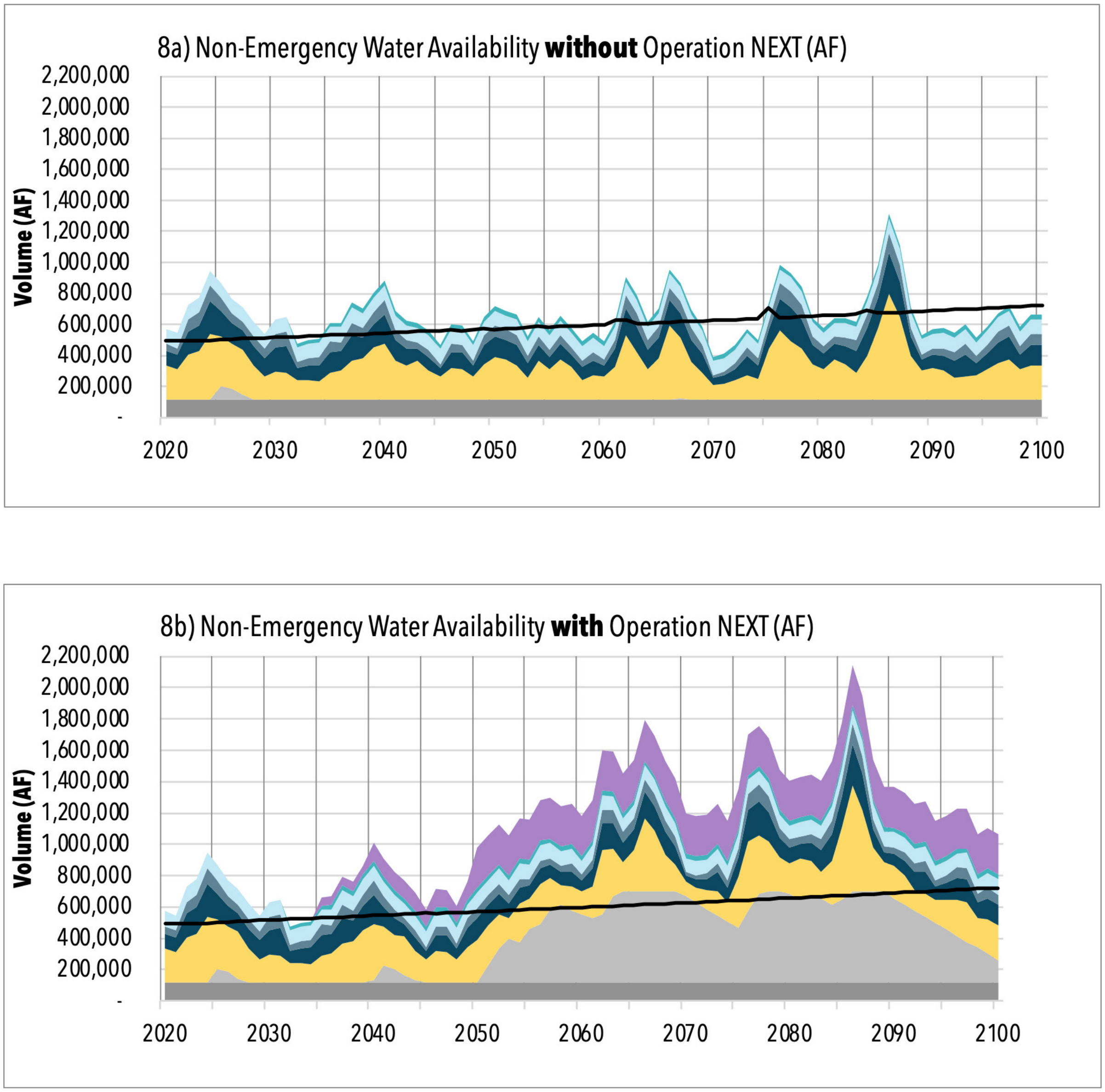
Water supply typologies used in the detailed model outputs displayed in Figures 8, 9, and 10

Water Supply Typologies **Used in the Water Supply Availability Assessment—Phase 1 of the AC Model**			
⬜	City of LA Water Demand (less conservation)	🟪	Operation NEXT Recycled Water Supplies
⬛	Required Groundwater Remediation Pumping	🟦	State Water Project—East Branch
⬛	Routine Groundwater Pumping Supplies	🟦	State Water Project—West Branch
⬜	Banked Groundwater Pumping Supplies	🟦	Colorado River Aqueduct
🟨	Los Angeles Aqueduct Supplies	🟦	Pure Water Southern California Supplies
Additional Water Supply Typologies **Used in the Water Supply Procurement Assessment—Phases 2 of the AC Model**			
⬜	Additional Groundwater Storage Opportunity	⬜	
⬛	LADWP Emergency Groundwater	🟦	Required Purchases from MWD
🟫	LADWP Emergency Local Reservoirs	🟦	MWD Tier 1 Untreated Supplies
🟧	MWD Emergency Supply-West	🟦	MWD Tier 1 Treated Supplies
🟧	MWD Emergency Supply- East	🟩	MWD Tier 2 Untreated Supplies
🟥	Backstop Water Supplies	🟩	MWD Tier 2 Treated Supplies
Additional Water Supply Typologies **Used in the Water Supply Cost Assessment—Phases 3 of the AC Model**			
Total Supply Cost		🟦	Conservation Practices

Below we show how the outputs of the model appear in detailed view both with and without Operation NEXT, in a joint, simplified diagram that is utilized for illustrations throughout the remainder of the report. The results shown here are illustrative for developing an understanding of the methodology, but they represent only one realization of many alternatives. The realization represented here reflects a "baseline" scenario that was selected because it most closely reflects a median water shortage across the future climate projections examined. This realization was selected from the MPI-ESM1-2-HR Global Climate Model (MPI). The results section presents the model outputs for this baseline and further expands on other characteristics of climate futures, as well as a multi-variable sensitivity analysis.

FIGURE 8A&B

Step 1 of the AC model's approach, where it evaluates available water supplies against demand both with and without Operation NEXT under the baseline scenario.



Figures 8a and b show futures without and with Operation NEXT, where water supply availability (colored) and demand (solid black line) are influenced by climate. The main variability in supplies across the model's study period (2020–2100) comes as a result of climate variability. When viewing available water supplies, the model broadly categorizes supplies by source: groundwater (grays), LAA imported water supplies (yellow), purchased imports (blue), and

Operation NEXT recycled water (purple). Figure 8a serves as an illustrative example where natural water supplies might not continuously meet demand (the blank space between supplies marked by different colors and the black demand line) without further water management actions. Figure 8b includes the additional water supplies made available by Operation NEXT beginning with piloting in 2033, followed by full operation in 2050. Importantly, Figure 8b also includes “Banked Groundwater” supplies, which represent stored groundwater that was either unused or stored from previous years’ actions. This supply strategy is greatly enabled by Operation NEXT.

FIGURE 9A&B

Step 2 of the AC model’s approach, where it meets demand with available supplies both with and without Operation NEXT under the baseline scenario.

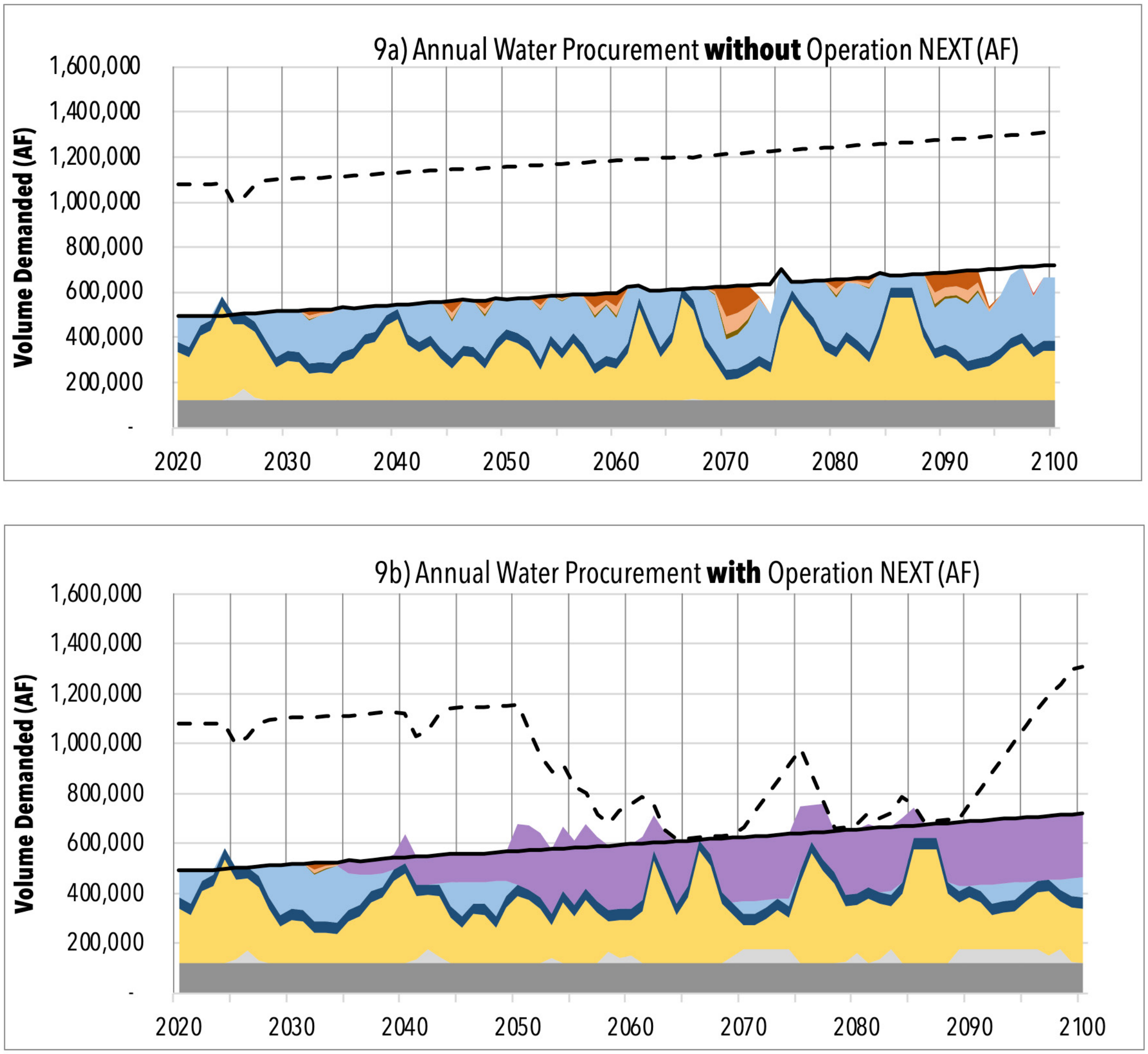
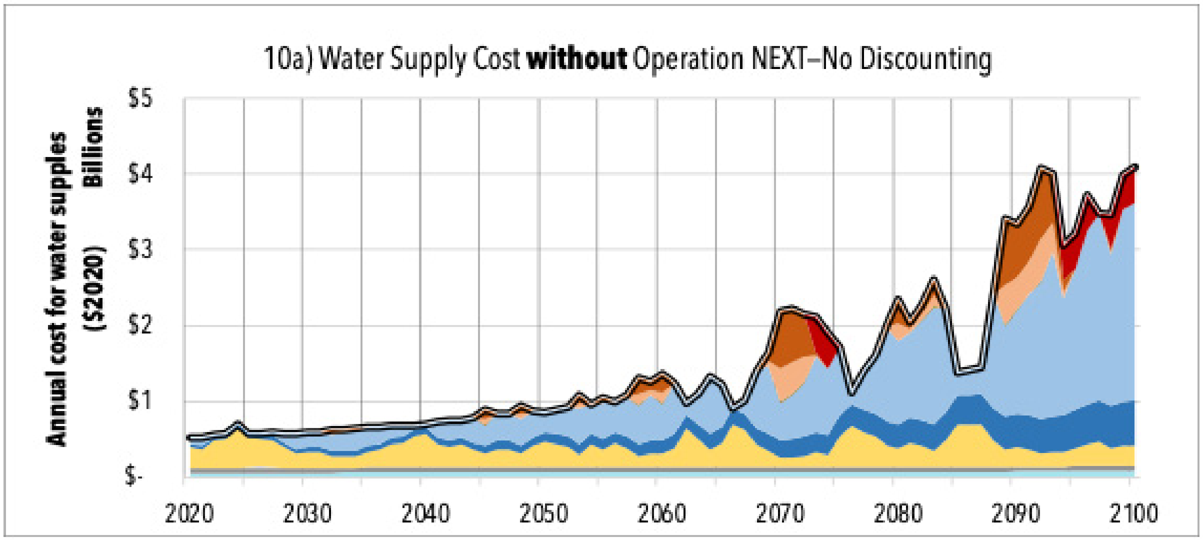
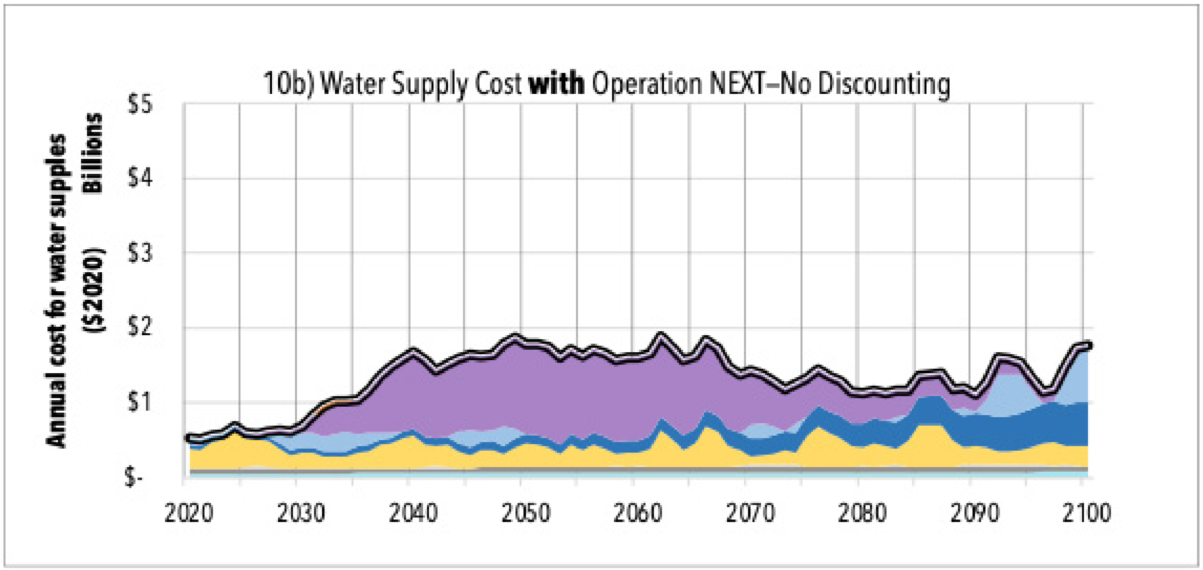


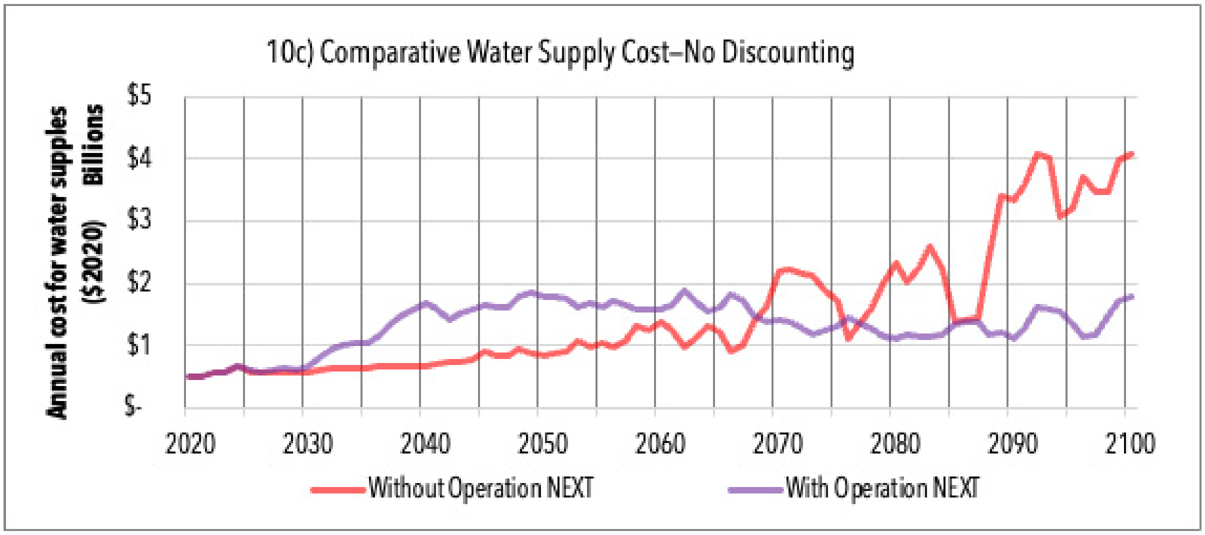
Figure 9a demonstrates Step 2 of the AC model, where shortages are met using the rank prioritization in Table 5. During periods of expected shortage — where typical supply options are available — the model is given access to atypical supplies identified as emergency supplies (browns) and the City's final option of hauled water (red). A notable feature included in Figures 9a and b is the inclusion of the groundwater basin's storage capacity (dashed line), which is seen as a secondary demand to the City's needs and enables the model to produce supplies over demand to be stored as Banked Groundwater for use in later years.

FIGURE 10A,B,&C

Step 3 of the model's approach, where it meets the cost of the selected supplies and evaluates futures both with and without Operation NEXT under the baseline scenario. Figure 10c demonstrates the aggregated costs.







Figures 10a, b, and c demonstrate Step 3 of the AC model, where the costs of each supply are evaluated and compared. The crux of this economic evaluation is the relatively high upfront cost of Operation NEXT when compared to a relatively high later cost in a future without the Operation NEXT facility. The final stage of the AC model compares these costs to determine the net cost for the City across both futures. Importantly, here we show the costs without discounting for ease of visual comparison, but final cost quantifications used in our model include economic discounting, and the model evaluates outcomes at multiple possible discount rates. Figure 10c represents a simplified visual comparison of the data in Figures 10a and b, and this comparative layout is used to show results in later sections.

Broadly, the construction of the model is predicated on over 40 different assumptions, which can be found in greater detail in Appendix A2. Some model assumptions represent the best available data in the academic literature, while others are validated as expert assumptions in the field. Of the assumptions, those that had the greatest variability and likelihood to impact the model's outputs are identified as key variables. These variables and their most reasonable alternatives are described in summary below, with the baseline value of the model identified. The impact of these factors' variability is further assessed in Section 5 of the report, where we undertake a sensitivity analysis.

Population Growth and Water Demand

The U.S. Bureau of Reclamation (USBR) has proposed multiple action alternatives (AAs) for managing the Glen Canyon and Hoover Dams in response to the ongoing water shortages in the Colorado River Basin (USBR, 2023b, 2023a). AA1 prioritizes water reductions based on water rights seniority, while AA2 offers a more equitable distribution of reductions across all users. Initially proposed to take effect in 2024 or 2025, recent discussions have shifted the potential start date to 2025–2026. In light of the complexity and uncertainty regarding which alternative might ultimately be selected, this analysis opts to use a no-reduction scenario—consistent with current policy—as the baseline.

TABLE 6

Summary of alternatives in assessing the City's modeled demand.

Alternatives	Description	Annual Rate of Increase Past 2045
Increasing (baseline)	**Projecting with historic growth**	**0.47%**
Static	Projecting with noted uncertainty	0.00%
Decreasing	Projected following CADOF estimates	-0.53%

Colorado River Water Allocation Policies

The U.S. Bureau of Reclamation (USBR) has proposed multiple action alternatives (AAs) for managing the Glen Canyon and Hoover Dams in response to the ongoing water shortages in the Colorado River Basin (USBR, 2023b, 2023a). AA1 prioritizes water reductions based on water rights seniority, while AA2 offers a more equitable distribution of reductions across all users. Initially proposed to take effect in 2024 or 2025, recent discussions have shifted the potential start date to 2025–2026. In light of the complexity and uncertainty regarding which alternative might ultimately be selected, this analysis opts to use a no-reduction scenario—consistent with current policy—as the baseline.

TABLE 7

Summary of alternatives in assessing potential shifts in CRA policy

Alternatives	Description
Existing Policy (baseline)	**Existing Allocation Policy**
AA1-2024	Seniority-based reductions - 2024 start
AA1-2025	Seniority-based reductions - 2025 start
AA2-2024	Equitable reductions - 2024 start
AA2-2025	Equitable reductions - 2025 start

Rates of Change in MWD Costs

The relative value of Operation NEXT is strongly influenced by the cost of key alternative supplies like those from MWD. MWD rate data was collected from their rate reports from 2003–2020 (MWD, 2015, 2020) and changes in rate were evaluated across each of the tiers and water types: Tier 1 (T1) & 2 (T2), and treated (T) and untreated (UT) waters. To account for inflation over the period of historical data, a scalar was applied from the US Census Bureau enabling the evaluation of the annual change in water supply prices independent of inflation. This work acknowledges that the rate structure of MWD includes complex components, such as capacity charges, that are not modeled here.

TABLE 8

Summary of alternatives for projecting changes in MWD costs.

Alternatives	Description	Annual Rate of Increase
High	Highest rate of increase (T1T)	3.91%
Intermediate (baseline)	**Average across all classes**	**3.19%**
Low	Lowest rate of increase (T2U)	2.45%

Pure Water Southern California

We included MWD's Pure Water Southern California (PWSC) water treatment facility in this analysis due to its comparable scale to Operation NEXT and its projected production of 150 million gallons of advanced treated recycled water per day at peak operations. Although PWSC is not yet built, if pursued, it has the potential to significantly impact regional water availability, demand, and local reliance, which could affect the overall value and attractiveness of the Operation NEXT project. Thus, alternatives considered for PWSC are a scenario at its highest use or the possibility that the project does not proceed.

TABLE 9

Summary of alternatives for considering water availability from PWSC

Alternatives	Description	Annual Water Available (MGD)
Operational (baseline)	**Mixed IPR and DPR (Pilot 2032-2035)**	**150**
Not Operational	No investment in PWSC project	0

Operation NEXT Engineering Buildout

The alternatives for the model's engineering buildout were selected from a range of proposals for Operation NEXT provided by LADWP, each varying in timeline, cost, water supply, treatment methods, piping, and infrastructure needs. Of the 12 alternatives considered, Buildout 8 was chosen as the baseline for its recent development, adaptable water supply approach (mixing IPR and DPR), and intermediate cost.

TABLE 10

Summary of alternative engineering build outs for Operation NEXT

Alternatives	Description	Data Year	Max Annual Yield (AF)	Direct Capital Cost (Billion USD $2020)
Buildout 1	IPR Max Yield	2021	100,814	6.449
Buildout 2	IPR Reduced Yield	2021	61,609	4.641
Buildout 3	DPR Max Yield	2021	243,074	13.527
Buildout 4	DPR Reduced Yield	2021	193,787	11.345
Buildout 5	Hybrid-Regional Approach	2021	243,074	14.995
Buildout 6	Hybrid-Local Approach	2021	243,074	14.284
Buildout 7	IPR+DPR (Sepulveda)	2024	257,636	17.390
Buildout 8 (baseline)	**IPR+DPR (Cahuenga)**	**2024**	**257,636**	**17.077**
Buildout 9	IPR+DPR (Griffith Park)	2024	257,636	17.552
Buildout 10	DPR (Sepulveda)	2024	257,636	20.223
Buildout 11	DPR (Cahuenga)	2024	257,636	20.209
Buildout 12	DPR (Griffith Park)	2024	257,636	20.725

Institutional Discount Rates

For this analysis, we adopt a real social discount rate of 2.5%, consistent with LADWP internal approaches. This discount rate is also in line with recommendations from OMB for projects (Office of Management and Budget, 2023), which suggest between 2.0% and 3.0%, as well as recent recommendations by economists focused on analyzing projects that reduce climate change. Drupp et al. (2018, p. 110) surveyed 200 economists and found that "92 percent of experts report that they would be comfortable with a social discount rate somewhere in the interval of 1 to 3 percent, and over three-quarters find a social discount rate of 2 percent acceptable."

TABLE 11

Summary of alternatives for applying an economic discount rate to costs

Alternatives	Description	Real Annual Discount Rate
High	High-end OMB recommendation	3.00%
Intermediate (baseline)	**Consistent with LADWP approaches**	**2.50%**
Low	Low-end Drupp et al. proposed rate	1.00%

Cost Overruns

Infrastructure overspending is a well-documented issue in megaprojects globally (Flyvbjerg et al., 2004). Although LADWP is best positioned to estimate project costs, there is a reasonable likelihood that actual costs may exceed initial projections. In the absence of historical records or specific data on overspending in City projects, this analysis evaluates a range of potential costs, from current estimates to double those amounts. For the baseline analysis, LADWP's cost projections are considered the most reliable, while higher cost scenarios are incorporated into the sensitivity analysis to account for potential overruns and to ensure robust planning against financial risks typically associated with large infrastructure projects.

TABLE 12

Summary of alternatives in assessing potential shifts in CRA policy

Alternatives	Cost Scalar
High	**200%**
Intermediate (baseline)	150%
Low (baseline)	100%

The alternatives outlined in this report represent the most significant variables anticipated within the model; however, they do not encompass all potential scenarios. Due to the current model's extensive computation times, which exceed 25 hours, a reduction in the number of alternatives was necessary to enhance computational efficiency. For a comprehensive overview of additional variables, assumptions, and alternatives considered in this analysis, refer to Appendix A2.

3.2. Employment and Economic Impact Analysis

An employment and economic impact (EEI) analysis framework is included in our analysis to simulate the distribution of hypothetical water shortage burdens and estimate its effects on the regional economy. In the model, hypothetical water shortage (an output from the avoided cost (AC) model) among commercial and industrial users is distributed across the different types of industries so that the impacts on their respective economic activities can be properly estimated. The estimated penalties are then put into an input-output (I-O) model to capture the ripple effect on the regional economy. The I-O model utilized for this analysis is IMPLAN, an independent economic software tool widely used for economic analyses in the academic, private, and public sectors.

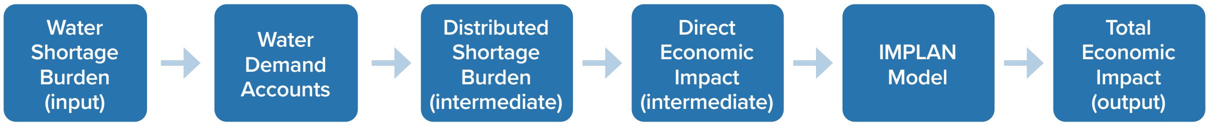
One of the key drawbacks of using IMPLAN at the time of the project's analysis (2020) was its limited geographic flexibility, which enabled economic modeling only at the level of Los Angeles County, as distinct from the City of Los Angeles—the smaller municipal area within the County where the investments in Operation NEXT are being made. The distinction between the two is important because the City's 3.9 million–person population is only a portion of the County's 10.0 million people (USCB, 2020). Despite this limitation, we found that IMPLAN was the best tool available at the time to assess economic impacts and that the results are still representative given that economic shortages and losses are accrued within the City, which is wholly subsumed by the regional geography. Still, this misalignment in geographies is a limitation of joining these analyses spatially, and results of the EEI model are thus always reported as regional economic impacts relative to the local costs faced by the City. For a further discussion on IMPLAN's operations and limitations, see Appendix A3.

The EEI analysis itself is conducted in three phases. The first phase creates a list of accounts to represent the industries in the regional economy of Los Angeles County and estimates their respective water demands. The second phase adopts the results of water shortage from the AC model, distributes the weighted water shortage burden across industry accounts, and translates those shortages into direct economic impacts on the customer account types. The third phase estimates the total economic and employment impacts using IMPLAN, where its outputs describe the indirect and induced economic impacts measured.

For this exercise, direct economic impacts encompass the losses to production and associated jobs in each industry, proportional to the water shortages faced. Indirect economic impacts encompass the effect of construction and supply chain changes on employment, taxes, and wages paid to employees. Lastly, induced impacts encompass the effect of reduced wages on households and how that shifts household purchases and expenses as well as tax receipts. The direct, indirect, and induced measures are reported in GDP and the number of jobs lost or saved. Shifts in household spending in response to increased billing from LADWP were not assessed due to data availability and privacy limitations. An overview of the analysis process is shown in Figure 11 below.

FIGURE 11

Employment and Economic Impact Model Process and Flow of Data



Creating Water Demand Accounts

In any given service area, different types of commercial and industrial water utility customers, for example, manufacturers, farms, households, restaurants, and stores, have different water consumption patterns and water reliance based on their production and consumption activities. We created a table of water demand accounts (see Appendix A3) to represent each type of customer, allowing the total water shortage during a supply disruption to be disaggregated proportionally across customer types to estimate their respective share of the burden.

To prepare for the estimation of total economic impact through IMPLAN in Phase 3, IMPLAN's industry categorization system is used to construct water demand accounts, which simplify and group similar industry types for use in the model. Different industries are assigned to each account to represent the production and consumption activities of its customers. In terms of how accounts are created and what industries are assigned to each account, the approach is adopted from a previous study done for a similar purpose (Rose et al., 2012). "Conversion bridges" provided by IMPLAN are used to convert an older version of industry categorization system used in the previous study to be compatible with the current version of IMPLAN models and datasets.

Distributing Water Shortage and Calculating Direct Economic Impact

To distribute burdens in the model, a set of weights are calculated based on historical water demand data provided by LADWP for 2017–2019. Necessary data cleaning and adjustment steps were performed to ensure data compatibility (see Appendix A3). Historical water demands are aggregated by North American Industry Classification System (NAICS) code and assigned to industries under each account based on IMPLAN "conversion bridges."

Total hypothetical water shortage is presented disaggregated across four major account types: industrial (including agricultural), commercial, residential (including single-family and multi-family households), and government. The water shortage is proportionally disaggregated based on each account type's use relative to the City's total use. For customers under each account, the water shortage burden will have economic consequences, namely, a reduction or "penalty" on their capacity to make and fulfill demands for goods and services contingent on their water dependence. For customers heavily dependent on water, such as the high tech and movie industries, for example, the penalty can be high. For more resourceful customers that are less dependent on utility water, such as parking or real estate sales, the penalty can be more manageable.

To represent water dependence, the concept of a Water Importance Factor (WIF) is adopted from both the aforementioned study (Rose et al., 2012) and the Federal Emergency Management Agency (FEMA, 1991) to serve as a percentage multiplier of a water shortage before it is applied as the penalty. For example, if an account has a 90% WIF and on average consumes 10,000 acre-feet (AF) of water per year, that means water is not substitutable in 90% of its production or consumption activities. If the supply is 40% below demand, each customer represented by that account will face an assumed 40% x 90% = 36% reduction on all of its economic activities or bear the requisite extra costs to procure 3,600 AF from alternative sources.

Note that the WIF is a conceptual nationwide value defined by FEMA that enables a quantified analysis of water shortages in the industry and is very similar to the concept of demand elasticity. It is reasonable to assume that the unique reality of California, including, for example, climate factors and water-thirsty economic crops like almonds and avocados, might generate a relatively higher state-specific WIF, if one existed. This potential discrepancy between a national WIF and a locally relevant WIF leads our work to call for a renewal of the FEMA analysis at the state and county levels. In lieu of this more nuanced and current value, the WIFs used are likely lower than current California WIFs, where conservation and the rising price of water have already pushed users to be judicious in water use and reliance. This means that the results of this analysis are conservatively low when describing the “penalty” on the local economy.

As mentioned in the example above, there are two ways to quantify the direct economic impact of this penalty. For accounts representing industrial, agricultural, and commercial customers, the direct impact is calculated as a percentage reduction of overall regional economic activities, that is, a reduction in both economic output and the number of jobs lost based on the IMPLAN dataset. The overarching assumption is that industrial and commercial customers will not be able to mitigate the impact of utility water shortage via alternative water sources. Considering that the most accessible alternative source of water is bottled water, this is a reasonable assumption because it is unlikely that bottled water can replace utility water en masse for irrigation and manufacturing purposes.

Calculating Total Economic Impact

To calculate total economic impacts, direct impacts related to water shortages are used as an input to the IMPLAN model. The direct impacts would be negative due to the shortage shutting down a portion of the economy’s activities and cutting down on household spending on goods and services. For industrial and commercial customers, portfolios containing the same industries and services (i.e., IMPLAN sectors) are created within IMPLAN models to represent each account. The input for each IMPLAN sector is calculated as the penalty percentage multiplied by the total economic output and jobs of that sector as recorded by the IMPLAN dataset.

For all calculations in the EEI modeling process, the key model parameters are set as follows:

1. Local Purchase Percentage is set to the system default level for all industries. The Local Purchase Percentage accounts for the portion of the economic demand lost to a water shortage penalty that would have otherwise been made and fulfilled locally, generating jobs within Los Angeles County instead of being fulfilled by imports from other parts of the U.S. or the world.

2. Full-Time Equivalent (FTE) job numbers are used as the measure for total employment impact. The job counts in the results of IMPLAN modeling account for both full-time and part-time jobs. To standardize this measure, an FTE converter provided by IMPLAN is used to convert all job counts into FTEs. 1 FTE equals 1 person-year or 2080 working hours.

Selecting the Discount Rate of Future Benefits Streams

In our project analysis, the rate at which future benefits and costs are discounted often determines whether a project passes the benefit-cost test. This is especially true of programs such as Operation NEXT, which have long time horizons. Its benefits may not materialize for 20 to 30 years, but they may last for at least a century and possibly more. However, the very large capital construction costs are borne in the first 15 to 25 years. This timing means that the ability of such projects to pass the benefit-cost test is especially sensitive to the rate at which its future benefits are discounted. The EEI model uses the 2.5% baseline discount rate described in Table 11.

4. QUANTIFIED BENEFITS OF INVESTMENT IN OPERATION NEXT RELATIVE TO COSTS

This section outlines the key output metrics which can be used to describe the value of Operation NEXT and how they will likely impact stakeholders and policy. The key metrics being evaluated are: 1) volumetric water supply benefits, 2) regional economic value, 3) project costs, and 4) reliance on purchased imported water. The report examines each of these key outputs using a "baseline" representative climate future (MPI). The MPI baseline was selected as it most closely reflects a conservatively median water shortage across all future climate projections. At the end of the section, we further present aggregated average values across all climate scenarios as an even more conservative estimate.

4.1. Volumetric Water Supply Benefits

The primary value of Operation NEXT is its local water supply benefit, which safeguards water stability for the City and region and makes supply provision more resilient against hazards like earthquakes and droughts. Figure 12 shows annual water demand (black) as compared to procurement in future scenarios: with Operation NEXT (purple) and without (red). The results show that without Operation NEXT, moderate droughts could impact the City as early as 2062, with at least one severe drought (greater than 100,000 AF) occurring before the end of the century in the 2072-2075 period (Figure 13). The presence of Operation NEXT removes the threat of demand shortages in this climate projection and instead shows that in some years, Operation NEXT produces recycled water greater than the City's demands for storage and later use. In these instances, Operation NEXT enables the model to engage in alternative water supply modes like in-lieu use or greater groundwater storage and remediation.

FIGURE 12

Annual water demand and procurement for the City of Los Angeles in futures both with and without Operation NEXT

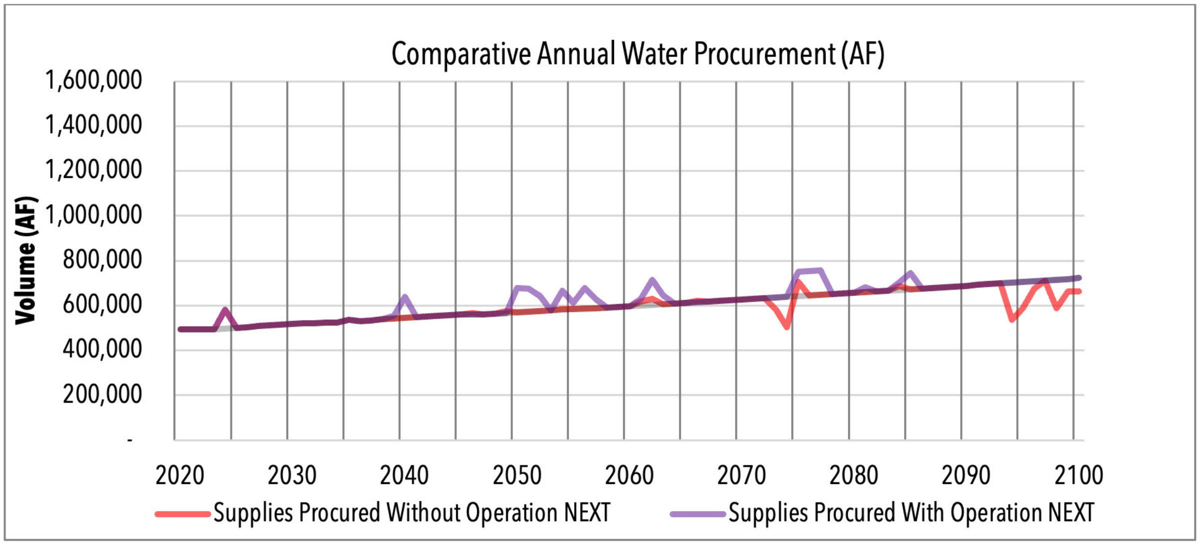
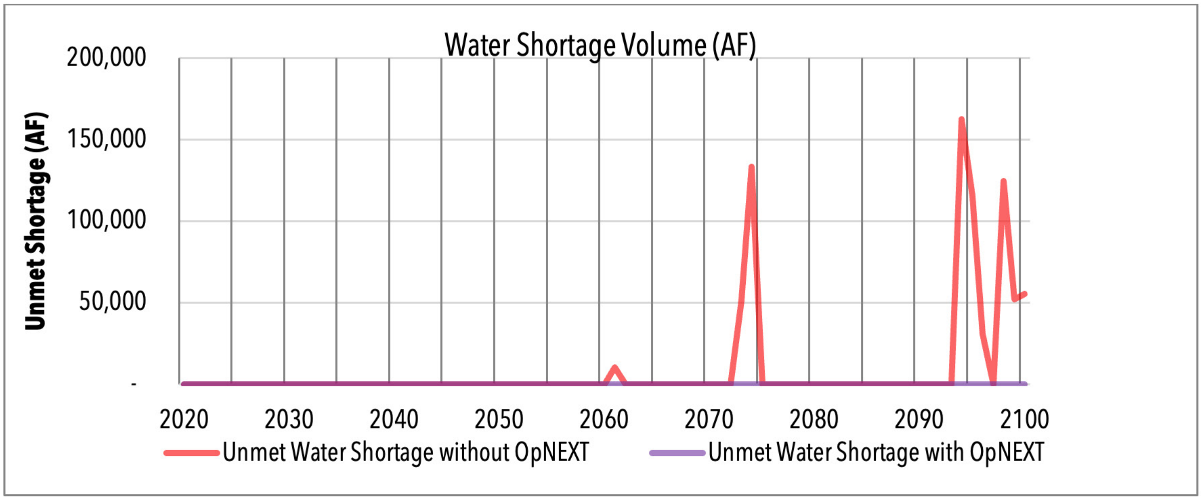


FIGURE 13

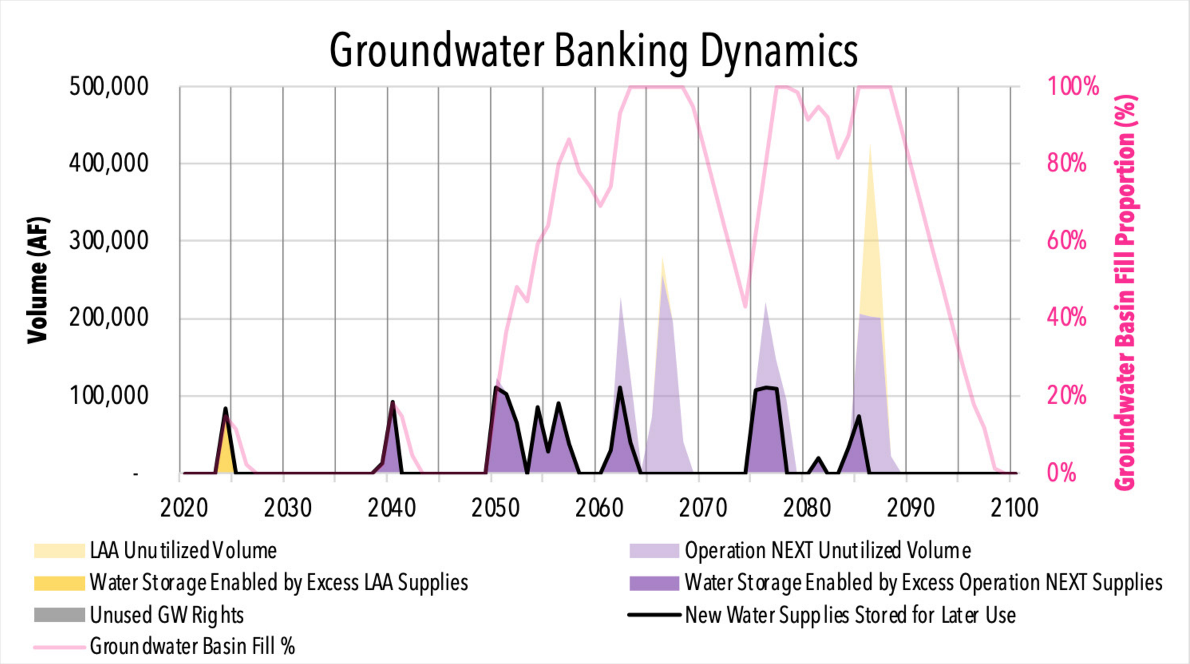
Annual water shortages and procurement for the City of Los Angeles in futures both with and without Operation NEXT



To further understand how Operation NEXT enables more dynamic water supply management systems for the City, we present below Figure 14, which shows the water supply opportunities utilized for new storage and how they relate to groundwater basin utilization in the Upper Los Angeles River Area (ULARA) Basin.

FIGURE 14

City of Los Angeles water banking dynamics including realized and missed groundwater, Operation NEXT, and Los Angeles Aqueduct flows, as well as groundwater basin storage capacity.



The baseline scenario in Figure 14 demonstrates that investing in Operation NEXT would enable more than 1.2 MAF of water supply storage under present-day constraints. It also highlights that there is an even greater, unrealized potential for regional storage and savings in management of both Operation NEXT and the LAA. In some instances, storage capacity of the groundwater basin is the limiting factor; in others, transport capacity limits the value seen in the model. By the end of the century, these unrealized supplies cumulatively represent an additional 1.9 MAF of water, which presents a strong incentive for developing additional water storage, conveyance, and utilization mechanisms, both physical (asset expansion) and through regional coordination (physical and virtual sales or trading)(Guzman & Pierce, 2024).

On net, across this climate future (MPI; 2020–2100), the presence of Operation NEXT avoids up to 680,165 AF of water shortage that may otherwise be faced by the City’s households, industries, and businesses. These model outcomes are most affected by variable climate futures and the potential for unexpected rates of population change.

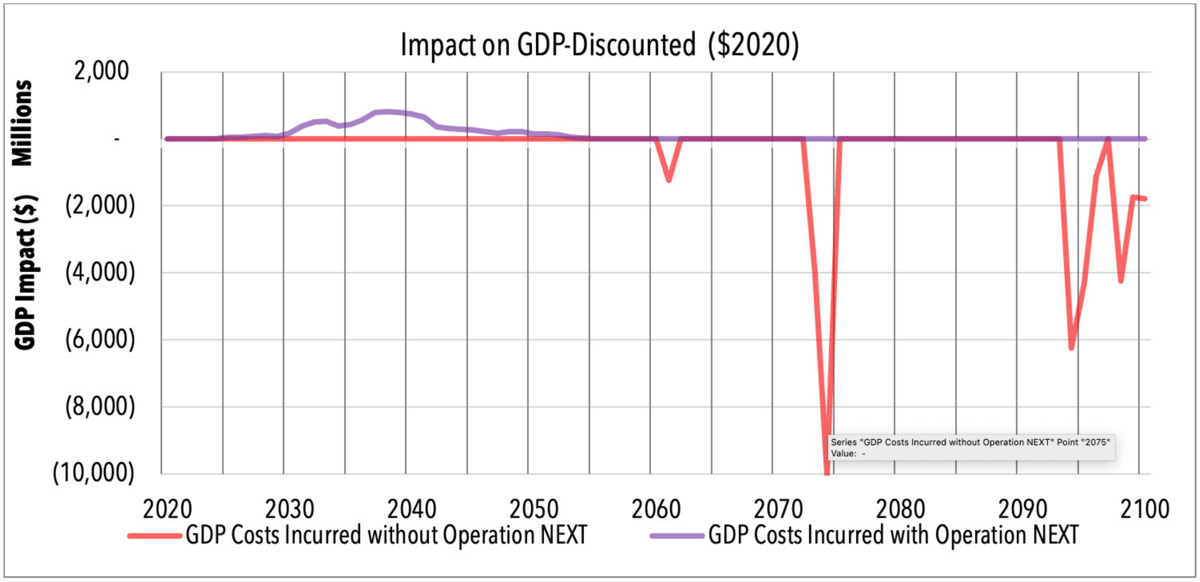
4.2. Regional Economic Value

One of the primary outcomes of investing in Operation NEXT is to provide additional supply resilience to buffer against shocks like climate change and seismic hazards. The economic impact model demonstrates that without Operation NEXT, individual water shortages drive industry slowdowns that cost up to $10.0 billion USD ($2020) in a single year, and $34.7 billion

USD ($2020) by the end of the century (Figure 15). The decision to invest in Operation NEXT, while a cost to the City, has a beneficial impact on the regional economy: 1) early on as capital investments are made to construct treatment, pumping, and conveyance facilities, 2) more significantly, where additional water security enables users to continue to operate unimpeded. Thus, the net regional economic impact of investing in Operation NEXT sits at $44.5 billion USD ($2020). The job-impact component of the analysis directly mirrors the GDP impacts with significant job generation in the project's development phase (2020–2050) of over 17,586 FTE job roles in a single year. This stands in comparison to the peak avoided job losses of over 250,000 FTEs when facing major shortage even in a single year (2074 and 2094 years in Figure 15).

FIGURE 15

Annual gross domestic product impacts to Los Angeles County in futures both with and without Operation NEXT



The engineering build of Operation NEXT determines construction investment and water availability, but because of the relatively large magnitude of GDP losses as a result of water shortages, climate is the most important variable in determining the net GDP implications of investing in Operation NEXT. Secondarily, key economic factors like the evaluation's discount rate play an important role in helping understand the relative value of future spending in today's economy.

4.3. Project Cost to the City of Los Angeles

As part of LADWP's 2021 internal analysis, the direct cost of investing in Operation NEXT was estimated to be between $6.4 and $24.0 billion USD ($2020), depending on which alternative is selected. These alternatives and costs are currently being studied and revised as part of the Operation NEXT Master Plan due out in 2025, but the 2021 analysis provides a range of reasonable estimates for this exercise. Despite knowing the stated costs of the project, the total value of the program is only fairly assessed when considering the water supply benefits that this facility is projected to bring. To accomplish this, the model evaluates the cost of all the water supplies needed to meet the City's demands both with and without Operation NEXT. Figure 16 shows these modeled values between 2020–2100, applying a real discount rate of 2.5%.

FIGURE 16

Annual cost of procuring available water supplies for the City of Los Angeles in futures both with and without Operation NEXT

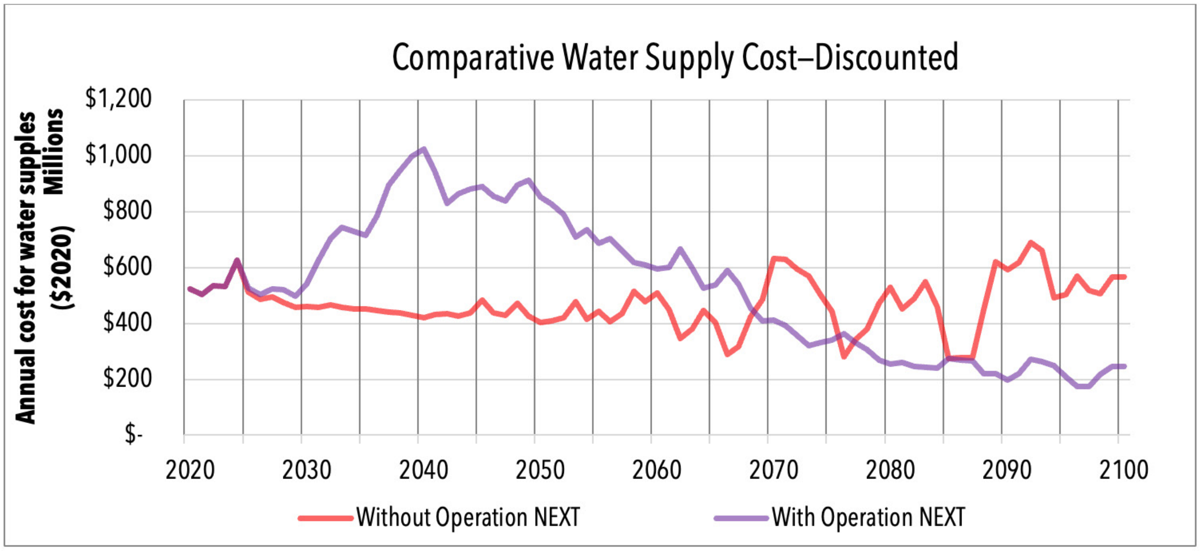


Figure 16 shows how investment in Operation NEXT creates a large upfront cost peaking in the 2040–2045 period, with decreased costs toward the end of the century. Conversely, the future scenario without Operation NEXT avoids the large upfront capital cost investment but sees relatively higher and more variable costs toward the end of the century. To evaluate the relative value of Operation NEXT, we examine the total cost of each alternative and quantify the difference between them (seen visually in Figure16). Under the given conditions of the baseline scenario, water supply until the end of the century will cost $43.2 billion ($2020) with Operation NEXT and $38.0 billion without it, a net difference of $5.2B. This finding would imply that investing in Operation NEXT has a net negative cost, but this does not consider the regional cost of shortages identified in the earlier sections of this chapter. When comparing these, we see that the City faces a net cost of $5.2 billion while bringing regional benefits of more than $44.5 billion, far outstripping the individual cost of the Program to the City.

Though the project's absolute costs are a result of the engineering build, the outcome of this metric is most strongly influenced by the City's discount rate, which is particularly relevant as undiscounted costs (Figure 10c) demonstrate an outsized benefit in investing in Operation NEXT. The discount rate plays a strong role in how costs and returns are perceived over time, with net costs by the end of the century ranging from -$5.2 billion in the most conservative scenario to +$0.9 billion in the most generous but reasonable estimate (a difference of $6.1 billion). This demonstrates that while the model takes a fairly conservative approach (2.5% discount rate resulting in a -$5.2 billion cost), there are feasible scenario estimates which demonstrate that Operation NEXT could provide direct savings to the City independent of the regional GDP benefits. Secondarily, this metric is greatly influenced by external cost changes seen from the regional water supplier, MWD. This is because MWD's supplies comprise a crucial component of the City's supplies later in the century, and even small amounts of supplies can be relatively costly if steady increases were to continue across the 80-year span.

4.4. Water Security Benefits from Increased Local Water Supplies

One of the key political discussions in the realm of Southern California water is the regional use of imports from Northern California and the Colorado River Basin. The presence of Operation NEXT enables the City to develop a new water supply to further diversify the City's local water supply portfolio. Following the language of the City's Green New Deal policies (City of Los Angeles, 2015), this analysis evaluates imported water supplies as those imported from the LAA, SWP, and CRA. Other supplies are considered local supplies and include flows from groundwater and recycled water in Southern California (which includes the MWD PWSC project).

FIGURE 17

Annual reliance on local water supplies (groundwater, Operation NEXT, PWSC) by the City of Los Angeles in futures both with and without Operation NEXT

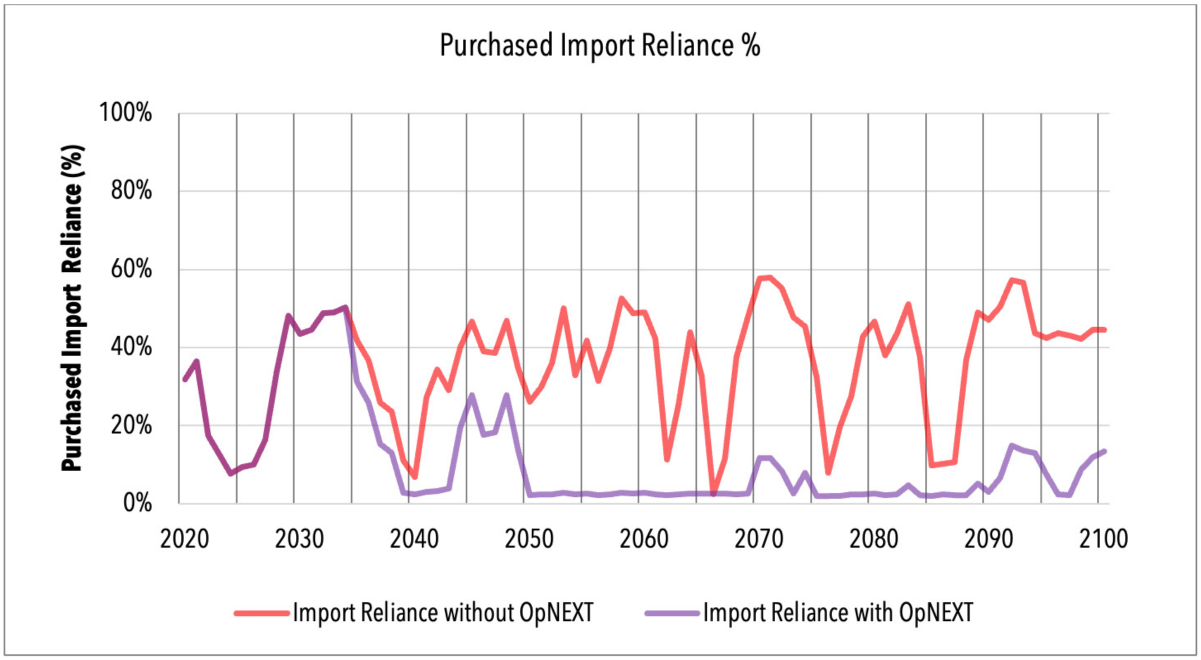


Figure 17 shows a deviation between the futures with and without Operation NEXT following 2035, when Operation NEXT is scheduled to come online in pilot form. Its full effect can be better seen following 2050.

The modeled results of the baseline scenario show that investments in Operation NEXT improve local water reliance by 32.2% on average—from 23.2% to 55.5% after 2050. The analysis demonstrates that investing in Operation NEXT could allow the City to meet its 70% local water reliance goals, but only occasionally (e.g., 2058 at 74%). Despite the likely benefit that this approach will have in insulating the City from external cost variability in imported supplies, it is important to note that even with Operation NEXT, the City occasionally chooses to rely on greater amounts of imports—upwards of 80% in years when LAA water is plentiful (e.g., 2066 and 2086). Unintuitively in the model, this higher import reliance comes during wetter years, when LADWP might choose to utilize imported LAA supplies over local Operation NEXT water production following their prioritization (Table 4). Future shifts in LADWP's Operation NEXT prioritization could further improve the City's consistency in meeting local reliance goals. This output metric is most strongly influenced by the engineering build selected as smaller facilities and different use types greatly reduce the ability of the Operation NEXT to provide large amounts of water locally during droughts.

4.5. Summary of Trade-Offs

In the previous sections, we present a reasonable climate future (MPI) as a baseline for analysis based on expert opinion. For a more robust analysis that accounts for climate uncertainty, we utilize the baseline assumptions and evaluate Operation NEXT across a range of climate scenarios. These include futures that show both need and a lack of need for Operation NEXT. Table 13 presents key metric results for several climate possibilities including: the baseline, the average, and the highest and lowest water need scenarios. Across the 10 climate models used in the model, eight show timely utilization of Operation NEXT supplies, and the remaining two show that Operation NEXT only provides water supply and import reliance benefits, but the supply itself is redundant to existing supplies. The report's final results utilize the baseline assumptions but present information across all 10 climate scenarios as the range for decision-making moving forward. A comparison among the selected scenarios is presented visually in Figure 18.

TABLE 13

Key output metrics for decision-making highlighting the range of possibilities while also providing a reasonable future expectation (baseline) and a conservative future (average across all climate scenarios)

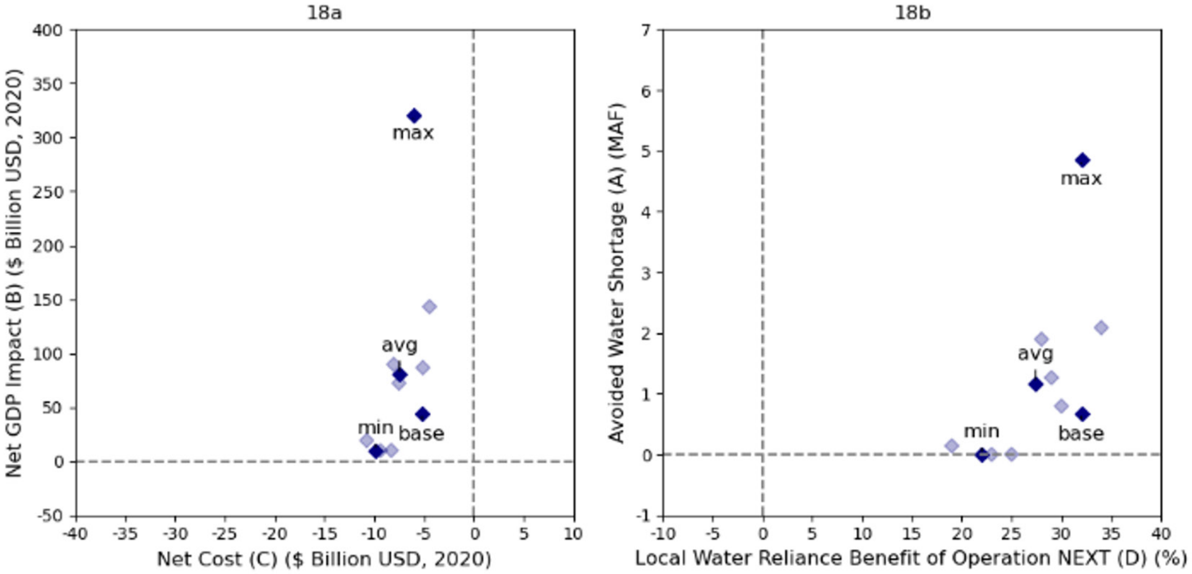
Scenario		Water Shortage Avoided	Net GDP Impact*	Direct Capital Cost (Billion USD $2020)	Local Water Reliance Benefit
		(MAF)	($Billion USD, 2020)	($Billion USD, 2020)	(%)
Metric	Metric Label		B	C	D
Baseline	Base		Net Cost*	Local Water Reliance Benefit	32.22
Mean Average**	Avg	1.17	80.58	7.47	27.48
Greatest Water Need	Max	4.85	320.90	6.08	31.65
Least Water Need	Min	0	9.80	9.86	21.83

*An expansion of net cost calculations is shown in Appendix A4

**Calculated specifically for the average scenario

FIGURE 18

Distribution of analysis results across 10 climate scenarios highlighting the position of the mean average, baseline, greatest, and least water need scenarios holding all other baseline conditions steady



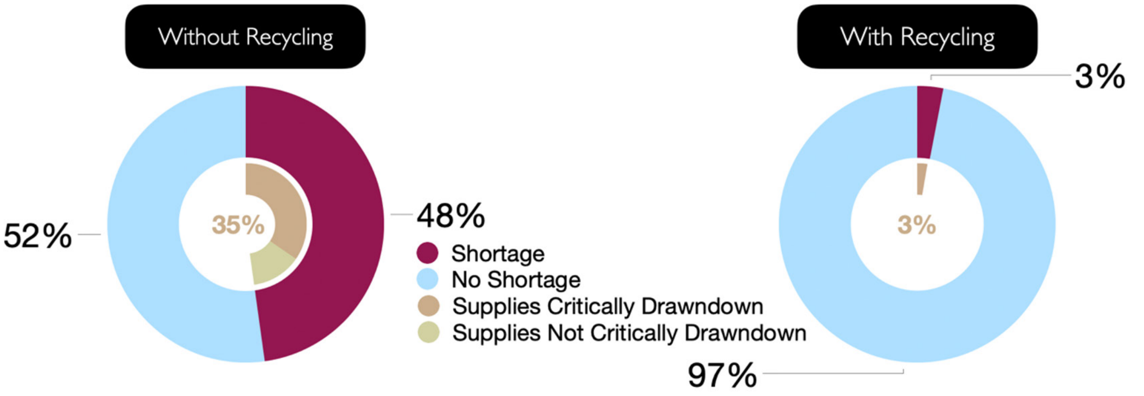
4.6. The Value of Operation NEXT in Facing Earthquake Hazards

The scope of this project was to evaluate the resilience value of Operation NEXT in regard to both climate and earthquake hazards. To robustly capture the value of Operation NEXT while preserving some computational simplicity, the model varies only the climate and earthquake timings input variables while holding the remaining assumptions constant.

Using this approach, the model assesses 6,000 simulated earthquake events between 2050 and 2100 across the range of 10 climate scenarios and 12 engineering builds. The results shown in Figure 19 highlight that Operation NEXT significantly reduced shortages immediately following large-magnitude earthquakes by 44.8% on average—that is, from seeing hypothetical supply impacts 47.8% of the time when Operation NEXT is not built, versus only 3.1% in future scenarios where Operation NEXT is built. This change represents a true reduction of 44.8% but a relative reduction of 93.7%. This finding strongly supports the value of Operation NEXT in building water supply sufficiency and resilience in the face of earthquake hazards.

FIGURE 19

Proportion of water shortages predicted by the model following earthquake hazards



6000 Simulated EQ Events, 2050-2100, 10 Climate Scenario, 12 Engineering Builds, PWSC-IPR&DPR

An additional finding of this analysis is that water shortages faced during and after earthquake hazards are being driven by prior droughts which critically draw down reservoir supplies. To evaluate this, we defined critical drawdown as the volume of absent reservoir supplies which would have otherwise avoided shortages in response to an earthquake hazard. The analysis demonstrates that in most model runs (88.5% with Operation NEXT and 72.3% without) the City only faces shortage after its supplies had already been strained and reservoir levels were critically drawn down. In this way, we identify that while earthquakes are a major concern for the City, their impact hinges greatly on the City's own ability to manage supplies in non-emergency scenarios, particularly to maintain water levels in its reservoirs and groundwater supplies. This analysis demonstrates that Operation NEXT is one way to build resilience to these shortages by creating a new water supply to the west of the San Andreas Fault, as well as enabling greater groundwater storage to be used in the face of such emergencies.

5. SENSITIVITY OF RESULTS

5.1. The Importance of Variability

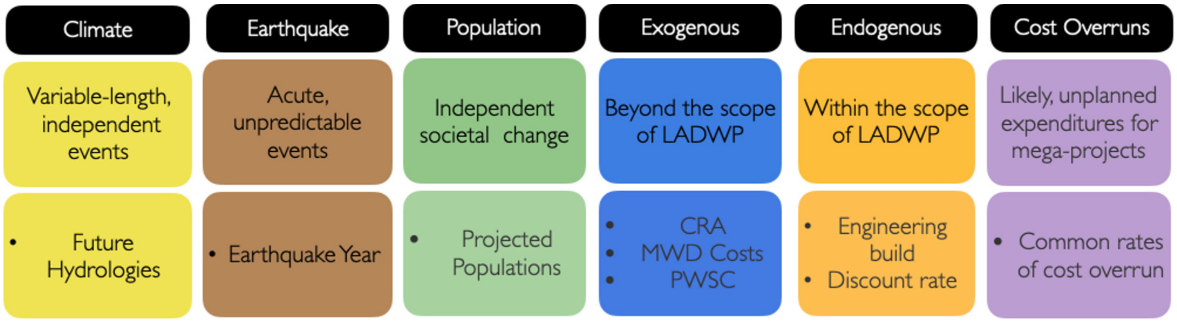
The ORA model is predicated on over 40 individual assumptions that represent physical, political, operational, and natural limitations of the modeled water system. They are categorized into six groups dependent on their locus of responsibility relative to the City and their relevance to the analysis:

1. **Climate**—These assumptions describe the model's use of drought natural hazards which cannot be influenced by the City.
2. **Earthquake Timing**—These assumptions describe when the model applies earthquake hazards which are unpredictable and cannot be influenced by the City.
3. **Population**—The assumptions around population change are based on externally developed projections from agencies like the Southern California Association of Governments and the California Department of Finance.
4. **Exogenous Institutional Factors**—These assumptions describe the external actions of entities beyond the influence of the City and thus represent scenarios that the City may face. Examples of this include changes in the CRA agreement or price changes by MWD.
5. **Endogenous Institutional Factors**—These assumptions describe variables which are within the control of the City and therefore represent a range of relatively controllable courses of action and outcomes. Examples of this include changes in a project's engineering design or economic valuation approach.
6. **Cost Overruns**—These assumptions reflect a challenge commonly seen in infrastructure development: a scenario where there are unexpected project expenditures pushing the cost of the project beyond initial estimates.

This categorization was selected to develop an understanding of which of these factors most strongly influenced the model's results and to provide insights as to how the City might best maximize the utility that is within its control when considering Operation NEXT. While the entirety of the assumptions, their possible values and justificatio=ns, and categorizations can be found in Appendix A2, the baseline analysis of the model identifies nine key variable inputs that strongly influence the model's results. To understand the sensitivity of the model to these inputs, we evaluate and compare their outputs from over 100,000 model runs. Figure 20 provides a summary of the characterization used in our analysis and how the key variables are distributed across each.

FIGURE 20

Conceptual categorization of key input variables dependent on the locus of responsibility in decision-making



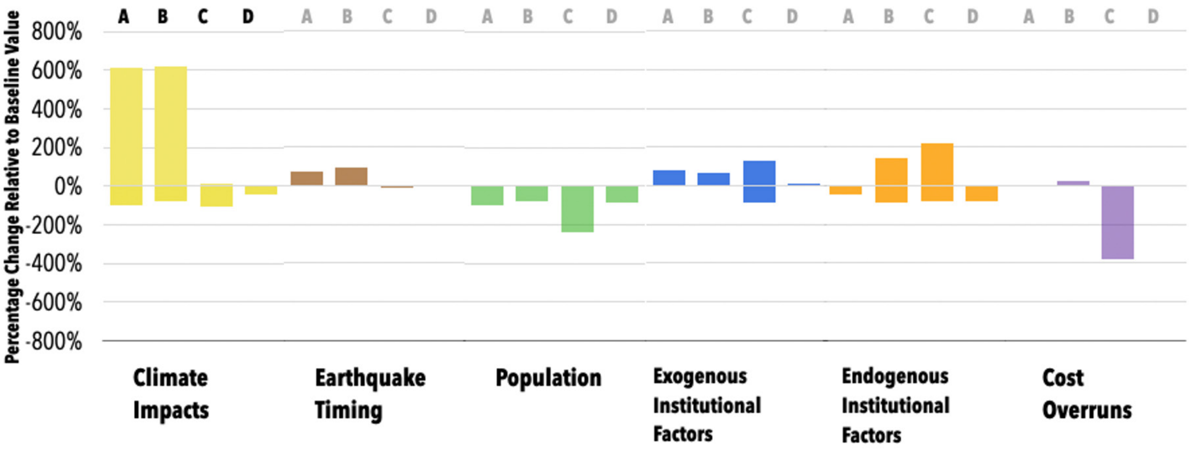
Climate	Earthquake	Population	Exogenous	Endogenous	Cost Overruns
Variable-length, independent events	Acute, unpredictable events	Independent societal change	Beyond the scope of LADWP	Within the scope of LADWP	Likely, unplanned expenditures for mega-projects
• Future Hydrologies	• Earthquake Year	• Projected Populations	• CRA • MWD Costs • PWSC	• Engineering build • Discount rate	• Common rates of cost overrun

5.2. Which Variables Are Most Important for Future Resilience?

Examining the impact of the key input variables on the decision-making metrics helps us understand how our model's sensitivity impacts decision-making. The results show that different key input variables have different impacts on the output metrics. Intuitively, economic input values impact cost outcomes and water supply policies directly influence water availability and shortage. Other variables, such as climate, however, have a more dynamic interaction within the model whereby they affect multiple factors. Intuitively, climate most strongly impacts hydrology and related water shortages, which are directly tied to GDP impacts. However, climate also affects the unit per cost of each facility design by influencing how much of the facility's capacity is utilized. Figure 21 below shows the extent to which each of the key input variables influences the four key output metrics influencing decision-making. A refers to water shortage; B refers to net GDP impacts; C refers to costs to the City; and D refers to the benefit in improving local water reliance.

FIGURE 21

The relative impact of key input variables on key output metrics (A, B, C, D)



The results of this analysis show that climate impacts the output metrics to a much greater extent than other inputs, shifting the results of some metrics by over 600%. These results are not uniform, however, with inputs differently influencing output metrics: water shortage and GDP are most impacted by climate while costs to the City and import reliance benefits are most impacted by potential overruns and engineering decisions. These findings highlight that engineering mega-projects that make decisions without considering climate implications are likely underestimating the range of possible outcomes, making this report critical in evaluating the Operation NEXT Program and other similar projects.

5.3. Building Toward More Accurate Outcomes

To better generate understandings from the model's results, we have combined the data and form of Figure 18 with the variability of Figure 21 to demonstrate the value of interventions to key inputs, especially those within the control of institutions, both endogenous, exogenous, and in reference to cost overruns.

FIGURE 22A&B

The relative impact of key input variables on key output metrics (A, B, C, D)

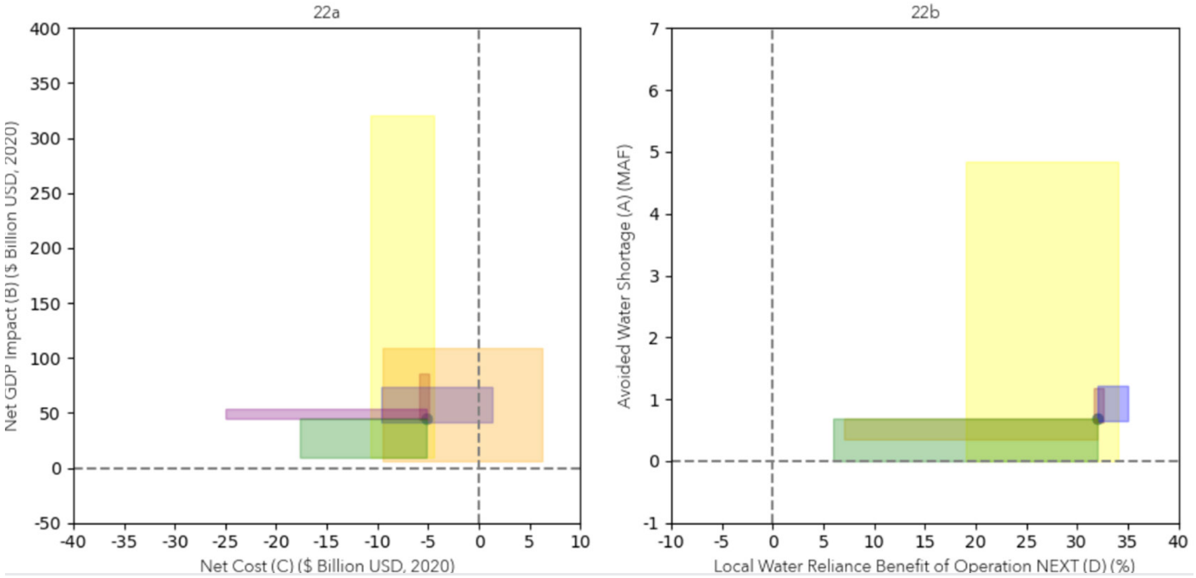


Figure 22a is primarily concerned with economic value and compares how net costs to the City vary alongside regional GDP benefits. The results show that climate hazards play a large role in impacting net GDP benefit but have a comparatively low impact on LADWP's net costs. Conversely, it shows that cost overruns and any decreases in population projections stand to increase the net costs of Operation NEXT more than other variables. Despite potential increased project costs caused by overruns, regional GDP benefits remain proportionally small compared to the cost. Both exogenous and endogenous factors show a relatively wide impact on net costs to the City. Importantly, both have the potential to shift and bring the program's net value fully into the positive cost range, meaning they can generate cost savings as well as help avoid water shortages. While the report's primary analysis demonstrates the appreciable value of Operation NEXT in avoiding earthquake-driven shortages, this sensitivity analysis shows that the timing of a potential earthquake has a relatively small impact across all sets of key output metrics.

Figure 22b is primarily concerned with water-related benefits and compares how much the City utilizes purchased water imports relative to the amount of shortages prevented through investment in Operation NEXT. It demonstrates that climate, once again, has a dominant impact on the possible water-related results. It also shows that exogenous factors like investment in other local water projects or regional water supply agreements can also have an influence on supplies. The input with the greatest potential to impact import reliance is population, whereby alternative futures with smaller populations require less water overall, resulting in underutilization of some of Operation NEXT's potential builds. In this scenario, cost overruns have less of an impact on overall results because they don't impact the volumes of water produced by LADWP or demanded by the City's users.

For the model overall, we note that the baseline scenario is a conservative estimate of the project's economic and water impacts and that the future is likely to be close to this baseline but not exact. This sensitivity analysis demonstrates the extent and directionality of the expected changes based on the most important inputs to the model. Taken together, these plots demonstrate that the impact of climate on key output metrics extends far beyond both endogenous and exogenous factors individually, but no single factor dominates across all dimensions. Recognizing that changes in the endogenous factors of Figure 22a could yield a positive benefit-cost tradeoff for Operation NEXT, the City should closely examine its decisions to capture more of this value. Similarly, though beyond the control of the City, LADWP should closely watch exogenous factors such as rising external costs and regional water supply decisions, including investment in the PWSC plant and the renegotiation of the Colorado River Agreement.

6. CONCLUSION

As California grapples with increasingly erratic precipitation patterns and the looming threat of earthquake hazards, the state's water providers are increasingly seeking new solutions to ensure water supply security through the end of the century. For the City, investment in the Operation NEXT project represents a critical opportunity for water resilience improvement through the provision of a new, reliable recycled water supply stream. The purpose of this analysis is to assess the value that investing in Operation NEXT brings to the City, and we present below a summary of the project's findings alongside its limitations and critical next steps for both the research and regional decision-making.

6.1. ORA Model Findings

This evaluation considers future climate, earthquake risk, water supplies and demands, policies, and economic factors to produce two key sets of results that demonstrate the resilience value of the Operation NEXT project: 1) a baseline scenario analysis that results from a single conservatively wet future climate that lies close to the group's median, and 2) an average of the results of the 10 climate futures assessed. The former provides useful insights on the importance of timing, and the latter provides an output that holistically includes climate futures both wet and dry. Both individually and together, these sets of results agree that investing in Operation NEXT delivers significant economic and water supply benefits across the likely climate futures that Southern California faces. The key findings include:

Economic Benefits

Our analysis highlights that Operation NEXT will contribute positively to the regional GDP by reducing water shortages and stimulating the economy through local development. By mitigating the economic losses induced by water shortages, the project protects against significant GDP losses—estimated to exceed $10 billion USD ($2020) in a severe single-year drought scenario. Moreover, the project's construction phase stimulates job creation, with long-term benefits realized through sustained economic activity enabled by water security. Across the key results, the net regional economic impact of investing in Operation NEXT is projected to be between $44.5 and $80.6 billion USD ($2020), demonstrating a compelling return on investment. These values far outstrip the net costs to the City, which range from $5.2 to $7.5 billion USD respectively. At minimum, we find an almost six-fold return on investment regionally for a sizable investment locally.

Avoided Water Shortages

By investing in Operation NEXT's large-scale local water recycling, the City creates a new, stable water source which can be used effectively to balance water budgets, better utilize existing assets, and be stored as a safeguard for hazard events like earthquakes and droughts. The analysis demonstrates that with Operation NEXT, the City can avoid climate-driven severe water shortages totaling between 680,000 and 1,172,000 acre-feet by the end of the century. In addition to the demonstrated supply benefits, all of the Operation NEXT build alternatives show an opportunity to engage underutilized groundwater storage capacity for the City. Additionally, in the presence of Operation NEXT, the risk of earthquake-driven water shortage falls precipitously from 47.8% to 3.1%, a reduction of 44.8%. This comes as a result of both Operation NEXT's ability to provide water supplies both directly during earthquake events and indirectly by enabling advanced groundwater storage west of the San Andreas Fault, which can be accessed during disruptions to import water channels caused by earthquakes.

Improved Reliance on Local Water

While water imports comprise a valuable component of LADWP's water supply portfolio, the presence of Operation NEXT would enable the City to provide for itself using waters that are more locally sourced while diversifying its portfolio to better balance supply costs. The investment in Operation NEXT has demonstrated the ability to help the City reach 70% local water in individual years, but on average it only raises the City's local water reliance up to 51.0% from 23.5%. This 27.5% increase, though modest in absolute terms, more than doubles the City's local water reliance. Although Operation NEXT represents significant progress toward the City's Green New Deal goal of sourcing 70% of its water locally, it alone cannot fully achieve that target.

6.2. Challenges and Limitations

While the ORA model presents mostly positive key decision-making metrics, it is essential to acknowledge limitations and considerations for both the project itself and in the uncertainty of the modeling process, which are not captured in the analysis.

Challenges in Implementing Operation NEXT

Operation NEXT faces implementation challenges due to its high initial capital cost, a challenging regulatory environment, and limited public acceptance and support.

The high initial capital costs of implementing Operation NEXT come from the necessary miles of new pipe, pumping stations, and coordination among numerous land-owning and infrastructure entities along the way. While the long-term benefits are expected to outweigh these costs, securing adequate funding and distributing that revenue effectively and equitably across customer bills promise to be critical challenges (G. Pierce et al., 2019, 2021).

Direct potable recycling (DPR) water use and its regulations are new, so LADWP faces a challenging regulatory environment as it develops Operation NEXT to its fullest potential. Although the project's teams have already anticipated uncertainty and built adaptability into their plans, LADWP must still navigate a complex and changing regulatory landscape. Facing and maintaining compliance in a strict regulatory environment may delay the timely implementation of recycled water efforts like Operation NEXT and thus reduce its value when compared to the ORA model's results.

Gaining public acceptance and support for potable water recycling has traditionally been challenging in California, but recent studies suggest that this sentiment is changing in the

United States (Barnes et al., 2023; D. A. Bass et al., 2022). Fostering this support is crucial for project success on socially contentious topics like potable water recycling and requires ongoing stakeholder engagement and education, as well as ensuring the reliable safety of operations to keep the trust of customers.

Limitations of the ORA Model Results

While the ORA model aims to simulate real-world conditions as accurately as possible, it is subject to inherent uncertainties and limitations, as is the case with any predictive model. This section outlines the key areas where uncertainty exists, both within the model's design and beyond its scope, and highlights how these factors may influence or alter the model's outcomes.

While the ORA model could evaluate millions of scenarios across the more than 40 assumptions (Appendix A2) utilized, the project identified the eight key input variables—those with the largest likely impact and most uncertainty—and engaged in a sensitivity analysis to address concerns of uncertainty in the presented answers. The results of the analysis suggest two key limitations: the first is that climate most strongly influences the project's results, and the second is that the directionality of change in response to the input variables is diverse. Together, these findings suggest that the reliability of the results could be improved through a more statistically robust sample of climate futures—though computational requirements may be a limiting factor.

Beyond the key assumptions in the sensitivity analysis, there are other variables that we were unable to verify alternatives for, and thus they remained static. These static assumptions include important aspects of water management and policy that are likely to shift over time like: FEMA's Water Importance Factors, the City's groundwater pumping capacity, the rate structure of water supply entities, and how the City's water demand shifts in response to hazards like droughts and earthquakes. Considering how important these variables are, the ORA results could be made more robust if given the data to reasonably operationalize them. The model makes conservative assumptions that undervalue Operation NEXT consistently, so we anticipate that changes in these otherwise static values would result in changes that make the Operation NEXT project more attractive.

The Employment and Economic Impact Model (EEI) had initially endeavored to evaluate how the investment in Operation NEXT might influence household economic practices, but limitations in data availability in customer classes and rate structures within the City pushed this topic beyond the scope of this iteration of the project. In a preliminary analysis with the EEI model, this household spending component demonstrated larger changes to the gross domestic product and job loss metrics than Operation NEXT's operations and maintenance, but even these were dwarfed by the potential impacts of construction and industry losses. While relatively small, the household impact of increasing water bills to finance the cost of Operation NEXT over long periods could influence GDP meaningfully by the end of the century. We anticipate that accounting for this limitation in future iterations of this work would likely negatively impact the economic value presented for Operation NEXT by reducing household spending power and thus dampening economic growth.

6.3. Recommendations

Despite the limitations discussed, the strategic and resilience value of Operation NEXT is clearly demonstrated by ORA's results. Further research is needed to develop a nuanced perspective on whether investing in Operation NEXT specifically should be the City's highest priority given the wider water supply context of Southern California. We conclude by raising recommendations for further study on this topic.

Comparative Evaluations of Water Supply Alternatives

While the ORA model results support investment in Operation NEXT, our study's role was limited to evaluating the resilience value of Operation NEXT specifically and thus does not fully inform whether this is a relatively attractive strategy compared to other local supply options (G. Pierce et al., 2019). In determining how to support strategic water investments in the City's future, it is important to holistically consider this work alongside other alternative water supply strategies that might demonstrate similar benefits, albeit at different costs or on different timelines. Commonly considered alternatives like conservation, leak repair, further groundwater remediation, stormwater capture, and desalination are all at the forefront of water supply engineering discussions in California and deserve full comparison when considering this investment. Optimally, evaluations of these alternatives would take place using comparable metrics to the ORA model and across a similar timescale.

Further Research Supporting Decision-Making

To enhance the value of this analysis of Operation NEXT, as well as other comparable water supply alternatives, further research is essential in a few key areas. Endogenous to LADWP, there is a need for more quantified and transparent data on how the City's demand would respond to disruption by earthquakes temporally and how costs are recovered across customer bills and finance periods for large infrastructure investments. Exogenous to the City, the key areas of needed research involve updating the WIF for California specifically and better understanding MWD's strategic actions regarding their pricing and water supply availability. Some of these needs can be addressed through technical analysis and wider data availability, while others can be supported through convenings and discussions. This recommendation calls for greater investment and support for both approaches. Addressing these areas will provide a more comprehensive understanding of Operation NEXT's broader implications and support informed decision-making for optimal implementation and sustainability.

In summary, to fully unlock the potential of Operation NEXT as highlighted by the ORA model, it is crucial for stakeholders to commit to sustained investment, strategic planning, and adaptive management. Overcoming key challenges such as high initial costs, regulatory complexities, and public acceptance will require broad-based public and policy support. Though the ORA model presents clear economic and water supply benefits, its limitations must be acknowledged. These results, though promising, should be viewed as a foundation for further exploration rather than definitive answers. We strongly urge the City and other water managers to evaluate this research alongside other water supply alternatives to ensure the most informed, most strategic decisions are made. Comparative research is essential to identify the best path forward, and continued study in the areas of greatest uncertainty will strengthen the foundation for future water supply resilience investments in Los Angeles and beyond.

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proposals. These newly proposed policy alternatives will be addressed in an upcoming iteration of this analysis.

[1] Mw, or moment magnitude, is the current United States Geological Survey (USGS) standard measure of an earthquake's size or strength. It is similar to the more commonly known Richter scale as both use a logarithmic incremental increase between whole units.

[2] This research study uses the previously defined policy scenarios (2023a). With the rapidly shifting policy environment, final decisions are uncertain and the most recent changes (2023b) superceed the previous

APPENDICES

A1. Earthquake Magnitude Computation

Equation for Moment Magnitude (Mw) based on Surface Rupture Length (SRL)

(Wells and Coppersmith, 1994):

$$Mw = a + b * \log(L)$$

Where:

- Mw = Moment Magnitude
- L = Fault rupture length (in km)
- a and b = Empirical constants (which vary depending on the fault type)

TABLE A1

The values for a and b depend on the fault type

Fault Type	a	b
All faults combined	5.08	1.16
Strike-Slip	5.16	1.12
Normal	4.86	1.32
Reverse	5.00	1.22

Example Calculation for Scenario E1 (as seen in Table A-1):

$Mw = a + b * \log(L)$

$Mw = 5.16 + 1.12 * \log(548)$

$Mw = 5.16 + 1.12 * \log(548)$

$Mw = 8.22$

A2. Avoided Cost Model Assumptions

TABLE A2

The values for a and b depend on the fault type

#	Key Variable	Notes and Justifications	Typical Value	Range of Values	Units	Classification
1	Climate Scenarios	The UCLA Centre for Climate Science have provided 10 climate realisations for realistic perspective on the future water supply likelihoods. The MPI alternative was selected as the baseline as its water shortages most closely and conservatively matched the median outcomes across all 10 models.	mpi-esm1-2-hr_r7i1p1f1_ssp370	access-cm2_r5i1p1f1_ssp370 canesm5_r1i1p2f1_ssp370 cesm2_r11i1p1f1_ssp370 cnrm-esm2-1_r1i1p1f2_ssp370 ec-earth3_r1i1p1f1_ssp370 ec-earth3-veg_r1i1p1f1_ssp370 miroc6_r1i1p1f1_ssp370 mpi-esm1-2-hr_r7i1p1f1_ssp370 noresm2-mm_r1i1p1f1_ssp370 taiesm1_r1i1p1f1_ssp370	N/A	Climate
2	Earthquake Timing	The model is designed to consider the impact of earthquake hazards which do not have a defined timing or expected realisation. When earthquakes occur is tremendously important to the analysis as coincident timings with droughts or at low reservoir volumes are likely to exacerbate water stresses on the city. To accommodate for this, the model evaluates earthquake timings beyond 2050 after which OpNEXT will be online.	2050-2100	2020-2100	year	Earthquake

3	Demand Reduction in Earthquakes	Estimating precise demand reduction in the extreme earthquake hazard scenario was beyond the scope of this project as it necessitated in-City analysis of demand and assets. Instead, the demand impacts are expected to be so severe such that the City only aims to meet indoor demand. The report recognises that there are numerous complexities in estimating demand reduction after an earthquake (fire suppression needs, broken service delivery pipes, impeded wastewater flows etc.).	35%	Water use (UWMP, 2020): 65% - Indoor 35% - Outdoor 31% - Average by water use type (residential, commercial, industrial, governmental) 0% - No Impact	%	Earthquake
4	Backstop water volume	The volume of emergency backstop water provided by the City of LA can vary, but is likely capped by the carrying capacity of hauling vehicles and the cost of labour. The estimate used here is based on calculations from an internal Emergency Service Office analysis by LADWP which considers water hauling trucks, refilling, and staffing.	2240	2240	AFY	Endogenous Institutional Factor
5	Backstop Provision Rate	In some scenarios, the City might reasonably forgo the provision of the maximum amount of backstop water requested given the significant prices per unit. Currently, the model assumes that all demanded hauled water is provided.	100	0-100	%	Endogenous Institutional Factor
6	Discount rate	The institutional discount rate in net present value calculations determines the value of future costs/money and it strongly affects the economic results across the 2020-2100 timeframe. The City of Los Angeles had been advised to utilise a real discount rate of 2.5% (up to 5.5% if considering a 3% inflation rate), which is the baseline assumption of the model.	2.5	0 - Future monies values equivalently to present day 1.0 - Low estimated discount rate suggested in Drupp, (2018) 2.5 - LADWP advised 3.0 - US Federal Office of Budget Management upper estimate (OMB, 2023)	%	Endogenous Institutional Factor

7	Backstop water cost	The cost of hauled water was developed through an internal estimate by the LADWP Emergency Service Office. The key current assumption for this is that trucks would be manned by paid labour. Alternative costs include those similar to desalination estimates ($3014/AF), hauled water with volunteer truck operations ($94170/AF), or emergency bottled water costs ($309558/AF). The current estimate conservatively assumes that LADWP will bear the cost of providing backstop water.	208146	3014 - Median cost of small project desalination with integration (Cooley and Phurisamban, 2016) 94170 - Volunteer-manned hauled water (LADWP, 2024) 208146 - Manned hauled water (LADWP, 2024) 309558 - Bottled water estimate (LCI internal calculation, 2020)	$/AF	Endogenous Institutional Factor
8	Cost of Conservation	While all costs in the model are assumed and have inherent error, we believe that this cost value is exceptionally prone to revision despite being provided by LADWP. Reasonably, the cost of conservation is difficult to estimate because water savings from conservations efforts may take years to be realised (eg-low-flow taps etc.). This simplified cost estimate taken from the LADWP 2020 UWMP.	410	410	$/AF	Endogenous Institutional Factor
9	Pipe Residuals	Despite the additional value that pipes from the Operation NEXT project might have to LADWP beyond the lifetime of Operation NEXT, measuring their value as a negative cost in the project was not undertaken in the model due to economic complexities. Instead, total capital and operation and maintenance costs were evaluated without pipe residuals.	N/A	N/A	N/A	Endogenous Institutional Factor
10	Spreading Excess Water	The amount of water which can be injected into available groundwater basin space is limited by the rate of water injection or spreading. Max injection in SFB is assumed to be 55,745 AFY. Max injection + spreading is 110,000 AFY.	110000	110,000 (LADWP, 2024)	AFY	Endogenous Institutional Factor

11	Banked Groundwater Pumping Cap	The amount of water which can be extracted from stored water credits has an upper safe limit.	60000	60000	AFY	Endogenous Institutional Factor
12	Groundwater Extraction Pumping Limits	The maximum extractable groundwater is limited by the available treatment capacity. All other groundwater assumptions are expected to fall under this amount unless considering a policy scenario where more capacity is installed.	159272	237250 (LADWP, 2023) 217190 (LADWP, 2024) 259272 (LADWP, 2024)	AFY	Endogenous Institutional Factor
13	Increasing Groundwater Pumping	In futures where LADWP pursued more groundwater pumping by increasing pumping capacity, the amount of stored water can be better utilised to avoid shortage.	0	0.0% - Current planning for increased capacity 0.1% - Low theoretical increased capacity 1.0% - High theoretical increased capacity	% annual increase	Endogenous Institutional Factor
14	Emergency Groundwater Pumping	In extreme cases where the City may have restricted supply access, it may choose to unsustainably extract groundwater up to some additional amount below the GW pumping limit	0	10000 (LADWP ,2020) 80000 (LADWP, 2023) 0 (LADWP, 2024-safe drinking water conservative focus)	AFY	Endogenous Institutional Factor
15	Increasing Groundwater Spreading	In futures where LADWP pursued more groundwater storage by increasing spreading activities, the amount of unutilised water can be instead stored for a later decreasing opportunity for shortage.	0	0.0% - Current planning for increased capacity 0.1% - Low theoretical increased capacity 1.0% - High theoretical increased capacity	% annual increase	Endogenous Institutional Factor
16	Rate of Reservoir Replenishment-LADWP	The model assumes that once LADWP's reservoir supplies have been drawn down that the City would replenish those supplies as soon as supplies become available.	Variable	Variable	AFY	Endogenous Institutional Factor

17	Max Take from LAA	In some climate scenarios, the Owens Valley is able to produce vast amounts of supply to be utilised by the City. Unfortunately, operational and legal limitations suggest that the entire volume cannot be abstracted by the City and so, the needs to be a maximum cap on the water taken from the Owens Valley.	457402	350000 (LADWP, 2023), 364335 (LADWP Historic Max, 2003-2018) 457374 (LADWP, 2024—Water Year Historical Max entire LAA history under current policy limitations) 457402 (LADWP, 2024—Calendar Year Historical Max entire LAA history under current policy limitations)	AFY	Endogenous Institutional Factor
18	OpNEXT Engineering Scenario	The purpose of the model is to evaluate the construction and cost of Operation NEXT, for which there are 12 different buildout scenarios	IPR+DPR (Cahuenga)	IPR Max Yield IPR Reduced Yield DPR Max Yield DPR Reduced Yield Hybrid-Regional Approach Hybrid-Local Approach IPR+DPR (Sepulveda) IPR+DPR (Cahuenga) IPR+DPR (Griffith Park) DPR (Sepulveda) DPR (Cahuenga) DPR (Griffith Park)	N/A	Endogenous Institutional Factor
19	Wastewater Conversion to Advanced Treated Water	The volume of water produced by Operation NEXT is a function of the City's demand to be met, and it is limited the capacity of the facility and the amount of wastewater available. The wastewater to recycled water yield amount is variable.	85	Range of Possible Estimates: 70,75,80,85,90	%	Endogenous Institutional Factor

20	Demand Conversion to Wastewater	How much water is available to be converted to ATW is controlled by wastewater flows, which are proportionally related to water use/demand. The true rate of demand which becomes wastewater is variable dependent on area, type of user, time of year, and whether other actors contribute to wastewater flows. The model simplifies this complex conversion to assume that the proportion of water demanded for indoor use is all converted to wastewater.	65	65	%	Endogenous Institutional Factor
21	LADWP Local Storage	Local LADWP Storage is composed of the reservoirs which are to the west of the San Andreas Fault. While routine operations would draw and refill these reservoirs, during drought or earthquake shortages the model allows for these to be drawn down.	64016	64016	AF	Endogenous Institutional Factor
22	OpNEXT Cost to 2100	While the OpNEXT project is only scheduled to run until 2095, the project's scope and climate data are projected until the end of the century. Knowing that water infrastructure projects routinely operate many years beyond their planned lifecycle the projects costs are slightly extended to represent continued operation until the end of the century.	Extension of 2095 costs	No future costs beyond 2095 Extension of 2095 costs to 2100	N/A	Endogenous Institutional Factor
23	Required Groundwater Pumping	LADWP has committed to pumping 119,123AF of groundwater each year for groundwater remediation purposes. This is in excess of their approximated 112KAFY raw groundwater rights. This value assumes that stormwater and water return credits provide at least the difference. In this circumstance, no banked groundwater credits are accumulated in the model as all groundwater rights waters are assumed to be pumped.	119,123	119,123	AFY	Endogenous Institutional Factor

24	Industry Reliance on Water	The model assumes that each industry has a specific reliance on water as was done using NAICS codes and Rose et al. (2012)	Variable	N/A	%	Exogenous Institutional Factors
25	Groundwater Storage Limits	The groundwater storage limit is based on theoretical groundwater basin storage space with the City of LA and groundwater rollover credit limitations.	577008	554500 (Previous ULARA Watermaster Report estimates, 2016, 2020) 577008 (Andrez Perez, 2024; ULARA Watermaster Report 2021)	AF	Exogenous Institutional Factors
26	Rate of Reservoir Replenishment-MWD	The model assumes that every year unused but available supplies are efficiently stored in reservoirs resulting in dynamic reservoir replenishment approach with shifting climate.	Variable	Variable	AFY	Exogenous Institutional Factors
27	MWD T1/T2 threshold	Metropolitan Water District T1/T2 Allocations are updated decadally, but current assumptions use a fixed volume threshold.	373623	373623	AFY	Exogenous Institutional Factors
28	MWD Tier 2 Limit	It is unclear how much of MWD's water LADWP will have access to beyond the T1 limit. The model assumes a proportional (roughly 18%) volumetric limit in accordance with excess average water available from MWD.	63328	63328	AFY	Exogenous Institutional Factors
29	MWD Cost Increases	As prices in the economy raise, so too do MWD's costs, but they are rarely directly aligned to steady economic escalation. Instead of guessing at a intermittent step-wise, asymmetric increase (between water types and tiers), we assume a steady, real, annual rate of increase based on historic values or as stated in public documentation.	3.19	2.45,3.19,3.91	% annual increase	Exogenous Institutional Factors

30	MWD Max Local Storage	MWD has supplies which are planned to be available during a major earthquake event—notably the volumes in Diamond Valley Lake, Lake Perris, and Castaic Lake. The model assumes that the volumes in each of these are proportionally available to LADWP. (323700-Castaic-https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Southern/Castaic-Dam-Modernization; 131,400-Perris- https://water.ca.gov/Programs/Engineering-And-Construction/Perris-Dam-Remediation)	221544	221544	AF	Exogenous Institutional Factors
31	MWD Max Regional Storage	MWD has listed wider supplies available to customers, but with little information on the supplies specifically, this volume is assumed to be MWD's available water in storage less the MWD Local Storage variable. The model assumes that the volumes in each of these are proportionally available to LADWP.	373864	373864	AF	Exogenous Institutional Factors
32	Proportional MWD Supply to LADWP	The amount of water available to LADWP from MWD is deliberately undefined in the context of emergencies so that actors can reasonable accommodate differential limitations and shortages within their systems. For the model, an assumption had to be made about how much of MWD's water is available to LADWP and this is calculated using the proportion of LADWP's contracted volume relative to all MWD contracted volumes. Using this number, the model proportionally allocates all MWD resource availabilities to LADWP. This is one of the most important variables in the model.	17.512	17.512	%	Exogenous Institutional Factors

33	Required MWD Purchase	Some portions of the City of LA cannot be served by the City's own existing infrastructure and so that water must be purchased from MWD regardless of cost. It is assumed to be treated water.	45000	45000 60000	AFY	Exogenous Institutional Factors
34	CRA Allocation	The Colorado River Compact is currently being renegotiated meaning that actors like MWD will likely have different allocation proportions into the future.	CRA-Stnd	CRA-Stnd AA1-2024 AA1-2025 AA2-2024 AA2-2025	N/A	Exogenous Institutional Factors
35	MWD PWSC Plant Volume	The PWSC plant operated by MWD at JWPCP is scheduled to make new water supplies available to the LA Region through a similar recycled water project to Operation NEXT. This supply is likely to produce some IPR and some DPR water and some portion of that will be available to LADWP.	168021.58	168021.58 20331.37845	AFY	Exogenous Institutional Factors
36	MWD PWSC Supply Costs	The additional cost of constructing a new facility has not been well-defined and thus some assumptions should be made to account for the project costs to LADWP. Unfortunately, without data to support a rate analysis for MWD this project opts to conservatively assume no additional change in MWD's rate structure.	No increase rate over standard scenario	No increase rate over standard scenario Slightly increased, but still within historic bounds	N/A	Exogenous Institutional Factors

37	Wastewater Flow Availability	The flows to Hyperion are in excess of only the flows produced by the City as the Hyperion wastewater network collects from neighbouring entities. This results in more wastewater availability than would be calculated by examining indoor use. Instead, a value from Jacobs 2024 (ONAT model) is used to identify influent wastewater to Hyperion, which can limit/dictate OpNEXT output.	129	129 (Jacobs, 2024)	%	Exogenous Institutional Factors
38	Initial Conditions	As part of a conservation analysis approach, the initial conditions of the model are assumed to be favourable. In particular, this assumption assumes all reservoirs begin each evaluate at maximum capacity.	Variable	Variable		Other
39	Tolerances	Due to limitations in the calculation software, values are rounded in to 0.00001.	0.00001	0.00001	#	Other
40	City of LA Demand	The model's demand is a function of population growth and the conservation approach pursued by the City. The City's projections are based on a confluence of data from the Southern California Association of Governments, the California Department of Finance, and their own conservation analyses. The population and conservation impacts the total demand applied in the model, and thus the total cost of the project—both as conservation costs are applied to every unit of water conserved, and as the remaining demand drives how much of each supply is utilised. The baseline assumption of the model is that population growth and conservation progress as they have been projected to by the City.	2020 UWMP Net Demand Estimates—CONSISTENT Growth past 2045 (0.54%yoy)	CONSISTENT Demand&Conservation Growth past 2045 (0.54%yoy) Demand&Conservation NO Growth past 2045 Demand Growth w/Aggressive Conservation—Technical Maximum Potential Demand Growth w/Moderate Conservation—Maximum Cost-Effective Potential Demand Growth w/Limited Conservation—Passive Program Potential	N/A	Population

41	Demand Reduction in Drought	During periods of extreme water shortage, LADWP anticipates the implementation of drought restrictions which should reduce demand to the City. This variable enables the city to see the effects of extreme conservation while recognising that it gets more and more difficult to conserve water at the same price. The typical value used is 0% year over year conservation during shortages with the expectation that while demand is being reduced, likely heat conditions increase consumptive needs so there is no net change in demand.	0	0 - Net neutral change resulting from decreased conservation demand and simultaneous increase heat demand. 4.887 - DWR water conservation portal estimated average for LADWP's demand reduction 2011-2016.	%	Population

A3. Employment and Economic Impact Model Assumptions

What is IMPLAN?

IMPLAN Pro 3.1 is a software for regional economic impact modeling built around the concept of Social Accounting Matrices (SAM). SAM is a generally accepted framework for economic impact analysis that estimates with reasonable accuracy the total effect of any “shock” to a regionally defined economy, e.g. private investment/divestment, fiscal spending, major disruption, etc. Such effects are measured by changes in the number of jobs, value added (GDP), economic output and tax revenue. Technically, SAM utilizes a collection of input-output tables, or I-O tables, first developed by Nobel Laureate Wassily Leontief specifically for this purpose.

For any industry or a provider of goods and services to fulfill the demand with production outputs, it needs labor and the outputs of their suppliers as inputs, generating further and indirect demand upward the supply chain and in the labor market. SAM maps the interdependent relationship between industry sectors by tracking the flow of money and commodities in all such transactions using secondary data obtained from multiple government agencies including the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA). These data are updated yearly based on the tax returns of all the entities and households in the region. It tracks not only the flows within the region, but also those going into and out of the region to capture trade flows. The model is a virtual representation of the region’s economic reality. In an accounting format, it tells the user for every dollar spent purchasing goods and services from any industry within the region, how many cents are paid to workers for their labor, how many cents are paid to suppliers for their goods and services, how many cents are retained as earnings or taxes, and how many cents go outside the region to import goods and services. In the process, the “ripple effect” of indirect and induced purchases from any direct impact or “shock” is captured and accounted for, giving the user a good idea on the total economic impact.

Since each industry and institution[1] makes demands of almost every other industry and institution while simultaneously producing to fulfill the demand of others, IMPLAN’s I-O tables are essentially N x N matrices showing such supply chain interdependence, or linkages. For each industry or institution, the column tracks the total demand, i.e. outflow of money and inflow of labor and materials, and the row tracks the total production, i.e. outflow of commodities (goods and services) produced and the inflow of money.

Built-in Assumptions and Limitations of IMPLAN

SAM models are a usually a good choice to estimate or forecast economic impacts in the complex environment of a regional economy where the collection of primary data for the same purpose is prohibitively costly. Thus, given the scale and complexity of any regional economy, such as Los Angeles County, and the necessary cost-effectiveness of the tool, SAM models often rely on built-in assumptions to simplify the economic reality they map and present it.

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[1] Institutions are defined within SAM as final demand customers such as residents, government, and exports.

Therefore, there are naturally some inherent limitations associated with these assumptions and simplification that prevent the user from getting a perfect model.

With respect to IMPLAN, such built-in assumptions and limitations are acknowledged as the following:

Static Relationships: The interdependent relationships between industries in IMPLAN are static (i.e., frozen in time), providing a snapshot of the economy in the year captured by the dataset. In this study, the IMPLAN dataset reflects the economy and industrial relationships of Los Angeles County in Year 2018. Therefore, all estimations and extrapolations are based on 2018 data and do not reflect or account for changes in such relationships after 2018, such as COVID-19, which significantly altered the economic reality. Similarly, IMPLAN does not account for price elasticity. The prices of goods and services are not affected by shocks to the economy, e.g. sudden shortage of water supply.

Linearity: The relationships between industries in IMPLAN are linear. This means IMPLAN's estimation of economic outputs and associated employment and GDP benefit follow a constant return to scale rule. For example, a major shock to the economy ten times as large as a minor one will generate exactly ten times of economic impact in all types and measures. However, in reality, things are rarely linear. Since the shortage of utility water analyzed here is a shock significant in both scale and duration, though manual adjustments are made whenever possible and to the extent possible, some degree of deviation from the reality is expected from the results.

Timing of Impacts: IMPLAN does not specify when impacts will actually be realized. However, IMPLAN model results are time-sensitive regarding the change dollar value of the economic shock and its impact due to inflation and commodity price change induced by other causes. Therefore, the lack of account for the timing of impacts is mitigated by the fact that all the water shortage inputs are manually distributed across the years.

Geographic Granularity: IMPLAN does not provide data on the exact location of economic impacts within the defined region. In this study, since we only focus on one county, the negative impact of this limitation should be minimum.

Limited Tracking: There are certain limits to how far IMPLAN tracks the flow of money and commodities once they start circulating in the economy, especially the flow of money. There are certain accounts in IMPLAN's Social Accounting Matrices where once the money flows into, it is considered "lost" to the economy and is no longer used to generate any more economic demands. Such accounts include sales tax, income tax, import, retained earnings, and capital income including stock dividends and interest payments, etc. This is because an IMPLAN dataset as a snapshot in time of the economy captures only one year of economic activities. It does not account for nor makes any assumptions about how corporate earnings, government tax income, and resident savings are spent the next year.

The process of applying IMPLAN in the Employment and Economic Impact (EEI) Model consists of three phases: 1) Creating Water Demand Accounts, 2) Distributing Water Costs, and 3)

Calculating Final Economic Impacts. A summary of each of these steps is provided below.

PHASE 1. Creating Water Demand Accounts

In any given service area, different types of water utility customers, (e.g. manufacturers, farms, households, restaurants, and stores) have different water consumption patterns, i.e. total amount consumed as well as water dependence levels, based on their production and consumption activities. Therefore, a table of water demand accounts (Table A3.1) needs to be created to represent each type of customers so that the total water shortage in the event of a supply disruption can be disaggregated proportionally across customer types to estimate their respective share of the burden.

To prepare for the estimation of total economic impact through IMPLAN in Phase 3, IMPLAN industry categorization system is used to construct water demand accounts. Different industries are assigned to each account to represent the production and consumption activities of its customers. In terms of how accounts are created and what industries are assigned to each account, the approach is adopted from a previous study done for a similar purpose . Simply put, there are 440 to 536 industries including government agencies, plus the residential sector, in a typical IMPLAN model depending on the version of the IMPLAN dataset used. “Conversion bridges” provided by IMPLAN are used to convert an older “440” version of industry categorization system used in the previous study to be compatible with the current “536” version of IMPLAN models and datasets. To build a table of water demand accounts based on IMPLAN is to further aggregate the 536 industries plus institutions into a shorter list of 31 x 31 categories (29 industries plus government and residential users) to accommodate the resolution of the historic water demand data from DWP in terms of customer types.

TABLE A3.1

Water reliance, and IMPLAN conversion bridge data summary

#	Account Type	Abbr.	IMPLAN Sector 440 version	Water Importance Factor	Indoor Water Reliance Percentage
1	aag agriculture - annual crops	aag	1-3; 7-10	70%	98%
2	pag agriculture - perennial crops	pag	4-6	70%	98%
3	oag agriculture - other	oag	11-19	45%	98%
4	mmp metals + minerals processing (incl mining)	mmp	20-30; 153-180	62%	98%
5	ele electric power	ele	31; 428; 431	40%	98%
6	wat water and wastewater utilities	wat	33	40%	98%

7	cns construction	cns	34-40	50%	98%
8	fdc food + drugs + chemicals	fdc	41-73; 115-141	63%	98%
9	lin light industry	lin	74-114; 142-152; 216; 257-275; 295-304; 309-318; 341-344	54%	98%
10	hin heavy industry	hin	181-191; 193-208; 210; 212-215; 217-233; 276-283; 289-294	60%	98%
11	hti high tech industry	hti	192; 209; 211; 234-256; 284-288; 305-308; 345; 350; 352-353	90%	98%
12	wst wholesale trade	wst	319	20%	76%
13	ret retail trade	ret	320-331; 362-364	20%	76%
14	pts profesional + technical services	pts	32; 332-340; 365-390	20%	76%
15	mpv motion picture + video	mpv	346	80%	76%
16	enr entertainment + recreation	enr	347-349; 402-410; 413	80%	76%
17	tco telecommunications	tco	351	30%	76%
18	bfi banking + finance	bfi	354-359	20%	76%

19	res real estate	res	360-361; 411-412; 426	20%	76%
20	scl schools + libraries	scl	391; 393; 438	40%	76%
21	uni colleges + universities	uni	392	40%	76%
22	med medical	med	394-396	40%	76%
23	hsp hospitals	hsp	397	40%	76%
24	nrs nursing homes	nrs	398	40%	76%
25	prs personal + repair services	prs	399-400; 416-422	23%	76%
26	prk parking services	prk	414-415	10%	76%
27	rnp religious activities	rnp	423-425	40%	76%
28	gvt government industry	gvt	427; 429-430; 432-437; 439-440	25%	76%
29	crs community food + housing + relief services	crs	401	40%	76%
	Residential Final Demand	resfinal		40%	56%
	Gov't Final Demand	govfinal		25%	59%

PHASE 2. Distributing Water Cost and Calculating Direct Economic Impact

This study considers two types of water cost:

- Water Shortage Burden: This is the amount of water shortage that still cannot be "covered" after both the supplier and the consumers have expended their means to mitigate like emergency water purchases, water conservation, rationing.
- Capital Investment Amortization: This is the dollar value of the capital cost associated with the construction of the project. This cost is assumed to be amortized across 20 years. This cost is spent on purchasing all the necessary labor, goods, and services to complete the construction of the project and is modeled as an increase in economic demand.

There are four major account types:

- Industrial: mainly manufacturing industries, including agricultural business.
- Commercial: various types of service providers, including government enterprises such as public utilities.
- Residential: single-family and multi-family households.
- Government: public agencies, excluding government enterprises such as public utilities.

The distribution (Dist.) and calculation (Cal.) of direct economic impact of each type of water cost on these account types is summarized in the table below. Note that this iteration of the model results do not include information from residential account due to privacy concerns and data availability around customer class information and the distribution of costs to customer bills.

TABLE A3.2

A summary of the data and calculations utilised in applying the IMPLAN model in this project's analysis.

	Industrial Accounts	Commercial Accounts	Residential Accounts	Government Accounts
Water Shortage Burden	Dist.: DWP Data Weights Cal.: % Penalty	Dist.: DWP Data Weights Cal.: % Penalty		
DWP Emergency Water Cost Recuperation				
Capital Investment Amortization				
Capital Investment Spending	Dist.: N/A Cal.: + Commodity Demand	Dist.: N/A Cal. :+Commodity Demand		

Key Assumption: Complete **price inelasticity** of water demand. The rationale is that water is such an essential and irreplaceable input to production and living activities that the increase of water cost on the utility bill will have negligible effect on the total water demand. Therefore, the direct economic impacts of DWP Emergency Water Cost Recuperation and Capital Investment Amortization are treated as quasi-tax income to local government and thus assumed to only affect corporate retained earnings, generating no impact on production activities to be captured by IMPLAN whatsoever. Thus, no distribution or calculation is needed for these two types of impacts on industrial, commercial, and government accounts.

1. Water Shortage Burden

To properly distribute water shortage across all accounts, a set of weights are calculated based on historical water demand data provided by LADWP for Years 2017 – 2019. The weights of government and residential sector water demand is derived from water shortage inputs from the Avoided Cost Model. In addition, agriculture demand is combined with industrial demand. Necessary data cleaning and adjustment steps are done to ensure data compatibility (Table A3.3). Historical water demands are aggregated by NAICS (North American Industry Classification System) code and assigned to industries under each account based on IMPLAN "conversion bridges". Total water shortage is presented disaggregated across four major account types: industrial (including agricultural), commercial, residential (including single-family and multi-family households), and government. The water shortage under each account type is disaggregated based on the weights of the accounts associated.

For customers under each account, the water shortage burden will have economic consequences, i.e. a reduction or "penalty" on their capacity to make and fulfill demands for goods and services contingent on their water dependence. For customers heavily dependent on water such as farms, for example, the penalty can be potentially devastating. For more resourceful customers that are less dependent on utility water such as restaurants and households, with proper rationing and alternative sources such as bottled water, the penalty can be manageable despite the costliness.

To represent water dependence, the concept of Water Importance Factor is adopted from both the previous study and Federal Emergency Management Agency (FEMA) to serve as a percentage multiplier to water shortage before it is applied as the penalty. For example, if an account has a 90% Water Importance Factor and on average consumes 10,000 acre-feet (AF) of water per year, it means water is not substitutable in 90% of its production or consumption activities. When there is a water shortage and the supply is 40% below demand, all the customers represented by that account will face a 40% × 90% = 36% reduction on all of its economic activities or bear the burden of the extra cost to procure 3,600 AF from alternative sources such as bottled water.

For accounts representing industrial, agricultural, and commercial customers, the direct impact of water shortage penalty is calculated as a percentage reduction of economic activities, i.e. a reduction in both economic output and the number of jobs lost based on IMPLAN dataset. The overarching assumption is that industrial and commercial customers will not be able to sufficiently mitigate the impact of utility water shortage via alternative sources. Considering the most common example of alternative sources is bottled water, this is a reasonable assumption as it is hard to imagine how bottled water can substitute utility water en masse for irrigation and manufacture purposes.

TABLE A3.3

Adjustments to LADWP Customer Class Data for IMPLAN uses

Data Type	Adjustment
Commercial	NAICS 0 entries are WITHOUT NAICS codes. The water demands associated with these entries are distributed proportionally to entries WITH NAICS code under type "Commercial" each year.
Fire Service	All dropped and excluded from weight calculations. Fire service is assumed to bear no impact of water shortage due to its priority in water demand.
DWP Water System	All entries are combined into NAICS Code 221320.
Irrigation	NAICS 0 entries are WITHOUT NAICS codes. The water demands associated with these entries are distributed proportionally to entries WITH NAICS code under type "Irrigation" each year.
Multi-Family	NAICS 0 entries are WITHOUT NAICS codes. The water demands associated with these entries are distributed proportionally to entries WITH NAICS code under type "Multi-Family" each year.
Recycled	NAICS 0 entries are WITHOUT NAICS codes. The water demands associated with these entries are distributed proportionally to entries WITH NAICS code under type "Recycled" each year.
Single- Family	NAICS 0 entries are WITHOUT NAICS codes. The water demands associated with these entries are distributed proportionally to entries WITH NAICS code under type "Single Family" each year.
NAICS Code 92	Accounted for as Government Final Demand. They are excluded from weight calculations under the assumption that water shortage does not bring down the scale of government activities nor does it disrupt the spending pattern of government agencies.

2. Price Adjustment

2020 dollars are used as the baseline to calculate the dollar value of all types of water cost. For future years, two adjustments are applied to each year to compensate for price change: a 2% inflation adjustment based on the annual inflation target of the Federal Reserve and a 2.1% real GDP growth based on the economic forecast of Los Angeles County of Economic Development Corporation (2.6%)[3] minus a 20% penalty due to the impact of COVID-19 according to California Economic Forecast[4].

PHASE 3. Calculating Total Economic Impact

To calculate total economic impacts, direct impacts from the water shortage is used as inputs to IMPLAN models. In the case of this study, the direct impacts are negative due to water shortage shutting down a portion of the economic activities and cutting down on household spending on

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[3] Available at: https://laedc.org/wp-content/uploads/2019/02/LAEDC-2019-Economic-Forecast-Report.pdf

[4] Available at: https://californiaforecast.com/covid-19-economic-analysis/

goods and services. They are modeled in IMPLAN exactly like they would were they positive impacts except for carrying a negative sign before the numbers. For industrial and commercial customers, portfolios containing the exact same industries and services, i.e. IMPLAN sectors, are created within IMPLAN models to represent each account.

The input for each IMPLAN sector is calculated as the penalty percentage multiplied by the total economic output and jobs of that sector as recorded by the IMPLAN dataset.

For all calculations in the modeling process, the key model parameters are set as the following:

1. Local Purchase Percentage is set to system default level for all industries. Local Purchase Percentage accounts for the portion of the economic demand lost to water shortage penalty that would have otherwise been made and fulfilled locally, generating jobs within Los Angeles County instead of being fulfilled by imports from other parts of the U.S. or the World.
2. Full-time Equivalent (FTE) job numbers are used as the measure for total employment impact. The job counts in the results of IMPLAN modeling account for both full-time and part-time jobs. To standardize this measure, a FTE converter provided by IMPLAN is used to convert all job counts into FTEs. 1 FTE = 1 person-year = 2080 working hours = 1 person working for 1 year = 2 people working for half a year each.

A4. Net Cost Quantifications

While we believe that net costs are the most appropriate way to evaluate and display the comparative analysis between futures with and without Operation NEXT, we offer the further expansion of the calculations to promote an understanding of the nuances inherent in providing summary data in the report. Importantly, we hope to communicate the values displayed are net values and not absolute values. In Table A4.1 below, we provide a disaggregated view on costs of future scenarios both with and without Operation NEXT, and the resulting net benefits which are summarily displayed in the full report.

TABLE A4.1

Adjustments to LADWP Customer Class Data for IMPLAN uses

		Cost of Water Procurement 2020-2100		
Metric	**Metric Label**	**With Operation NEXT**	**Without Operation NEXT**	**Net**
Baseline	Base	43,244,390,377	38,028,787,152	5.22
Mean Average	Avg	43,798,370,757	36,326,359,345	7.47
Greatest Water Need	Max	44,266,740,980	38,184,976,062	6.08
Least Water Need	Min	43,731,881,869	33,867,877,422	9.86

The table above shows that the net costs are calculated by comparing the total water procurement costs from 2020 to 2100 in different future scenarios. These net costs appear lower than the direct investment required for Operation NEXT (approximately $17 billion USD in 2020) because they take into account the broader context of water procurement. Interestingly, in most scenarios, the total procurement costs without Operation NEXT are lower than those with the investment. This is largely because, during periods of water shortages, there is simply no water available to procure, which means no procurement costs are incurred. However, this lower cost comparison does not accurately reflect the significant losses the City would experience due to water shortages. This is why the report further examines the economic impacts of these shortages using the Employment and Economic Impact Model.

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