City of Beverly Hills

Public Works Commission
Special Meeting

June 27, 2019
8:00 AM
Public Works Building Room 217

The Public Works Department provides services exceeding expectations to enhance and maintain a high quality of life and attractive physical environment in the Beverly Hills Community.

CITY OF BEVERLY HILLS
Room 217
345 Foothill Road
Beverly Hills, CA 90210

PUBLIC WORKS COMMISSION SPECIAL MEETING

AGENDA

Thursday, June 27, 2019

8:00 AM

I, Sandra Aronberg, M.D., Chairperson of the Public Works Commission, hereby call a Special Meeting of the Public Works Commission at the time and place noted above to discuss the matters listed on the attached agenda.

SPECIAL MEETING AGENDA

1. **Special Meeting Agenda**
   See attached agenda.

2. **Adjournment**

Shana Epstein, Director of Public Works

Posted: Friday, June 21, 2019

Pursuant to the Americans with Disabilities Act, the City of Beverly Hills will make reasonable efforts to accommodate persons with disabilities. If you require special assistance, please call (310) 285-2461 (voice) or (310) 285-6881 (TTY). Providing at least forty-eight (48) hours advance notice will help to ensure availability of services. City Hall, including the Council Chamber and Room 280A, is wheelchair accessible. The City Hall Council Chamber and Room 280A are also equipped with audio equipment for the hearing impaired.

A detailed Public Works Commission packet is available for review in the Library and City Clerk's Office.

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345 Foothill Road
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PUBLIC WORKS COMMISSION SPECIAL MEETING

AGENDA

Thursday, June 27, 2019

8:00 AM

OPEN MEETING

PLEDGE OF ALLEGIANCE

ROLL CALL

COMMUNICATIONS FROM THE AUDIENCE
Members of the public may address the Commission regarding any items on the Agenda that are within the subject matter jurisdiction of the Commission. By State law, the Commission may not discuss or vote on items not on the Agenda.

APPROVAL OF AGENDA
With the concurrence of the Commission, the Chair may choose to amend the order of the items on the agenda.

CONSENT CALENDAR
None.

REPORTS FROM PRIORITY AGENCIES
None.

CONTINUED BUSINESS
None.

This meeting will not be recorded.

NEW BUSINESS

1. Integrated Water Resources Master Plan (IWRMP) Workshop
Comment: Staff recommends that the Public Works Commission participate and provide input during the workshop to prioritize a variety of water resources programs/infrastructure investments.

PROJECT UPDATES & STATUS ITEMS

None.

COMMUNICATIONS FROM THE COMMISSION

COMMUNICATIONS FROM STAFF

ADJOURNMENT

This meeting will not be recorded.

CITY OF BEVERLY HILLS

PUBLIC WORKS DEPARTMENT

MEMORANDUM

TO: Public Works Commission

FROM: Gil Borboa, P. E., Assistant Director of Public Works/Utilities
Vincent Chee P. E., Project Manager

DATE: June 27, 2019

SUBJECT: Integrated Water Resources Master Plan (IWRMP) Workshop

ATTACHMENTS:

1. Hazen & Sawyer (H & S) Technical Memorandum, Integrated Water Resources Mater Plan Workshop

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RECOMMENDATION

Staff recommends that the Public Works Commission participate and provide input during the workshop to prioritize a variety of water programs/infrastructure investments.

DISCUSSION

H & S presented to the Public Works Commission the outline of the IRWMP study at the January 10, 2019 meeting. H & S completed the data collection, is concurrently updating the water, sewer and storm drain hydraulic models, conducting recycled water feasibility analyses and is developing a Capital Improvement Program (CIP) with recommended projects.

H & S is conducting the workshop to facilitate discussion on developing ranking and selection criteria for priorities related to the City's overall water resources including water, sewer and storm drain systems. The priority discussion topics include:

- Local water supply
- Emergency storage
- Demand projections
- Water efficiency
- Addressing aging infrastructure

The expected outcomes for the workshop include the following:

- Establishing a prioritization ranking for each of the priorities
- Establishing criteria to evaluate project implementation feasibility
- Answer questions related to each priority that will dictate project implementation

NEXT STEPS

The outcomes established in the workshop will be incorporated into the development of the IWRMP. Future reporting to the Public Works Commission regarding progress on the development of the IWRMP will be on quarterly basis.

ATTACHMENT 1

Hazen *Technical Memorandum*

June 20, 2019

To: Public Works Commission of the City of Beverly Hills

From: Cindy Miller, Project Manager for Integrated Water Resources Master Plan

cc: Shana Epstein, Director of Public Works
Gil Borboa, Assistant Director of Public Works
Vince Damasse, Water Resources Manager
Vincent Chee, Project Manager

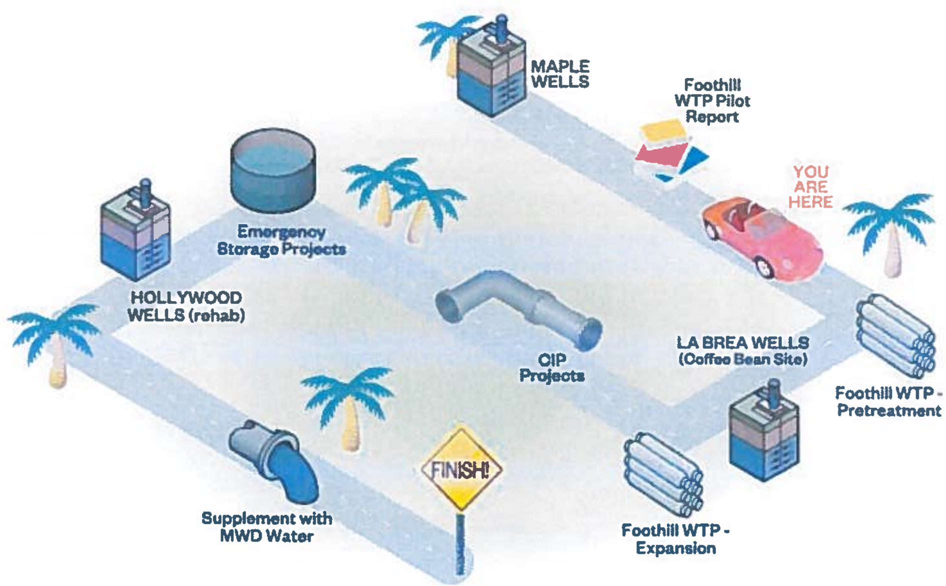
Integrated Water Resources Master Plan Workshop

Introduction

The purpose of this memorandum is to introduce the workshop format, expected outcomes, and project priorities for the Integrated Water Resources Master Plan (IWRMP) Workshop to be held on June 27, 2019.

What is the Integrated Water Resources Master Plan?

The Integrated Water Resources Master Plan (IWRMP) is a comprehensive analysis of the water resources systems in the City of Beverly Hills. The IWRMP will provide an actionable and achievable capital improvement plan for the existing water system, sewer system, and stormwater system. It will address key issues such as local water supply, emergency storage, and aging infrastructure. The IWRMP will be the roadmap for addressing the needs of the City's water resources systems.



Graphical representation of the City's "Water Roadmap"

The City has contracted with Hazen and Sawyer to prepare the IWRMP. The Hazen and Sawyer team is led by Cindy Miller and Steve Bucknam, with Mike Rudinica in an advisory role. The Hazen and Sawyer team is working under City staff including Shana Epstein, Gil Borboa, Vince Damasse, and Vincent Chee.

With the proposed PWC workshop on June 27th, the IWRMP team is concluding the data collection and workshop phase, and moving into analysis and final report preparation. The IWRMP is scheduled for completion in April 2020.

Workshop Format

The IWRMP team will facilitate an open discussion on priorities related to the City's water resources systems. The priority discussion topics include:

- Local water supply
- Emergency storage

- Demand projections
- Water efficiency
- Addressing aging infrastructure
- Other (as-needed)

A presentation will be used to facilitate discussion on each priority. A brief background on each will be provided, with questions posed.

Expected Outcomes

The expected outcomes for the workshop are the following:

- Establish a prioritization ranking for each of the IWRMP priorities: local water supply, emergency storage, demand projections, water efficiency, aging infrastructure, or others as identified in the workshop.
- Establish criteria to evaluate project implementation feasibility. Potential criteria include cost, reliability, schedule, emergency resiliency, risk of doing nothing, or others as identified in the workshop.
- Answer questions related to each priority that will dictate project implementation.

It is expected that the following table will be completed by the conclusion of the workshop.

IWRMP Priorities Ranking and Project Criteria Table

IWRMP Priorities	Ranking	Ranking Criteria				
		Cost (or TBD)	Reliability (or TBD)	Schedule (or TBD)	Emergency Resiliency (or TBD)	Risk of Doing Nothing (or TBD)
Local Water Supply	#	Weight/%	Weight/%	Weight/%	Weight/%	Weight/%
Emergency Storage	#	Weight/%	Weight/%	Weight%	Weight%	Weight%
Demand Projections	#	Weight/%	Weight/%	Weight/%	Weight/%	Weight/%
Water Efficiency	#	Weight/%	Weight/%	Weight/%	Weight/%	Weight/%
Addressing Aging Infrastructure	#	Weight/%	Weight/%	Weight/%	Weight/%	Weight/%
Other	#	Weight/%	Weight/%	Weight/%	Weight/%	Weight/%

A description of each criterion is described below.

- Cost – Is the project cost effective in terms of total cost and cost per unit? Are there outside issues driving costs that are beyond the City's control?
- Reliability – To what extent does this project increase the system's reliability?
- Schedule – Can the project be implemented in the near future? Is the project within the City's control or are there outside agencies involved? Will permits or other regulatory requirements impact implementation?
- Emergency Resiliency – Does the project make the system more resilient to emergencies? Does the project prevent potential emergencies from occurring?
- Risk of Doing Nothing – What is the risk of either deferring, or not implementing this project at all?

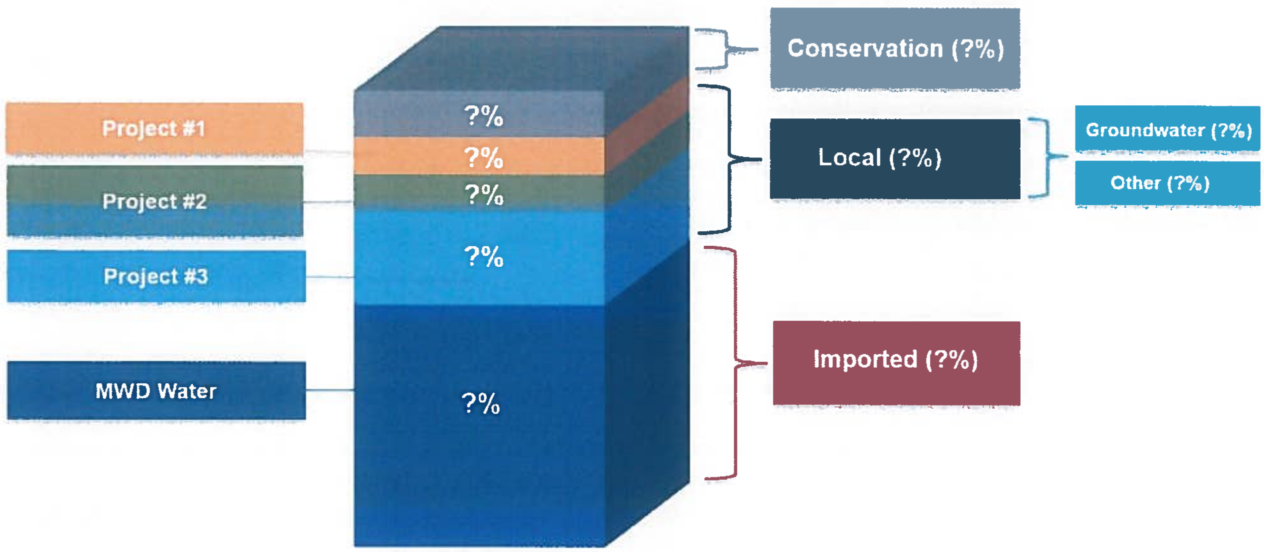
IWRMP Priorities

A brief background on the IWRMP priority to be discussed at the workshop is included below.

Local Water Supply

Local water supply means water supplied to the City from sources other than imported water from Metropolitan Water District. This primarily includes local groundwater available to the City from the Hollywood Basin, Central Basin (La Brea Subarea), and Santa Monica Basin. Key questions to be answered include:

- What is the City's local water supply goal (percentage) for the near term? long term?
- To what extent should the City consider other water supplies including recycled water, water exchanges, or other?



Water Supply Portfolio

Emergency Storage

Emergency storage is the amount of available water in the City's reservoirs that can be used to supply water to the service area in the event of a short-term disruption in water supplies. The difference should be noted between catastrophic emergencies, and short-term disruption of supplies. Urban water systems are typically not designed for catastrophic emergencies, like regional wildfires or major earthquakes. However, water systems should be designed for short-term disruption of water supplies. An example of a short-term disruption of supplies was when the primary pipeline from Metropolitan Water District experienced a leak in December 2018 and was temporarily taken out of service.

Key questions to be answered include:

- Should catastrophic emergency scenarios be prioritized in project evaluations? If so, what type of catastrophic emergency scenarios?
    - Wildfire
    - Earthquake
    - Widespread contamination
    - Other
- How much emergency storage should the City maintain in their reservoirs (number of days)?
- What is the expected level of water conservation during a short-term disruption in supplies when the City implements public outreach?

Demand Projections

Demand projections are used for water supply planning, financial planning, capital improvement planning, and operations analysis. Developing an appropriate methodology for demand projections is part of the analysis for the IWRMP. The Beverly Hills water system service area has seen several significant developments planned and built since demand projections were completed for the 2015 Urban Water Management Plan.

New Developments within Last 3 Years (Top 15 Projected Water Usage)

Address	Usage	City
9900 Wilshire Boulevard	Multi-family Residential & Hotel	BH
9040 West Sunset Boulevard	Multi-family Residential & Hotel	WH
9876 Wilshire Boulevard	Multi-family Residential & Hotel	BH
9200 Wilshire Boulevard	Mixed Use	BH
9060 Santa Monica Boulevard	Mixed Use	WH
8899 Beverly Boulevard	Mixed Use	WH
702-714 North Doheny (completed)	Multi-Family Residential	WH
8600 Wilshire Boulevard	Mixed Use	BH
9001 Santa Monica Boulevard	Mixed Use	WH
627 North La Peer Drive	Hotel	WH
121 San Vicente Boulevard (completed)	Commercial	BH
563 North Alfred Street	School	WH
8750 El Tovar Place	Park	WH
837-850 North San Vicente Boulevard	Hotel	WH
948 & 954 North San Vicente Boulevard	Mixed Use	WH

Key question to be answered:

- Are there desired analyses or outcomes of the IWRMP in regard to new developments within the City's service area? Potential analyses could include:
  - Forecasted demand compared to actual demand
  - Emergency storage impacts
  - Demand projections for new development compared with 2015 Urban Water Management Plan projections
  - Are any new developments significantly changing the current land use?

Water Efficiency

Water efficiency is a measurement of water losses compared to water produced for a particular system. Water losses occur through system leakage and pipe breaks, but also through accounting errors, meter inaccuracies, and unauthorized consumption (AWWA Manual M36). All utilities experience a certain level of water loss.

Water efficiency also involves evaluations on water conservation. Passive water conservation include measures that do not change user habits, like using low-flow plumbing fixtures. Active water conservation is a change in user habits, like the City's current water conservation measures that residents are encouraged to follow.

The Department of Water Resources (DWR) requires all urban water systems to quantify and report water loss statistics and water loss management measures, however, there is no specific performance target required by DWR. Water loss statistics for Beverly Hills and some other southern California agencies are shown below.

Current Water Loss Statistics

City/Agency	# of Connections	Water Loss %
Beverly Hills	10,600	7.6%[1]
LADWP	712,000	5.2%
Moulton Niguel Water District (Orange County)	55,000	8.7%
Simi Valley	25,000	6.0%
Culver City	9,000	3.2%

[1] *2017 Water Loss Audit per SB 555 performed by Psomas.*

It should be noted that water loss for the City of Beverly Hills was 9.6% in 2005, 8.4% in 2010, and 6.0% in 2015 (2015 Urban Water Management Plan).

It is generally accepted as a best management practice that water loss of under 10% is acceptable for urban water systems. For systems with water losses exceeding 10%, there are leak detection technologies that can be implemented that provide the benefit of the early detection of leaks to reduce emergency pipe breaks, and the reduction in water loss.

Key question to be answered:

- Should the City develop additional programs to further reduce water loss?
- Should the City implement a proactive leak detection program?

- Should the City implement measures to increase passive water conservation, like plumbing fixture rebates?

Addressing Aging Infrastructure

The City owns and operates the existing water system, sewer system, and stormwater system within their service area. The water system includes 173 miles of pipelines, ten reservoirs, and ten pump stations. The sewer system includes 98 miles of pipelines. The stormwater system includes 47 miles of pipelines, culverts, and channels. Data on the age of pipelines for the water and sewer system is shown in the following table.

Pipeline Age Statistics

Decade	Water	Sewer
	Percent of System	
<1930	31%	1%
1930	10%	49%
1940	< 1%	7%
1950	12%	11%
1960	5%	13%
1970	14%	15%
1980	5%	2%
1990	12%	0%
2000	5%	1%
2010	5%	< 1%

Through the first 3 quarters of FY 18/19, the City reported eight (8) sanitary sewer overflows. The City's goal is to have less than four (4) overflows per year. Through the first 3 quarters of FY 18/19, the City reported twenty-six (26) waterline breaks. The City's goal is to have less than seventeen (17) breaks per year. The current year data shows the recent deferrals in addressing aging infrastructure may be the cause for not meeting the City's goals in minimizing sewer overflows and waterline breaks.

From the 1990s to early 2010s, the City has historically carried out an aggressive waterline replacement program, replacing older and undersized pipelines on an annual basis. During that same period, the City has implemented minimal pipeline replacements for the sewer or stormwater system.

Key question to be answered:

- Where does addressing aging infrastructure rank compared to other priorities?
- Should the City's infrastructure upgrades prioritize one system above another? For example, should the water system be prioritized over sewer and stormwater?
- Assuming projects for each system are implemented each year, what percentage should be allocated to water, sewer, and stormwater?

Other

It is understood that there may be additional priorities that will be addressed in the IWRMP. Key question to be answered:

- Are there any other priorities that should be addressed in the IWRMP?

Conclusion and Next Steps

In summary, the expected outcomes for the workshop are the following:

- Establish a prioritization ranking for each of the IWRMP priorities: local water supply, emergency storage, demand projections, water efficiency, aging infrastructure, or others as identified in the workshop.
- Establish criteria to evaluate project implementation feasibility. Potential criteria include cost, reliability, schedule, emergency resiliency, risk of doing nothing, or others as identified in the workshop.
- Answer questions related to each priority that will dictate project implementation.

It is expected that the following table will be completed by the conclusion of the workshop.

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- Emergency Resiliency – Does the project make the system more resilient to emergencies? Does the project prevent potential emergencies from occurring?
- Risk of Doing Nothing – What is the risk of either deferring, or not implementing this project at all?

As a result of this workshop, the IWRMP team will move forward in developing the optimal projects that align with the IWRMP priorities and project criteria rankings. These projects will be incorporated into a capital improvement plan identifying project costs and implementation year. The IWRMP will be a comprehensive document addressing the IWRMP priorities and recommended capital improvement plan.

Additional Reference Information

Additional documents and research papers are attached to this memorandum to provide a background on the topics to be addressed in the IWRMP. The following documents are attached:

- Pincetl, S. et al. (2018). *Adapting Urban Water Systems to Manage Scarcity in the 21st Century: The Case of Los Angeles*. Environmental Management.
- Naik, K.S et al. (2015). *Water Distribution Efficiency: An Essential or Neglected Part of the Water Conservation Strategy for Los Angeles County Water Retailers?* UCLA Institute of the Environment and Sustainability.
- Kiefer, J.C. et al (2016). *Uncertainty in Long-Term Water Demand Forecasts: A Primer on Concepts and Review of Water Industry Practices.* Water Research Foundation.

Environmental Management
https://doi.org/10.1007/s00267-018-1118-2

Adapting Urban Water Systems to Manage Scarcity in the 21st Century: The Case of Los Angeles

Stephanie Pincetl[1] · Erik Porse[1,2] · Kathryn B. Mika[1] · Elizaveta Litvak[3] · Kimberly F. Manago[4] · Terri S. Hogue[4] · Thomas Gillespie[5] · Diane E. Pataki[3] · Mark Gold[6]

Received: 11 May 2018 / Accepted: 29 October 2018

Abstract
Acute water shortages for large metropolitan regions are likely to become more frequent as climate changes impact historic precipitation levels and urban population grows. California and Los Angeles County have just experienced a severe four year drought followed by a year of high precipitation, and likely drought conditions again in Southern California. We show how the embedded preferences for distant sources, and their local manifestations, have created and/or exacerbated fluctuations in local water availability and suboptimal management. As a socio technical system, water management in the Los Angeles metropolitan region has created a kind of scarcity lock-in in years of low rainfall. We come to this through a decade of coupled research examining landscapes and water use, the development of the complex institutional water management infrastructure, hydrology and a systems network model. Such integrated research is a model for other regions to unpack and understand the actual water resources of a metropolitan region, how it is managed and potential ability to become more water self reliant if the institutions collaborate and manage the resource both parsimoniously, but also in an integrated and conjunctive manner. The Los Angeles County metropolitan region, we find, could transition to a nearly water self sufficient system.

Keywords Water scarcity · Socio-technical systems · Integrated water management · Water self-reliance

Introduction

The 2018 water supply crisis in Cape Town, South Africa, once again focused attention on the acute consequences of failing to plan for future water needs in cities. Throughout the globe, many urban areas face water scarcity in coming decades. Cities in Mediterranean climates, which experience highly seasonal precipitation, have particular challenges to meet year-round water demands and growing populations (Padowski and Jawitz 2012; McDonald et al. 2014; Padowski and Gorelick 2014).

This is not a new challenge. Cities in many types of climates have long imported water from distant watersheds to provide clean and reliable supplies (Baker 1948; Tarr et al. 1984; Melosi 2001). In the arid regions of western North America, such imports occur at grand scales. The

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✉ Stephanie Pincetl
spincetl@ioes.ucla.edu

✉ Erik Porse
erik.porse@owp.csus.edu

1 Institute of the Environment and Sustainability, University of California, Los Angeles, 619 Charles E. Young Dr. East, La Kretz Hall, Suite 300, Los Angeles, CA 90095-1496, USA

2 Office of Water Programs, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-6025, USA

3 Department of Biology, University of Utah, 257 S 1400 E, Salt Lake City, UT 84112, USA

4 Civil and Environmental Engineering, Colorado School of Mines, Golden, CO 80401, USA

5 Geography Department, University of California, Los Angeles, 619 Charles E. Young Dr. East, Los Angeles, CA 90095-1496, USA

6 Institute of the Environment and Sustainability and Sustainable LA Grand Challenge, University of California, Los Angeles, 619 Charles E. Young Dr. East, La Kretz Hall, Suite 300, Los Angeles, CA 90095-1496, USA

prospect of accessing readily available freshwater sources in faraway places led cities in California, Arizona, and Nevada to build pipelines over long distances to deal with regular seasonal scarcity. Such actions, undertaken in the early and mid-twentieth century, helped mitigate regular water shortages and set the stage for long-term growth in the regions (Davis 1993; Reisner 1993; Hundley 2001).

But during drought, available water in these semiarid and arid regions is especially limited. In California, for instance, urban population growth through the mid-twentieth century was enabled by vastly expanded water transfer infrastructure. But severe droughts in the 1970s and 1990s showed that many cities were unprepared for the water cutbacks resulting from water shortages. Cities instituted emergency measures and imposed significant cutbacks, reinforcing rationing as a standard approach to periodic drought[1] (Bruvold 1979; Shaw et al. 1992; Dixon and Pint 1996; Mitchell et al. 2017).

California cities have made progress in the past decades to promote conservation and diversify supply sources, but they once again faced challenges during the 2011–2016 drought, the most severe on record. Larger cities fared better, though they were still mandated to cut water up to nearly 40% of 2013 consumption, depending on prior conservation actions (Office of the Governor of California 2016). But smaller communities with limited supply sources, such as Healdsburg and Cloverdale in Sonoma County, faced the risk of running out of water in 2014 (Gore and Bourbeau 2014).

Expectations of water availability for all these urban areas will likely continue to change in coming years, with more cities spending more money to ameliorate the effects of drought (MacDonald 2007; McDonald et al. 2014). But emphasizing the role of climatic drought, or the high variability in rainfall, as a driver of scarcity (both current periodic drought and future more prolonged events with climate change) misses the important role of societal expectations of water availability. In particular, engineered water conveyance systems bred confidence in in the availability of nearly unlimited water supplies for many end-uses, despite a historic record that clearly shows long periods of aridity in the southwest US. In cities, this translated to security of indoor, commercial and industrial uses, but especially supported highly irrigated landscapes full of nonnative species. Perceiving water shortages as caused by natural events like *drought* deflects attention from the ways that current conceptions of scarcity has been constructed over many decades, driven by the reliability of infrastructure that facilitates continued water use.

Modern water management systems are comprised of both technical systems and organizational hierarchies. Within social science literature, such combinations of human social structures and technologies are characterized as *sociotechnical systems* (Pincetl et al. 2016a). For urban water management, sociotechnical systems include municipal governments and regulatory organizations, associated rules, regulations, codes and procedures, and the technical systems comprised of dams, reservoirs, pipes, and water treatment plants. Sociotechnical systems interact with environmental resources, such as groundwater basins that provide water storage (Foster et al. 1999; Gelo and Howard 2002). These in turn connect to larger systems of dams and water conveyance, along with the rules that regulate how those systems operate. Understanding water systems in cities as comprised of both social and technical aspects reveals how periodic water scarcity may result from existing management systems, rather than solely attributable to climatic drought. Many problems of urban water management result from governance failures at multiple levels, rather than scarcity of the resource itself (Pahl-Wostl 2017). Such governance failures are inscribed in the operation of infrastructure systems that reflect assumptions about water quantity and distribution. Policy innovations must engage with historically developed hard infrastructure and its management (Kiparsky et al. 2013).

This paper examines the social and technical adaptations necessary for one Mediterranean-climate urban region, Los Angeles County (LA), to adapt to future water management challenges. Like many modern cities, LA's water management systems were designed to exploit highly available imported water from remote places to supplement regional water sources such as groundwater. Such local sources, while long-utilized, have not necessarily been managed to ensure long-term sustainability (Blomquist 1992). Summarizing results from research spanning a decade, we synthesize the findings of empirical investigations into the sociotechnical water system, elucidating potential actions for long-term water reliability in LA. We show how the embedded preferences for distant sources—and their local manifestations—have created and/or exacerbated fluctuations in local water availability due to changes in climate. This case study offers insights for other cities across the globe about sociotechnical system lock-in that creates water scarcity, and also pathways forward toward potential water self-reliance.

Sociotechnical systems

Urban infrastructure, and how it is connected to supply chain infrastructures, is critical to providing necessary

[1] Drought is, of course, a term that implies a kind of referent of about rainfall normalcy. In the US southwest, dry periods are not uncommon historically. We use the terms shortage, scarcity, or aridity in some places to convey this concept.

goods and services to urban populations. Cities are products of complex interactions between sociopolitical, cultural, institutional, and technical networks, which are all dependent on infrastructures that can be configured in different ways (Swilling 2011). Sociotechnical systems co-produce each other (Trist 1981), and rely on an elaborated social network of agencies for structure and organization. Pahl-Wostl (2017) argues that the understanding of water governance is underdeveloped, with much work being descriptive. This is, in part, due to a failure to recognize how decisions, agency networks, and other social factors intimately influence the evolution of the physical infrastructure network. Early work in sociotechnical systems was developed for energy systems, such as the grid (Hughes 1993), which pointed to the importance of institutions and people in determining the trajectory of infrastructure development.

A sociotechnical perspective highlights that systems are not only comprised of technical artifacts, but also include economic, political, scientific and legislative components (Hughes 1993). Together, the social and technological elements form a web of interactions that contribute to the process of system building. The technological parameters and rules devised as part of system operations create a kind of "lock-in" (Unruh 2000), which is not only physical and regulatory, but also conceptual. That is, once systems are in place, patterns of expectations and notions of possibility also become fixed, limiting opportunities for system change even in the face of significant evidence. Aspects of this concept of lock-in, where previously-taken actions affect future decisions, are noted across many disciplines, including innovation economics (Liebowitz and Margolis 1995). Institutions build expertize that grows obdurate. Funded projects become sunk investments, perpetuating them as they are generally cheaper to use over short-term planning horizons. This pattern is often reinforced by budgetary rules. Legal and regulatory frameworks develop and generally solidify current practices.

Established practices within resource-exploiting sociotechnical systems may also mask potential resource availability, despite the paradox of over-allocated systems—that is a resource may be available that is obscured by established measurement or allocations. Existing laws, rules, and expertize can also inhibit opportunities for doing things differently—a simple self-censorship in seeing other ways of constructing the future and systems of implementation. Another way of stating this concept is to understand that information incorporated by sociotechnical systems is the result of a process of selection by which the system decides what is meaningful and what is disregarded; sociotechnical systems create a set of implicit filters (Luhmann 1984).

Water Systems in Los Angeles County

In 2015, Los Angeles County and its 10.5 million people used approximately 810 million cubic meters (1.4 million acre-feet) of water. Over the past decade, over half LA County's demands (55–60%) were consistently met by imported water from three main import infrastructures: reservoirs that store water from the Colorado River Basin that spans western North America, the California State Water Project (SWP) that brings water from mountain rivers in northern California, and finally the Los Angeles Aqueduct that brings water from the Owens Valley to the City of Los Angeles (Fig. 1). These water conveyance systems were built in a time of confidence in climate patterns—primarily the predictable presence of alpine snow pack that, melting slowly through spring and early summer months, is captured and dispatched through the drier summer and fall months to support the state's agricultural regions and its cities. Paleo and historic records of precipitation were either unavailable or ignored in these twentieth century infrastructure development projects.

In Southern California, the primary water importer, the Metropolitan Water District of Southern California (MWD), was created through state legislation in 1927 and approved by local voters to import water to the region, first from the Colorado River federal complex and subsequently from California's SWP. MWD distributes imported water to over 100 different water delivery entities within a hierarchy of agencies in LA County (Pincetl et al. 2016b). In addition, there is one area of the county with its own water district organized to also contract with the SWP for water imports.

For local sources of supply and water storage, LA County benefits from significant groundwater resources. The basins were adjudicated through agreements that set pumping rights, established governance structures, and guided long-term management actions to maintain yield (Ostrom 1990; Blomquist 1992; Porse et al. 2015). In support of the agreements, considerable investigations of hydrogeology and capacity were undertaken, though many of the findings upon which the adjudications were based are now likely out-of-date, as the LA metropolitan area overlying the basins has grown more urbanized. Reduced imported availability also led MWD to significantly cut its allocation of imported water for basin recharge. In response to such changes, pumpers, and groundwater managers in several basins have recently taken actions to incentivize recharge through groundwater storage pools or collectively limit pumping (ULARA Watermaster 2013; CB/WCB Amended Judgment 2013; LADWP 2015).

The modernist-era water infrastructure that currently supplies much of urban California will be strained as future climate change reduces seasonal snowpack storage

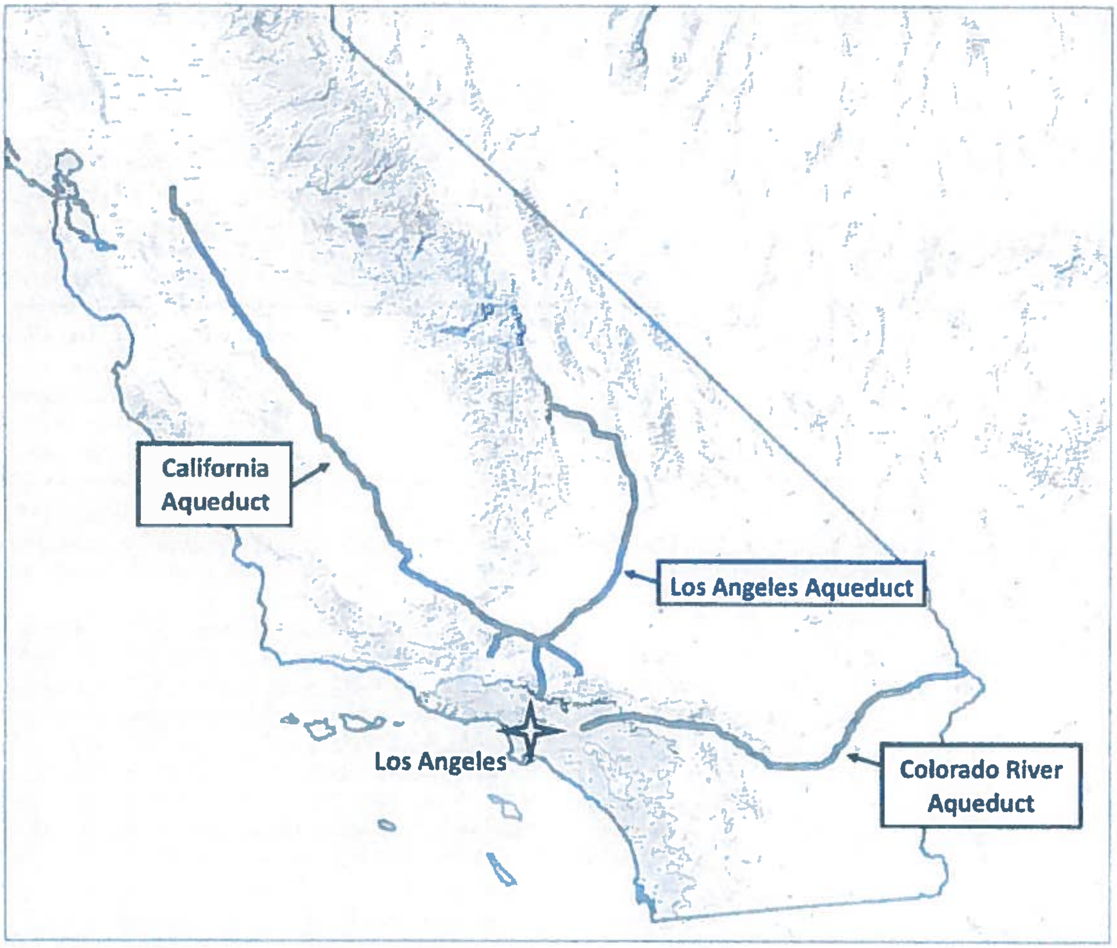

Fig. 1 Major conveyance systems for importing water to the Los Angeles metropolitan region. Two aqueducts, the Colorado River Aqueduct and the California Aqueduct, serve the greater Southern California region

(Diffenbaugh et al. 2015; Berg and Hall 2017). The severe multiyear drought showed vulnerabilities of reliance on imported water. In Los Angeles, the availability of imported water affects not only direct water supplies, but also groundwater recharge in LA's groundwater basins that provide critical sources for many communities. Increased conservation over recent decades has allowed the city and county populations to grow without increasing total water use, but such conservation—over time—may reduce the viability of acute water use restrictions alone to deal with dry climate cycles over time (Mitchell et al. 2017).

In the past 2 decades, new water awareness has been building in the region, urging better water management (Green 2007), including distributed stormwater infiltration zones, water recycling and reuse, water conservation and turf removal, and greater use of groundwater basin storage potential (Hughes and Pincetl 2014; Porse et al. 2015; Mika et al. 2017a). But these strategies must take hold across a highly diverse, fragmented, and complex water management system that combines natural features, such as the groundwater basins, rivers and run-off, and human-created institutions such as water districts and groundwater adjudications. These are all interconnected by technical infrastructure like pumps, pipes, and filters. There exist multiple human, engineered, and environmental systems that overlap to form hierarchical structures and interact in distinct ways that solidify dependent relationships between natural and human systems (Fig. 2).

The LA metropolitan region spans five major watersheds and over twenty groundwater basins with significant storage capacity (MWD 2007). Management decisions are dispersed among hundreds of agencies who lack

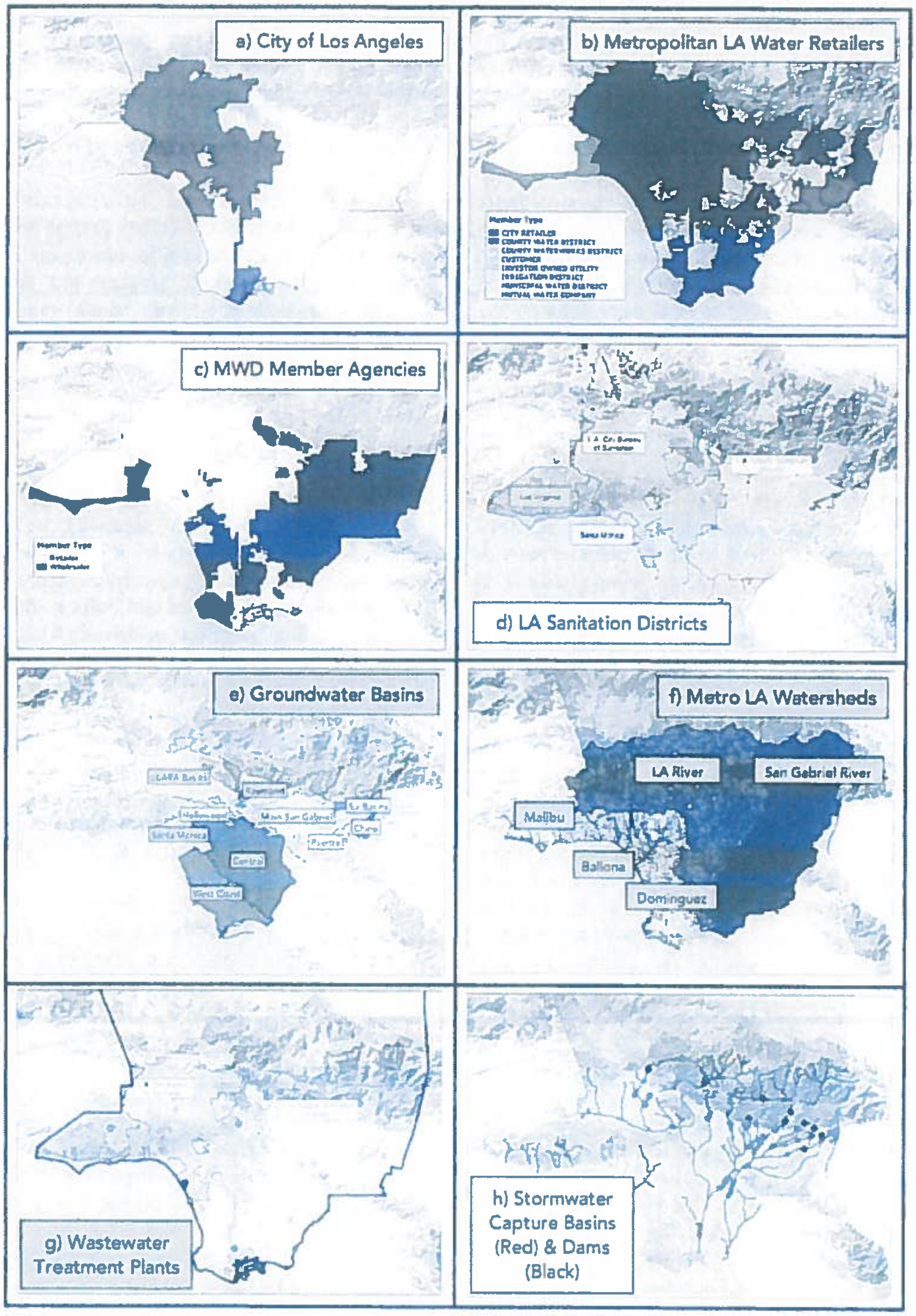

Fig. 2 Visualizing the layers of water management in Los Angeles. Each layer, including social, environmental, and engineered systems, is represented and linked through modeling

comprehensive region-wide quantifications of local water reliance potential (Supplemental Data File). Historic and contemporary ways of thinking, the disjointed institutional architecture of water management, and successful reliance on water imports, has meant the development of region-wide water resources quantification, has not been undertaken; it has not been seen, or perceived, as necessary. The most recent 4-year dry period points to the need for better quantification and modeling of this system under different scenarios and flows. We suggest the same applies to most urban areas across the globe with high reliance on imported water and poor understanding of local water flows.

Constructing the Empirical Basis for Change in LA Water Management

Analyzing complex systems driven by both human and environmental factors often requires composite assessments that draw on multiple modeling approaches based on extensive empirical data. To this end, we compiled methods and findings via a decade of interdisciplinary research to systematically deconstruct the complex and layered water system in the county metropolitan area using modeling, data collection and interviews, and field studies. Methods and key findings are summarized below. Full descriptions of the new modeling methods and results are provided in the Supplemental Data section.

Study Methods

We integrated operations research modeling, urban hydrologic modeling, field experiments, interviews and stakeholder outreach, policy and scenario analysis, historical and institutional analysis, and program evaluation to assemble a comprehensive understanding of the potential for local water reliance in the Los Angeles metropolitan area. Studies focused on LA City and LA County. The sections below briefly summarize key methods. Further details are included in the appendix and associated references.

(1) *Field experiments and program evaluations of tree and turf water use in Southern California:* Tree and turf water needs in LA were estimated based on experimental measurements taken between 2010–2011 (Litvak et al. 2012, 2017a, 2017b; Litvak and Pataki 2016). In particular, evapotranspiration (ET) in urban landscapes during pre-drought conditions (before the 2011–2016 record drought) was systematically estimated. For lawns, ET of irrigated turf lawns was measured using small chambers across lawns with varying levels of shading and irrigation (Litvak et al. 2013). For trees, transpiration rates, a reasonable proxy for tree ET in LA, was measured using thermal dissipation probes (Granier 1987) that recorded sap flux in urban tree species common in LA (Pataki et al. 2011). The experiments sampled trees of varying species across a variety of land use types, working with public and private landowners to gain access. These experiments provided an empirical basis for understanding landscape water conservation potential through a water budgeting approach for urban retailers.

Additionally, we evaluated the effectiveness of turf replacement programs in LA County through work funded by MWD. We examined participation trends in MWD's 2014–2016 turf replacement program and developed a landscape classification typology using openly-available imagery to evaluate changed landscapes (Pincetl et al. 2018). The findings from this project provide important context to understand whether turf replacement programs can be a successful strategy for promote landscape change and outdoor conservation to reduce urban demand.

(2) *Urban hydrology modeling to understand stormwater and water quality actions:* Through a multiyear project funded by the LA Bureau of Sanitation, we performed watershed-by-watershed analysis of stormwater capture potential from distributed green infrastructure to assess potential water supply benefits and water quality implications. Results from calibrated models, built using the US EPA's SUSTAIN modeling platform that supports multi-objective optimization (Lai et al. 2007), we investigated the maximal potential for stormwater capture via distributed stormwater control measures to augment groundwater recharge given available data. Associated effects on key surrogate pollutants were also examined to understand water quality outcomes and potential pollutant load reductions (Read et al. 2018; Mika et al. 2017b) (Mika et al. 2017a–2017c).

(3) *Systems analysis with optimization for integrated water management:* For both LA City and LA County, integrated systems analyses with quantitative and qualitative assessments were developed to understand relationships among water supply reliability, water conservation, alternative supply sources, current policy goals, and existing regulations. For the city of LA, results from the urban hydrology modeling with SUSTAIN were combined with systematic data collection and analysis of groundwater pumping, wastewater treatment, and water supply operations. The potential role of stormwater and recycled water to augment existing supplies was evaluated in the context of stated goals for local water reliance in LA City (Mika et al. 2017a). For the county of LA, a comprehensive network flow model of water management (*Artes*) was developed to simulate and optimize promising actions (and associated tradeoffs) for local water supply across more than a hundred institutions with existing allocations and water rights, environmental features, and engineered infrastructure (Porse 2017; Porse et al. 2017). For both study areas, economic

Table 1 Nine themes toward water self reliance for semi-arid cities

Theme 1.
Use Scientific Knowledge for Outdoor Water Conservation
Measure water use for outside vegetation, including, for each, trees, shrubs and lawns
Theme 2.
Maximize Use of Groundwater Basins
This includes detailed hydrologic analysis, recharge capacity and users
Theme 3.
Upgrade Wastewater Systems for Water Quality and Reuse
Wastewater is a misnomer going forward in the 21st century. This is important water supply.
Theme 4.
Emphasize New Water Cycles
Develop closed loop systems where water is reused and kept in the urban system, including groundwater
Theme 5.
Import Water only in Wet Years
Many semi-arid regions do have high rainfall years. Maximize storage to take advantage of those years.
Theme 6.
Capture Stormwater in Large and Small Infrastructure
Stormwater is an important water supply that needs space to infiltrate. Maximize that capacity throughout the urban system.
Theme 7.
Recognize Tradeoffs in Water Uses
Instream flows versus infiltration is an issue that can have esthetic and recreational implications
Theme 8.
Integrate Old and New Infrastructure
Take advantage of existing infrastructure, adapt and reoperate as well as create new infrastructure.
Theme 9.
Recapitalize and Consolidate Retailers
In places where there is a proliferation of small providers and fragmented systems, cost effectiveness and coordination is enhanced by consolidation.

effects were examined and implications for current water supply and groundwater management institutions were evaluated (Mika et al. 2017a; Porse et al. 2018b).

(4) *Interviews and stakeholder outreach:* Across water management institutions in LA County, we worked with regional agencies to collect key data for modeling, such as water treatment plant outflows and historic imported supplies. We conducted interviews for two additional purposes. First, we interviewed regional managers and experts to capture and understand views on local water reliance potential. Second, we conducted interviews with key regional experts to understand operations of key system components that informed the systems analysis. Assistance from and collaboration with regional water managers was critical to the success of the multi-year research agenda (Hughes and Pincetl 2014). We interviewed approximately 20 persons, spanning groundwater masters that manage regulated basins, water utilities, local elected officials, environmental nonprofit staff, and scientists.

Key Findings

Findings from the research (Table 1) detail the changes in system governance, along with the investments in existing infrastructure, which will be necessary to achieve water self-reliance in a region such as Los Angeles. Additionally, such changes are not without potential consequences that must be considered in advance to understand ripple effects throughout the system. The findings are organized into key themes below.

Theme 1: Use Scientific Knowledge for Outdoor Water Conservation

Urban vegetation of Los Angeles, like most of Southern California, is predominantly characterized by lawns and plants from more humid parts of the world. Substituting this vegetation for California/Mediterranean ecosystem plants that are adapted to dry summers and extended dry periods would potentially reduce regional water use by 30% (Litvak et al. 2011, 2012, 2013, 2017b; Litvak and Pataki 2016).

Field experiments derived a dataset of tree water use by particular species, including variance within a single species across locations and water availability. Such pertinent scientific knowledge can help drive regional tree planting and landscape conversion programs. In particular, to maintain LA's urban tree canopy in a future locally reliant water supply regime, the current canopy composition must be converted to trees that are adapted to Mediterranean climate conditions (winter precipitation and dry, hot summers) that are also drought-tolerant (can survive arid periods), a long-term conversion process. Additionally, this will involve not only changing perceptions of what an attractive yard looks like, but plant offerings of local nurseries will need to evolve so as to support a change toward different resident decisions (Pincetl et al. 2013). For example, promoting wider availability of native plants can provide options for changing decades-old landscape types.

But regional water managers have limited understanding of species-specific water use by trees in LA and other landscape elements. Landscapes are outside of the domain of responsibility and expertize, though multiple agencies offer turf replacement incentive funding. Some agencies, notably the City of Long Beach, provide more robust guidance in good designs for replacement landscapes, but resident and contractor expertize is scarce. To date, a few local nonprofits have spearheaded the task of piloting programs that engage residents in the process of remaking the urban landscape of Southern California cities. Much more needs done in transforming water agency practices to recognize the value of promoting landscapes that are appropriate to the region in partnership with property owners.

Theme 2: Maximize Use of Groundwater Basins

The groundwater basins of LA currently provide up to 40% of annual supplies across the county. The adjudicated basins have a pumping limit of approximately 555 million cubic meters (mcm, or 450,000 acre-feet) annually and are LA's most critical natural resource for achieving local water reliance. Groundwater basins provide readily available local storage capacity that would otherwise not exist in a highly urbanized basin where land prices outstrip the value of building reservoirs. Urban areas without such groundwater basins face greater challenges from imported water reductions.

But current groundwater management practices must adapt to future conditions. Recent assessments have estimated that 985mcm (800,000acre-ft) of unutilized available storage capacity exist in three of the region's larger basins: The Central and West Coast Basins 407mcm (330,000acre-ft) and the San Fernando Basin 555mcm (450,000acre-ft) (ULARA Watermaster 2013; CB/WCB Amended Judgment 2013). This constitutes approximately half of the LA metropolitan region's historic annual water use, which has been approximately 2000mcm (1.6 million acre-feet), but less during drought. Additional storage may be available in other groundwater basins as well. In the Central and West Coast Basins, the new groundwater master for the basins, the Water Replenishment District of Southern California, led basin stakeholders to develop a regional storage pool, whereby infiltrated water could fill the depleted void and provide pumpers over-year storage capacity. Such agreements can encourage greater utilization of local groundwater basin resources, bringing back into production depleted aquifers to offer pumping rights to more parties, though current adjudications will need to be significantly revised to do so.

Many retailers throughout the county do not have current rights to pump or store groundwater in underlying basins (Porse et al. 2015). To benefit the region, current management regimes with adjudicated storage and pumping rights need updating. Restructuring groundwater pumping rights can provide greater access to groundwater resources among agencies, especially those that have no existing rights and would suffer significant supply shortages with imported water cutbacks. In addition, implementing groundwater storage pools that open up water rights to more parties could significantly reduce the effects of imported water cutbacks by allowing vulnerable retailers access to alternative sources of supply (Porse et al. 2018a). Yet, even as key regional agencies are promoting more recharge to address overdraft, past industrial operations have also left many parts of LA with underlying contaminated groundwater plumes. Pumping, treating, and using or reinjecting water from these plumes will be critical in opening up greater access to available groundwater resources.

The state of current groundwater basins is also a challenge. A number of aquifers in the metropolitan region are contaminated, a legacy of past industrial practices from aerospace and other industries that disposed of chemicals on-site. In some areas, such as the upstream San Gabriel Valley, remediation activities have taken place for years. But much more needs done. Groundwater basin managers are concerned about disturbing current contaminant plumes, which restricts wider pumping (ULARA Watermaster 2013). New "pump-and-treat" technology investments will be necessary to remediate contaminated groundwater pockets and mitigate risks of spreading plumes (Mika et al. 2017a). Such actions could help open more groundwater areas to active management, supported by robust modeling to ensure that infiltration and pumping activities do not pose undue risks for water supplies.

Theme 3: Upgrade Wastewater Systems for Water Quality and Reuse

Recycled water (treated and disinfected to regulatory standards) comprises approximately 10% of current supplies in LA County. But this source is only for non-potable uses (e.g., outdoor irrigation) or indirect potable reuse (groundwater recharge). Due to its consistent output, recycled water provides critical reliability in a future water regime dependent on local sources. New water reuse projects are already underway throughout the county, (detailed in the Supplemental Data section), but could be vastly expanded as sewage flows and water treatment capacity are relatively predictable and could thus be a stable source of water going forward.

Current recycled water operations deliver nonpotable water at affordable prices in comparison to the rising cost of imported water supplies (Mika et al. 2017a; Porse et al. 2018b). Storing recycled water in LA's substantial groundwater resource capacity provides a critical supply chain for future water management in LA. Direct potable reuse, which is the subject of statewide policy development proceedings in California, would provide, if enacted, additional options for creating closed loop urban water management (SWRCB 2016).

Water reuse is an important emerging supply source that requires new infrastructure, but the changing dynamics of urban water in Southern California will affect current systems. The large existing wastewater treatment plants in LA, in particular, will see lower inflows as a result of water conservation and reduced imports. This serves to concentrate waste streams, leading to increased costs of treatment. Results of our systems modeling in LA County showed that this prospect would likely continue if advancing goals of local water supply and increased conservation (Fig. 3). This phenomenon represents one of the perhaps

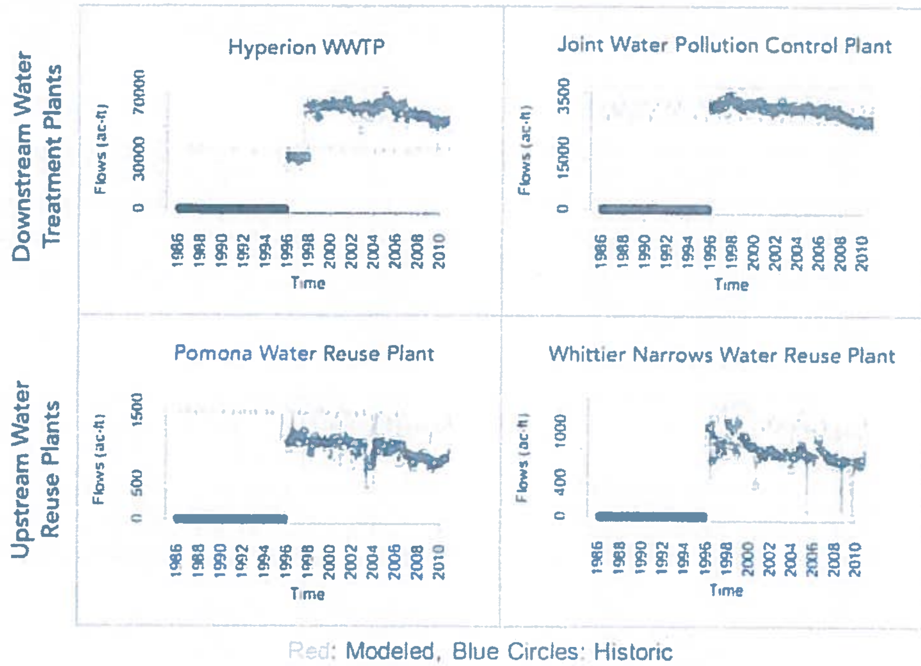

Fig. 3 Modeled inflows to selected wastewater treatment plants in the Metropolitan LA region. Downstream wastewater treatment plants (top row) see much lower inflows due to conservation and stormwater capture, while upstream indirect potable reuse plants (bottom row) see greater inflows, as imported water cutbacks emphasize alternative sources

undesired, but predictable, outcomes of changing the urban water systems of coastal Southern California. Additionally, the increasing concentration of effluent waste streams flowing into treatment plants, resulting from less dilution from imported water and stormwater, will also require new investments in aging facilities. But while these issues are definitely challenges for future infrastructure management, in the context of historical actions to bring water to the region, they seem manageable given the economic prowess of the region.

Theme 4: Emphasize New Urban Water Cycles

A water supply regime more dependent on local sources requires reconfiguring the ways regional agencies conceive of and manage supply sources and the cycles of water management in LA. Most water is predominantly imported, used, treated, and disposed to the ocean. In the future, flows need to form closed loops, with in-basin or imported sources undergoing treatment and reuse that retain much more of the volume within the basin, either through direct use or recharge. Moving towards a greater closed loop perspective of urban water management is a significant change in historic operating practices and is known as *One Water*. It means the development of a new sociotechnical system with integrated planning at the watershed scale and regional institutions and/or collaborations, transcending the fragmented historical system. The network flows, illustrated in Fig. 4 for a modeled scenario with significantly reduced imported water, would change current operations significantly.

Within the complex water management regime in LA, with its many agencies and bureaucratic silos, closed loop projects can be accomplished through either: (1) laboriously negotiated, bilateral agreements among agencies with detailed plans for funding new infrastructure, or (2) systematic, multilateral, and regional strategies that aim to create a water system that relies on local water resources by water recapture and reuse. This latter approach would entail crafting new regional water analysis for optimizing reuse, reinjection and treatment and management structures to ensure full use of groundwater basins with equitable access to water by all areas in the urbanized Los Angeles basin. The regional *Artes* model provides a heretofore inexistent platform for doing so.

Theme 5: Import Water Only in Wet Years

Importing water during only "wet" years, used to supplement local water resources and recharge groundwater, is a novel strategy for mitigating potential shortages from over-reliance on continual imports. Such a configuration enables

Fig. 4 Sankey diagram of system flows for a model scenario with 50% reduction in historic imported water, using a cost-minimizing formulation. Wastewater treatment plant inflows, in particular, are far reduced from current levels. MWD Municipal Water District, MWD-SoCal Metropolitan Water District of Southern California, SGVMWD San Gabriel Valley Municipal Water District

conjunctive use strategies for jointly managing surface and groundwater supplies. In times of high statewide precipitation, water is imported and infiltrated into the basins and local surface water is deferred and water is infiltrated, maximizing water in basins for later use. When there is no precipitation, groundwater is pumped. But, in this scheme, groundwater recharge and storage allows for the imports that arrive only in wet years to be banked overall years. Agreements will need to be altered to increase storage and expand pumping rights to ensure management for long-term resource availability and equitable access. Currently, there are about 300 groundwater pumpers that have historic rights to the exclusion of all others and many cities have no groundwater rights.

The finding about the potential of groundwater to buffer drought, stems from previously unpublished modeling results, which are detailed in the Supplemental Data. We developed alternative models to create scenarios to help understand the balance between conservation potential and imported supply being cut back. Using several scenarios of imported water availability and water conservation. Reducing water use to 280–380l per capita per day (75–100 gallons per capita per day, gpd) across the county metropolitan area (total water use) would go far in promoting cutbacks in imported water (Porse et al. 2017, 2018b). With investments in infrastructure and landscape conversion to drought-tolerant species, this means importing water in only the 25% wettest years, which would significantly reduce upstream environmental impacts of water diversions (see Supplemental Data). Water conservation to achieve 75gpd is on par with other global industrialized cities, and would allow for completely cutting water imports in LA City (4 million inhabitants) when coupled with other infrastructure improvements (Mika et al. 2017a), though not for the rest of the region. Reconfiguring state agreements to use risk-based procedures that promote timely importation of water from distant sources during wet years, rather than consistent imports that are only curtailed by drought, would require significant changes in current operating conditions and agency practices, at all levels: federal to state and local. The primary purpose of the imported water would be to recharge regional groundwater basins and reservoirs, which would be carefully managed between years of high precipitation. The region would then be largely living within its means. This would have the additional benefit of alleviating ecosystem impacts in regions of origin.

Theme 6: Capture Stormwater in Large and Small Infrastructure

LA currently has an extensive network of large stormwater capture basins that capture 246mcm (200,000acre-ft) of runoff annually, and have captured as much as 800mcm (650,000acre-ft) in a year (LACDPW 2014). Agencies are looking at cost-effective and achievable options for increasing these values, including re-operating flood control release schedules, building new pipelines for recycled water, and even inflatable dams to temporarily capture runoff. Going forward, both regional and distributed stormwater capture systems will be necessary to promote reliability and achieve stringent Clean Water Act regulations that municipalities must current meet as part of regional stormwater discharge permits (LA RWQCB 2016).

The results from multiple models indicated that existing centralized stormwater recharge infrastructure is a key regional asset. It provides a cost-effective way to recharge a significant volume of water on an annual basis. Modeling indicated that they could infiltrate much more water with changes in land use, management practices, and additional infrastructure that connects recycled water facilities with recharge basins. But distributed stormwater capture facilities, including low-impact development strategies such as bioswales, retention basins, and others, can also significantly contribute to groundwater recharge. In three of the main riversheds, the Los Angeles River, Ballona Creek, and Dominguez Channel, runoff for potential capture totaled 121 mcm (150,000acre-ft) in a dry year and more than 810mcm (1 million acre-ft) in a wet year. This is before implementing any distributed BMPs to capture and retain runoff throughout the landscape, which can also significantly improve water quality.

However, many regional agencies view such distributed capture as too expensive and plagued with challenges regarding siting and maintenance. These management realities are valid. Promoting more broad-based accounting procedures for projects can help in this regard. As an example, stormwater projects that capture and infiltrate runoff to groundwater basin supplies can consider the averted costs of imported water as a project benefit. But stormwater utilities typically do not sell water and cannot directly include these benefits as part of project planning. In jurisdictions where stormwater and water supply agency boundaries differ, assembling projects becomes a complex negotiation that requires activities outside the norm of agency mandates. New accounting structures and multilateral agreements, such as large water supply agencies funding distributed stormwater capture that has both water quality and supply benefits, would help open latent investments in stormwater capture. Alternatively, as has been proposed, water retailer, stormwater and sanitation agency duties should be merged or better coordinated under one roof as a way to achieve goals of local *"One Water"* initiatives.

For many regional agencies, however, enhancing water supply through stormwater management is secondary to regulatory realities in the region. LA municipal agencies with stormwater management duties face steep bills to build new stormwater capture measures (SCMs) that meet water quality goals (Upper LA River Watershed Management Group 2015). Detailed plans outline millions of dollars of spending that will be necessary, according to modeling, to meet water quality targets in downstream watersheds. For these places, incorporating multibenefit accounting procedures, which recognize the benefits to social, economic, and environmental systems from better stormwater management, is a well-documented strategy, though its enactment has been slower to emerge.

But even if distributed SCMs became widespread, there is no single best type of stormwater capture device to use, and some water quality targets will be hard to meet, especially for some contaminants such as heavy metals (Mika et al. 2017a). For instance, the watershed modeling for LA City showed that scenarios with distributed SCMs could manage up to the "design storm" runoff (85th percentile of the historic distribution of precipitation events), but trade-offs existed. Some SCMs achieved runoff mitigation targets more cheaply, while others were more effective at reducing water quality exceedances or peak flows. Still others provided greater water supply benefits. Modeling scenarios that emphasized SCMs that treated and released stormwater, such as vegetated swales and dry ponds, resulted in fewer exceedances of the regulatory stormwater exceedance limits for metals. But treat-and-release SCMs provided less potential recharge than those that emphasized infiltration to groundwater. Thus, both types of distributed infrastructure provided the most economical solution to achieving both water quality and supply goals for the region. Agencies with significant financial capacity are, at present, most likely to have sufficient capital to invest in such measures. Such trade-offs are likely in most regions, with or without strong water quality regulations.

Theme 7: Recognize Tradeoffs in Water Uses

Water supply regimes dependent on local sources can have many benefits. But tradeoffs exist. For instance, capturing, and using more stormwater for groundwater recharge may reduce flows in the highly channelized urban streams of LA County (Porse and Pincetl 2018). The LA River basin, in particular, is a useful case study in examining these tradeoffs. Currently, a broad planning process has been examining opportunities for the channelized Los Angeles River to promote economic development and multibenefit uses such as recreation. But water conservation and cuts to imported water reduce treatment plant outflows that constitute a significant percentage of the artificial summer stream flows, would be reduced (Manago and Hogue 2017). In addition, promoting more stormwater infiltration in upstream basins would decrease downstream urban stream flows across the county in most seasons and years (Porse and Pincetl 2018t; Mika et al. 2017b). These infiltration projects would recreate the historic predevelopment water regime in the region where water infiltrated rather than being captured by stormwater systems to send the storm flows out to sea.

Theme 8: Integrate Old and New Infrastructure

Existing infrastructure in LA will not go away. It will continue to be used and likely adapted and reoperated to meet current management needs. Current assets, such as LA City's Hyperion Water Treatment Plant or LA County's Joint Water Pollution Control Plant that provide sewage treatment and disposal, can be retrofitted to support greater water reuse. Yet, many assets key for a local water supply regime of urban water are not located in optimal locations. For instance, some of the regional sewage treatment plants lie in locations where water recycling opportunities would need new pumping infrastructure. Local applications—or decentralized infrastructure—may reduce the need for new construction or expensive retrofitting of recycled water distribution systems. A major question will be the scale (centralized, decentralized and size) and cost/benefit of such retrofits.

Additionally new areas for large-scale stormwater capture in the highly urbanized basin are limited. Public lands that are well situated can serve hybrid purposes, including stormwater retention and infiltration, will need to be identified and strategies developed to optimize the opportunity. New approaches will require shifting the modernist-era sociotechnical system toward gray/green infrastructures to enhance local sustainability and resilience. Opportunities for distributed stormwater infrastructure exist in stormwater channels (some of which are already soft bottomed, but others could be unpaved), parking lots, alleyways, parks and more, but have not been seen as such due to the lock-in thinking of the current system. The barriers to these alternative systems include cost, fear of failure in increased flooding risk, lack of experience in assessing the infiltration potential, and inadequate experience in such alternatives in the region. However, repurposing such areas for multiple use is an important component of achieving greater local water self-reliance (Gold et al. 2015; Mika et al. 2017a–2017c). This type of opportunity exists in cities throughout the globe, but requires new approaches and funding mechanisms.

Theme 9: Recapitalize and Consolidate Retailers

The complex hierarchy of water management agencies in LA developed slowly over time. It is not the result of any single act of planning. The agency network includes municipal utilities, special water districts, private investor-owned utilities, nonprofit landowner-controlled mutual water companies, and irrigation districts. The agency network spans over 100 sizeable water delivery entities and, when including extremely small retailers, more than 200 (Ostrom et al. 1961; DeShazo and McCann 2015; Pincetl et al. 2016b).

All of these agencies make policy and investment decisions based on an existing system, where revenues are predominantly tied to water sales (volumetric). This creates a structural disincentive for conservation, including turf removal. Some larger and more financially secure agencies have systematically invested in conservation, but not to the extent possible. But without long-term planning and changes in rate structures, conservation detracts from revenues, causing economic ramifications for risk-averse utilities.

The agencies most prone to status quo management serve hundreds of customers only and are managed by property owners who vote according to property share. Many of these are poorly capitalized and cannot finance basic infrastructure repairs such as leakage (Naik and Glickfeld 2017). Consolidating water utilities is seen as an enormous uphill battle and impossibly expensive. Small water utilities' infrastructure would have to be upgraded, and any private utilities would have to be purchased. Yet consolidation into regional utilities could be more effective at implementing wastewater reuse facilities, a systematic approach and funding of landscape change, and planning and implementation of stormwater capture and infiltration projects, in addition to infrastructure repair and upgrading. Such larger scale entities would also have greater capacity to revise revenues and strategies to decouple infrastructure funding needs from volumetric water sales, which has proven a significant constraint to investment. Going forward *one-water* agencies, combining stormwater, sanitation, supply and groundwater, are a strategy toward greater fiscal health and moving toward integrated water management.

Theme 10: Promote Openly Available Data and Models

Studies of water management in LA County, like many places, benefit from agencies that publish significant amounts of data. One example of openly available data in LA is LA County's hydrologic model, the Watershed Management Modeling System (LACDPW 2013). This open-source model and its underlying data has facilitated numerous studies for government planning processes and external research. LA-area agencies that publish data and models to date have significantly contributed to integrated water management in the region. Through this research, we similarly sought to contribute to available data by publishing reports and open-source repositories of results and contributing data, such as a *Github* repository with databases of countywide local water reliance analysis (Porse 2017). For other regions in the world, implementing and facilitating data collection and access will be important to addressing water planning for shortages.

Discussion

The key themes elaborated above offer a framework for policy goals and necessary actions to achieve greater local water supply reliance across LA County and can provide a template for replication. They draw on an integrated perspective of urban water management from a socio-technical systems perspective, to understand how infrastructure, management regimes, and behavior all interact to influence future trajectories.

The water supply regime transformation that emerges from the synthesized findings has the following key components: (1) Water conservation, supported by scientifically informed transformations of the urban landscape, is critical to reducing demand to levels that can be supplied locally; (2) groundwater basins have hundreds of thousands of acre-feet of capacity for additional water storage, but the current agreements for pumping are based on 20th century assumptions of imported water availability. Conjunctive use can be tied with timely storage of imported water in years of high rainfall to keep basins productive and adequately supplied; (3) water reuse, including wastewater and increased opportunities for stormwater infiltration are part of this trajectory toward regional water self-reliance; (4) transformation of current siloed water management systems toward a *One Water* management regime that integrates water supply, groundwater management, water infiltration and recycling will shift the system toward water self-reliance. This is likely the most difficult change of all, requiring overcoming the 20th century establishment of single-purpose agencies for each jurisdiction.

While the synthesized results from modeling, analysis, and interviews show the possibility for a regional future of water sufficiency, the sociotechnical system's lock-in makes the transition challenging. We suggest this is the case for many cities and regions that have developed over the course of the 20th century. Rules, codes and conventions, piping and infrastructure coupled with expectations of water use and landscapes, create obdurate circumstances that effectively create water shortages amidst the potential for there being enough water.

Current groundwater adjudications, in particular, are highly codified and pose challenges for quickly adapting LA's water systems. For example, if agencies without pumping rights invest in stormwater capture and recharge, they do not benefit from opportunities for seasonal or annual storage. Moreover, the status of captured stormwater in many adjudications is even in question. It is seen in some basins as part of the natural recharge regime, which is only available to pumpers with current rights. In this way, additional water storage, including the injection of treated sewage water in locations where groundwater basins are adjacent to those plants, faces a sociotechnical conundrum. This social construction of groundwater management and water rights, impedes the full utilization of the groundwater basins to their maximum potential for water storage and use. Thus they are a physical water resource in the region which the sociotechnical system has marginalized.

Planning for Climate Variability and Change

Climate change is often noted as a contributing driver of local water reliance efforts in LA, but precipitation in Los Angeles is already highly variable. In a given year, LA receives a handful of storms, often via large events driven by atmospheric rivers that inundate the Pacific Coast. This type of rainfall will likely grow in frequency and intensity in coming years (Dettinger et al. 2011; Warner et al. 2015; Gao et al. 2015). But climate change will also intensify drought in a region that already experiences seasonal and annual periods of extreme dryness (MacDonald 2007; Diffenbaugh et al. 2015; Allen and Luptowitz 2017). Studies indicate that the alpine sources of runoff in the Sierra Nevada that feed much of LA's imported water will likely experience decreased snowpack accumulations in future years. This increases spring runoff volumes and, without additional surface storage or groundwater recharge, changes the timing and availability of imported water during the late summer and early fall months (Costa-Cabral et al. 2013).

Within the LA basin, increases in mean surface temperatures associated with climate change will affect hydrologic cycles and water supplies that support aquatic habitat, irrigated landscapes, and protected areas. In particular, more extreme rainfall events will require infrastructure capable of capturing larger storms to recharge groundwater basins to meet future water supply goals (USBR 2015; Porse et al. 2017). Aquatic habitats and marshlands will be affected by water conservation, imported water losses, and precipitation changes that reduce runoff (Read et al. 2018; Thorne et al. 2016; Manago and Hogue 2017), themselves artifacts of the current engineered system. Urban trees may suffer in future years without conversion of the tree canopy to low-water species (Pataki et al. 2011; Litvak et al. 2013, 2017a, 2017b; Vahmani and Ban-Weiss 2016).

Many of the adaptation actions for dealing with the effects of climate change align with research findings for enhancing local reliance. First, promoting continued outdoor water use conservation is key. Residential lawns constitute half of all urban water use throughout much of California, including LA (Hanak and Davis 2006; Mini et al. 2014b). Some parts of LA, notably coastal areas with high-density urban development and small yards, have much lower use, while other parts of LA, especially inland areas and affluent neighborhoods with sizable well-irrigated yards, use more (Mini et al. 2014a; Litvak et al. 2017a, p 20; Porse et al. 2017). Smarter investments in lawn replacement programs, driven by scientific knowledge and community engagement, are the best strategies for achieving long-term water savings and enhanced urban landscapes. Second, agencies must enhance supplies that are resilient to climate change. This includes increasing groundwater recharge and storage capacity for drought contingency, reducing reliance on distant imported sources, enhancing investments in alternative sources, and promoting capacity for timely use or storage of distant water during wet years.

Conclusions

Going forward a closer understanding of the ways in which sociotechnical systems evolve to construct resource availability and/or scarcity and vulnerability in cities is called for (Pincetl et al. 2016a). The *idea* that Los Angeles or Cape Town face natural water shortages due to climate change, rather than ones that result from how these systems are constructed and managed over time, preclude the possibility of change. California's water systems, which are highly capital intensive, engineered, and technocratic, are similarly the products of expectations and rules constructed to support those systems and twentieth century modernist assumptions. Water was assumed to be plentiful, with the only obstacle being proper conveyance systems and management of the new engineered infrastructure. With the impacts of a shifting climate that result also from human decisions, we cannot afford to simply accept the conditions of those systems and must tackle unlocking them—rules, regulations and pipes and pumps. They are coupled and self-reinforcing and work together.

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Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

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Water Distribution System Efficiency

An Essential or Neglected Part of the Water Conservation Strategy for Los Angeles County Water Retailers?

Prepared by

Dr. Kartiki S. Naik and Madelyn Glickfeld

UCLA Water Resources Group
Institute of the Environment and Sustainability
University of California Los Angeles

UCLA Institute of the Environment and Sustainability

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Photo courtesy: www.reddit.com

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Water Distribution System Efficiency: An Essential or Neglected Part of the Water Conservation Strategy for Los Angeles County Water Retailers?

Prepared by

Dr. Kartiki S. Naik* and Madelyn Glickfeld**

*Staff Research Associate, Institute of the Environment and Sustainability, University of California Los Angeles, kartikin@gmail.com

**Director, Water Resources Group, Institute of the Environment and Sustainability, University of California Los Angeles, madelyn.glickfeld@ioes.ucla.edu

Executive Summary

The water governance system in Los Angeles County is complex and fragmented. Potable water supply in metropolitan Los Angeles County relies on over 100 water retailers, both public and private. It is unclear how the current system with many small water retailers will succeed in promoting integrated water resource management. Among other changes, there will need to be a shifting of water supply sources from predominantly imported to more local resources through conservation, recycled water usage, stormwater capture and groundwater management. The institutional capacity of water retailers to instigate this transition will depend heavily on their capacity to maintain reliable water deliveries without significant losses from leakage and failing infrastructure. Additionally, with drought conditions prevalent in eleven of the last fourteen years in California, and increasing evidence of climate change impacts on all water resources in California, it is crucial that water retailers minimize water losses through their distribution systems to match the increasingly stringent conservation efforts required of their customers, and to efficiently utilize scarce supplies.

Until this year, existing regulations for water agencies in California only requested information about system losses for potable water systems with more than 3000 connections. These numbers were reported through Urban Water Management Plans every five years. However, loss estimates through breaks and leaks have not been separated out from other non-revenue uses of water. To date, the most effective efforts to monitor water losses in California are voluntary and limited to members of the California Urban Water Conservation Council. To understand water distribution efficiency in urban Los Angeles County, we developed a questionnaire regarding leakage monitoring, system-wide water losses, and the implementation of pre-emptive best management practices. We surveyed 10 of the approximate total of 100 water retailers. The sample was representative of retailers of many types, sizes, and geographical locations in metropolitan Los Angeles and divided into tiers of size (small, mid-sized and large) based on the number of connections served. The survey questionnaire also addressed other metrics including per capita water consumption, leakage volumes, water loss estimation methodology, water loss estimates and infrastructure monitoring and replacement.

The survey indicated several findings. First, the *percentage* of water loss due to breaks and leaks, though possibly misrepresentative, is still a widely used metric to measure water losses. Sixty percent of the agencies sampled still monitor only 'unaccounted for water' and not 'real losses'. Retailers that do measure real losses reported them to be between 3-4% of total water supplied, which is an improbably low compared to international estimates as elaborated in the literature review section. Different water retailers were divided on the efficacy of leak detection technologies, which demands more education on available leak detection technology and their usage.

Larger retailers reported greater use of most of the best management practices addressed by our survey to maintain storage and distribution systems. Most small retailers did not report prioritizing adoption and implementation of best management practices to minimize water loss. Also, small Mutual Water Companies that we contacted did not have information on distribution water losses available publicly. To improve water efficiency, small retailers could pool resources and expertise to better detect, monitor and reduce distribution water losses. Investor-owned utilities and special water districts serve a large customer base, but as a group, they were least responsive of all the sample water retailers we contacted. . In summary, California water regulations should aim at recommending crucial best management practices, ensuring accurate and verifiable water loss monitoring and prescribing an effective water loss metric and maximum acceptable standard as a roadmap for water retailers.

Contents

Introduction

The largely varying precipitation and large population of Los Angeles County renders it dependent on imported water for majority of its water supply. The County of Los Angeles imports more than 60% of its water supply from three major sources, the Los Angeles Aqueduct supplied by the Eastern Sierra watershed, the Colorado River Aqueduct, and the California Aqueduct supplied by the Sacramento-San-Joaquin River Delta (Bay Delta). Groundwater forms 35% of the total water supply in the region (Los Angeles Department of Public Works, 2014).

Twelve of the last sixteen years have been drier than normal for California.[1]. The Sierra snowpack has been reduced to a historically low 5% (California Department of Water Resources, 2015). For the Eastern Sierras, global climate models predicted a temperature rise of 2 to 5 °Celsius, leading to an increase in the mean fraction of precipitation falling as rain (Costa-Cabral, Roy, Maurer, Mills, & Chen, 2013). Recent work by Diffenbaugh (2014) finds that anthropogenic warming has increased the risk of severe drought in California. Such warming outweighs the increased soil-water availability due to early runoff during the cooler low evapotranspiration period (Diffenbaugh, Swain, & Touma, 2014). Global climate models have consistently predicted that runoff in the Colorado Watershed will reduce by 10-30% and have already translated as reduced storage levels in Lake Mead and Lake Powell. (Barnett & Pierce, 2009). The Bay Delta is threatened by future rise in sea levels as predicted by climate models, which might lead to restrictions in water allocations to southern California via the State Water Project. Additionally, dramatic increases in "permanent" versus "annual crop" irrigated agriculture (United States Department of Agriculture, 2011), all have increased water demand, creating a potentially chronic water shortage across a state with widely variable precipitation.

Because of the drought emergency, California has quickly moved into a new era of water management. The Governor issued an executive order on April 1, 2015 that will require every water user, from farm to industry to urban users to cut back on water use (Governor of California, 2015). The State Water Board is preparing to issue emergency regulations for mandatory cutbacks averaging 25% to all urban water suppliers (State Water Resources Control Board, 2015). In response, the Metropolitan Water District of Southern California which serves region of 18 million people, passed a mandatory allocation reduction on April 14, 2015, averaging 15% to all of their member agencies, with heavy fines for excess delivery (Metropolitan Water District, April 2015).

While some of these drastic cuts will be reduced when the drought abates, major changes in water use will be expected and water suppliers will need to pay new attention to their distribution efficiency as well as customer conservation. Retail water systems in Southern California can lose a significant amount of water and thus, revenue through leaks and breaks in their distribution systems. Large main breaks can also cause severe property damage. For instance, in July 2014, the 93 year old main on Sunset Boulevard in Los Angeles not only lost

[1] Personal Communication, William Patzert, Climatologist, NASA's Jet Propulsion Laboratory

10 million gallons[2] (2% of the daily use of 3.4 million customers in Los Angeles city), but also caused tremendous damage to university property and hundreds of parked vehicles at the University of California Los Angeles campus. Based on an assessment of over 11,000 miles of water mains, the deterioration in the potable water infrastructure in evident across Los Angeles County (American Society of Civil Engineers, 2012). As part of conservation efforts, water retailers need to monitor their distribution systems to manage them for efficiency.

The Environmental Protection Agency describes water efficiency as the "long term ethic of saving water resources through the use of water-saving technologies and practices" (United States Environmental Protection Agency, 2015). The state of a retail water distribution system determines the retailer's efficiency in conveying it to their customers. The water distribution efficiency of a given water retailer can be evaluated by their competence in maintaining, operating and monitoring the storage and distribution system, and developing their financial resources to rehabilitate infrastructure. This capacity can be as significant a determinant in the retailers' contribution to water conservation as consumer efforts are. The 2007 US Conference of Mayors assessed that revenues collected by city departments, account for about 80-90% of the capital required to replace their sewer and water infrastructure. This backlog combined with the financial implications of regular rehabilitation and maintenance of old infrastructure can lead to a high increase in monthly service charges to customers (Sedlak, 2014). Retailers should gauge their water distribution efficiency by measuring the loss of water during conveyance to their customers and take steps to reduce revenue losses via water leakages.

In this study, we investigated the water distribution efficiency of a sample of water retailers in metropolitan Los Angeles County. The study consists of reviewing prior research, developing a survey for water retailers, and analyzing results. Much work exists regarding water efficiency. To inform the interpretation of our survey results, we surveyed the literature on water efficiency and the development of best management practices related to losses from breaks and leaks, as well as practices to manage systems to minimize losses. The American Water Works Association releases a manual on best management practices to reduce water loss reduction. In this study we considered recommendations such as monitoring breaks, leak detection, infrastructure testing and replacement. In particular, we overview the existing reporting requirements for the State of California and voluntary reporting solicited by the California Urban Water Conservation Council.

The entire agglomeration of water retailer jurisdictions that we sampled from in urban Los Angeles County are shown in Figure 1. Thus, water service in urban Los Angeles County is highly fragmented and involves many small retailers (Cope & Pincetl, 2014; Cheng & Pincetl).We developed a stratified sample survey, including in depth interviews with approximately 10% (10 out of about 100) of the water retailers in urban Los Angeles County. We examined how they measure water losses from leakages or breakages in their systems, as well as technical expertise and financial investments to reduce leakage. We have considered leakages as subsurface water losses, whereas breaks are water losses above the ground surface. The survey was designed to obtain a balanced stratified sample. The stratified sample ensured

[2] Main break near UCLA. http://ktla.com/2014/07/29/water-main-break-in-westwood-prompts-flooding-of-streets-strands-people/ (Accessed 06/18/2015)

that the number of participants in each category based on size, type and geographic location of water retailers, was proportional to those in the corresponding categories of the population. The survey was designed to collect information on the estimation and reporting of typical water loss, existing infrastructure maintenance and replacement strategies and distribution system failures.

Figure 1 Study area and potable water retailers in metropolitan Los Angeles County (Deshazo & McCann, 2015)

Literature Review and Background

Emergence of Global Water Efficiency Standards and Practices

Water loss through distribution systems is a global issue. In 1987, the American Water Works Association (AWWA) addressed the issue of loss of revenue for agencies via water distribution leakages. Dr. L.P. Wallace and his students from Brigham Young University, overviewed techniques of monitoring and minimizing losses in an AWWA Research Foundation report (Wallace, 1987). In the early 1990s, AWWA released Water Audits and Leak Detection manuals after which it joined the International Water Association (IWA) Water Loss Task Force in 1996. AWWA released manuals of water supply practices in 1991, 1999, 2009 describing benefits of water balance audits, their water audit method and recommended measures for water loss control (Fanner, et al., 2007).

The IWA Water Loss Task Force (WLTF) was a small group of water utility professionals from around the globe which was formed in 1996, Allan Lambert from the United Kingdom was the Chair. The American Water Works Association (AWWA) was one of its members from 1997 to 2000 (American Water Works Association, 2009). The goal of the WLTF was to create a common global framework for water loss performance indicators using common terminology and a standardized water balance equation[3]. The IWA published Performance Indicators for Water Supply Service which described this global methodology developed by the IWA WLTF (Alegre, 2000).

The IWA methodology was based on the original Water Audits and Leak Detection Manual published by the AWWA in 1990 (American Water Works Association, 1990). The IWA WLTF published a series of 8 articles on a 'Practical Approach' for global best management practices in water loss assessment and reduction strategies in the Water21 magazine in through June 2003 to December 2004. In this second article, they separated various water loss components and proposed this as 'best practice' standard water balance as shown in Fig. 2. (Lambert A. , 2003).

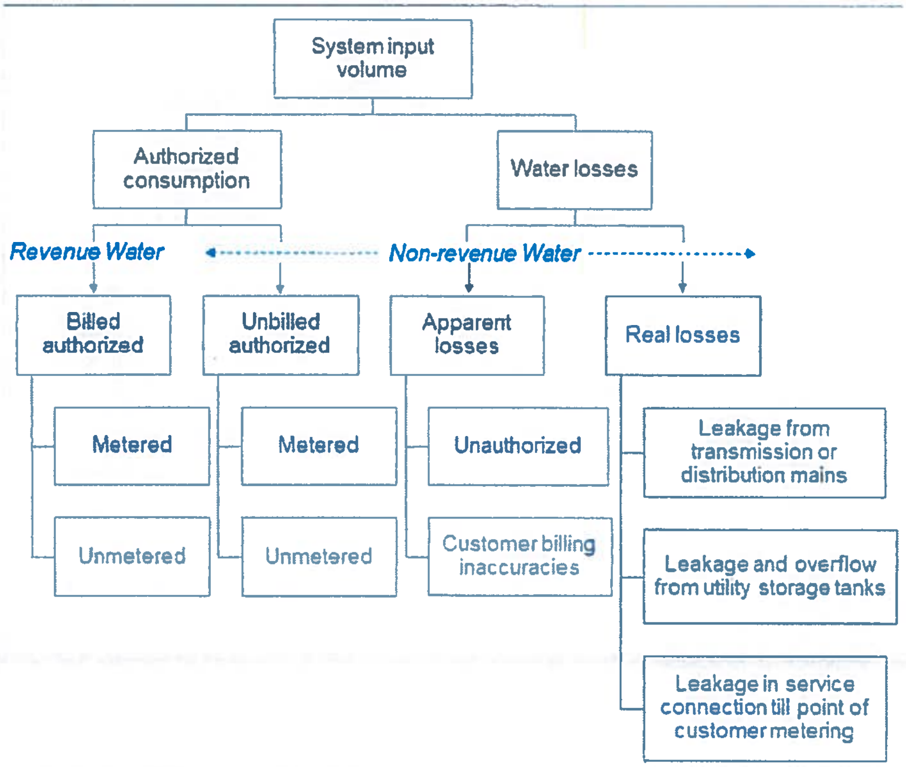

Figure 2 IWA water balance *(Lambert A. , 2003)*

The IWA conducted surveys across many geographic regions to gather data from water retailers to develop a framework for determining water losses. The primary motivation for this study was to reduce losses in revenue from water losses. They compared water retailers across England, Wales, California, the Nordic[4] countries, Japanese and German cities, Australia, Singapore and Malta in terms of water losses. The data from various nations was collected by the IWA Water Loss Task Force in the form of an International Dataset and was presented in

[3] Water Ideas 2014 – Committees, http://www.waterideas2014.com/?page_id=65 (Accessed 3 23 2015)
[4] Denmark, Norway, Sweden, Iceland, Finland

their report from 2001 (Lambert A. O., Water Losses Management and Techniques, 2001). They discouraged using the term "unaccounted for water" to designate losses from a distribution system due to its varying interpretations globally. They discussed that real losses represented as percentage can be ambiguous. They observed that an equivalent real loss volume expressed as percent appears higher for regions with lower water consumption per connection. The percent water loss reported was about 15% for Australia and 6% for California, which may be heavily skewed by the difference in their daily water consumption per connection. Lambert (2002) summarized the motivation behind this study, resulting conclusions and recommendations by the IWA Task Force.

The AWWA Water Loss Control Committee adopted the updated Best Management Practices for water loss prevention recommended by the IWA WLTF based on their international study and dataset and published and endorsed their conclusions on Best Management Practices in their 2003 committee report (American Water Works Association, 2009).

Many global efforts exist regarding improved water auditing technology. McKenzie et al (2005) overviewed standard water audit software in South Africa, Australia and New Zealand and the methodology. Soon, after its joint efforts with the IWA, AWWA Water Loss Committee Control launched a free Water Audit Software in 2006 followed by several updated versions. The latest version available now is version 5 released in 2014. The software uses a top-down approach to calculate the real losses, that is, the actual leakage from the system- what is left after all other losses are accounted for (American Water Works Association, 2009). Real losses are defined as the volume lost "the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering" (Lambert A. , 2003). The AWWA Water Audit Software can be a good indicator of water distribution system losses if used accurately. The model used in the software includes certain assumptions for the user, such as, an ability to extricate different kinds of authorized and unauthorized usage from the supply volume and a high confidence level in reporting unmetered usage. The end product grades the water distribution system with the corresponding Infrastructure Leakage Index value, which represents the condition of the distribution system as compared to a system in "perfect" condition (American Water Works Association, 2009).

The software lists recommendations for overall and immediate measures to improve the system's condition and reduce water losses based on the "Infrastructure Leakage Index" which is a "grade" that the system receives based on its water losses and efforts such as efficiency of repairs, leakage control and upgrades calculated in the AWWA Water Audit. This methodology then formed the backbone of many water audit software packages globally. Fantozzi et al. (2006) discussed the common approach for leak detection and control efforts in North America, Canada, Australia and Europe. The observations in this study were based on the authors' experience in these regions.

The AWWA released a report in 2007 to provide guidelines on how to use appropriate performance indicators for losses, conduct a water audit, determine leakage and formulate and execute loss reduction programs (Fanner, et al., 2007). The IWA WLTF has now evolved into the Water Loss Specialist Group, a consulting firm offering software and other tools aims at reducing water losses from urban water systems.

Studies on Infrastructure Rehabilitation Strategies

Simultaneously, several studies focused on the cost-effectiveness of infrastructure replacement and influential factors. Colombo and Karney (2002) determined the economic consequences of leakages in a system and deduced that energy costs increase with increasing leakage volumes. Southern California Edison conducted a study to determine water and energy savings through leak detection and repairs for three utilities and demonstrated the economic significance of minimizing water losses[5]. They used the AWWA methodology for water auditing and field leakage measurement to obtain data on water losses. The engineering consulting organization implementing the study, selected suitable cost-effective leakage intervention tools for each water utility, while an independent team evaluated the water and energy savings. These intervention tools were based on the guidelines to calculate the 'Economic Level of Leakage', provided by this consulting organization and Alliance for Water Efficiency (Sturm, Gasner, Wilson, Preston, & Dickinson, 2014). They estimated cumulative water savings of 83 million gallons per year (255 acre-feet per year) and cumulative energy savings of about 500 Mega Watt-hours per year for the three utilities via this leak detection study. Engelhardt et al. (2000) discussed physical causes for deterioration of pipes, such assoil and water corrosivity, traffic loading and high alkalinity in pipe material in the United Kingdom. They described the regulatory process for the privatized water industry in the U.K., which consists of an external agency that regulates the economic and water supply performance. They reviewed distribution system rehabilitation decision models adopted in the U. K.

Several studies proposed optimization models for strategizing rehabilitation. Dandy and Engelhardt (2001) proposed using the Genetic Algorithm to optimally schedule replacement of water mains in a distribution system. They optimized with respect to available funds and applied it to a pressure zone in metropolitan Adelaide in Australia. Nafi and Kleiner (2010) used the Genetic Algorithm to optimize for economies of scale and road improvements and applied it to a community in Ontario, Canada as an example. Dandy and Engelhardt (2006) followed up their study in 2001 by suggesting a multi-objective genetic algorithm approach for constraints such as replacement and repair cost and reliability (lack of interruptions). Bogardi and Fulop (2012) used a space-time probabilistic model to minimize cost and pressure drops in the distribution system. Roshani and Filion (2014) optimized the timing of water main rehabilitation and replacement using a sorting genetic algorithm. Li et al. (2015) developed a decision-making algorithm based on a sorting genetic algorithm for pipeline replacement minimizing cost and service interruptions.

Global Evaluation of Water Distribution Efficiency

The U.S. Environmental Protection Agency and the Water Research Foundation jointly funded a study by an engineering consulting firm, Water Loss Optimization to review of water loss reporting guidelines for state agencies, and organizations in Austria, New Zealand and Australia. The study also reviewed guidelines and standards for nine North American state agencies and organizations (including California). According to the review, Austria and

[5] Southern California EDISON Water Leak Detection Program and Water System Loss Control Study, by Water Systems Optimization (2011)

Australia achieved very low levels of real losses in their distribution systems. They also reviewed literature for frequency of breaks in the system and observed large variance in the collected data. The study found a weighted average annual frequency for main breaks in North America of 25 failures for every 100 miles of pipeline. Nine North American utilities participated in this study to demonstrate the use of AWWA's Component Analysis Tools. For California, the understanding of the usage of the tool and the quality of collected data was less than satisfactory. About 35% of the water audits from member water agencies of the CUWCC shows implausible results, out of which 28% of the utilities claimed that their distribution system was in better condition than the 'theoretically perfect condition' prescribed by the water audit. (Sturm, Gasner, Wilson, Preston, & Dickinson, 2014).

National Water Efficiency Standards and Regulations

Beecher obtained information on water loss policies for forty-three states in the U.S.A. addressing the existence of policies, terminology defining water loss, monitoring methodology, targeted maximum losses, planning and technical assistance, data collection and performance incentives. From the seventeen jurisdictions defining "unaccounted for" water, only three state agencies provided a method of calculating it. Twenty-threc states and three regional authorities reported the use of a standard for water losses which varied from 7.5-20%; most commonly 15%. Only fifteen state agencies required some form of auditing to enforce standards. (Beecher, 2002).

Recommendations regarding water loss targets are scarce. The only target or recommendation for maximum water losses found in literature dates back to an article published by AWWA in 1957 (American Water Works Association, 1957). It noted that the water losses from well-maintained systems with a consumption of 100-125 gallons per capita per day (GPCD) can vary from 10-15% (Liston, et al., 1996). AWWA later refuted this value in their committee report in 1996, deeming the loss value obsolete due to significant changes in operating costs and technological resources. The average losses from a system depend on system age, size, material and population density, which calls for a more customized cost-benefit analysis (Alegre, 2000). We observed in our interviews of water retailers in urban Los Angeles County, that this standard has been followed by most of these retailers who practice leakage monitoring and use the AWWA software. According to Beecher's survey in 2002, the California Urban Water Conservation Council (CUWCC) mandates that the member agency conduct the complete Water Audit if their unaccounted for water exceeds 10% of the total volume supplied. (Beecher, 2002).

In 2002, US EPA completed seventeen case studies of water conservation and efficiency by urban water utilities across the country, and in Canada (United States Environmental Protection Agency, 2002). Of those seventeen case studies, leak detection and repair is named as a key strategy in six locations: Ashland, Oregon; Gallitzin, Pennsylvania; Houston, Texas; the Massachusetts Water Resources Authority; New York City and Seattle, Washington. 46% of the utilities studied outside California reported leak detection and repair as a major strategy, while none of the five utilities studied in California had this focus.

In 2012, The Alliance for Water Efficiency[6] conducted a survey of all states to collect information on State regulations for water efficiency and conservation. While the study mostly targeted conservation policies, one of the twenty questions asked if "the state has regulations or policies for water utilities regarding water loss in the utility distribution system" (Alliance for Water Efficiency, 2012). They concluded that though most states have regulations for monitoring utility distribution water loss, some states do not rely on state-of-the-art methodologies for water auditing, whereas others lack in legal foundation for their requirements. For California, the Department of Water Resources is the agency authorized to require water retailers to submit distribution water loss estimates.

Existing Measures for Water Loss Monitoring in California

The California Department of Water Resources (DWR) released a workbook in 1986, which contained a manual and a guidance tool for estimating the value of the leak volume[7]. The latest version of the Workbook was in released in 2002. The overall goal of this project was to prepare a comprehensive guidance document which can be used by water utilities to: (1) ensure accurate measuring of supplied water and meter and billing accuracy, (2) prepare an accurate water audit (and water balance), (3) evaluate the economic implications of leakage, plan and (4) suggest water loss-reduction programs (Fanner, et al., 2007). This guidebook is different from the new AWWA Water Audit, as the main focus of the Workbook is to guide the utility in accurately estimating the total water supplied subject to meter and billing inaccuracies. The Guidebook does not specify methods to estimate all these values, but suggests general measures to correct leak issues. It also overviews leak detection techniques.

Since 1990, DWR has collected Urban Water Management Plans (UWMP) from Urban Water Suppliers every five years. Urban water suppliers are defined by the most recent amendment of the Urban Water Management Act[8] as "a supplier, either privately or publicly owned, providing water for municipal purposes either directly or indirectly to more than 3000 customers or supplying more than 3000 acre-feet of water annually". The aim of the UWMP is to help urban water suppliers plan for a 20 year horizon of water supply and include a reliability study for existing and planned water sources for normal, dry, multiple dry years.

The Water Act of 2009 adds deliverables such as a map of the water supply area, methods for estimating conservation targets and baseline water usage, population estimation methods and sources, metered or measured flows, groundwater management plans, description of the groundwater basins and an report on the location, amount and sufficiency of the groundwater pumped by the supplier in the past five years and a schedule of implementation for water management measures. To comply with the Water Act of 2009, agencies included plans to decrease per capita water usage by 20% by 2020 in the 2010 UWMPs. DWR assesses these plans based on the Urban Water Management Planning Act.

[6] Alliance for Water Efficiency, http://www.allianceforwaterefficiency.org/, a nonprofit organization focused on the efficient and sustainable use of water

[7] California Department of Water Resources Website, http://www.water.ca.gov/wateruseefficiency/leak/ (Accessed 3/23/2015)

[8] California Water Code Division 6, Part 2, Section 10610-10610.4

Up to this year, the Water Code required reporting "system losses" in the UWMP. The term system losses has not been defined, except as the general loss of water through any method from the supplier's distribution system. In California and elsewhere, water losses from potable distribution systems are primarily being measured by many utilities as "unaccounted for water", which represents the deficit between the purchased and metered supplied water volumes. This term encompasses various types of water losses in addition to actual leakages, such as demand for fire-fighting water, fire training, routine testing and maintenance of fire hydrants, street cleaning or municipal parks, billing errors, meter errors and water theft. Losses from storage leaks, pipe leaks and breaks have been hard to isolate with current approaches.

The Water Act of 2009 required an Independent Technical Panel (ITP) to advise the DWR on new demand management measures, technologies and approaches to improve water use efficiency every five years after 2010 (Senate Bill AB 1420, California Water Code 10631.7). The DWR convened the ITP in May 2013. The ITP recommended reporting of distribution water loss by urban water suppliers supported by water loss audits based on past ten years as part of the UWMPs. They also recommended a standardized reporting system for the UWMPs (Independent Technical Panel, 2014).

This recommendation became law this year. SB 1420 (Wolk)[9] was effective on January 1, 2015, requiring that all water retailers submitting 2015 Urban Water Management Plans use the American Water Works Association Water Audit Methodology (AWWA) to specifically report on pipe leaks and breaks. This methodology and the method of interpreting its results and estimates are described in the AWWA M36 Manual with their recommended Best Management Practices. SB 555 (Wolk)[10] was introduced in February 2015 and then amended in April 2015 for water loss management. This bill would require each urban water supplier to submit completed water audit reports based on the AWWA water audit methodology and provide information on measures adopted toward water loss reduction. These reports would need to be validated and posted on their website for public viewing and comparison. It would also require the DWR to provide technical assistance for water loss detection programs conducted by urban water suppliers. The DWR would also require to develop rules for performance standards, validation process and metrics for the reporting of annual water loss reduction by urban water suppliers with the State Water Resources Board. After 2015, water loss from leaks and breaks would have to be reported on for each year and included in the next five year update.

California Urban Water Conservation Council: An Independent Approach

The California Urban Water Conservation Council (CUWCC) is a membership organization of water retailers and suppliers that has developed Best Management Practices for water usage efficiency. The CUWCC has three groups of members, water suppliers, businesses and public advocacy organizations. Water retailers that are members are required to report their Best Management Practices (BMPs) for water conservation and loss with AWWA water audits every two years. Reclamation Contractors or members of Bureau of Reclamation are required

[9] Ch. 490, California Water Code, amending Sections 10631 and 10644
[10] Ch. 490, California Water Code, amending Section 10608.34

to submit these BMPs annually[11]. California's Urban Water management Plan (UWMP) Act allows urban water suppliers that are CUWCC members and that comply with CUWCC's BMPs can submit audits in addition to the Demand Management Measures suggested by the DWR.

Member water retailers include an assessment of real (leaks and breaks) and "apparent" losses and the economic value of real loss value of real loss recovery in terms of avoided cost of water. The CUWCC adopted the AWWA Water Audit Software based the AWWA/IWA methodology and requires members to use it for their analysis. The estimated losses require data validation by methods recommended by the AWWA methodology. The CUWCC also requires a Component Analysis every four years which analyzes the estimated losses and their causes[12].

These BMPs were formulated using the 10% maximum standard for unaccounted for water recommended by the AWWA Leak Detection and Water Accountability Committee (Dickinson, 2005). The above mentioned full-scale water audit is mandated by the CUWCC for the member utilities, provided the deficit or unaccounted for water exceeds 10% of the total distributed volume. The conditionality of the full-scale audit is not stated on the CUWCC website, but it is stated in the original BMP Retail Coverage Report input sheets used by the member utilities[13]. The full scale audit using the AWWA audit methodology would provide clear leak and break loss estimates.

To summarize, the most advanced efforts toward water loss reduction in California are voluntary (by CUWCC members). Water auditing relies on the method of data collection and accuracy in reporting and water retailers are not required to report on other best management practices to reduce water loss from their distribution system. There are no regulatory standards for maximum allowance of water loss and high quality data to create a benchmark.

Survey of Real Water Losses for Water Retailers in Urban Los Angeles County

Current regulatory and reporting standards in California raised certain issues on their effectiveness which are described as follows.

1. Are real water losses measured by water retailers, and if so, are these verifiable?
2. Are crucial Best Management Practices followed by water retailers to minimize water losses?
3. How regularly do water retailers monitor and maintain their distribution system for water loss reduction?

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[11] http://www.cuwcc.org/Resources/Reporting-Database/Reporting-101 (Accessed 9/25/2014)
[12] http://www.cuwcc.org/Resources/Memorandum-of-Understanding/Exhibit-1-BMP-Definitions-Schedules-and-Requirements/BMP-1-Utility-Operations-Programs (Accessed 9/25/2014)
[13] The Long Beach Department of Water BMP Coverage Report (2009-2010)
http://www.water.ca.gov/urbanwatermanagement/2010uwmps/Long%20Beach%20Water%20Department/Attach_K.pdf

4. How publicly accessible are data and measurements of water losses from a distribution system made by the water retailer?
5. How do water retailers of different sizes and types compare in addressing the above issues?
6. What is a reliable and accurate metric for real water losses for a water retailer irrespective of its size and type that can be validated via available data?
7. Do California's legal and regulatory requirements under the Urban Water Management Act ensure accuracy in reporting and accomplish real water loss reduction?

Improving water distribution efficiency relies on aspects such as an effective water loss metric and standard, accuracy and frequency of monitoring and reporting, and data quality. The currently available literature, and collected data from the CUWCC and DWR were not sufficient to address these issues. We conducted this survey aiming to answer these questions and provide a snapshot of the current practices in urban Los Angeles County.

Methodology

Study area and Sample set

The Urban Los Angeles Region includes all areas south and west of the Angeles National Forest in Los Angeles County, as shown in Figure 1. It includes approximately 100 retail water systems (serving water to customers) with between 15 and approximately 680,000 connections[14] (Cope & Pincetl, 2014; Cheng & Pincetl). Many types of water retailers exist in the county, including city water departments and city water utilities, county water districts, county waterworks districts, municipal water districts, irrigation districts, nonprofit mutual water companies and private independently owned water utilities (IOU). Each has its own authorizing legislation, state oversight, governance, and customer accountability. Within the study area, water retailers include 41 Cities, 26 Mutual Water Companies, 10 County Water Districts, 8 Investor Owned Utilities, 3 Irrigation Districts, 3 County Waterworks District, 1 Municipal Water District (uniquely, also retailers), and 1 California Water District (Cope & Pincetl, 2014; Cheng & Pincetl). We based our sample selection on this population of retailers and the geospatial database cited above.

The number of connections that each retailer serves in this population follows a Gaussian distribution in the logarithmic form. The population has a large number of smaller retailers in our study area, and a portion of them are not urban water suppliers (serving more than 3000 users), and thus, are not required to submit UWMPs. We used percentile ranking to bin the population into three size-based categories depending on the number of service connections: Retailers ranking below 50 percentile in size as small, between 50 and 75 percentile as mid-sized and above 75 percentile as large retailers.

To represent the population of water retailers accurately, we developed a stratified sample set based on type, size and location of the retailers. We considered a sample size of 10 retailers, that is, 10% of the statistical population for our analysis. We offered the choice of anonymity

[14] We were not able to contact water retailers which served under 200 connections.

and confidentiality to the participating agencies. We only report results and not names to protect confidentiality of survey respondents. To accommodate and correctly represent all types of retailers, we did not include the type 'California Water District', as there exists only one such retailer in our study area. We represented Irrigation Districts, County Waterworks District and Municipal Water Districts as 'Special Districts' (SD) to maintain anonymity.

We contacted 20 retailers and received responses from 10, indicating a 50% response rate. When water retailers decided to not participate in the study, we substituted with other similar retailers to maintain the unbiased distribution in size, location and type. We contacted three mid-sized retailers, while sustaining our requirement for different types and locations of retailers, but did not receive a response from these mid-sized retailers. Hence our analysis will reflect performance of small and large retailers only. We had a low response rate from Special Districts, hence the low representation. Figure 3 shows the final sample set after the replacements. The two tables on the bottom-left show the categorization in our sample. The percentages in the parentheses are the percent representation of such retailers from the entire population in our sample. The pool of participants was dependent on the will for participation and legal binding of the water retailers that we contacted.

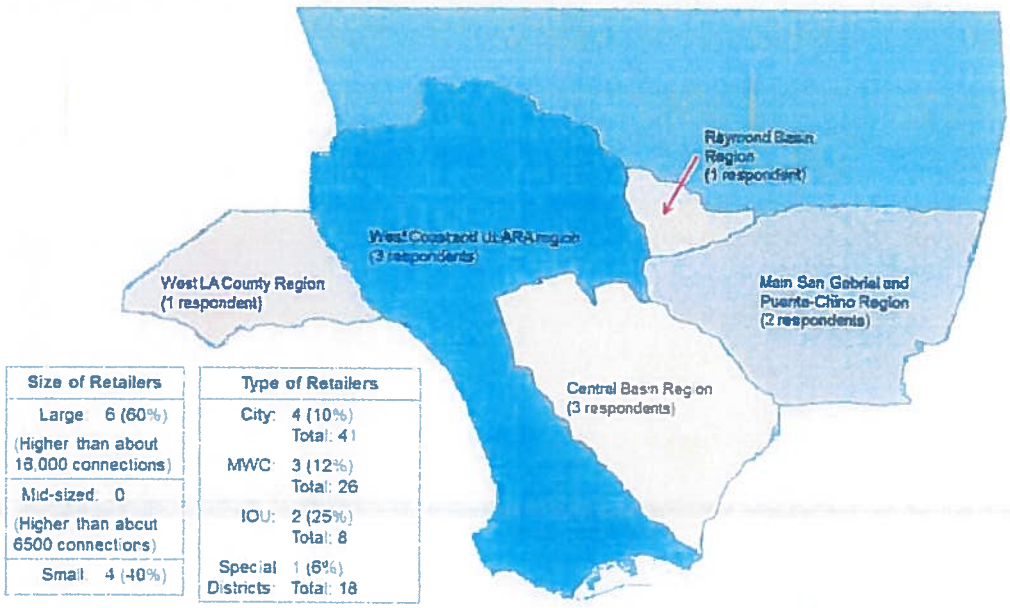

Figure 3 Final sample set for study

Data Collection and Analysis

We conducted reconnaissance interviews with the local water system experts who manage, work with or oversee water retailers to better understand how to develop the interview instrument. Through literature research and these preliminary interviews, we determined that performance of retailers is dependent on monitoring of their distribution system and planning of investments in infrastructure maintenance and replacement. We hypothesized that the institutional capacity and competency of a water retailer can be indicated by their ability to management its water distribution system efficiently, without excessive loss of water due to leaks and breaks and other system defects. We also concluded that maintaining public data is necessary for each retailer to develop an effective strategy for water distribution efficiency improvement. Based on these conclusions, we formulated a set of interview questions to collect data from water retailers in our sample. The interview questions are presented in Appendix A.

We evaluated the retailers' responses using the following criteria and allotted performance indices to each sample retailer:

Table 1 Performance indices allotted for Best Management Practices for water distribution

Best Management Practices	Indices allotted
Monitor GPCD	1
Awareness and regularity of usage of AWWA Water Audit Methodology	3
Existing or future programs for smart meters	1
Preventive maintenance (exercising of valves and flow testing of meters)	2
Infrastructure replacement (for pipes, valves and meters)	3
Monitoring of annual number and location of pipe breaks and implementation of leak detection programs	2
Monitoring of age and material usage on GIS	1

We also assessed the participating water retailers based on their own target parameters. In addition to prescribing to any of above measures, their proposed and achieved targets reflect their efficiency in water distribution. We also conducted a statistical t-test between each type and size of retailer with the rest of the sample.

- Water losses
  - Annual Real Losses in volume or percent i.e., true losses or leakages from transmission and distribution mains, leakage and overflows at utility storage tanks up to customer meters
  - Annual Unaccounted for water in volume or percent
- Percent of distribution pipeline replaced annually
- Number of main breaks for every ten miles of distribution pipeline

During data collection, we asked participating retailers for information that would verify the data, such as reports, monitoring charts and urban water management plans. We awarded points to retailers that provided us with documentation that verified the data. The documentation was either directly provided by the retailer or obtained from the website, urban water management plan, or water master plan. We also examined the accessibility of information through responses to the interview and follow-up questions and available or provided documentation and awarded the retailers points.

Since some respondents did not respond to all of the questions, we followed up with the individual respondents via, email and phone. In case of a lack of response from a retailer after several attempts, we were compelled to remove that retailer from the sample for this particular analysis of overall performance. Owing to this process we could assess the overall performance for 8 water retailers.

Results and Discussion

The survey results yielded findings regarding the responsiveness of different types of entities to participate in the survey public availability of data on distribution system water loss, infrastructure replacement standards, adoption of best management practices and water loss estimates and metrics. All the following results and discussion are based on our sample of water retailers. Any reference to entire population is included explicitly.

Responsiveness and Public Water Losses Reporting

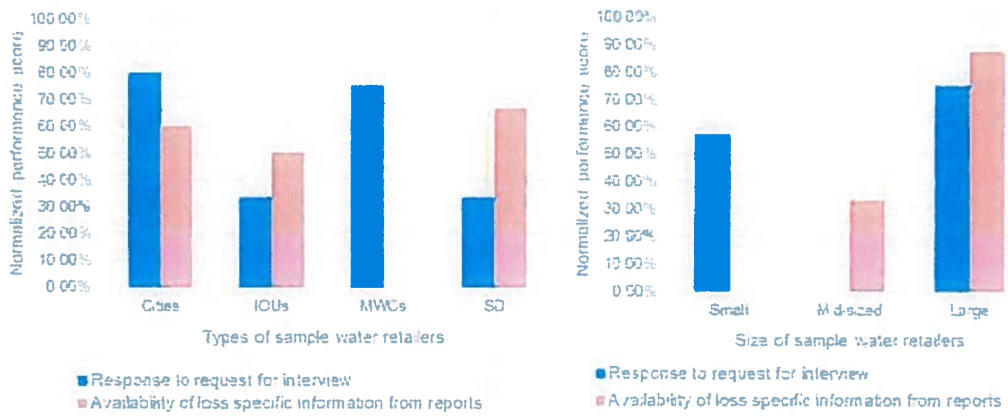

Figure 4 Accessibility and verifiability of water retailers of various types and sizes

To determine the transparency, accessibility and verifiability of various types and sizes of retailers, we assessed the retailers that we contacted, including the ones not participating, based on their responsiveness to the interview and follow-up questions. *Figure 4* depicts the accessibility of these 20 water retailers that we contacted to researchers or citizens seeking information, without the use of the Right to Information Act.

There significant differences in the willingness of retailers to respond to survey request as shown in *Figure 4*. Three large IOUs that we contacted refused to participate in the study declared legal issues. Together, these IOUs serve a large number of consumers in Los Angeles County. but out of the 6 we contacted, only 2 participated in the survey. It was also very difficult to verify the information that large IOU A (from our sample) provided due to lack of responsiveness to follow-up questions. On the contrary, Large IOU B (from our sample) was very responsive and was transparent about its methods of monitoring breaks. impediments and current infrastructure status, and has also formulated its own water audit tool to determine real losses. Overall, IOUs as a group were not responsive to requests for information.

Large retailers serving cities were very responsive and provided documentation to verify their data. Small City B provided incomplete information and showed a lack of responsiveness to follow-up questions. Small City B also discussed several economic issues and political hurdles with respect to infrastructure maintenance and replacement. Another small city did not respond to our several requests for participation.

The MWCs were responsive to attempts of contacting them, but could not provide validating documentation to verify information. Small MWC A could not provide us with complete data and small MWC B could not verify the data they provided on the number of main breaks, reflecting their poor monitoring practices. Thus, though two out of the three MWCs were responsive in this study, due to lack of verifiability, it was difficult to rely on the data that all three MWCs provided. The Large SD (from our sample) was very responsive and provided verifiable information promptly. Other smaller retailers that we contacted included two special districts, an MWC and a City which were not responsive to our request of interview. Overall, we had a 50% success rate in obtaining information from the retailers we contacted, not including the ones unresponsive to follow-up questions.

Infrastructure Replacement Schedule

Most of the participating retailers allocate annual budget funds for replacing a fixed number of miles of distribution pipeline. In our sample set, six out of ten retailers allotted some budget for the same, whereas the other four replaced their distribution pipeline 'as needed'. Figure 4 shows the number of years it will take to replace the entire distribution pipeline based on their current targeted rate of pipe replacement for 2013.

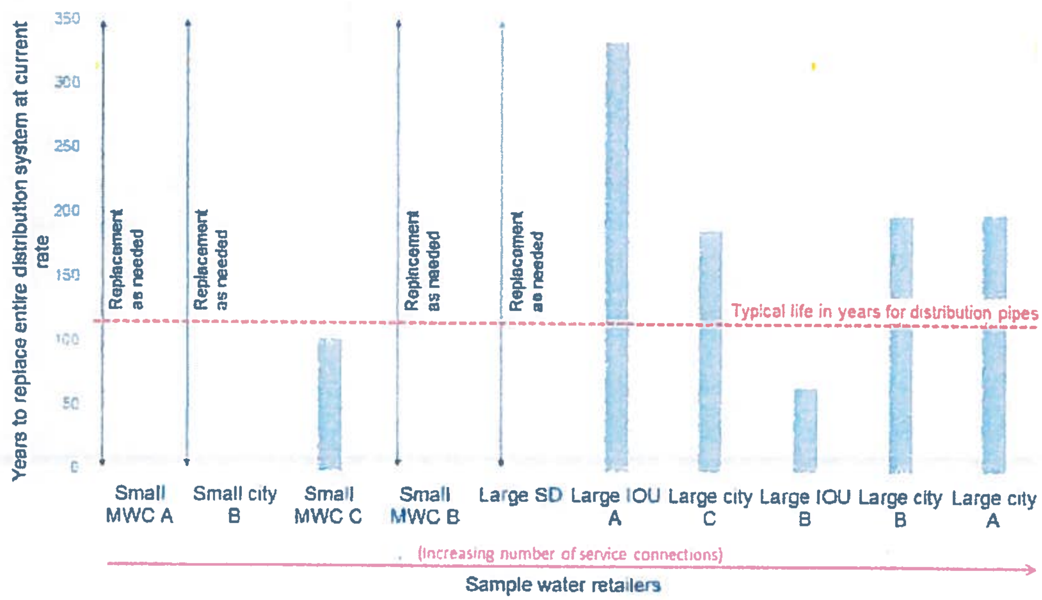

Figure 5 Number of years to replace distribution system for participating retailers

The timelines for replacing current systems are long. Four out of six retailers that replace a fixed number of miles every year will take about 190-330 years to replace their entire distribution pipeline. The typical life in years of the pipes used in their systems was reported to be 100-120 years. For very highly maintained pipes using state-of-the-art materials (e.g. ductile iron), they report the maximum lifespan to about 140 years. Only two participating retailers successfully replacing their pipelines by estimated pipe lifespan. With reliance on pipes potentially beyond their usage life, the water distribution system in urban Los Angeles is susceptible to further pipe failures with tremendous amounts of water loss and significant property damage.

Figure 5 shows the number of breaks for all 10 water retailers. We normalized the number of main breaks for each sample water retailer by the water distribution length of the system, which makes them comparable. Factors such as age of pipes and storage facilities, the pipe materials and construction quality, the valves, meter accuracy, soil acidity, high operational pressure and variation due to undulating topography or acute diurnal variation can strain distribution system components. According to some water suppliers from the study sample, the longevity of distribution system components is also determined by overlying traffic density.

Small MWC A and small MWC C claimed to have zero and one break in the entire year of 2013. The other small retailers had 22-26 main breaks every 100 miles of pipeline, which is high compared to large retailers had 3-16 main breaks every 100 miles. Sturm et al. (2014) estimated the weighted average of failure frequency in main and distribution lines for North American water utilities from previous literature as 24.68 failures every 100 miles per year. The estimates by our sample water retailers are lower than the national average as these do not include sub-surface leaks.

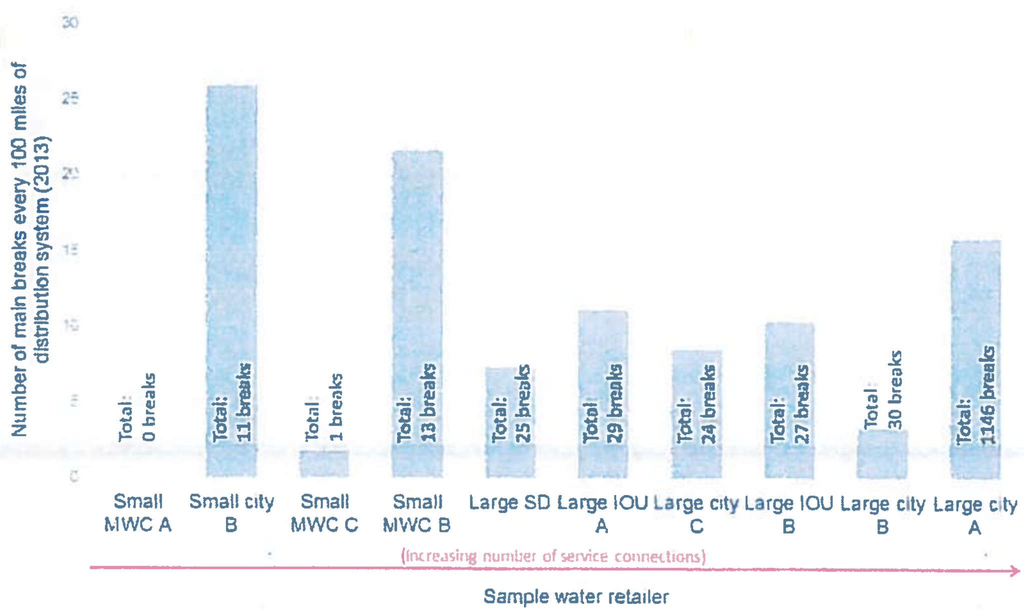

Figure 6 Number of main breaks every 10 miles of distribution system for sample water retailers in 2013

Age of pipes and storage facilities, the pipe materials and construction quality, the valves, meter accuracy and pumps all matter, Soil types also affect system efficiency, as corrosive soils reduce pipe life. High operational pressure and variation in hillside areas can further strain distribution system components. According to some water suppliers from the study sample, the longevity of distribution system components is also determined by overlying traffic density.

Small MWC A and small MWC C claimed to have zero and one break in the entire year of 2013. The other small retailers had 2-3 main breaks every 10 miles of pipeline, whereas large retailers had 0.3-1.1 main breaks every 10 miles. The largest retailer had higher number of breaks.

We asked the sample water retailers for their estimates of real water losses. Table 1 shows water loss estimates and the verifiability of these estimates. Only four out of the ten sample water retailers estimated real losses for their distribution system. All the retailers that measured real losses were large. These retailers reported having 3-4% of real water losses, which are improbably low as compared to estimates all over the nation (United States Environmental Protection Agency, 2010). The rest still use the metric of 'unaccounted for water' to assess their distribution system efficiency. The nation-wide average estimate for "unaccounted for" water for Israel was 10-12% in 2011 (Planning Department of the Israeli Water Authority, 2011). The national average for Australian water utilities with more than 100,000 connections is 18 gallons per connection per day in 2011. (Real Loss Component Analysis: A Tool for Economic Water Loss Control, 2014).

Table 2 Estimates for water losses by sample water retailers

Sample Retailer	**Real Losses (%)**	**Unaccounted for water (%)**	**Verification**
Large City C	Not measured	2.8 % (18.1 gal/connection/day)	No
Large City B	3.4 % (19.9 gal/connection/day)	4.5 %	Yes
Large City A	4.1 % (31 gal/connection/day)	Measures real loss	Yes
Small MWC A	Not measured	3 % (16.7 gal/connection/day)	No
Small MWC B	Not measured	11.35 % (67.4 gal/connection/day)	No
Large SD	4 % (40.5 gal/connection/day)	Measures real loss	Yes
Large IOU A	No response	1 % (5.6 gal/connection/day)	No
Small City B	No response	6.5 % (32.3 gal/connection/day)	No
Large IOU B	4.02 % (11.6 gal/connection/day)	Measures real loss	Yes
Small MWC C	No Response	No Response	No
Responders	7 out of 10	9 out of 10	**4 out of 10**

Overall Performance - Best Management Practices

We used survey results to develop an index of performance based on the criteria described in the Methodology section: monitoring per capita water consumption, awareness and usage of the AWWA water audit tool or equivalent analysis, usage of smart meters, infrastructure testing and replacement, leak and break detection and monitoring, age and material of infrastructure on Geographic Information Systems.

Figure 6 summarizes the performance of different types of retailers from our sample set in these categories.

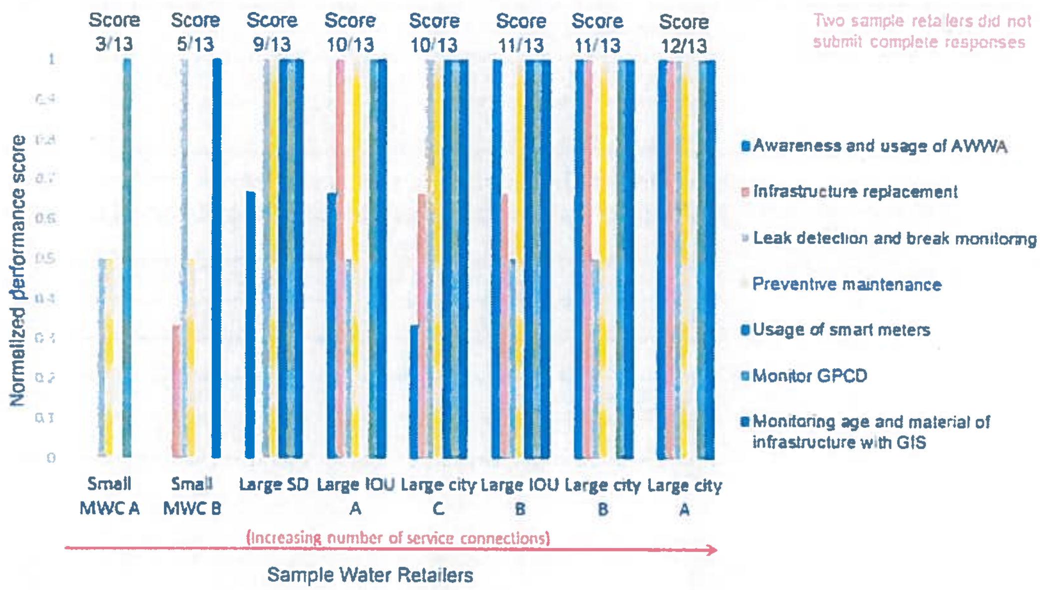

Figure 7 Scoring of participating retailer with respect to best management practices followed

Large cities in our sample reported adhering to most of the best management practices, but their targeted pipe replacement is low. Small city B lags in these practices and also had a high number of main breaks in 2013. The IOUs were almost at par with the cities in implementing these Best Management Practices. The California Public Utilities Commission requires IOUs that are Class A utilities[15] to conduct and submit the results of a water loss audit in their General Rate Case applications (CPUC. 2006). The IOU respondents conducted water audits as they are members of the CUWCC but did not share information about this CPUC rulemaking. The MWCs had a low performance in preventive maintenance, awareness and usage of the AWWA Water Audit and infrastructure replacement. The performance score for the sample increases as the number of service connections increases.

Table 3 T-test results for performance based on size and type

Criteria	Size	Type
Overall performance	Large retailers (high, p=0.0034)	MWCs (low, p=0.0035)

[15] Utilities serving 10,000 customers or more

Main breaks	Not significant	Not significant

Statistical analysis indicates that the large retailers had a significantly higher overall performance with respect to following best management practices ($p=0.0034$). The MWCs had a lower overall performance than the rest of the sample ($p=0.0035$). It is difficult to isolate the performance by type in this reduced sample, as there were not sufficient number of MWCs with complete information and monitoring. The t-tests were conducted with a significance of 5%.

Monitoring and Quantifying Real Water Loss

The AWWA M36 Manual (American Water Works Association, 2009) calculates that underground leakages, which are usually undetected, can lose more water than surface main breaks if not repaired over a period of several days. Leak detection to locate small underground leaks is necessary to reduce continuous, undetected water losses. Yet, only 4 out of the 10 water retailers in our sample invest in installing or leasing leak detection technology. Moreover, one city commented that small leaks do not lose as much water as large main breaks. Based on our interviews, water retailers in our sample who cannot afford to buy leak detection equipment find it more suitable to lease basic equipment (of high quality), which provide an accurate location of the underground leak within a few feet.

Recommendations and Discussion

Out of the 10 in our sample, 6 water retailers still used the term 'unaccounted for water', which is now an obsolete term to quantify water losses as it lumps real losses together with other non-revenue water. Only 3 out of 10 regularly use the AWWA Water Audit to determine real losses. They cited several reasons for their inability to estimate real losses: (1) Monitoring consumption over uncoordinated billing cycles among their connections (2) Lack of metering for non-revenue water uses (for instance, parks and fire hydrants) (3) Difficulty in tracking water volumes in interconnected networks with other retailers. One solution for estimating non-revenue water is to install meters at locations using non-revenue or unbilled water and avoid under-reporting.[16]

The AWWA Water Audit relies heavily on self-reported data, which is subject to non-standardized data collection, especially for non-revenue water volumes. For example, in 2014, 35% of the audits submitted to the CUWCC were invalid, whereas in our survey, two small MWCs reported to have had zero and one main break in year of 2013 in their distribution system. Mandating submission of the completed AWWA Water Audit without verification of data may provide us with underestimated water loss values, thus pre-empting any vigorous attempts to improve water infrastructure in Los Angeles. For effective auditing and distribution efficiency, it is practical to verify the submitted data of randomly selected water suppliers with monitored data records, similar to the functioning of the CUWCC or the privatized water industry of the United Kingdom (Engelhardt, Skipworth, Savic, Saul, & Walters, 2000).

[16] Personal communication, Mary Ann Dickinson

Further, in the current CUWCC procedures, the detailed AWWA Water Audit is not required if the non-revenue water is less than 10% of the total supplied volume based on a preliminary audit. Since this is an obsolete recommendation, we suggest and prescribing realistic maximum water loss standards for retailers. Post Senate Bill 555, the data collected from valid water audits should be used to develop a benchmark for the average real water losses across California. This database can also be used to recommend a more realistic maximum real water loss standard. All the sample retailers measured real losses as a percent of total supply. For large retailers, expressing water loss as a percent of the total volume supplied can mask the actual volume of water lost. While comparing a large and small retailer, a similar percent water loss for a larger retailer implies a large volume of loss, as shown in Table 2. Measuring the losses in volume units, such as 'gallons per connection per day' is a more representative measure, especially for a stringent conservation framework as California's.

Auditing water losses, while an improvement on current practices of many retailers, is not a complete solution to planning systematic allocation of resources for different parts of the distribution system. It is equally important to strategize infrastructure replacement based on these independent factors affecting the distribution system. The occurrence of a leak or break can be caused by the age of pipeline or peripheral infrastructure such as valves and meters, wear and tear due to traffic and pressure and flow variation at that location. We suggest developing a compendium of the best management practices to reduce water losses that pertain to various deficiencies in distribution systems from which water retailers can adopt measures crucial to their system.

The AWWA M36 Manual (American Water Works Association, 2009) estimates that undetected subsurface leakages can lose more water than surface main breaks if not repaired over a period of several days. Leak detection technology is necessary to reduce continuous, undetected water losses. Yet, only 4 out of the 10 of our sample water retailers invest in installing or leasing leak detection technology. The sample water retailers were divided on the validity of leak detection equipment. In case of restricted budgets, small retailers could pool resources to buy leak detection equipment, and set up a regular schedule based on the size of the distribution system. Leak detection needs to be an ongoing process with water auditing, subject to the cost-effectiveness of repairing specific leakages, to obtain returns in revenue on the water saved[17].

Last, water retailers with less than 3000 connections are now exempt from submitting an urban water management plan to the state, which is now the reporting vehicle for real water loss. Similarly, the PUC exempts IOUs under 3000 connections from their water loss analysis. However, in large urban areas, there are many small retailers and many small irrigation districts that now serve water, as do mutual water companies and small IOUs. In fact, in Los Angeles County, over 46,000 connections are served by retailers with less than 3000 connections. Currently, these retailers are exempt from the requirements imposed on larger systems, including reporting on losses from leakage and breaks. The state needs to think about how retailers who cumulatively serve a large number of customers in an urban area can pool

[17] Personal Communication, Reinhard Sturm

resources and receive technical assistance to do water audits, and to use best management practices to replace old pipe, clean and repair inaccurate meters and monitor breaks and leaks, thus reducing real water losses.

Conclusions

To support intensifying conservation requirements in California, minimizing water losses from infrastructure is crucial. Some recent and upcoming legislation in California is looking to prioritize this issue. For instance, state Senate Bill 1420 mandating the use of the AWWA Water Audit aims to reduce water losses from infrastructure. After interviewing several types and sizes of water retailers distributed across various geographical locations in urban Los Angeles, we conclude that assessing the efficiency of a water distribution system only via the AWWA Water Audit will be insufficient and may underestimate actual losses. Sixty percent of our sample still relies on monitoring only "unaccounted for" water to control water losses. Using an external authority to validate data and metering for non-revenue water can improve the efficacy of the AWWA water audit methodology. Another effective metric of infrastructure quality is consistency in following prescribed best management practices customized to the size and type of retailers.

Water retailers should invest regularly in water infrastructure to avoid loss in revenue and damage claims. Decision-making for rate increases can be more informed with detailed knowledge of the state of the distribution system and the investments and practices necessary to minimize water, losses and economize water distribution. In Los Angeles, many pipelines are past their useful life, with leakages or points of imminent failures, potentially causing tremendous water loss.

As suppliers of potable water to the public, the Investor-Owned Utilities must be responsible to provide more accessibility and transparency to information about their respective distribution systems. This can also facilitate proposing capital improvements to the CPUC as more transparency can garner public support. The MWCs can bolster their cooperation in water conservation by maintaining verifiable information on water losses in their system in the form of reports or monitored data. The MWCs are organized in the state, and could develop a mutual assistance and cost sharing agreements with other mutual or with adjacent retailers. Such verifiability will aid them in addressing concerns from the State and water quality authorities, as well as in monitoring their system efficiently. Smaller retailers can improve their performance by coordinating their efforts in leak detection and minimization.

In conclusion, strategizing best management practices and assessing cost-effectiveness of leakage repairs based on the accurate infrastructure assessment for retailers can improve management of water infrastructure and reduce water losses. These strategies have been made available by AWWA M36 Manual (American Water Works Association, 2009) and other literature reviewed in this study. Transparency and verifiability in information is crucial to implement such a system. With this paper, we have provided a glimpse of the current status water loss reporting state wide, of water retailers in urban Los Angeles County and have thrown light on their deficiencies while outlining their strengths. This paper also provides a context for upcoming policy decisions to reduce water losses through infrastructure, thus supporting conservation efforts.

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Appendix

Document of Interview Questions for Study

In this interview, we are asking you to respond to questions about water distribution efficiency and related measures in your water agency, company or department.

[At this point, read and sign consent form and begin responding]

Urban Water Supplier: According to the Urban Water Management Act, it is "a supplier, either privately or publicly owned, providing water for municipal purposes either directly or indirectly to more than 3000 customers or supplying more than 3000 acre-feet of water annually."

1. Which service does your water agency provide? *Indicate all options that apply.*

    a. Water Distribution to End Users

    b. Raw Water Treatment to Drinking Water Standards

    c. Water Reclamation or Ground Water Replenishment

    d. Stormwater Treatment

    e. Power

2. What is your agency's **annual** water distribution volume for potable/recycled water in **acre-feet**, as most recently monitored?

3. What is the residential population in your service area? If your service area is geographically divided into isolated segments, please give totals for each segment.

4. How many residential service connections do you have?

5. How many business service connections do you have?

6. How do you measure/calculate the **volume of water in acre-feet** that is being brought **into** your system, either through local or imported sources? How do you measure this?

7. Do you know your agency's average **per capita per day** usage for **potable** water for **residential** users in your service area? (Y/N) *If yes, please answer Q8, if not go to Q9.*

8. What is the per capita per day use for **residential** customers? (GPCD) How do you calculate it?

9. What is the **per capita equivalent usage** for **businesses**? How do you calculate the usage? *If you don't know, please indicate and move to the next question.*

10. Are you a member of the California Urban Water Conservation Council (CUWCC)? (Y/N)

11. Have you used the **AWWA** tool for estimating all real losses? (Y/N) If yes, **when** was the last time you used it? *If not, skip to Q14*

Real Water Losses are defined by the AWWA Water Audit Tool as "true losses of water from the utility's system, up to the point of customer metering. They consist of leakage on transmission and distribution mains, leakage and overflows at utility storage tanks, and leakage on service connections up to the point of customer metering"

12. What is the **current** estimate of the **Real Water Losses** associated with your distribution network for the 2013-14 year? (July 1st 2013 to June 30th 2014). *If you don't know please indicate and move to Q15.*

13. Can you give an estimate in volume or percent, the **real losses** in various **parts** of your agency's distribution system? *If you don't know, please indicate below and move to Q15.*

	Estimated Volume	Estimated Percent
a. Transmission/distribution mains		
b. Overflows at storage tanks		
c. Service connections		
d. Don't know		

14. If you have **not** used the AWWA tool, do you calculate your real losses? (Y/N) If so, how? Can you give an estimate of your real losses? *If you can't estimate losses, please indicate and move to the next question.*

15. How much of your agency's distributed volume is **metered**? (Volume or percentage of total) Do you have **smart meters**?

16. Does your agency have a regular **schedule** for water distribution system **replacement** and **upgrades**? (Y/N)

17. If so, do you have a **standard number of miles** of distribution system that you **replace/repair each year**?

18. Do you have a **schedule** for checking and replacing **valves**? Do you have a schedule for checking **meters** for accuracy and replacing them?

19. Does your agency have a Leak Detection Program? (Y/N) If yes, can you describe it?

If yes then go to Q20 and skip Q21; if not, go to Q21.

20. If you do have a leak detection program, do you use it to plan **budgets** and **investments** in pipe and other distribution system replacement? (Y/N)

21. If you don't have a leak detection program now, do you think that you will be developing one in the next year? (July 2014-June 2015)? (Y/N)

22. Do you keep records of the number of **line breaks per year**? (Y/N)

23. Do you keep records of the **material** and **age by location** of various parts of your distribution system? (Y/N) What is the pipe material that your system uses?

24. What is the **average life** in years for pipes in your system? Which specific **factors** affect pipeline life in your system? (E.g. corrosion, material, earth movement, etc.)

25. Do you report your system losses from water supply to any **government agency** in addition to the DWR? If yes, what parameters pertaining to system losses do you report?

    If yes, please name the agencies below:

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26. What other **current** or **past measures** has your agency implemented to prevent or reduce real losses?

27. Can you tell us if your agency is thinking about new **future measures** to prevent or reduce real losses?

28. Are you able to secure enough revenues out of your annual resources to prevent or reduce real system losses? (Y/N) If not, what kind of assistance would you need to minimize system losses through monitoring, rapid response and replacement?

29. In your opinion, what requires to be done to improve water distribution efficiency across various agencies in urban Los Angeles?

List of Figures

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Uncertainty in Long-Term Water Demand Forecasts: A Primer on Concepts and Review of Water Industry Practices

Project #4558

EXECUTIVE SUMMARY

Long-term water demand forecasts serve as critical inputs to water utility planning efforts and decision making, and they play many roles in those processes. Uncertainties about the future, as well as about the causes of historical and recent trends in water usage patterns, can affect how long-term water demand forecasts are constructed and why they are seldom realized with very high degrees of accuracy. Inaccurate forecasts can lead to costs to water utilities, water rate-payers, and the environment. For example, over-building of supply and water treatment capacity can lead to stranded capital assets, higher water rates than might otherwise be necessary, and additional stress on watersheds. On the other hand, under-investment could result in imposition of water shortage restrictions, economic damages from water shortages, and harm to the credibility of utility management. These risks, the ways they are affected by planning uncertainties, and how utilities cope can be perplexing and present complex challenges for the drinking water community.

This study conducted a review of the uncertainties related to forecasting long-term demand for water resource and infrastructure planning, including strategies to account for and manage these uncertainties. The study resulted in a primer on risk and uncertainty as they relate to long-term water demand forecasting, a corresponding annotated bibliography, and a categorized reference list pointing to additional literature resources. The project team conducted a web-based survey of water utilities and a project workshop involving utility professionals and other practitioners with experience in long-term forecasting. These efforts addressed current water utility practices and perspectives regarding risk and uncertainty. Readers are strongly urged to review the main body of the report to absorb important concepts related to risk analysis and how uncertainty can be addressed in the context of water demand forecasting. The following summarizes some of the key findings of the study.

SYNTHESIS OF WATER UTILITY SURVEY RESULTS

- System size (as defined in terms of population served) seems to be positively related to the overall level of attention devoted to long-term water demand forecasting.
- Aside from future growth in customers, future climate, the condition of the economy, and water efficiency top of the list of key future uncertainties.
- Many utilities would like to include additional variables in their respective forecast models, but cannot due to data limitations.
- The development of qualitative scenarios is the most common method for addressing uncertainty in long-term forecasts, though the likelihood of using statistically-based forecast intervals increases with system size.
- In the context of infrastructure planning, the risks of under-predicting future demands tend to outweigh the risks of over-predicting future demands. This risk attitude may be naturally at odds with risk attitudes associated with financial planning objectives.
- Monitoring water demand and periodically adjusting forecasts with new information were the most frequently indicated strategies for coping with uncertainty.
- Utilities employ additional structural strategies that provide flexibility for coping with forecasting inaccuracies, such as building facilities that can be easily expanded and phasing supply development projects into smaller increments.

- Recent declines in water use rates, coupled with past over-predictions of demand, could be providing a luxury of time to monitor demand trends and more carefully assess future supply needs.

EMERGENT THEMES FROM THE DEMAND UNCERTAINTY WORKSHOP

- There isn't a single prescriptive approach everyone should follow for forecasting. The best approach for any utility depends on its situation, and there are aspects of certain methods that make them better or worse than other methods.
- More complicated models are not necessarily better for reducing uncertainties. The addition of more variables to explain historical variability in water use could superficially increase uncertainty about the future, since their future values are unknown, or at least lead to diminishing marginal returns with respect to forecast accuracy. On the other hand, the addition of more variables may be reflective of better knowledge and provide a more complete picture of why demands may vary in the future.
- Understanding recent causes of historical demand variability appears to be the focus of water agencies, but some are beginning to incorporate uncertainty into forecasts. The best approach to incorporating uncertainty into forecasts depends on a utility's specific situation, including technology, data availability, staff expertise, and uncertainties about available budget resources.
- There are greater appetites for accepting the risks of over-predicting long-term demands. In practice, the perceived costs associated with water shortages tend to outweigh the perceived costs of having excess supply capacity (and some degree of stranded assets).
- Concepts, perceptions, and appetites for risk can vary within a utility organization. Discussions confirmed that tensions can exist between the forecasting needs of financial and infrastructure planning, and that each planning element could have its own forecasting biases and appetites for risk.
- There is a lack of experience in estimating risks, defining risk metrics, and evaluating the costs of risk reduction. The consequences of forecasting inaccuracies tended to be well understood and articulated. However, there appears to be limited experience in assigning financial (or monetary) costs from forecasting inaccuracies, which would help decision makers.
- Communication of demand forecasting uncertainties is just as difficult as, and perhaps more important than, incorporating uncertainty into forecasts. The value of making "risk-informed" judgments needs to be better articulated, along with educating decision makers and public stakeholders about forecast uncertainties and the potential risks at stake.

REACTIONS AND RECOMMENDATIONS

Uncertainty in water demand forecasts can affect a utility and lead to exposure to risks in all of the following areas:

- Strategic

- Human health and safety
- Environmental
- Regulatory/Compliance
- Financial
- Operations
- Reputational

Addressing long-term demand uncertainty, in consideration of the impacts of demand uncertainty among all of these areas, would present a more complete and holistic basis for decision making. One model for doing this is to adopt an "enterprise risk management" approach to decision making that cuts across organizational silos. Water utilities should take advantage of existing enterprise risk management models and tailor them accordingly.

Simple forecasting models may be preferred for many reasons. If planning objectives are broad enough to consider alternatives to supply expansion and generate information to assess appetites for risk, then more advanced models and forecasts are both desirable and practical, especially because of the value of the information they provide. Water utilities should identify and evaluate key forecast uncertainties and examine whether their current long-term forecasting models adequately incorporate these factors.

Examples of probabilistic demand forecasting, robust scenario development, and risk-based level of service metrics already exist, but these efforts cannot yet be considered the norm. Efforts should continue to demonstrate how uncertainty can be incorporated into various water demand forecasting methods, comparing data requirements and contrasting the advantages and disadvantages of different approaches. Water utilities should seek out ways to improve their knowledge of water demand trends and look for opportunities to make incremental improvements to forecasting models and methods.

Some utilities manage risks through multiple strategies, including periodic monitoring of water demand trends, incremental or phased planning of facilities, demand management alternatives, and more flexible or innovative financing. Based on the literature and experiences shared during the course of this study, there seems to be a heightened interest in adaptive management strategies such as these. Further assessment of risk attitudes in water supply planning could examine how attitudes have evolved and whether they have the potential to change. Water utilities should consider whether and how their demand forecasts and underlying forecasting methods reflect their attitudes about risk.

Effective communication of forecast uncertainty is a stumbling block at multiple levels. Incorporation of uncertainty into forecasting and decision making is still foreign to many, and adopting the risk analysis paradigm carries with it new analytical processes, terminology, and ways of thinking. It takes time for modelers, forecasters, water managers and others to not only learn how to gather and process this information, but also to appreciate its usefulness. Additional guidance is needed on effective ways to portray and explain forecast uncertainty and to translate this information into actionable knowledge for decision makers. Water utility decision makers need to be receptive to this guidance.

Finally, water utilities should direct more attention to measuring risks, and, to the extent possible, monetizing the full costs of managing forecast uncertainty and communicating these costs to the public. Improvements along these lines could ideally result in a process where water planning and management actions represent a clearer and more traceable expression of the risk attitudes of water utilities that are sensitive to the desires of a risk-informed public.