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Authors
Pincetl, Stephanie
Porse, Erik
Cheng, Deborah

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Fragmented Flows: Water Supply in Los Angeles County

Stephanie Pincetl[1] · Erik Porse[1] · Deborah Cheng[2]

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Abstract In the Los Angeles metropolitan region, nearly 100 public and private entities are formally involved in the management and distribution of potable water—a legacy rooted in fragmented urban growth in the area and late 19th century convictions about local control of services. Yet, while policy debates focus on new forms of infrastructure, restructured pricing mechanisms, and other technical fixes, the complex institutional architecture of the present system has received little attention. In this paper, we trace the development of this system, describe its interconnections and disjunctures, and demonstrate the invisibility of water infrastructure in LA in multiple ways—through mapping, statistical analysis, and historical texts. Perverse blessings of past water abundance led to a complex, but less than resilient, system with users accustomed to cheap, easily accessible water. We describe the lack of transparency and accountability in the current system, as well as its shortcomings in building needed new infrastructure and instituting new water rate structures. Adapting to increasing water scarcity and likely droughts must include addressing the architecture of water management.

Keywords Water · Governance · Complexity · Accountability · Climate adaptation

✉ Stephanie Pincetl
spincetl@ioes.ucla.edu

[1] California Center for Sustainable Communities, Institute of the Environment, UCLA, Los Angeles, USA

[2] Social Science Research Council, New York, USA

Introduction

Climate change in the American southwest will bring increasing uncertainty in the timing and volume of precipitation (Garfin et al. 2013). In many states, highly engineered systems of water conveyance bring water over hundreds of miles, across watersheds and jurisdictional boundaries, to supplement local surface and groundwater sources. Likely reductions in snowpack (a major source of annual water storage) and changes in the seasonality of rainfall will stress current systems built on historic hydrologic assumptions (Mote et al. 2005; Stewart et al. 2005; Hamlet et al. 2005; Barnett et al. 2005; Mote 2006; Palmer et al. 2009). Changes in system operations and policies will have to deal with such effects of changing climates, especially in arid regions (Medellín-Azuara et al. 2008; Hanak and Lund 2011).

The consequences of water scarcity and prolonged drought for existing policies are exemplified by recent experiences in California. In a system reliant on large-scale water conveyance, severe and ongoing statewide drought since 2011 has spurred key policy changes to address short-term water scarcity and promote long-term preservation, including mandatory urban water use reductions and statewide regulation of depleted groundwater basins. Urban and agricultural users in Southern California rely on drought-affected imported water supplies from multiple sources to supplement local water. The State Water Project, administered by the California Department of Water Resources (DWR), brings water from the northern portion of the state, first stored in dams fed largely by snowpack and mountain runoff, then conveyed to coastal and southern regions through rivers, aqueducts, and the San Francisco Bay Delta. The Metropolitan Water District of Southern California (MWD), authorized by legislation in

1928 to deliver Colorado River water to the region, distributes water to a network of largely self-organized agencies (Ostrom 1965; Blomquist 1992; Hundley 1992; Green 2007). Additionally, the city of Los Angeles has imported Owens Valley water since 1913 through the Los Angeles Aqueduct. For cities like Los Angeles, imported supplies supplement limited local rainfall (12–15 inches per year in L.A.), which is also typically reduced in drought years. Recent years have seen unprecedented policy responses to drought, including the state's first mandatory water restrictions (25 %) for urban areas in 2015. Such actions exemplify the types of policy responses necessary for current systems of water management, both physical and institutional, to effectively deal with future climatic uncertainty in the face of climate change.

Despite the importance of imported water supplies in Southern California, the politics and complexity of water governance in the area receives relatively little attention (Blomquist 1992; Erie 2006; DeShazo and McCann 2015). Instead, policy and management discussions often focus on scientific assessments of opportunities to augment groundwater infiltration, recycle sewage and gray water for reuse, and calculate savings from lawn replacement programs. While necessary, these technocratic approaches do not address shortcomings in regional water management institutions. Yet, the arrangement of institutions, or the institutional architecture of water management, may significantly inhibit system adaptability. The absence of data limits the capacity for empirical assessments of crisis actions such as drought response among agencies, while more case studies of complex environmental management networks are necessary to evaluate effective governance structures (Lubell and Lippert 2011; Lubell 2015). In particular, the network of institutions that govern water supply in Los Angeles is poorly understood, likely due to system complexity, a shortage of centralized information sources, a lack of agencies with both jurisdiction and motivation for systematic analyses, and limited enthusiasm for changing institutional practices.

Fragmentation and specialized governance, including its organization, has received significant attention (Bollens 1957; Perrenod 1984; Foster et al. 1997; Felock et al. 2001; Marks and Hooghe 2003; Besley and Coate 2003; Wlezien 2004; Mullin 2008, 2009). Yet, how potential complexity may affect potential responses to crisis across a diverse geographic region—in this case responses of Los Angeles water agencies to drought and climate change—remains underexplored and thus fails to inform potential policy changes. An initial step towards more integrated water management at multiple geographic scales begins with developing a shared understanding of agency authorities and creating better centralized data repositories based on common standards.

In this article, we present an analysis of institutional architecture for water supply management in Los Angeles (L.A.) County. The research seeks to answer key questions. First, what agencies are involved in water supply management across metropolitan L.A. and how are they organized? Second, how do agencies interact in terms of transferring water, and can classification schemes with categories or hierarchies describe the interactions? Third, what data sources provide comparable information to assess differences in reliance on imported water across L.A. County and how does the institutional architecture relate to water supply sources for various retailers? Finally, how do agencies respond to climate-induced policy changes and do inequities in response capacity exist across agencies? To quantify relationships among agencies, our analysis necessarily focuses on sizable water supply agencies that report water supply and demand data. With its 88 cities and large areas of unincorporated county land, L.A. County offers a uniquely complex case study of how researching institutional dynamics in human-dominated environmental systems can consider questions of accountability, legitimacy, transparency, data, and climate change adaptation.

Methods

To describe the institutional architecture, we drew on historical, policy, and technical sources using a mixed methods approach with quantitative and qualitative aspects. We surveyed and summarized historical research to understand evolution of water development in both the region and statewide, as well as factors leading to the development of contemporary water supply agencies (wholesale and retail, public, private, and non-profit) in Los Angeles. To characterize quantitative water supply trends such as imported water deliveries and groundwater pumping, we used multiple sources, including reported documents on water supply and demand from agencies; on-line data from regulatory agencies such as the Los Angeles County Local Agency Formation Commission (LAFCO) that oversees local special districts and the California Public Utilities Commission (CPUC) for private water utilities; reported data from MWD; and data from the California Department of Water Resources (DWR). Together, empirical data on current operations, combined with historical understanding, helped elucidate system-wide management trends.

We collected and assembled available Geographic Information System (GIS) shape files for water retailers. Knowing the type of water agency (special district, city utility, private utility, etc.) led researchers to the correct source of information for the shape files. We acquired shape files of water agencies from the L.A. county GIS portal, MWD, LAFCO, DWR, and the agencies themselves, assembling them into a central database with associated attributes of service area, population, water supply sources, and water rates. MWD provided shape files of County Water Districts and Municipal Water Districts, as described below. For some shape files, particularly for non-profit Mutual Water Districts, we translated paper maps into GIS polygons of reported service areas. We also conducted telephone interviews to verify data and check for overlaps or gaps. Once assembled, we calculated service areas (square miles) using geometry calculation tools in the open-source software QGIS (QGIS Development Team 2014). We then determined population density for retailers reporting standardized estimates of residential population in their service area to SWRCB using standardized reporting tools. We used the linear regression tool in Microsoft Excel to determine linear relationships between population and service area.

We mined data and information from reported policy documents, including the Integrated Regional Water Management Plan (IRWMP) reports and agency-specific Urban Water Management Plans (UWMPs) for textual analysis of supply sources and transfers. IRWMPs are required by DWR and are collaborative efforts to identify and implement water management solutions of a regional scale. They are developed by self-identified regions to integrate and implement water management solutions for their regions and were required by the 2002 Regional Water Management Planning Act (SB 1672) and supported through grants provided to IRWM members through statewide bond funds. IRWMs estimate water use in the cooperating region, as well as water supply.

UWMPs are prepared by California's urban water suppliers to support their long-term resource planning and ensure that adequate water is available for current and future use. Urban water agencies that supply over 3000 acre-feet a year or more than 3000 urban connections must report operations data to DWR using UWMPs to assess water source reliability and report progress towards a 20 % reduction in per capita urban water consumption by the year 2020, as required in the Water Conservation Bill of 2009 SBX7-7. Using these sources, we created a database in spreadsheets of the reported data to track the amount of water delivered to different utilities throughout the region.

We verified to the greatest extent possible recorded data. Some data, such as the self-reported IRWMP data, cannot be independently verified. Reports from MWD and major utilities such as the City of L.A. Department of Water and Power (LADWP) were consulted to understand spatial arrangements and interactions of institutional entities. We categorized agencies according to their regulatory and statutory authorities to understand the categorizations within the context of historical developments of various regulatory agencies, including

- The California Public Utilities Commission (CPUC) that oversees private electric and water utilities;
- The Department of Water Resources (DWR), which manages of the state water project, administers funds for IRWMPs through bonds monies, and collects UWMP data;
- The State Water Resources Control Board (SWRCB), which regulates water quality and discharges but now additionally oversees public drinking water systems and implements statewide water use restrictions; and
- The California Department of Corporations (DoC), which collect and report data on small non-profit Mutual Water Districts that operate based on land ownership voting shares.

No single state source documenting all of the water agencies exists, nor is there a central repository that compiles all of the water flows to each local entity in the county. Rather, to assemble the water systems of the region, researchers gathered information from distinct sources. To do so, a basic understanding of the institutional differences among the types of agencies was developed to determine the respective locations of raw data for size, shape, location, service area, and decision-making structure. However, not all agencies could provide GIS shape files of service area maps. City agencies, special districts, and the IOUs had maps available. In addition, the IRWMs themselves, as they are written by public agencies of different sizes and types (special district or city utility), vary in scope and depth. Throughout the paper, we use the terms agency, utility, water provider, and entity to mean an entity that provides a water service.

Findings

We describe below the findings from this study that summarize (1) historical water development trends that led to fragmentation; (2) the classification of water agencies; (3) quantitative and geographic trends regarding agency size; (4) descriptions of water supply sources and imports across agencies; (5) trends in water rates across retailers; and (6) trends in imported water as a percentage of total supplies across retailers.

Historical Water Development

Water governance and institutional capacity in Los Angeles County is intimately linked with water infrastructure development throughout California. The 1848 Gold Rush sparked an uncoordinated scramble for water across the state, with miners and other early settlers competing with established water users. Prior to this scramble, water was allocated using the common law riparian system of rights, whereby property owners with land adjacent to water sources could use water. This system was adopted from wetter climates of the Eastern U.S. (Hundley 1992). Miners, however, allocated water based on a system of appropriative rights, governed by the principle of "first in time, first in right." State Supreme Court decisions inscribed both approaches in California water law, subject to the restriction of beneficial use.

With the decline of mining, irrigated lands increased, prompting a period of more organized, local water development. Local efforts prevailed. Communities began experimenting with private collectives known as mutual water companies, creating a more structured system of management in which ownership was proportional to acreage owned that was served by the system (Erie 2006). In 1887, the Wright Act enabled agricultural communities to form irrigation districts by building canals on land obtained through eminent domain, in part because despite appeals to do so, the state did not wish to invest in water infrastructure development (Pincetl 1999). These irrigation districts were the first "special districts" to be formed—local agencies created to deliver specific public services within defined boundaries, and, in contrast to non-profit Mutual Water Companies, were public and governed through either appointed officials or elected ones (Senate Local Government Committee 2010).

In 1888, the earliest charter cities were established in California. This designation allowed cities to create constitutions and finance large infrastructure projects through municipal bonds. In contrast, general law cities must follow state legislation, even for municipal affairs. Non-charter cities are General Law Cities governed by the laws of the state. Los Angeles became a charter city in 1903, setting the stage for the subsequent development of its own large-scale water delivery system. Water in the City of LA was initially managed privately by individuals, and then by the Los Angeles City Water Company. In 1902, voters approved the municipalization of the water system. At the same time, the state Supreme Court awarded the City of Los Angeles exclusive rights to water from the L.A. River and its watershed, guaranteeing long-term supply and establishing the basis for municipal water management. In 1913, the Los Angeles Department of Water and Power (LADWP)—the city's utility—completed construction of an aqueduct that brought water from the Owens River, some 240 miles away, later extending it north into the Mono Basin. The L.A. aqueduct allowed the City a ready source of water supplies to sustain expected growth and water consumption that exceeded local availability. LADWP is a city agency with a General Manager and an appointed oversight commission. Rate increases and some expenditures must, however, be approved by the City Council.

Yet, many other communities were forming in the areas around L.A. City. Throughout the county, many types of agencies persist and fulfill multiple roles for importing and distributing water. Some of the earliest water suppliers that remain today include Covina Irrigating Company (formed in 1882); Sunny Slope Water Company (1895), a private company; California Domestic Water Company (1889), a private company; and Valley View Mutual Water Company (1907). In 1928, The Metropolitan Water District of Southern California (MWD) was established as a special district by the state legislature and approved by Southern California voters in 1931 to import Colorado River water. MWD enabled the suburbanization of LA County, Orange County, and eventually most of Southern California. MWD has 37 member agencies and is governed by a Board of Directors with representatives each appointed by the local agency. Voting power is weighted by city size, cost of infrastructure, and other criteria. Each of the directors is appointed by the member city (Erie 2006). MWD's supply was bolstered by the 1973 extension of the State Water Project—a lengthy system of canals and dams that transports water south from the Sacramento-San Joaquin River Delta into Southern California, and is managed by the Department of Water Resources. MWD's contracts with the Colorado River Compact and the State Water Project make it the preeminent wholesale water distributor in the County. L.A. County member agencies of MWD have rights to approximately 41 % of the nearly 2 million acre-feet per year imported on average between 1976 and 2010 (MWD 2013; SGVMWD 2013).

In subsequent years, other types of special districts were formed; those that continue to supply water in LA County are described in Table 1 [notably, there are 458 independent special districts focused specifically on water in California (Little Hoover Commission 2000)]. Currently, the majority of water is imported from three sources: (1) the Colorado River, which is the principle source of water for seven states and parts of Mexico; (2) the Sacramento-San Joaquin Delta in Northern California, from which water is transported south through the State Water Project; and (3) the Owens Valley, just east of the Sierra Nevada mountains, where the City of L.A. holds diversion rights to water from the Owens River. In addition to these imported sources, 23 groundwater basins are wholly or partially located in the County (LACDPW 2011–2012) and supply water through a complex system of basin-specific pumping rights. Regional groundwater management is intimately linked with imported water, as aquifer depletion, contaminated aquifers, and adjudicated groundwater rights restrict the potential for large groundwater basins to broadly supply urban end-uses across retailers (Porse et al. 2015).

Typology of Water Supply Agencies

In L.A. County today, there are over two hundred public and private entities formally involved in the management, distribution, and conservation of potable water supplies across cities and unincorporated areas (DeShazo and McCann 2015). As noted, this analysis focused on sizable water retailers (Fig. 1) with reported water demand and supply data as described below.

Mutual water companies (MWCs) typically have directing boards with 5–7 members who are landowners and own shares of the MWC. Most mutual water companies have rural origins. They were typically water providers for orchards and ranches that, as urban development in Southern California expanded, transformed into suburban communities. Most do not report UWMPs because they are too small.

Private water companies, some of which evolved into what are now known as Investor-Owned Utilities (IOUs), are among the region's oldest water suppliers. For instance, Golden State Water Company began its operations in 1928, when the Chicago-based American States Public Service Company ventured west in search of market opportunities. American States initially acquired six groups of utilities in Los Angeles and Orange counties, including systems that served portions of L.A., Claremont, and Bell.·By 1950, the company had nearly 95,000 customers and was expanding into the San Gabriel Valley (Harnish 1976). Although LADWP eventually bought portions of the utility that were within the city's limits, the company's rapid expansion into the Valley allowed for its continued growth. IOUs are regulated by the state's Public Utilities Commission, which oversees rate increases, infrastructure investments, and safety requirements.

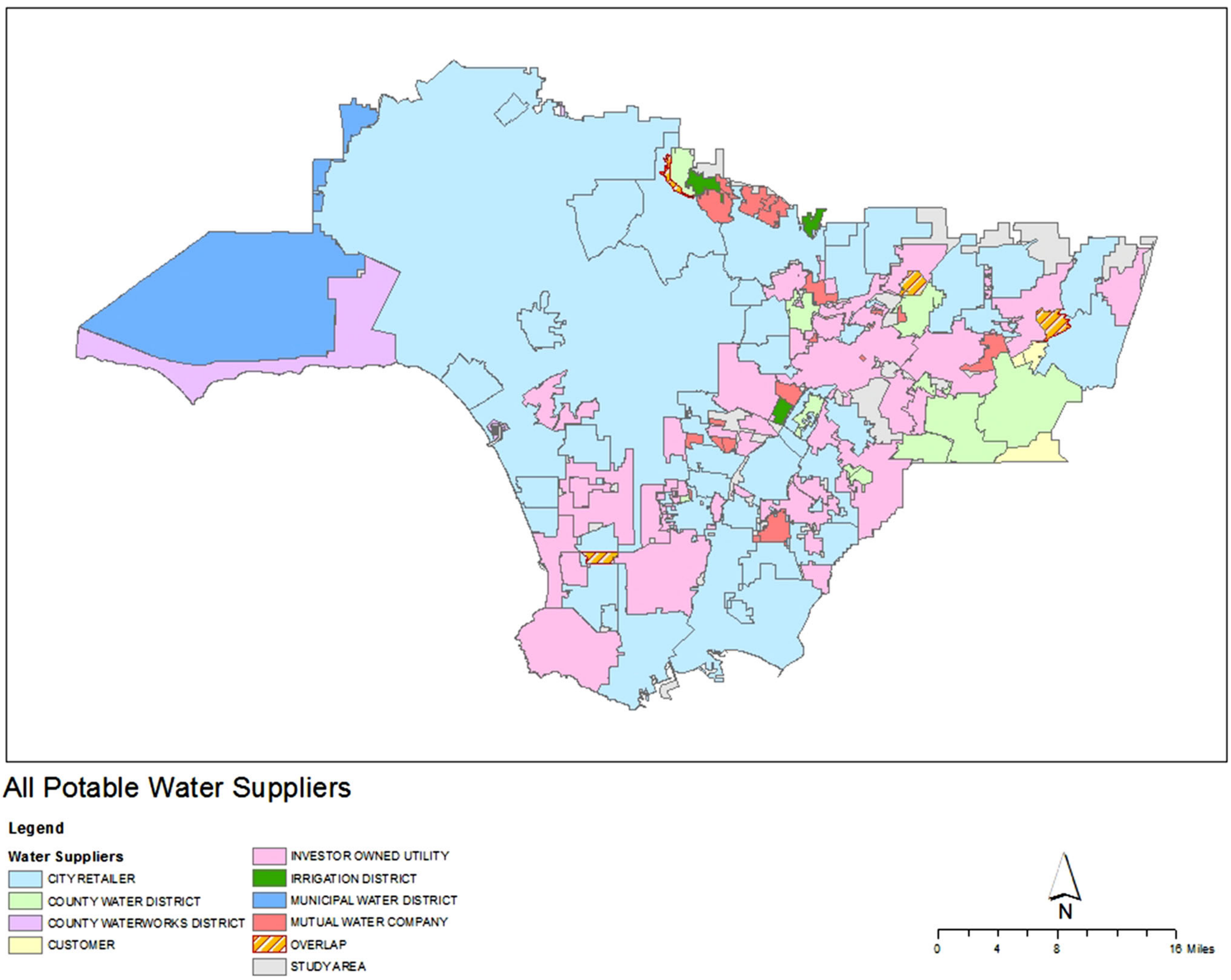

Fig. 1 All water suppliers Source: shapefiles from the LA County GIS Data Portal, California Environmental Health Tracking Program, LAFCO, and individual suppliers (California Water Service Company, Golden State Water Company, Suburban Water Systems, Park Water Company, City of Azusa, City of Torrance, City of Downey, and Foothill MWD)

IOUs typically have boards of directors with 9–11 members that are appointed by shareholders. The PUC itself is made up of 5 gubernatorial appointees and is headquartered in San Francisco. The PUC sets proceedings in order to address rates and other issues. For the public to participate in such discussions, they must be parties to the proceedings, a formal requirement. As parties, they may submit written comments or attend rate or other hearings in San Francisco. While proceedings are public, slow and detailed processes limit the ability of residents to follow important proceedings that can affect rates and policies affecting future sources of supplies.

City water utilities provide water in many cities such as Los Angeles, Burbank, and Glendale. Some utilities like the Los Angeles Department of Water and Power provide multiple services including electricity and water supply. The water utility may be a department with a manager that is accountable to the City Manager, to the city council, Mayor, or an appointed commission. This differs by charter or common law incorporation cities.

Special Districts of Single Retailers provide water supplies in some areas, but district jurisdictions may not correspond with city boundaries. Such special water districts have elected commissioners or boards that oversee operational and finance decisions and report to the LAFCO as explained above. Their governance varies—elected or appointed—with the year enacted.

Special Districts of Multiple Retailers add yet another layer of complexity in the county, when these larger special districts, comprising multiple member agencies, serve as intermediaries between hierarchical layers. For instance, Municipal Water Districts and County Water Districts (CWDs) were created to provide organizations with authority to generate revenue in a particular region for key water management tasks. In particular, many of the region's Municipal Water Districts were created to acquire imported water from MWD, which required smaller disparate agencies (retailers) to create new broader coordinating agencies for moving water (Blomquist 1992). Over time, Municipal and County Water Districts became middlemen, streamlining management decisions, distributing water allocations, and allowing MWD to negotiate with fewer water retailers. CWDs have elected leadership boards. In the case of the County Water Works District, the Board is the 5-member Board of Supervisors; the County Water District is governed by 5 district-based elected representatives. Note the confusing similarity of the designation. (See Table 1) Voters may vote for their special district board, the board of the County Water District, and for County Supervisor.

Entities are divided into three types: contractors, which receive annual allocations of imported water from the State Water Project and Colorado River authorities; wholesalers, which purchase and resell water from the contractors or other wholesalers (for example, many Municipal Water Districts); and retailers, which sell water directly to residential, commercial, industrial, and agricultural customers.

Two water supply contractors exist in our study area: (1) MWD, the regional special district that supplies imported water to 26 member agencies across six counties (17 of its member agencies are in LA County), and (2) the San Gabriel Valley Municipal Water District, which has four member agencies. The San Gabriel Valley Municipal Water District purchases water from the State Water Project and uses it to replenish water in the Main San Gabriel Basin. It was created by the member agencies to avoid contracting with the expanding MWD (Blomquist 1992). Replenishment water is made available to member agencies when needed by the State Water Project. These member agencies are the wholesalers, whose boards establish the price of water to retailers based on available imported supplies and their internal fiscal needs.

Within the MWD, six municipal water districts serve as wholesalers in L.A. County, acting as middlemen that charge for infrastructure and services while also bringing new abilities to raise funds in their jurisdictions. The Central Basin Municipal Water District is the largest of these, serving 37 retailers located in the area over L.A. County's Central groundwater basin. In most cases, imported water moves from contractors to wholesalers to retailers. However, in some areas, contractors may sell water directly to retailers (e.g., if cities purchase water directly from the MWD) or water may pass through to wholesalers before reaching a retailer. Eleven of MWD's member agencies in L.A. County are cities. Furthermore, many retailers also withdraw groundwater from basins, while many agencies produce or reuse recycled water from sewage, exclusively for non-potable uses and groundwater recharge. The Sanitation Districts of Los Angeles County are primarily responsible for recycling water collected from wastewater treatment plants, which they then sell to interested suppliers. A few retailers, like the City of LA, recycle their own wastewater.

Water Supply Retailers by Size

Across water supply retailers, the average service area is 14 square miles, ranging from 0.1 to 476 square miles (L.A. City). When not including the very large City of L.A., however, the average service area drops to 9.4 square miles. Further, the data are highly skewed, with the median only being 3.9 square miles and 75 % of retailers having service areas less than 9.3 square miles. The smallest retailers have a few hundred customers (too small to meet the purview of the state's requirements for IRWMPs), while the largest retailer, LA City's Department of Water

Table 1 A typology of water suppliers in Los Angeles County Source: Department of Water Resources 1994; Green 2007 Sources: DWR, MWD, LAFCO, County GIS Portal, Personal communications, PUC, state reports, and entity websites

Type of supplier	Scale	Role	Description	Number	Governance structure
Metropolitan water district	Several counties	Contractor	Special district that contracts water from the State Water Project and Colorado River Aqueduct, then sells to member agencies. Established through the Metropolitan Water District Act of 1927.	1	37 directors appointed by member agencies. Each member has at least one representative, with additional representatives based on each agency's assessed valuation.
Municipal water district	Several cities	Contractor wholesaler retailer	Special district that typically wholesales water to member agencies. Established through the Municipal Water District Laws of 1911 and 1935.	7	5–7 directors elected by registered voters. Each director represents a division.
City retailer	City, portion of city	Wholesaler retailer	Publicly owned utility. Serves some or all consumers within city limits (and sometimes beyond).	41	5–7 City Council members elected by city residents, or Commissioners appointed by the Mayor and/or the City Council.
Investor-owned utility	City, portion of city	Retailer	Private company that sells water for profit. Some IOUs are part of multinational corporations, and most are publicly traded. The California Public Utilities Commission regulates operations and rates of return.	8	9–11 directors elected by corporate stockholders.
Mutual water company	Portion of city	Wholesaler retailer	Private, non-profit company. Must submit basic company information to the California Department of Corporations.	24	5–7 directors elected by shareholders. Shares are often based on the amount or value of land owned, restricting the vote to property owners.
County water district	City, portion of city	Retailer	Special district. Established through the County Water District Law of 1913.	9	Five directors elected by registered voters.
County waterworks district	City, portion of city	Wholesaler retailer	Special district. Established through the County Waterworks District Law of 1913 (originally County Irrigation District). Initially served unincorporated areas.	2	5-member County board of supervisors elected by registered voters. The LA County Department of Public Works manages the system.
California water district (or water district)	City, portion of city	Wholesaler retailer	Special district. Established through the California Water District Law of 1913.	1	Five directors elected by registered voters (originally voting was based on the assessed value of land).
Irrigation district	Portion of city	Retailer	Special district originally formed to serve agricultural land. Established through the Irrigation District Law of 1897.	3	Five directors elected by registered voters.

These suppliers also exist throughout California, but roles and governance structures may vary slightly across the state. Unincorporated areas are typically served by nearby retailers

and Power (also an importer), has nearly 700,000 connections. Across agencies with comparable population estimates (48), the average population served within the retailer jurisdiction is 158,100, though this value does not include many of the small retailers that lack population estimates. Moreover, the median is significantly less (58,300), indicating a distribution dominated by a limited number of large retailers. This variation in size and type (see Figs. 1, 2) represents the spatial geographies in water provision. Through this perspective, we see that city retailers serve much of the County, but cities vary widely in size—from Los Angeles with its 4 million inhabitants—to much smaller cities. Retailer size relates noticeably to population trends. For retailers with comparable estimates of residential population using SWRCB data (48), the population density of retailers ranges from less than 7000 persons per square mile to over 27,000 persons per square mile (Fig. 3). Moreover, graphing retailer service area and residential population reveals a linear increasing relationship ($R^2 = 0.22$) shown in Fig. 4 plotted on logarithmic axes for scaling. The City of L.A. (upper right) and the City of Vernon (far left) are large outliers and were not included in calculating the coefficient of determination.

Retailer service areas can also depend on the historical circumstances affecting development of retailer jurisdictions and not the actual political boundaries of cities. For

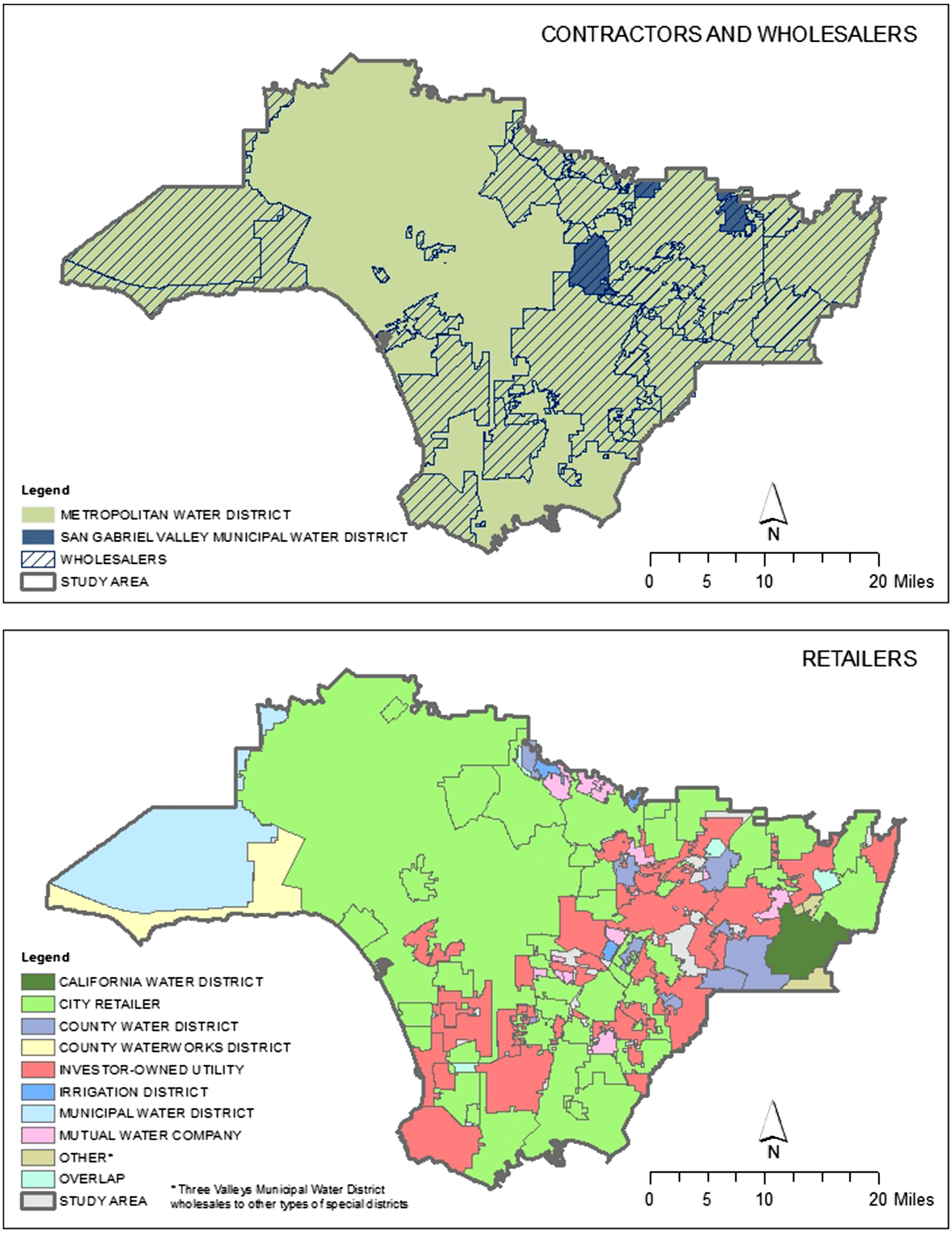

Fig. 2 Water supplier types Source: shapefiles from the LA County GIS Data Portal, California Environmental Health Tracking Program, LAFCO, and individual suppliers (California Water Service Company, Golden State Water Company, Suburban Water Systems, Park Water Company, City of Azusa, City of Torrance, City of Downey, and Foothill MWD)

instance, in the City of Beverly Hills, a city utility serves residents of Beverly Hills along with those in the neighboring community of West Hollywood. The tiny city of Bell, which occupies 2.6 square miles and has 35,000 residents, has five water suppliers, including two IOUs and three mutual water companies. The cities of Compton, El

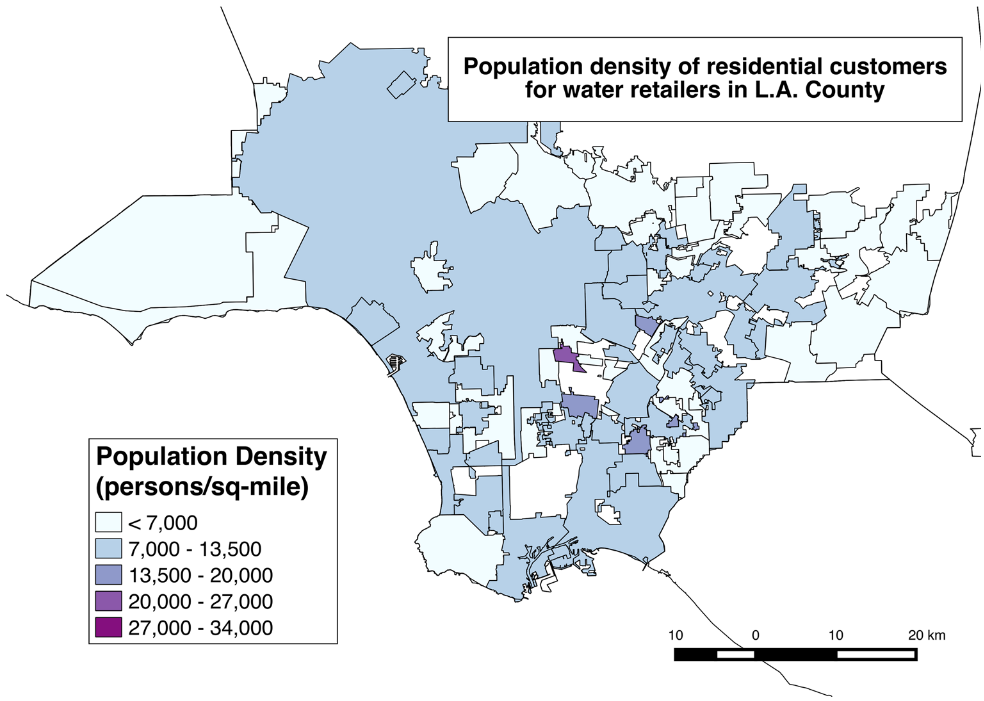

Fig. 3 Geographic distribution of population density (persons/sq-mi) across water retailers in Los Angeles County. Geographic area was calculated using QGIS geometry functions, while population data were derived from the State Water Resources Control Board. Only retailers with verifiable population estimates as reported to SWRCB are included Source: SWRCB 2015 per capita use database

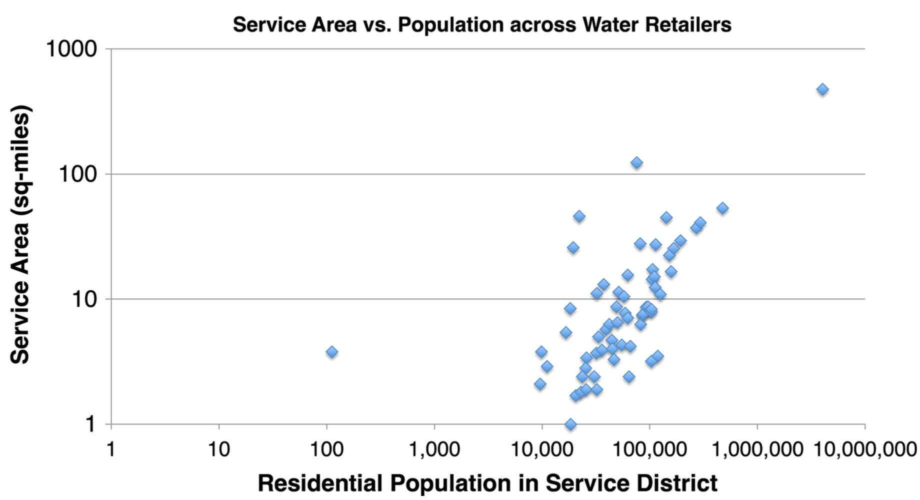

Fig. 4 *Graph* showing a linear relationship of service area vs population for water retailers in Los Angeles County ($R^2 = 0.92$), shown on *logarithmic axes* for scaling. The City of Los Angeles is a large outlier (*upper right*) Source: SWRCB 2015 per capita use database, QGIS Geometry functions, and calculations by the authors

Monte, and West Covina each have eight water suppliers. These reflect the unique historical developments, political decisions, and available funds across geographies. Private IOUs serve a significant portion of the population; often these areas are not geographically contiguous, but still allow for economies of scale. To add yet another layer of complexity, while many cities have rights in underlying groundwater through their municipal utilities, many do not. Those without rights rely almost exclusively on imported water, typically supplied through private utilities or mutual water companies (Porse et al. 2015).

The map of water suppliers is revelatory in showing the highly fragmented and complex nature of water provision in Los Angeles County. But it is also interesting to note what it does not show. Assembling the map revealed how boundaries of some water suppliers remain publicly unknown or uncertain. That is, while individual water suppliers surely know the extent of their service areas on the ground, this is not always accurately translated into GIS shape files, and there is no central repository or public authority with such information. The LA County GIS Data Portal has a shape file with an incomplete database of water purveyor (retailer) boundaries (LACDPW 2008–2009).

Further, in comparing these data with maps from the Urban Water Management Plans and other reports, we found several inconsistent boundaries. In Fig. 2, gray areas indicate areas of missing data. The shapes do not form a contiguous layer across the region because GIS boundaries are uncertain. Small private entities service many of these areas relying on single and potentially tenuous sources (DeShazo and McCann 2015). In 2002, Assembly Bill (AB) 54 sought to increase the transparency of mutual water companies by establishing additional performance requirements. One of these requirements tasked the Local Agency Formation Commission (LAFCO) with collecting boundary information for all the mutual water companies in the region. But LAFCO data showed that many submissions consisted of old engineering drawings and highlighted Internet maps. Moreover, some mutual water companies did not submit shape files. Even for LAFCO, an agency charged with monitoring the boundaries of mutual water companies and special districts, the system of water governance remains opaque.

Water Pricing

Water pricing throughout the metropolitan area varies widely, reflecting the complexity of water sources. Performing a detailed investigation into causes of this wide variation among prices was beyond the scope of this research, though there are likely several reasons for rate disparities. These include the age of the system and its size, whether the utility has access to ground water, and if the utility is public or private. Different private utilities apply to PUC for rate increases independently, and PUC determines if the rate hike is warranted. One factor to keep in mind is that revenue is pegged to sales. Water conservation reduces revenue. Presently, a single-family residence consuming an average amount of water can spend anywhere from $20–$131 a month, depending on the supplier, as shown in Fig. 5. The standard measurement of water consumption in the United States is the centum cubic foot (ccf). One ccf is equivalent to 100 cubic feet or 748 gallons. Municipal Service Review reports, prepared for LAFCO, suggest that an average household consumes 20 ccfs per month (Dudek 2006), though this has most likely decreased during recent drought years. The highest water rates are charged by the City of Huntington Park ($131), a city retailer; Mesa Crest Water Company ($118), an IOU; and Kinneloa Irrigation District ($118). The least expensive water rates are in the City of Covina ($20); Valley County Water District ($20); and Bellflower Home Garden Water Company ($27), a mutual water company. Groundwater tends to be less expensive than imported water, and those suppliers that own or lease groundwater rights can often offer lower rates. However, as mentioned, not all utilities or cities have access to groundwater (Porse et al. 2015).

Like water rates, the quality of urban water supplies varies as well, particularly if retailers tap groundwater aquifers without full treatment technologies. Lack of democratic transparency and accountability is especially evident in this situation. Though state agencies have historically regulated drinking water quality across supplies, problems still arise. Recently, the three mutual water companies that serve the tiny town of Maywood, which occupies just over one square mile, have come under scrutiny. For years, residents complained of discolored, smelly, and foul-tasting tap water. Drinking water quality tests in Maywood revealed elevated levels of manganese, a mineral that is not subject to federal or state drinking water regulation, but that does have an esthetic water quality standard. Trichlorethylene has also been detected in Maywood's drinking supply, likely resulting in past industrial operations in the vicinity over the last half-century. Several attempts at legislative action have been taken, including AB 890, which mandates the City of Maywood to assess manganese concentrations, and AB 240, which, in response to issues in Maywood, requires all mutual water companies to adopt transparency measures. Despite those bills and the efforts of community-based organizations, many of Maywood's water quality problems remain and the legislation did nothing to change the capacity of a small water utility to address significant contamination problems. Further, Maywood is not the water purveyor, so while the city may be able to test and report, it is not in charge of the water quality.

The governance structure of mutual water companies is inherently insulated from customers and the municipalities they serve, and many do not create UWMPs due to their size. Legally, landowners are shareholders who run the company by electing a board. For cities with many renters, a majority of residents have no voice in operations, water prices, or drinking water quality. Many of these small mutual water companies also lack technical and fiscal capacity to act on contamination. At the same time, public agencies with directly or indirectly elected governance structures are not insulated from graft. For instance, in the Central Basin Municipal Water District, there is an ongoing, high-profile investigation of several directors implicated in a regional corruption scandal. Furthermore, special district elections often have low voter turnouts (Senate Local Government Committee 2010), suggesting that popular elections alone do not guarantee sufficiently representative elected boards, especially when the entity is obscure. This highlights one of the problems with special districts whose boards are elected and are not part of a local city government.

In addition, establishing water rates that support infrastructure repair needs or help curb water use in the face of drought is challenging for several reasons. Most

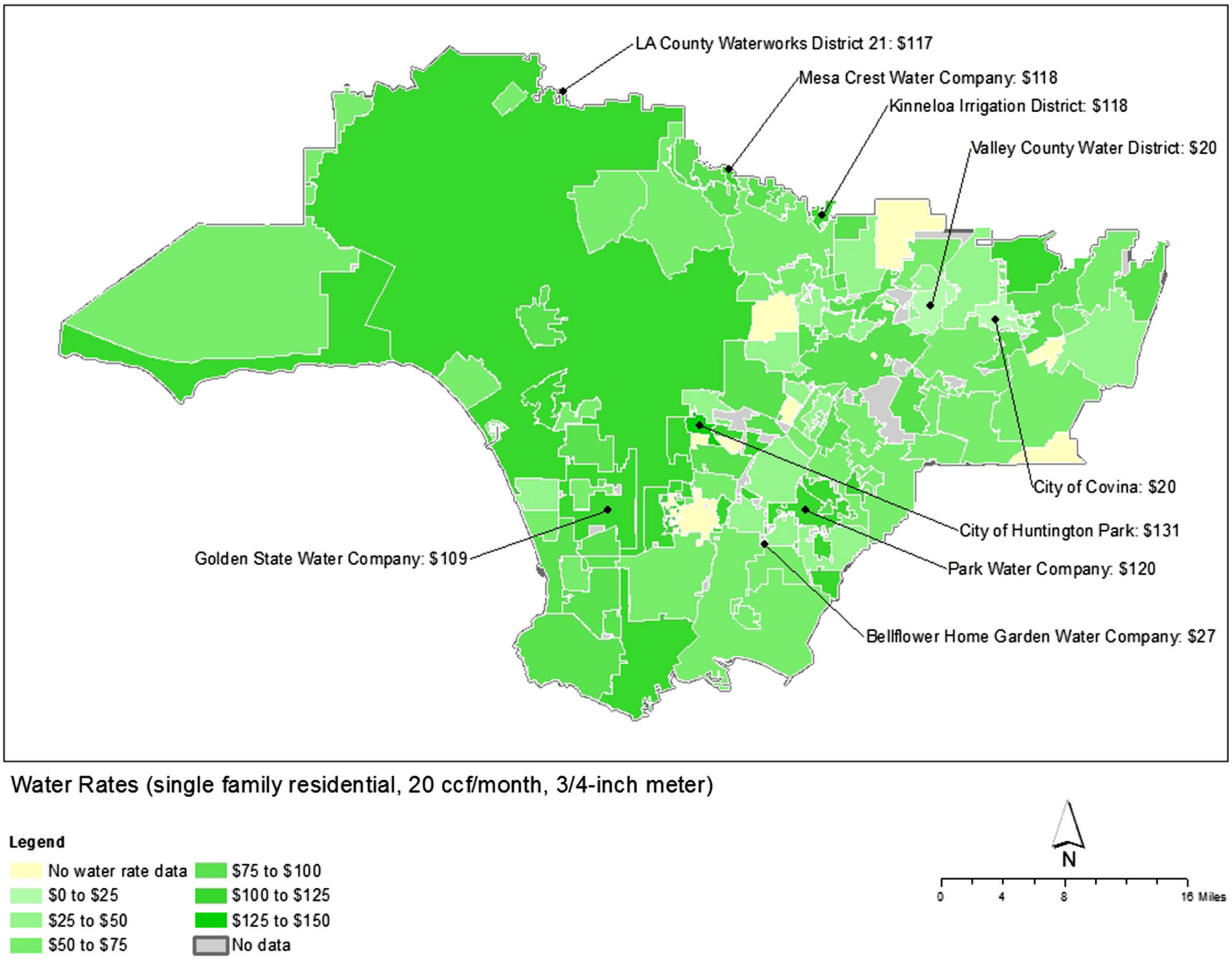

Fig. 5 Geographic distribution of water pricing across water retailers in Los Angeles County Source: each individual water purveyor's website

utilities charge volumetrically. If customers voluntarily reduce water use to conserve due to the drought, agency revenues decline, challenging the utilities' ability to invest in infrastructure, including repairing leaks or creating new programs such as water recycling. And, while rate increases are always difficult, in the case of public utilities, elected officials are wary of rate increases in their quest to remain electable and localities are additionally hamstrung by Proposition 218. Proposition 218 requires rate increases to have a close nexus to the cost of delivering water. To raise fees, localities must directly link the fee with the cost of service. A fee increase in San Juan Capistrano was challenged under 218 and the courts found that the fee was illegal as the nexus between the rate increase and the cost of water was not well established (Capistrano Taxpayers Association, Inc. 2015). Proposition 218 also may make it more difficult to create lifeline rates, as there needs to be a nexus between rates and the cost of water. Prop 218 specifies that fees may not exceed the cost of service for each parcel, thereby making it harder to cross-subsidize rates (Hanak et al. 2014). Some IOUs have lifeline rates for qualified low-income and/or senior customers, however, authorized by the PUC.

Imported Water

Across L.A. County, imported water augments available local water, comprising a sizable, but varying, percentage of total supplies across retailers (Fig. 6). On average, using data from 2010 that are comparable across retailers, imported water provides 36 % of total supplies for a retailer, though the median is lower at 22 %. Over 20 agencies, including the City of Los Angeles, California Water Service Company, and the City of Santa Fe Springs, relied on imported water for more than 75 % of 2010 annual supplies. Yet, some retailers (25) meet demands almost entirely through local surface and groundwater sources. Considering population, however, which excludes

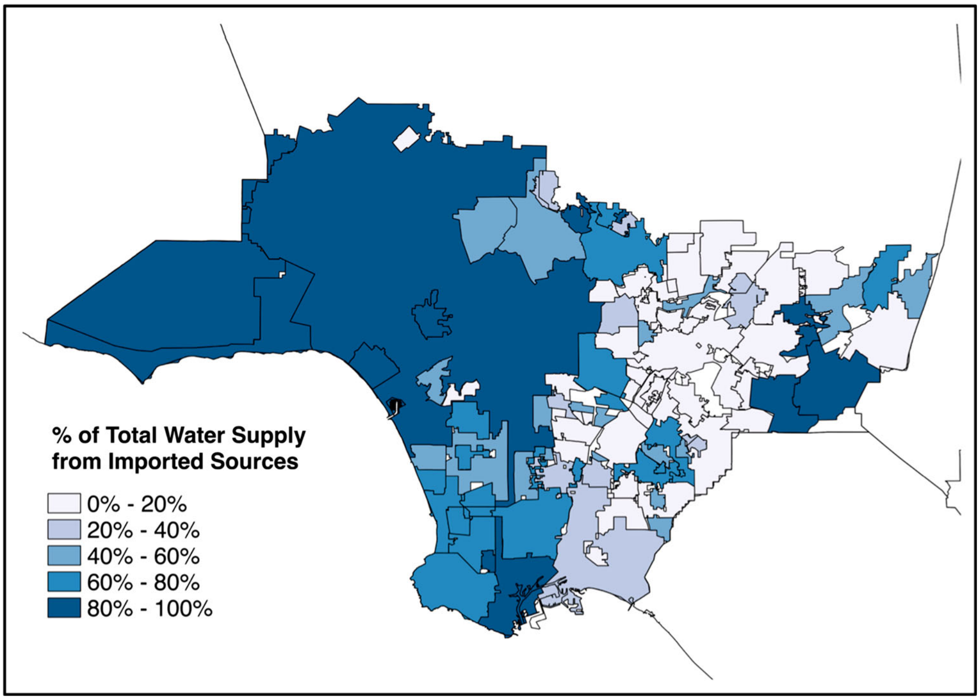

Fig. 6 Percent of total water supplies from imported water, by retailer. Notably, some retailers, such as Santa Monica, have made significant progress towards reducing imported water use since 2010 Source: data derived from 2010 Urban Water Management Plans (UWMPs) and the L.A. County Local Agency Formation Commission (LAFCO)

many small mutual water companies from the analysis that do not have accurate population information, retailers that receive almost no imported water (18) serve approximately 1.5 million people, while retailers heavily reliant on imported water serve 5.3 million people, dominated by the City of L.A. Thus, while significant diversity exists across the region, imported water is a critical source for much of the population. As a caveat, these totals are based on analysis of pre-drought 2010 data, as readily comparable data across retailers are only published every 5 years through the UWMPs.

Discussion

Water management in Los Angeles County is far from a modern infrastructural ideal (Graham and Marvin 2001) where rational and efficient infrastructures are managed by professionals in cities. Rather it could be described as an anachronism, an artifact of late 19th century water law and legislative intent that was predicated on the ideology of local control in a time where there was no large-scale water conveyance and little urbanization. At the time, the state legislature was reluctant to finance expensive water projects. While state government set up processes for local water development—rules for developing an irrigation district, for example—supervision of implementation was absent (Pisani 1992). The processes enabled home rule. For instance, district farmers who organized an irrigation district held individual water rights, with water apportioned in that district according to the ratio of an individual's taxes to the combined district tax revenue. No regional or state monitoring arose to oversee the creation of districts, water allocations, pumping, or fiscal integrity (Pisani 1992). For the state's first 100 years, it did not even have a state engineering office, let alone a state water agency (though there was a state water engineer from 1878 to 1883 who advocated state involvement in water development and regulation especially around flood control for the Sacramento River). The Department of Water Resources was only created in 1956, largely to operate and maintain the California State Water Project, regulate the state's dams, and provide flood control protection (Pincetl 1999).

Given the likelihood of future water scarcity from drought and population growth, regional agencies and the SWRCB must deal with this fragmented landscape of water providers, where each has distinct regulatory requirements. Clearly, smaller utilities, mostly mutual water companies who serve less than 3,000 connections or provide less than 3000 acre-feet a year, fall entirely out of the SWRCB purview because they are non-profit organizations and not required to report to the SWRCB. Tracking change over time is challenging when there is poor boundary information, no centralized repository for water supply and demand information, and a lack of detailed reporting of water use.

Substantive reform would likely require utility consolidation and far greater reporting requirements about water use, infrastructure repair, and long-term planning and coordination, and would be strongly resisted. The state legislature could require fiscal capacity thresholds, for example, that ensure the local utility is able to detect and repair leaky pipes, report water use over time, and implement programs to enhance water conservation. Non-compliant utilities would face consolidation proceedings. For small mutual water companies that are not geographically contiguous, this could mean consolidation with a public or private utility, but funding to purchase them would be necessary as this would involve condemnation or eminent domain processes. Proposition 218 would likely make this scenario challenging even if an adjacent public utility were interested. Without state or regional involvement, local utilities would have little appetite for such mergers as they would entail a great deal of change and investment. Further, without state agency oversight, such consolidations could be haphazard.

For public water utilities, consolidations, revised boundaries that correspond with cities, or fewer elected or appointed boards to ease voter participation could all help improve transparency and efficiency of governance. For example, all special districts could become city water utilities supervised by city councils.

The management of water in Los Angeles offers a useful case study for understanding resilience of some forms of distributed water systems under conditions of climate uncertainty. Water agencies in this region vary from non-profit share-owner run Mutual Water Companies that have only a few thousand hookups to the largest municipal utility in the country, the Los Angeles Department of Water and Power, as well as private water utilities, special districts and sub-regional middlemen water agencies, neither purely wholesale, nor retail. Each agency or utility has its own set of rules, institutional structure and oversight, and constraints regarding rates and infrastructure investment and maintenance, creating a patchwork across the region.

Overall, the weight of history and the role of rights create potentially obdurate systems that become difficult to change due to lock-in between rights and infrastructure, despite new climate and regulatory conditions and needs. This situation and its outcomes offer insights into the match of institutional scale relative to service in question and the organization of service delivery institutions themselves.

Finally, water revenue and consumption are intimately linked. Currently, if water consumption declines, so do revenues, and utilities are under state mandate to reduce per capita water consumption. It is evident that in the current situation water utilities need assistance in developing new budgetary structures to ensure that they can invest in infrastructure and new technologies, as well as to reconfigure rates. State policy change to Proposition 218 would help, and also state guidelines relative to capacity reserves and other measures to help the utilities invest in upgrades and innovations would be useful. The state legislature is probably the only avenue for local agencies to create new budgeting processes and procedures.

Conclusion

The analysis indicates that state policy to reduce urban water use in a transparent manner is severely challenged by a complex and obscure system and that institutional capacity to invest in new infrastructure, water conservation programs, rate structures that curb high water use, and even detecting and repairing leaking pipes depends on a number of issues of organizational structure, fiscal capacity, and oversight. At this time, the complexity of the system inhibits democratic accountability for all of these issues (it can be difficult for people to understand who delivers their water and what the rules are about the governance of that entity), a troubling situation given that water supply is ultimately a shared resource. Following Mullin (2009), we find that in the case of Los Angeles County, fragmentation does not lead to greater flexibility or resilience.

Given the disparate nature of governance across water agencies, it is also difficult to coordinate planning for integrated water management at the regional level, surely important given the impacts of climate change. One issue is the verification of local UWMP data, and the internal governance of the IRWMP given that they are supposed to operate and a more regional level. They themselves create yet another layer of governance—or at least planning—that lacks transparency to the ordinary rate payer. Then, IOUs are regulated by the CPUC, which conducts periodic rate rebasing exercises and allows a certain return-on-investment, while the rates of all other suppliers are subject to approval by either board members (elected or appointed) or city councils, as shown in Table 1. This means that pricing decisions for the public utilities may be politicized—politicians will have to justify rate increases—and the rates will have to comply with Proposition 218. The tendency is risk aversion and a growing failure region wide to adequately incorporate long-term capital investments. Based on our analysis, while water rates for public special districts vary widely, IOUs tend to have higher rates than city retailers and mutual water companies—their rate increases are protected from local political influence since the PUC in San Francisco approves the rates. How to develop a more integrated approach when each of the utility types is so different has not been thoroughly investigated for possible reform.

The historical legacy of water management in California has structured the present state of water management in Los Angeles County. While water supply to the region is quite simple, provided by 20th century modern infrastructure and agencies, but then the water disperses through a system that is an artifact of late 19th century regulatory ideology. The historic lack of centralized oversight, perhaps acceptable when there was plenty of water, has meant layers of water utilities with varying nuanced governance, piled atop each other, creating an uneven waterscape across the region.

More generally, the Los Angeles case shows the importance of understanding institutional governance and how it may respond to shocks like climate change. Current water governance in Los Angeles County successfully delivers reliable water to the vast majority of 10 million people who live in the 88 different cities. But long-term water reliability challenges will increase, with climate-induced recurrent water supply shortages, unequal access to groundwater, and needed capital for new water infrastructure such as water recycling and groundwater recharge. In particular, small private water companies and special districts, squeezed by water reduction requirements from the SWRCB and limited abilities to raise new funds from ratepayers, seem increasingly ill-adapted. State-mandated consolidation with larger regional entities is one solution, but the weight of historical entitlements and institutional arrangements make this difficult to achieve from the ground-up. State-mandated change would force local change, but would most likely be strongly resisted. Yet, with increasing droughts, water retailers that rely on unreliable sources may be forced out of the water retailer business requiring policy to be developed to address this situation.

Technological options for enhancing water resources in the County exist. There is increasing evidence that the County could greatly reduce imports through water recycling, better stormwater capture and infiltration, better management of groundwater basins, conservation and efficiency programs, and turf removal. But such options are highly constrained by the historically driven institutional architecture of water management. Fragmented and siloed agencies, limited state supervision, lack of capital, and poor accounting of water use all conspire to slow a transition toward greater integrated water management and more efficient water use at the regional level. The LA case thus provides a glimpse into institutionalized fragmentation, showing the difficulties of political transformation once these configurations have solidified.

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