Urban Water-Supply Reinvention

Richard G. Luthy & David L. Sedlak

Abstract: Cities in drought-prone regions of the American West and Australia provide examples of innovative approaches to utilizing local water resources to achieve more resilient water supplies. Geographical realities, population growth, and favorable economic conditions can create the impetus for investments in new technologies, while support by activist groups and NGOs can encourage more sustainable approaches using locally sourced water. New approaches – whether desalination, stormwater use, water recycling, or potable reuse – share a common path to mass adoption. After a period of piloting and demonstration-scale projects, water providers with few options become early adopters of new technologies. And after the early adopters have gained experience and have used it to support the new approaches, the costs and risks of failure decrease for other providers. Thus, a wider cross section can adopt the new approach. The pioneering projects described herein are the first stage of the reinvention of our urban water systems.

The solution to the challenge of urban water security will likely consist of a combination of demand management and the development of a portfolio of new water supplies. For reasons described in this essay – in addition to competing demands for imported water and the impacts of climate change on the hydrologic cycle – it is likely that new water supplies will rely on a mixture of localized strategies such as desalination, urban stormwater capture, and water recycling. To gain insight into the factors influencing the process through which cities pursue new forms of local water supply, and to identify policies that can be used to encourage the transition to more resilient urban water supplies, it is instructive to consider four specific technologies – desalination, stormwater use, water recycling, and potable water reuse – and the preconditions that have led cities to adopt different solutions. With respect to the development of urban water systems, local conditions play a major role in the decision-making process. Nonetheless, some common themes are evident among the early adopters of urban water-supply reinvention and water reuse. For example, rapid population growth coupled with favorable economic conditions

RICHARD G. LUTHY is the Silas H. Palmer Professor of Civil and Environmental Engineering and a Senior Fellow at the Woods Institute for the Environment at Stanford University.

DAVID L. SEDLAK is the Malozemoff Professor in the Department of Civil and Environmental Engineering and Codirector of the Berkeley Water Center at the University of California, Berkeley.

*(*See endnotes for complete contributor biographies.)*

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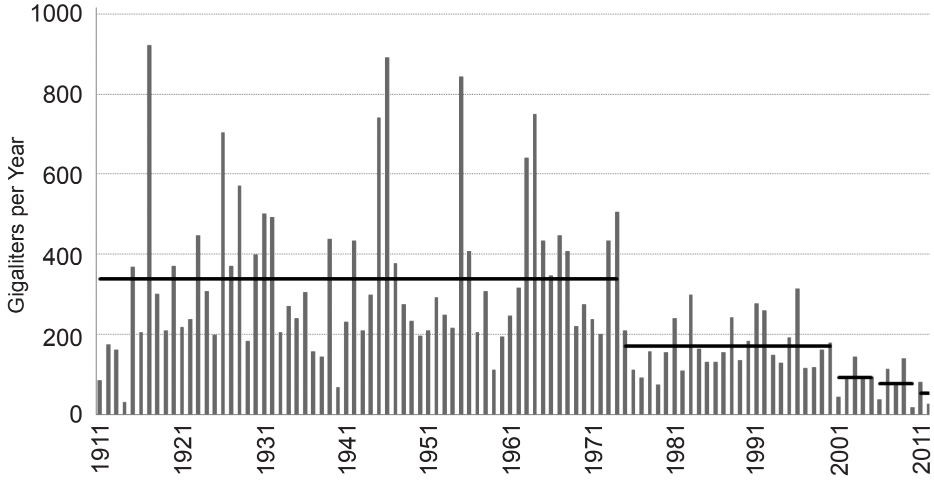
can create an imperative for responding to water stress through investment in new water-supply technologies, rather than by imposing growth restrictions or expecting further gains once demand-management solutions are in place (such as mandates for specific types of landscaping or changes in plumbing codes). In addition, the concerns of activist groups and NGOs, the ability to develop alternative supplies (as opposed to limiting choices), local geographic constraints, and water quality concerns – particularly with respect to salt management – all play an important role in the selection of the specific technologies used in decisions about future water supplies.

Australia is the driest inhabited continent; and its population is concentrated in urban areas along the coast. Australia has experienced many droughts, but the most severe drought since British settlement was what came to be known as the *millennium drought*, which lasted from approximately 1997 to 2009. The millennium drought altered public opinion about climate change and water-use behavior, and energized governments to take swift action to "drought-proof" their water supplies.[1] In what is described as one of the most dramatic and swiftest water infrastructure transitions ever undertaken,[2] Australia's five major metropolitan areas (Sydney, Melbourne, Brisbane, Perth, and Adelaide) embraced seawater desalination to augment drinking-water supplies and commenced on a rapid five-year infrastructure construction program.

Perth is a case study of the key factors that influence the choice of desalination: permanent decline in rainfall, technological developments, and cost reductions in desalination technology and sustainability considerations. Located in Western Australia, Perth is a very dry city, and 2001 was its driest year on record. Perth was among the first regions to feel the impact of climate change and to confirm the belief that climate change had altered the hydrologic cycle. Figure 1 shows what was unique about Perth: permanently reduced step-down average inflow to its catchments that became apparent in 1975.[3] The permanently reduced water supply for Perth resulted in planning for desalination prior to the millennium drought; desalination was the insurance against a worsening situation. At the time of its completion in 2006, the Perth Seawater Desalination Plant in Kwinana was the first large desalination plant of its kind in Australia, and it now provides about 17 percent of Perth's water supply. The clear step-down in Perth's water inflow over three decades from 1971 to 2001 was not mirrored by Eastern Australian cities like Melbourne and Sydney until the millennium drought, and even then it was not sustained after the major rains that followed the drought. Thus, hindsight supports the scale and urgency in Perth's desalination decisions; less so for the cities in Eastern Australia, where potential water sources and management alternatives are more diverse and where public support favors more smartly used grids, stormwater harvesting, and wastewater recycling.[4]

The second factor is that, over the past forty years, seawater desalination costs have greatly declined. Advances in reverse osmosis technology – in which seawater is pressurized against a semipermeable membrane that allows diffusion of water but holds back the salts – are more cost-effective today than older thermal distillation systems. The amount of power required to treat one cubic meter of seawater has declined steadily due to technological improvements in more permeable membranes, energy recovery devices, and more efficient pumps. The energy required for the reverse osmosis step has decreased nearly eight-fold since 1970.[5] The timely advances in reverse osmosis systems reliability and the power and cost efficiencies

Figure 1
Historical Decline in Yearly Inflows into Perth's Dams



Source: Western Australia Water Corporation, *Water Forever, Whatever the Weather: Drought-Proofing Perth* (Leederville, Perth: Water Corporation, 2011). Figure updated with permission.

clearly influenced Perth's decision to embrace this technology.

A third factor in Perth's decision to desalinate water was sustainability considerations. Environmentalists were opposed to using coal-fired plants to power the desalination plants and thus pressured the Water Corporation to find a nonpolluting, renewable power source.[6] The result was a partnership with a regional power company to build an eighty-megawatt wind farm at Emu Downs, two hundred kilometers north of Perth. Two-thirds of the wind farm's production would power the Kwinana desalination plant. Continuing this trend, the Water Corporation purchased renewable energy from solar and wind farms to power a second desalination facility: the Southern Seawater Desalination Plant in Binningup, south of Perth. Australia is the first country to link desalination with renewable energy.[7]

In short, desalination was the option of last resort for a desperate Perth and two desalination facilities now deliver almost half of Perth's water-supply needs.[8] Spain and Israel have followed Perth's lead and have similarly chosen desalination to boost their water supply.[9]

Los Angeles, along with many cities in California, was built with imported water. Beginning early in the twentieth century, massive water infrastructure investments – from cities, the state, and the federal government – led to the creation of a vast network of reservoirs, dams, and aqueducts that supported California's stunning population growth and booming economy. However, by the beginning of the twenty-first century, it was apparent that California's metropolitan regions had reached their limits in terms of reliance on imported water. The City of Los Angeles provides a model of how a major policy change at the municipal level can achieve a more sustainable and reliable water supply.

In 2007, the situation in Los Angeles reached a crisis: it was the driest year on record for the city and the lowest snowpack on record in the Eastern Sierras, from which the city receives a major portion of its water supply. Continued population growth and uncertain climate change impacts put additional stresses on the water-supply system. Meanwhile, court rulings invoking the Endangered Species Act led to reduced exports from the Northern Sacramento–San Joaquin Delta southward to Los Angeles via the California aqueduct. Court actions enforcing the state's public trust doctrine also mandated less flow to the Los Angeles aqueduct, requiring more water for environmental mitigation and enhancements in Mono Lake and the Owens Valley in the city's Sierra Nevada catchments.

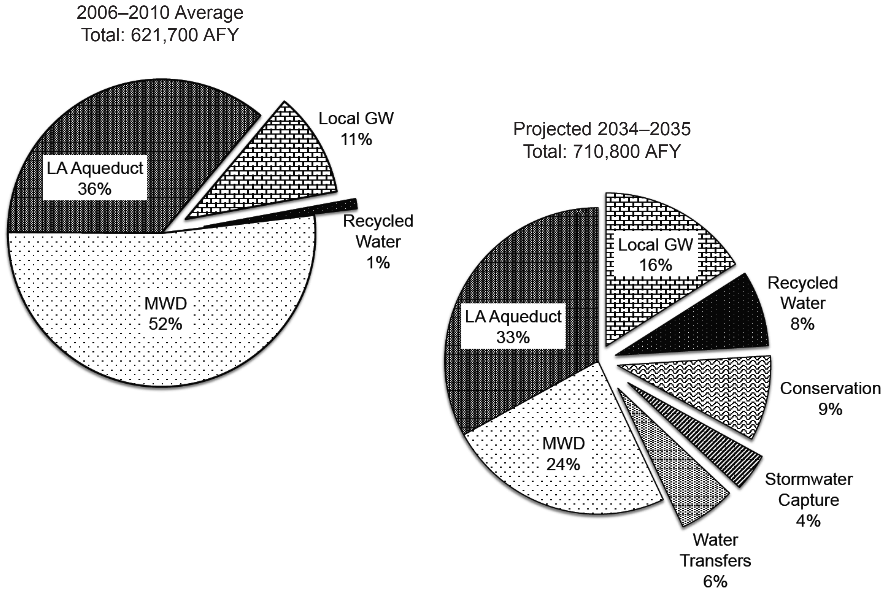
The convergence of these factors caused Mayor Antonio Villariagosa and the Los Angeles Department of Water and Power (LADWP) to embark on a new course of creating sustainable sources of water for Los Angeles. This landmark blueprint for action, described in the document *Securing L.A.'s Water Supply*,[10] seeks to reduce reliance on imported water and meet all new demand through conservation and expansion of water recycling, stormwater capture, and groundwater cleanup and storage.

Figure 2 shows two pie charts that describe the makeup of Los Angeles' water supply today and what it will look like in 2035 in acre-feet per year (AFY; one acre-foot is about 0.32 million gallons or 1,200 cubic meters).[11] Note the reduction in reliance on imported water from the Metropolitan Water District (MWD), which is the major wholesaler for water supplied from California's State Water Project and the Colorado River aqueduct. Today, the Metropolitan Water District supplies about one-half of Los Angeles' water. In twenty years, this will decrease by 50 percent in absolute terms despite continued population growth. This is achieved by increasing the water-supply portfolio, especially through development of local sustainable water supplies.

As depicted in Figure 2, LADWP's future water-supply portfolio does not include seawater desalination. This is a result of concerns about costs and the environmental impacts – raised by local activist environmental groups in Southern California – associated with desalination.[12] For example, the Surfrider Foundation has voiced concern about open-ocean intakes, advocating instead for subsurface intakes to prevent harm to marine life, and has pointed out that concentrated brine discharge can degrade marine habitat if not properly diluted. The Sierra Club has raised these same concerns, adding questions about the energy intensity and increased greenhouse gas emissions associated with seawater desalination. In short, the cost, environmental impacts, and unpopularity of desalination with the public and NGOs – and the ready availability of alternatives – led the city and the LADWP to meet the city's future water-supply needs through conservation and significantly enhanced stormwater capture and water recycling.

As Figure 2 illustrates, Los Angeles aims to reduce water demand by 64,000 AFY by 2035, which is in addition to the 100,000 AFY already conserved since the 1990s. From 1980 to 1990, population grew at 1.7 percent per year, with water demand growing at the same rate. But after the LADWP began implementing water conservation measures in 1991, demand has remained flat despite a population growth of 1.1 million people. From 2010 to 2035, Los Angeles' population is projected to increase by 367,300 persons, and the city's conservation goal is to reduce per capita water use

Figure 2
Comparison of Existing and Projected Water Supply Sources for the City of Los Angeles



GW: Groundwater. MWD: Metropolitan Water District. The charts do not reflect the 100,000 acre-feet per year (AFY) of existing conservation. One acre-foot is about 0.32 million gallons or 1,200 cubic meters. Source: Los Angeles Department of Water and Power, *2010 Urban Water Management Plan* (Los Angeles: Los Angeles Department of Water and Power, 2010; rev. 2011).

to 138 gallons per person per day by 2020.[13] Thus, with aggressive water conservation, the amount of water needed for an additional 367,300 persons is about 57,000 AFY. This illustrates that water conservation can reduce the future increase in demand for water caused by population growth, but conservation does not significantly reduce the overall demand for imported water. Clearly, aggressive conservation can accomplish much. But after low-flow devices are installed in new and older buildings, plumbing codes are changed, and incentive programs are implemented for landscaping conservation, there is not much more that can be done using existing conservation techniques. For these reasons, stormwater capture and water recycling play critical roles in reducing overall water imports for Los Angeles.

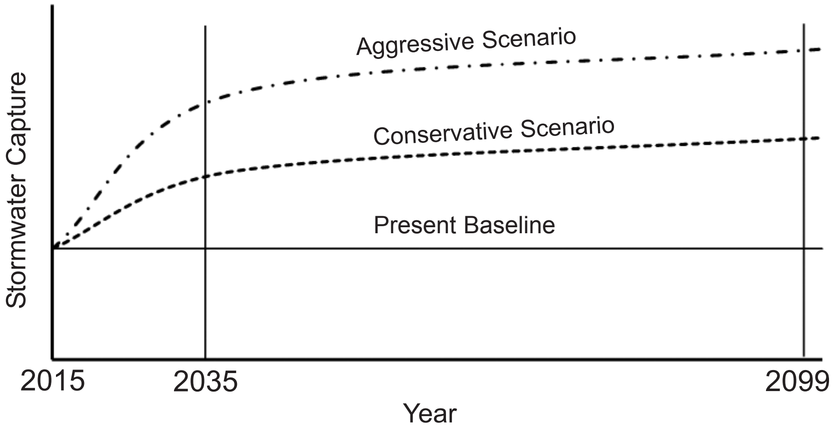
Work is now underway to upgrade and construct centralized projects for stormwater capture and groundwater recharge (the hydrologic process through which surface water becomes groundwater) to increase capture/recharge productivity by at least 25,000 AFY by 2035. An additional 10,000 AFY of conservation is expected to result from decentralized systems like rain barrels and neighborhood-scale cisterns. To achieve these goals by 2035, the LADWP created the Watershed Management Group, a partnership among agencies and environmental groups (including TreePeople and the Green LA Coalition) responsible for developing and coordinating stormwater projects among stakeholders. The Watershed Management Group's primary purpose is to enhance Los Angeles' water supply by increasing stormwater capture at existing centralized facilities and promoting distributed stormwater infiltration systems.[14] Stormwater capture is popular with environmental groups and NGOs because, in addition to groundwater recharge, capture leads to the creation of green space and reduction of pollution load at beach sites.

Los Angeles has captured stormwater for over eighty years in the San Fernando Basin through the flood plains and tributaries of the Los Angeles River. But urbanization increased the city's hardscape, resulting in less infiltration of stormwater and a decrease in regional groundwater storage. Los Angeles is currently developing a stormwater capture master plan to determine stormwater capture potential, feasible locations for centralized and decentralized stormwater capture systems, and costs and milestones.

The low-lying flatlands of Los Angeles are not adjacent to large tributaries. In these areas, distributed, smaller stormwater infiltration strategies will be implemented at the neighborhood scale and the scale of landscape changes on individual citizens' property. Because of its permeable soils, the San Fernando Basin provides the best locations for new and enhanced facilities for large-scale stormwater capture. Figure 3 shows an estimate of the twenty-first-century stormwater capture potential for Los Angeles under two scenarios: 1) an aggressive path with nearly 150,000 AFY captured in centralized facilities and 44,000 AFY captured in decentralized facilities; and 2) a more conservative path with modest increases beyond the 2035 goals outlined above.[15] Although theoretical, the curves shown in Figure 3 are based on specific projects implemented at the land-use level. The conservative approach assumes that stormwater capture is limited to areas with no contamination, while the aggressive-action scenario assumes that groundwater contamination is no longer an issue. The long-term potential for upgraded and new centralized facilities for stormwater capture and recharge would significantly change the water-supply portfolio shown in Figure 2. But uncertainty in how to safely capture, treat, and recharge stormwater in ways that protect groundwater quality, provide community benefits, and gain the support of activist groups and NGOs remains a significant challenge to achieving these ambitious goals.

Enhanced water recycling is expected to grow eight-fold by 2035. Los Angeles also has a history of using recycled water for parks, golf courses, and cemeteries. Recycled water is currently in use at the Los Angeles Japanese Tea Garden, Wildlife Lake, and Balboa Lake, after which water continues to flow to the Los Angeles River, where it supports native plants and wildlife. Recycled water is also injected into the ground near the coast to prevent seawater intrusion into local aquifers (underground layers of rock through which water can flow, and from which water can be drawn using a well). *The Urban Water Management Plan* calls for expanding the recycled water pipeline system and using recycled water for groundwater replenishment. Recycled water pipeline systems are expensive to install and often are the major obstacle for expanding water reuse beyond areas adjacent to a centralized treatment plant.[16] Los Angeles' solution is to expand the recycled water distribution system for nonpotable uses for major consumers like parks, lakes, refineries, and generating stations. Groundwater replenishment with recycled water is also an objective, but this requires advanced treatment, as is explained below. For groundwater replenishment with recycled water,

Figure 3
Illustration of the Potential for Stormwater Capture and Recharge to Provide More Reliable and Sustainable Water Supplies for Los Angeles



The Stormwater Capture Master Plan (SCMP) considers scenarios that, using aggressive action, could nearly triple the amount of stormwater captured. Source: Rafael Villegas, *Stormwater Capture Master Plan: The Master Planning Process* (Los Angeles: Los Angeles Department of Water and Power, 2014).

Los Angeles will employ additional treatment steps of microfiltration, reverse osmosis, and advanced oxidation to ensure healthy water and to address low levels of contaminants of increasing concern.[17]

The first large-scale, permanent potable water reuse system in the United States was built by the Orange County Water District in 1976 in response to recognition that rapid development of the urban area south of Los Angeles was degrading the quality of the local groundwater basin.[18] Specifically, excessive groundwater extraction had caused seawater intrusion into the coastal aquifer, leading to closure of drinking water wells as far as six kilometers inland.[19] To support the region's ambitious plans for continued growth, the water district adopted a policy of reversing the damage to the coastal aquifer through enhanced freshwater recharge. The main strategy involved the installation of a seawater intrusion barrier (a line of freshwater injection wells) approximately two kilometers from the coast. After ruling out the use of seawater desalination due to its high cost, the utility turned to the local municipal wastewater treatment plant as the source of freshwater for the injection wells.

The initial potable water reuse project, known as Water Factory 21, employed a series of advanced water-treatment technologies (its name refers to its use of twenty-first-century technology). The "factory" consisted of two parallel treatment trains operated side-by-side to purify 0.7 m^3/s (16 million gallons per day) of wastewater effluent. One treatment process train employed activated carbon filtration to remove organic chemicals that might compromise the taste of the water or pose public health risks, while the other train used reverse osmosis to remove contaminants. The reverse osmosis process, which was the more expensive of the two, had the added benefit of reducing the salt content of the water – a necessity due to the fact that the local tap water was rich in salt to begin with, and the modest increase resulting from use and recycling raised the ion content to unpalatable levels.

As the region's need for water increased, the water district tripled the capacity of the system by replacing the original facility with a new treatment plant employing reverse osmosis and an advanced oxidation system against contamination.[20] That facility, the Groundwater Replenishment Facility, has become a standard design replicated by new potable water reuse facilities worldwide, such as the NeWater system in Singapore. Further, the water district's clear communication to the local community of its intentions and commitment to the protection of public health serves as an example of how a water provider can foster legitimacy and public support.[21]

Although the example set by the Orange County Water District established a common design for many potable water recycling systems, the use of reverse osmosis is problematic in inland communities that lack a means of disposing of the salts removed from wastewater effluent. To safely reuse potable water in its inland community, Aurora, Colorado – a rapidly growing suburb of Denver – built a 2.2 m^3/s (50 million gallons per day) facility that subjected water from an effluent-dominated section of the Platte River (where Denver discharged its wastewater effluent) to treatment processes that removed chemical contaminants and waterborne pathogens without producing a salt-brine waste stream.[22] Employing riverbank filtration followed by advanced oxidation and activated carbon filtration, the Prairie Waters Project proved that it was possible to recycle wastewater effluent without reverse osmosis.

Local conditions were key contributors to the design of Aurora's treatment system. The geology of the South Platte River site was favorable to the installation of groundwater extraction wells adjacent to the river (riverbank filtration) and the availability of a drinking-water aquifer made it possible to store the treated water underground. Further, the absence of a convenient means of disposing of salts produced by reverse osmosis created an incentive for the water service provider to purify the water without removing salt. Similarly, local conditions also determine water storage strategies: communities that lack access to a suitable aquifer are forced to store treated water above ground. In addition to posing a greater risk that the public might reject a potable water reuse project due to concerns about the origin of the water (empirical evidence suggests that underground storage plays a role in overcoming concerns about the past history of water),[23] existing surface water storage facilities are usually located at the highest elevations in the city, necessitating significant use of energy to pump recycled water – typically produced at the lowest elevations in the city – to the reservoir.

The issue of salt management and pumping costs were important to the recent decision of a water utility located near Odessa, Texas, to build a potable water reuse facility that recycles approximately 0.11 m^3/s (2.5 million gallons per day) of wastewater effluent. Due to the high concentrations of salt in the local water supply, the Big Spring Water Recycling Facility, like the Orange County Water District's Groundwater Replenishment Facility, employs reverse osmosis and advanced oxidation, though instead of storing the water underground, the facility pipes it directly into a water-supply canal.[24] The decision to recycle the city's wastewater instead of importing freshwater was encouraged by the relatively high cost of pumping water to the city from potential sources, all of which were located at considerably lower elevations than the reservoir.

As illustrated by the examples of potable water reuse in the United States; seawater desalination in Australia; and urban stormwater capture, treatment, and recharge in Los Angeles, new water-supply approaches can provide a viable means of breaking the longstanding dependence of cities on imported water. However, these pioneering efforts were prompted by severe water stress and cities' new willingness to pay for technologies that were expensive relative to conventional options. For cities that are not currently facing acute water stress or that lack the financial means to pay for new technologies, these new approaches may not seem like viable alternatives to existing water-supply approaches. This situation is a common attribute of technology transitions that occur when a new approach replaces an established system.[25] For familiar examples, like wireless communication replacing landlines or data storage moving from floppy discs to cloud-based storage, the time between the first appearance of a new technology and the displacement of an existing technology is shorter than that of a change in civil infrastructure because the replacement cycle is shorter. Nonetheless, transition processes are similar in many respects: initially, new technologies are often more expensive than existing approaches. While they provide benefits relative to existing approaches, the risk of failure in the water sector discourages widespread adoption.[26] After a period of piloting and demonstration-scale projects, water providers with few viable alternatives turn to new technologies and are willing to bear the extra costs and higher risks of failure. After these early adopters have gained experience and thus supported the start-up of a new industry, the costs and risks of failure decrease and a wider cross section of the community can adopt the new approach.

Viewed from the perspective of technology transitions, the pioneering water-supply projects described above are the first stage of the reinvention of urban water systems. After the early adopters have implemented their pioneering projects, the institutional barriers to financing, regulating, and operating these new technologies will diminish and the overall costs of new forms of water supply will become favorable when considered in a triple-bottom-line analysis. We anticipate that in much the same way that urban water systems have undergone periods of rapid change,[27] we will in the coming decades reinvent the way in which we plan, manage, and operate urban water systems.

ENDNOTES

* Contributor Biographies: RICHARD G. LUTHY is the Silas H. Palmer Professor of Civil and Environmental Engineering and a Senior Fellow at the Woods Institute for the Environment at Stanford University. He is also the Director of the NSF Engineering Research Center for Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt) and a member of the National Academy of Engineering.

DAVID L. SEDLAK is the Malozemoff Professor in the Department of Civil and Environmental Engineering and Codirector of the Berkeley Water Center at the University of California, Berkeley, and Deputy Director of ReNUWIt. He is also the author of *Water 4.0: The Past, Present and Future of the World's Most Vital Resource*.

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