SEWERS, PONDS, AND GARDENS

Climate change and ongoing urban growth intensify water scarcity, flooding, and water pollution in cities worldwide. To tackle these challenges, cities have widely endorsed urban water circularity as a new paradigm for infrastructure development that enables more circular water flows. *Sewers, Ponds, and Gardens* draws on a case study of Los Angeles, California, to explain shifting constellations of urban water and wastewater infrastructures in the context of growing water challenges and proliferating ideas of circularity. The study shows how attempts to realize urban water circularity through infrastructure renewal produce novel, power and value-laden arrangements of governing urban nature and space. Conceptually, the study draws from debates in urban political ecology, science and technology studies, and studies on urban infrastructures. Its analysis of the political power constituted by technology emphasizes the instability of different technological cultures of urban nature through which urban environments become known and governed. Ultimately, the study highlights avenues for rethinking institutions, actor roles, as well as knowledge and values in water governance to overcome contemporary urban water challenges.

Valentin Meilinger

Valentin Meilinger was born on 27 December, 1990 in Landshut, Germany. He obtained his BA in Human Geography in 2014 and his MA in Human Geography in 2017 from the Goethe University in Frankfurt am Main. In 2017, Valentin was awarded a PhD scholarship and started his doctoral studies at Utrecht University. As a PhD candidate, he visited the California Center for Sustainable Communities at UCLA in 2018 and in 2019, and spent one year at the Federal University of Rio de Janeiro. Since 2021, Valentin is a Research Fellow at the German Environment Agency, working on urban climate change adaptation. Drawing from science and technology studies, urban studies, and debates in critical geography, his research revolves around the shifting relations between infrastructure, water, and landscapes in cities under climate change. In particular, he focuses on the political role of infrastructure in the creation and remaking of urban natures to analyze contemporary technological cultures of urban nature.

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SEWERS, PONDS, AND GARDENS

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Technology and the Politics of Circular Water Flow in Los Angeles

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Sewers, Ponds, and Gardens
Technology and the Politics of Circular Water Flow in Los Angeles

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Sewers, Ponds, and Gardens

Technology and the Politics of Circular Water Flow in Los Angeles

Riolen, Vijvers en Tuinen

De Technologie en Politiek van een Circulaire Waterstroom in Los Angeles

(met een samenvatting in het Nederlands)

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INTRODUCTION

"[Technology is] not merely a servant of some predefined social purpose; it is an environment within which a way of life is elaborated." (Feenberg, 2010: 15)

FIGURE 1 A Bigger Splash by © David Hockney (1967)

When we think about the city of Los Angeles, images of palm trees, lush gardens with green lawns, or swimming pools might come to mind. Abundant water – brought into the city by extensive aqueducts – has shaped the imaginations and the material realities of modern Los Angeles. The image of Los Angeles as a green oasis in the midst of a desert, where suburban life is comfortable and prosperous, have been broadcast around the globe through depictions such as David Hockney's *A Bigger Splash* (see Figure 1). Yet, these imaginations conceal the environmental dynamics that deeply unsettle contemporary life in Los Angeles. In 1998, Mike Davis famously depicted the sprawling late-twentieth-century city as being on the brink of disaster, threatened by floods and droughts co-produced by rampant urbanization. Today, the consequences of climate change have brought irreversible disruptions to the management and usage of water and wastewater the city. Recurring droughts have spurred far-reaching public policy responses, while the effects of climate change are being increasingly felt in everyday life. Water-hungry lawns and ongoing water pollution are now recognized in public discourse as key elements of the city's unsustainable ecology.

This dissertation explores Los Angeles as a quintessential modern city where twenty-first-century global urban water challenges are strikingly apparent. While there may be differences in urban water management and use between the Global North and South, scholars assert that cities worldwide are experiencing a worsening "urban water crisis" (Bell, 2017). In 2018, Cape Town's "Day Zero," which was the day the city was projected to run out of water during a severe drought, made headlines worldwide. While the city was eventually able to avoid this crisis, it highlighted the growing issue of water scarcity in urban areas. Other cities from São Paulo to London face water shortages and persistent water pollution, while Jakarta has become synonymous with the challenges of urban flooding. The combination of climate change, ongoing pollution, and urban population growth has placed significant stress on urban water systems and contributed to the unsustainability and inequity of many cities. Urban population growth, paired with ecosystem deterioration and increased weather variability, has made water security a critical concern in urban water management (Krueger et al., 2019). However, scholars also point to governance failures (Bakker, 2010; Pahl-Wostl, 2017), inherited infrastructure systems designed to meet the social needs and engineering standards of the past (Pincetl et al., 2019), and uneven capitalist urbanization processes (Kaika, 2005; Goh, 2020) as contributing to urban water crises.

Ambitious policy visions and new paradigms in urban water management to address water challenges in cities in the Anthropocene have emerged. One central idea is to integrate water supply, water quality, and flood control tasks by managing water within a "total water cycle" (Brown and Farrelly, 2009: 839). This approach adopts the principles of the "circular city" concept, which emphasizes the circular organization of material and energy flows to enhance urban sustainability and prosperity. Integrated approaches are also being increasingly adopted to strengthen the climate resilience of urban water systems, particularly in response to water scarcity and extreme weather events (Butler et al., 2017; Khirsen et al., 2018). These developments in urban water management reflect wider dynamics in urban ecology, where approaches to understanding and governing urban environments as complex adaptive systems have become dominant (Gandy, 2022). Urban infrastructures are strategically deployed in such approaches as levers to create more sustainable and resilient cities (Derickson, 2018; Bulkeley, 2021). Simultaneously, there is a growing diversity of technologies being developed for urban water management, including large-scale technological solutions like desalination and wastewater recycling practices, as well as a plethora of nature-based practices. Policymakers and practitioners envision realizing circular water cities by combining these diverse technologies into new infrastructure arrangements.

In light of these developments, this dissertation emphasizes the importance of exploring the political relations between the visions of urban water circularity and the socio-technical change of urban water infrastructures that are emerging in efforts to tackle contemporary urban water crises. This focus builds on a widely established idea within critical urban scholarship that ecological crises and potential remedies are internal to society (Swyngedouw, 2004). However, the emergence of concepts related to urban water circularity calls for closer scrutiny of the political role of technology in addressing urban water challenges. Especially the ways in which policy and planning visions put high hopes for urban water sustainability and resilience on a suite of different technologies to transform linear urban water systems into circular ones merit detailed inquiry. This observation is based on the premise that technology is not a neutral tool to modernize cities and societies, but rather a contested site where different visions of urban futures are negotiated and fleshed out (Hecht, 2009; Gopakumar, 2020).

This dissertation adopts the politics of technology as a vital but underutilized lens to examine the contested governance of circular urban water restructuring. Attention is drawn to how different actors' technological interventions aim to bring forth novel arrangements of urban water and wastewater infrastructures. By foregrounding the social processes underlying technology, we can analyze how circular water futures are forged and contested within the context of historically evolved urban environments and modernist cultures of urban nature and technology that have given rise to circularity visions. Exploring technical disputes over urban water circularity also reveals diverse and at times competing proposals for governing urban nature and space.

In this introduction, relevant academic literature is reviewed to create an analytical framework that will guide the inquiry. The key questions and research methods used to explore the Los Angeles case are also outlined. The next section provides a summary of scholarship on water and wastewater politics in Los Angeles to situate the analysis within this vivid debate. Then, academic debates that aid in developing a critical understanding of circular water restructuring in Los Angeles are reviewed. These include literature on cities in the Anthropocene, scholarship in urban water governance, and debates in urban political ecology that explain the historical production of urban nature. This study also draws on critical debates on urban infrastructures and work in science and technology studies (STS) to frame technology as a structural force that shapes urban development and as a dynamic site where urban futures are contested. As a whole, the literature review highlights the need for a critical inquiry into the social processes underlying technology that shape the political relations between urban infrastructures and urban nature, particularly at a time of proliferating ideas of urban circularity.

1.1 The infrastructural city – water and wastewater politics in in Los Angeles

> "No belief is more deeply rooted in the Southern Californian mind than the self-serving conviction that Los Angeles would be Death Valley except for the three great aqueducts that transfer the stolen snow melt of the Sierra and Rockies to its lawns and pools." (Davis 1998: 10)

Located in Southern California, Los Angeles is the second-largest city in the United States. With a population of 3.95 million inhabitants in 2021 (United States Census Bureau, 2022), Los Angeles is at the heart of a heavily urbanized region stretching along the Pacific coast. The County of Los Angeles is one of the wealthiest and most productive urbanized areas globally, with a gross domestic product of $707 billion (World Trade Center Los Angeles, 2022). From the outset, the history of modern Los Angeles was one of rampant development. In the late nineteenth century, Los Angeles was mostly an agricultural town. However, by the twentieth century, the former Spanish mission had transformed into an epitome of a modernist metropolis. Rapid urbanization was spurred by the local petroleum and automobile industry, Hollywood, and a vast military-industrial complex (Abu-Lughod, 1999). Post-war economic growth and a large influx of immigrants turned Los Angeles into America's "suburban metropolis" (Fishman, 1987), characterized by vast single-family home neighborhoods connected by a monumental freeway system (Banham, 1971). The development of this "infrastructural city" was made possible by the expansion of centralized infrastructure networks that mobilized flows of resources, goods, and people while controlling environmental hazards (Varnelis, 2009).

Despite infamous stories of economic elites creating Los Angeles out of thin air, public policies played a fundamental role in the city's development (Wolch et al., 2004). The historical expansion of water and wastewater infrastructures is a prominent example of this. Scholars have documented the links between public water management and urban growth in Los Angeles (e.g., Kahrl, 1983; Reisner, 1993; Erie and Brackman, 2006). At the center of the city's water infrastructure is the 233-mile Los Angeles Aqueduct, which has supplied the city with drinking water since 1913. Owned by the public Los Angeles Department of Water and Power (LADWP), the aqueduct symbolizes a modernist approach to water management, focused on ensuring a cheap, abundant, and reliable water supply through water imports. To this day, LADWP functions as a quasi-independent public entity with its own governing board, while a ratepayer advocate strictly controls water rates and infrastructure investments. As a proprietary department of the city of Los

1 The Colorado River Aqueduct was inaugurated in 1941 and the California State Water Project delivers water to Southern California since 1973.

Angeles with largely unionized employees, LADWP has resisted stronger commercialization of water supply (Hughes et al., 2013). Nevertheless, scholars have demonstrated how LADWP's expansionist water management approach fueled an "urban growth machine" (Logan and Molotch, 1987), generating private profits for local economic elites and tax revenues from urban development (MacKillop and Boudreau, 2008). Later, this regime was further supplied with water from the Colorado River Aqueduct and the California State Water Project[1] by the Metropolitan Water District of Southern California (MWD) – the regional water wholesaler whose member agencies form Southern California's public and private water utilities (Fulton, 2001; Erie and Mackenzie, 2010). Although receiving less scholarly attention, the City of Los Angeles Bureau of Sanitation (LA Sanitation), which owns and manages Los Angeles' centralized sewers, also supported urban growth by collecting, treating, and rapidly discharging wastewater (Sklar, 2008). The agency is directly controlled by the Los Angeles City Council and operates on a significantly smaller budget than LADWP. Lastly, tax-financed flood control infrastructures managed by the US Army Corps of Engineers and the Los Angeles County Flood Control District were crucial in confining floods to a narrow channel system, enabling urban development (Orsi, 2004).

However, just as the achievements of modern urbanization have become apparent in Los Angeles, so have its uneven and destructive consequences for nature and society. The so-called "Los Angeles School of Urban Studies" uncovered the striking social injustices linked to urbanization in Los Angeles since the late 1960s (Soja and Scott, 1996; Dear and Flusty, 1998). Los Angeles became a focal point of postmodern urban theory developed to grasp the deeply uneven process of socio-spatial differentiation driven by post-Fordist economic restructuring (Nicholls, 2011; Soja, 2014). In Mike Davis' (1998) iconic book *Ecology of Fear*, Los Angeles was portrayed as a modern metropolis on the brink of partially self-induced environmental disasters. Rampant urban growth in the region's Mediterranean climate gave rise to deadly floods, health-threatening water pollution, and exacerbating water scarcity (see also, Desfor and Keil, 2004; Gandy, 2014). Scholarship has also documented how economic and state reforms since the 1970s have impacted Los Angeles' water and wastewater regime. Most notably, California's Proposition 13 in 1978 drastically reduced local property taxes – the primary source of income for local governments – resulting in reduced budgets for public infrastructure provision. This pushed municipalities to increase local sales taxes through urban growth to generate revenue (Wolch et al., 2004; Pincetl, 2010). To avoid a downward cycle of declining infrastructure, high interest rates, and insufficient investments, municipalities resorted to debt-financed infrastructure investments that bet on future urban development (Kirkpatrick and Smith, 2011).

Driven by environmental activism around water pollution and recurring droughts, water sustainability became increasingly prominent in public policy in the 1990s. Likewise, academic debates evolved, and Jennifer Wolch (2007: 374) famously called for an interdisciplinary research agenda to “carve out geographies of hope from […] urban landscapes of fear.” Building on the work of Wolch, scholars have examined the limitations and potential for systemic change in water and wastewater governance in Los Angeles. They have identified a “water scarcity lock-in” resulting from the rapid discharge of stormwater before it can infiltrate into groundwater aquifers, the widespread use of cheap water, and the reliance of public water utilities on water sales revenues, which thwarts conservation efforts (Pincetl et al., 2019). Dwindling water imports caused by reduced snowfall in sourcing areas due to climate change, along with stricter environmental regulations in those areas and recurring droughts, have put Los Angeles’ water system under immense pressure (Hughes et al., 2013; Pincetl et al., 2019). At the same time, water quality regulations and environmental activism have pushed public officials to reconfigure stormwater systems to better mitigate pollution and reuse stormwater as a local resource (Porse, 2013; Cousins, 2017). Research that combines governance analysis with modeling has demonstrated opportunities for achieving water sustainability through transitioning to near-regional water self-sufficiency (Porse et al., 2017; Pincetl et al., 2019). Achieving this would require a drastic increase in water conservation efforts, the reuse of stormwater and recycled wastewater as local resources, and the activation of currently poorly managed and often polluted regional groundwater aquifers as storage for infiltrated stormwater and recycled wastewater. Especially landscape change to reduce outdoor water use in historically irrigated landscapes is seen as a significant possibility for achieving water sustainability (Mini et al., 2014).

However, scholars have identified several barriers to achieving more sustainable water futures in Los Angeles. Following neoliberal state reforms, water systems have remained underfinanced, and the reliance of water utilities on volumetric water sales impedes conservation efforts (Pincetl et al., 2019). In particular, funding for stormwater infrastructure has been scarce, with little to no budget for maintenance (Park et al., 2009). Furthermore, fragmented institutions and political jurisdictions hamper water sustainability. LADWP and LA Sanitation are institutionally separated, and water-related decisions relevant to the city are made on a regional level (Hughes et al., 2013). In addition, regional groundwater basins cut across political boundaries, and pumping rights are splintered among a plethora of public and private owners, complicating the use of these basins for water storage (Pincetl et al., 2016). Critical scholarship has further highlighted how political interests and power relations serve as barriers to water sustainability. For instance, Cousins (2017) has shown how technocratic practices dominate stormwater management in Los Angeles. Public engineers frame stormwater as a problem of volumetric control for pollution mitigation, which maintains their institutional interests but undermines decentralized stormwater practices.

Whereas the political economies and urban governance orders of water and wastewater management in Los Angeles are richly documented, the politics of technology shaping water and wastewater restructuring have been less explicitly studied. One exception is Randle's (2021) excellent ethnographic exploration of the technopolitics of greywater reuse in Los Angeles. Although it does not explicitly address broader infrastructural change, the study is a valuable contribution to the field. Cousins (2017, 2020) has also made significant contributions by skillfully fusing urban political ecology with the analysis of technopolitics, exposing uneven stormwater politics and the changing political role of flood control systems in Los Angeles.

Current efforts to promote water sustainability in Los Angeles focus on integrated water management. LADWP and LA Sanitation aim to tackle water pollution, flooding, and water scarcity by managing water through a "One Water" cycle that combines centralized and decentralized water management technologies (LA Sanitation, 2018). The city's Green New Deal sets a goal of sourcing 70% of water locally by 2035 through the recycling of all wastewater, capturing and infiltrating stormwater into local groundwater aquifers, and implementing water conservation measures (City of Los Angeles, 2019).

Studying the politics of technology in creating a more circular water flow in Los Angeles can shed light on the contradictions, ambivalences, and frictions involved in this process. This makes a novel scholarly contribution, especially since global urban policymakers and practitioners are increasingly promoting water circularity through technological advancement. Therefore, it is crucial to better understand the political relations between ideas of water circularity, infrastructural change, and urban environmental governance. The next section reviews various academic debates that help to grasp these political relations while identifying gaps in the literature regarding the political role of technology in circular city-making. This review places the Los Angeles case within broader debates in critical urban scholarship and provides the basis for constructing a theoretical framework guiding this study.

1.2 State of research

1.2.1 Cities in the Anthropocene

Disruptive and potentially irreversible global environmental change is increasingly understood through the term Anthropocene (Röckstrom et al., 2009). Scientists describe the Anthropocene as a new geological era marked by major disturbances in the carbon cycle, temperature rise, biodiversity loss, ocean acidification, and sediment erosion that can be traced back to human activities. A deep sense of uncertainty prevails in the Anthropocene as societies grapple with the eroding of a planetary system essential to their existence.

Urban scholars have highlighted the major role of cities in the Anthropocene. As epicenters of a globalized economy, cities are scrutinized as drivers of global environmental change, but also strategic sites of sustainability and resilience (McGuirk et al., 2016; Bulkeley, 2021). Derickson (2018: 426) has underlined the need to critically study systemic responses to social and environmental crises that frame the city as a "deus ex machina of the Anthropocene". Concepts like the "smart city", "urban resilience", or the "circular city" promise to govern and transform cities as complex adaptive systems to enhance sustainability and prosperity (Monstadt and Coutard, 2019). Although these concepts and the ways in which they are locally adopted are shaped by certain knowledge communities and often strongly focus on particular technologies, they have become influential templates for urban policymaking in the Anthropocene more broadly. Scholars highlight the deeply normative character of purportedly smart or resilient urban interventions through which actors seek to govern cities as if there was a general consensus on certain goals associated with these often vaguely defined concepts (Braun, 2014; Derickson, 2018). This scholarship examines urban resilience or smart cities as powerful "dispositifs" of urban governance (Braun, 2014, using Michel Foucault's term). These concepts guide actors' endeavors to combine diverse ideas and practices in new heterogeneous constellations that promote specific social interests in attempts to rework the crisis-stricken ecologies of cities in the Anthropocene.

Implicit in the discussion is an epistemological critique of concepts that frame cities as complex adaptive systems, which guide urban environmental interventions. Gandy's (2022) critical analysis of urban ecology as a "system-based approach" to urban nature that dominates contemporary efforts to render cities more sustainable and resilient makes this explicit. This approach aims to develop a holistic understanding of cities as complex adaptive systems where socio-economic and biophysical dynamics interact. However, Gandy's (2022: 26) critique highlights that this perspective tends to overlook important historical and political dimensions of urban development which explain how certain ways of framing environmental problems that guide environmental action are produced and contested. This critique suggests interpreting system-based approaches to urban nature, which contain rigid notions of system boundaries, values, and assumptions about social phenomena, as inherently political and normative. Searching for counter-narratives to dominant ideas of urban sustainability and resilience, Gandy investigated various alternative cultural, political, and scientific interventions in urban nature that have their own ways of understanding and valuing urban nature. In sum, this suggests that ideas of cities as complex adaptive systems prevalent in contemporary endeavors to make cities more sustainable and resilient are produced, contested, and sought to be put into practice differently in historical urbanization processes.

So far, circular city initiatives as a response to the environmental challenges in the Anthropocene have hardly been scrutinized along these lines. Even less so, scholars have explored the political role of technology in processes of circular city-making. Wakefield (2018) noted that by providing an essential material basis upon which cities thrive and mediate their impacts on the earth's biosphere, "infrastructure has become perhaps the political question of the Anthropocene." This calls for a stronger focus on technology as a site of political struggle that influences how circular city concepts are forged, contested, and put into practice in different urban contexts. Circular water management practices can be analyzed as responses to urban water challenges that strategically conflate technology and politics. It has not been explicitly studied how the relationship between a modernist culture of managing urban nature through technology and alternative technological interventions into urban nature shape circular cities. This focus can help understand how novel forms of governing urban nature in the Anthropocene, grounded in ideas of cities as complex adaptive systems, are established and challenged through technology. The debates in urban water governance reviewed next outline the primary discourses, ideologies, and institutions that influence urban water management practices

1.2.2 Urban water governance

Water governance has emerged as a dynamic research field over the past two decades. This perspective focuses on the "processes that determine the delivery of water-related services for societal needs and that provide the context within which water management operates" (Pahl-Wostl, 2017: 2917). Formative work on urban water governance has scrutinized how the practices of decision-making and actor coordination in urban water management are shaped by institutions and the ideological preferences of different actors (Brown et al., 2009; Bakker, 2010).

Martin Melosi's (2008) historical work on the "sanitary city" has profoundly influenced debates in urban water governance. The notion captures how political objectives to sanitize industrialized cities and advances in science and engineering since the nineteenth century have produced urban water regimes that are inherited until today. Inspired by Melosi, researchers have further characterized modern urban water systems and their governance arrangements (Bakker, 2010; Gandy, 2014). Under a "municipal hydraulic paradigm" (Bakker, 2010: 31), which involved heavy public regulation, financing, and ownership, centralized water and sewer networks were constructed to ensure universal water supply and safe wastewater discharge. Territorial monopoles of public utilities were established to achieve economies of scale. This coincided with the institutionalization of new scientific disciplines of water supply, sanitation, and flood control engineering in separate public bureaucracies. Overall, a belief in improving public health and economic prosperity through rationalizing public management drove water governance in modern cities. The builders of the sanitary city regarded nature as a resource base and a sink that was separate from the city and controlled by technology (Melosi, 2008).

Contemporary debates in urban water governance emphasize that a governance failure is a central cause of water unsustainability, and they revolve around the question of how urban water systems can be reformed in response to the current urban water crisis (Brown and Farrelly, 2009; Bell, 2017; Li and Bergen, 2018; Pincetl et al., 2019). These reform efforts are shaped by interrelated dynamics in political economies, environmental discourses, and scientific debates.

First, and since the 1970s, neoliberal economic policies and a discourse of state failure in providing effective public services have fostered privatization in urban water management (Bakker, 2010). In many cities, the liberalization of the water sector to attract private investments has disrupted public service monopolies. The introduction of cost-recovery principles has further advanced the rationale of managing water as an economic good, partly contradicting ideas of universal service provision (ibid.: 87ff.). Although privatization has not taken hold everywhere, spending cuts and skepticism about public bureaucracies have increased the pressure on many public utilities operations. Frequently, economic imperatives drive utilities to prioritize large-scale technological fixes for water challenges that promise safe investment returns (Millington and Sheba, 2021). Although public water utilities have adopted market paradigms, their institutionalized missions stipulated under the municipal hydraulic paradigm have often remained unchanged, which raised the burden on them (Pincetl, 2010). Since return rates of privatized water management frequently remain behind initial expectations, re-municipalization of services has gained pace since 2010 (McDonald, 2018). Nonetheless, cost recovery principles and the imperative to pay back debts to lenders powerfully shape investments in water infrastructures (Loftus et al., 2019; Furlong, 2021).

Second, the postwar environmental debate, sparked by pioneers such as Rachel Carson (2002) and Garrett Hardin (1968) who problematized toxicity and resource scarcity, has profoundly impacted urban water governance. As a response to water scarcity and pollution, the "water cycle city" (Brown et al., 2009) has emerged as a new paradigm for governing urban water that promotes water conservation, recycling, and reuse. The uptake of circularity thinking in urban water management can be understood in the context of broader debates on the circular economy as an economic model focuses on extending resource productivity in a closed loop of material and energy flows (Ghisellini et al., 2016). The idea behind the water cycle city is that managing water in a more closed urban water loop can enhance sustainability. Governance scholars discuss how such urban futures can be achieved by improving the integrated management of water supply, water quality, and flood control tasks (Brown et al., 2009; Bell, 2017). For instance, urban water scarcity and pollution challenges have led to the reframing of wastewater as a valuable resource (Lee and Jepson, 2020). Efforts have been made to re-regulate wastewater under this emerging resource paradigm (Hughes, 2013). However, scholars also show how paradigms of water circularity and integrated management are hindered by the institutional separation of water supply and wastewater tasks. Distinct budgetary rules, mission statements, and historically grown forms of expertise of separate utilities obstruct a transition toward circularity (Pincetl et al., 2019).

Third, advances in science and technology have far-reaching implications for urban water governance, which can result in divergent or even contradictory outcomes. Since the 1970s, environmental science has played a crucial role in informing more ecological water management practices. McHarg's (1969) Design with Nature deployed principles of ecology to guide a new landscape design approach that aimed to integrate nature and cities in mutually beneficial ways. Today, green infrastructures that promote the use and mimicking of natural processes of soil and vegetation for water management and to create multiple social and environmental benefits have gained significant importance (Meerow and Newell, 2017). However, the governance of green infrastructures is complex, with responsibilities often fragmented among separate city departments and private actors. Urban water governance infrastructures also rely on knowledge of landscape design and ecology, while water utilities have mostly evolved with advances in the disciplines of public and environmental engineering (Lui and Jensen, 2018). Furthermore, urban water governance is influenced by advancements in water management practices that focus on large-scale technological facilities. What Green and Bell (2019) call a "neo-hydraulic" approach that promotes "supply-side, centralized responses to urban water management" is increasingly embraced to tackle urban water challenges. This approach is more aligned with inherited institutions of urban water management, sustaining ideas of centralized control, entrenched financing and accounting practices, and an "end-of-pipe" logic. Apart from desalination, which promises to "tap the ocean" but has high energy costs and produces a highly polluting waste product of concentrated salt and chemical residues (Williams, 2022), centralized wastewater recycling at the end of the pipe of existing sewer networks is expanding as a sustainability fix for urban water pollution and scarcity (Lee and Jepson, 2020).

Scholarship on urban water governance uncovers broader social dynamics that hamper urban water sustainability. Such "counter-trends in urban infrastructure provision" (Bell, 2015: 12) unsettle techno-optimistic ideas of achieving urban water sustainability. Therefore, scholars demand to rework the cognitive, normative, and regulative orders within which particular water management technologies are deployed (Brown et al., 2009; Lui and Jensen, 2018). For instance, increasing connectivity between public policy sectors and between different levels of government can improve water governance in institutionally fragmented settings (Driessen et al., 2018). Other suggestions are that cities should enhance their governance capacity to manage uncertainty in increasingly complex, integrated water systems. This can be done by improving participation processes and training water managers as arbiters in complex negotiation processes (Koop et al., 2017; Nieuwenhuis et al., 2021). Furthermore, experimentation has been foregrounded as a strategy to drive institutional change. Experiments with new water management practices and actor constellations are claimed to give new meaning to evolving scientific and technological discourses to institutionalize alternative practices (Brown et al., 2013). Overall, discussions on urban water governance draw significant attention to the institutions and ideologies that underpin urban water systems. Many of these systems were developed to address issues faced by cities of the twentieth century, but are no longer effective in the twenty-first century.

This study, which analyzes the politics of technology in processes of circular water restructuring, can leverage governance debates that identify the political economic, ideological, and institutional conditions that shape decision-making in urban water management, instead of treating technology as something that evolves and is put to use within certain governance arrangements, this focus requires highlighting more explicitly how urban water governance orders shape, and are shaped by, different technological interventions through which actors aim to realize water circularity. As an example, the introduction of new technologies to an urban water system can bring about new types of responsibility and actor roles in water management that challenge established institutions and the power dynamics embedded within them. Some scholars have criticized research in urban water governance for not adequately addressing the power and authority dynamics that structure urban water governance (Lawhon and Murphy, 2012; Cousins, 2017). Before reviewing research that delves into the political power that emerges from technology (Section 1.2.5), the next section outlines the contributions of urban political ecologists in analyzing the intersections of urban water and social power.

1.2.3 Urban political ecology

Urban political ecology is an established critical research perspective that investigates the unequal power relations involved in producing urban nature (Swyngedouw, 2004; Heynen et al., 2006; Loftus, 2012; Goh, 2020). Fundamentally, this perspective breaks with a nature-society dichotomy that is prevalent in modern thinking by "'recognizing that the antithesis between nature and history is created' only when 'the relation of man to nature is excluded from history'" (Harvey, 1996a: 184 quoting Marx and Engels, 1975: 55). Urban political ecologists thus study the "urbanization of nature" as a historical process "through which all types of nature are socially mobilized, economically incorporated (commodified), and physically metabolized/ transformed in order to support the urbanization process" (Swyngedouw and Kaika, 2014: 462). Revealing the uneven power relations shaping urban nature serves to inform a normative agenda aimed at making the production of urban nature more democratic, just, and sustainable. Seminal work in urban political ecology has used urban water flows as an empirical entry to research power in the urbanization of nature (Gandy, 2002; Swyngedouw, 2004; Kaika, 2005). This scholarship has established important foundations for understanding how urban nature is created and contested by linking water flows with political economic dynamics such as shifting regimes of production, labor relations, and consumption patterns, as well as with ideologies of nature and technology. The concept of "urban metabolism" captures how social and bio-physical flows are interconnected and co-produce urban nature, providing a holistic perspective for studying urbanization as a historical and political process (Gandy, 2004). Technical infrastructures act as important "material mediators between nature and the city" (Kaika and Swyngedouw, 2002: 120) as they control the material and social flows of the urban metabolism. Scholars investigate how the role of technology in making urban space follows the rationales of capitalism. This reflects David Harvey's (1996: 46) notion that capitalist production unfolds "against the background of the technological possibilities it has itself created." Accordingly, the empirical study of infrastructures in urban political ecology ultimately serves to uncover the socio-cultural forces of capitalism that shape urbanization.

In recent years, a "second wave" of urban political ecology scholarship has been influenced by poststructuralist and postcolonial influences (Heynen, 2015). Gandy's (2005) idea of "cyborg urbanization" conceptualizes tensions between the structural dynamics of capitalist urbanization and the city as a space of everyday life. Since this early initiative, numerous studies have shifted their focus to the everyday practices and bodily experiences of the city, highlighting injustices and everyday forms of resistance in urban life, such as water access (Loftus, 2012) and community resistance to technocratic flood control (Ranganathan, 2015; Goh, 2020). In this way, urban political ecologists have also revealed how environmental injustices are bound up with identity and intersectional dynamics of race, class (caste), and gender (Robbins, 2007; Truelove, 2019; Sultana, 2020).

Critical research on urban water scarcity illustrates how scholars have followed Lawhon and colleagues' (2014) call for a "situated urban political ecology" that traces everyday practices of city-making and conceptualizes power as distributed. This research demonstrates how scarcity can be socially produced through cultures of abundant water consumption, for instance, in suburban gardens (Parés et al., 2013) and through uneven access to water and individual responses to water insecurity (Millington and Sheba, 2021). Meanwhile, scholars highlight that infrastructural responses to urban water scarcity are often developed in the context of financialization. Sustainability fixes, such as desalination, promise safe returns for investors but could potentially place a higher cost burden on consumers (Loftus and March, 2016; Bigger and Millington, 2020). Responding to ideas of "planetary urbanization" (Brenner, 2014), urban political ecology has developed further by showing that responses to local water challenges are entwined with flows of money and expertise that can extend into the urban hinterland and often across the globe (Goh, 2020). Ultimately, recent work in urban political ecology has problematized knowledge and expertise to explain unsustainable and unjust forms of urban water governance. Scholars have shown how dominant technocratic discourses of water management can marginalize alternative practices that have the potential to provide multiple social and environmental benefits (Finewood, 2016; Diep et al., 2022).

Urban political ecology research has greatly helped in understanding the uneven power dynamics involved in the production of urban nature. Arguably, its key merits are to conceptually link urban water flows to socio-cultural forces that shape urbanization. Infrastructure research in urban political ecology has traditionally examined infrastructures as catalysts of urbanization that adhere to the logic of capital, whereas more recent research has started to engage with the knowledge cultures that enable this process. Nonetheless, the exploration of technology as a site of political struggle, where specific cultural meanings and ways of life are shaped, has not been extensively studied in urban political ecology. Urban infrastructures embody the dynamic and inherently political nature of technology. But the hybrids of technological practices and artifacts, institutions, governance structures, expertise, cultural meaning, and economic relations that constitute infrastructures as sites of political struggle remain less explicitly analyzed and conceptualized in urban political ecology.

1.2.4 Urban studies of infrastructure

Over the past two decades, urban scholars have refined the study of urban infrastructures as a way to explore evolving relations between societies, technologies, and ecologies that shape urban life and development (Graham and Marvin, 2001; McFarlane and Rutherford, 2008; Monstadt, 2009; Rutherford, 2020). Instead of limiting the analysis to the functional aspects of infrastructures, emphasis is placed on the relations between infrastructures, urban space, and social power. In this way, studies on urban infrastructure have contributed to wider efforts in human geography to bring back the materiality of the city into a critical analysis of urban culture, life, and politics (Latham and McCormack, 2004; Amin and Thrift, 2002, 2017).

This research focus highlights infrastructures as more than the mundane "systems of substrates" (Star, 1999) such as pipes, wires, or technical facilities that exist independently while social life and politics occur on them. Rather, it centers on the complex and often obscure connections between the social dimensions of urban infrastructures and their technical features. Studies on urban infrastructure have largely been influenced by Thomas Hughes (1987), who demonstrated how infrastructures emerge, consolidate, and transform as "socio-technical systems" in which social and technical components are mutually dependent. Accordingly, Coutard and Rutherford (2016: 13) assert that urban infrastructure "matters not as a single readily identifiable artifact somehow separated or carved off from the rest of urban development and urban life, but as a 'seamless' [...] relational system or arrangement of technology, actors, skills, knowledge, practices, cultural meanings and values, resources, money, and politics."

Sparked by Graham and Marvin's (2001) seminal book *Splintering Urbanism*, the universalization, fragmentation, and absence of centralized infrastructure networks have become key foci in urban infrastructure research (Kooy and Bakker, 2008; Coutard and Rutherford, 2016; Monstadt and Schramm, 2017; Guma, 2020). Building on this basis, scholars have debated the political entanglements between infrastructure and urban life that shape state power (Kooy and Bakker, 2008; Usher, 2018), forms of citizenship (Anand, 2017; Piló, 2020) or urban sustainability (Bulkeley et al., 2014; Rutherford, 2020). The idea that infrastructural change engenders new politics of urban infrastructures is typically more or less explicitly addressed here. Mobilizing the tension between technological determinism and social constructivism in STS for a critical analysis of the city, scholars have captured the politics of urban infrastructures by foregrounding infrastructures' obduracy and malleability.

On the one hand, urban infrastructures are studied as relatively stable socio-technical arrangements that serve as a powerful mechanism for ordering the social and material processes that constitute the city. Monstadt (2009) has shown how, over time, the heterogeneous components of infrastructure networks condense into relatively stabilized "urban infrastructure regimes" where institutions, artifacts, and practices are tightly interlinked (see also Dorst et al., 2022). The power of these regimes in shaping urban life and development is rooted in entrenched socio-technical arrangements that reflect the particular social interests of their builders. While obstructing radical transformation, urban infrastructure regimes evolve historically in non-linear ways. In the face of shifting social needs public discourses, and environmental change, these regimes can become reconfigured at multiple sites (Moss, 2020).

On the other hand, scholars have emphasized how infrastructures are constantly remade through practices and are grounded in everyday experiences of urban life (Graham and McFarlane, 2014; Guma, 2020). A focus on the incremental practices of using infrastructures or adjusting them for specific local needs – and thereby often appropriating and transforming them – reveals the malleability of urban infrastructures (Furlong, 2011; Tiwale, 2019). Instead of analyzing infrastructure networks as distinct objects, scholars trace the diverse social practices linked to these networks. Thereby, research can reveal socio-political and cultural processes that might, at first sight, appear disjointed from infrastructure networks while, in fact, influencing the vitality and political significance of infrastructures. The underlying idea, drawn from Star and Ruhleder (1996), is that infrastructure emerges through contingent interactions between multiple actors and artifacts.

By examining the interplay between the structural force of infrastructure and its emergent nature, researchers highlight that urban infrastructures cannot be fully controlled from a single center. Urban infrastructures, which have highly contingent and contested influence on urban life and development, reflect what Coutard and Guy (2007) called the "ambivalence inherent to all technology." Therefore, urban infrastructures can be understood as "a key political site through which urban futures are negotiated and forged" (Rutherford, 2020: 3). This understanding brings critical attention to infrastructure artifacts that are reconfigured by different actors who pursue their distinct social interests and thus give rise to the "material politics" that shape urban futures. For instance, how actors incorporate digital technologies (Guma, 2020) or green infrastructures (Usher, 2018) into infrastructure arrangements to influence urban development has become a vital research interest recently.

Urban infrastructure research vividly illustrates that the agency shaping urban development and politics is distributed, with diverse humans and nonhumans together forming infrastructure in a particular moment. These actors may be scattered geographically across the city and bound up with different institutional settings and epistemological perspectives. At times, they might not be identifiable as infrastructure components at first sight and yet come to exert power over urban and infrastructure development in specific temporal and spatial constellations. The discussions on technopolitics that follow further clarify how such power is constituted and contested.

1.2.5 Technopolitics and the city

In the field of STS, scholars explore the ways in which science and technology are produced, and how societies reinvent themselves through these processes. According to Langdon Winner (1986), technologies are not simply neutral tools, but rather expressions of particular "forms of life." If we are to understand technologies simply as neutral tools, he argues, we miss how technologies can only fulfill their purpose within a particular social context marked by distinct rules, conventions, and norms. This line of thought critically interrogates the technocratic belief that "technology is […] a sufficient end in itself" (Bijker, 2001: 22). A central aim is to uncover how such a belief is rooted in hegemonic forms of knowledge and values underlying technology, which often sustain uneven relations of power. Although technical rationality and efficiency are represented as universal values in modern societies, Feenberg (2010) emphasized that they are, in fact, defined and controlled by particular social actors with their own interests. Making and remaking technology thus needs to be understood as an inherently political process that shapes society while itself being structured by social dynamics.

To grasp the political nature of technology, Gabrielle Hecht (2009: 56) has coined the concept of "technopolitics," which refers to "the strategic practices of designing or using technology to constitute, embody, or enact political goals." The concept suggests that the material properties of technical artifacts, in relation to social dynamics, play a vital role in shaping how new forms of power and agency emerge. Carroll (2012) demonstrated how large-scale water infrastructures enable actors to accumulate political power through their control over water flows. However, researchers have also shown that the practical reconfiguration or manipulation of technologies can serve as a means to challenge dominant technopolitical strategies (Edwards and Hecht, 2010). The context of urban water challenges further illustrates the limits of total technological control over the material world, which can undermine technopolitical strategies. Nonetheless, ongoing scholarly debates underscore various social dimensions that shape how actors strategically pursue technopolitics. Three of these dimensions can be mentioned here.

Firstly, discourses offer a powerful way to organize technopolitics. Technological discourses, as relatively stable ensembles of ideas and beliefs, connect the functional aspects of technology with broader cultural meanings (Hecht, 2009: 15). Particular assumptions about sustainability, democracy, or risk conveyed in such discourses often shape the evolution of technology and influence the creation of environments (Bijker, 2007) which can promote particular social interests. For instance, modern water infrastructures supported the political agendas of their builders by evoking gleaming promises of a better future (Gandy, 2014). The capacity to influence technology's functional aspects endows actors with political power, as it "shapes the *kind* of political voice that technologists have" (Hecht, 2009: 16, emphasis in original). Frequently, actors strategically utilize technological discourses to "displace political agendas into technical acts and fantasies" (Edwards and Hecht, 2010: 638). Overall, scholars of technopolitics underline the structural power of technological discourses – most prominently, ideologies of technological determinism. But they make clear that the relations between technology's functional aspects and its discursive meaning are socially constructed.

Secondly, actors can organize technopolitics to achieve distinct goals depending on established knowledge orders. This is because technological expertise grants actors more control over defining the social purpose of technology through design practices, thereby representing what technology can or cannot do.

Scholars have shown that achieving dominant forms of representation involves laborious processes of measurement, standardization, and adjustment (Bowker, 1994; Mitchell, 2002). They argue that these representations reflect the norms, values, and interests of the actors, organizations, and scientific disciplines involved in creating knowledge in a specific domain of society. However, once certain forms of knowledge are broadly accepted as scientific facts and expert knowledge, their constructed and normative character is often downplayed. Technological expertise grants power to actors because their ways of designing and using technology often appear to non-experts as natural consequences of universal principles of efficiency and therefore, are deterministic (Bijker, 1995). Exposing the often messy and makeshift processes through which experts design technology and get to represent it in particular ways can challenge dominant technopolitics (Edwards and Hecht, 2010).

Finally, efforts to create and reconfigure technology occur in institutional contexts that reflect and advance distinct social interests. Social studies of technology scholars have extensively documented how institutions, which establish particular rules of interaction between social actors and between humans and their material surroundings, co-evolve with technology (Hughes, 1987; Pinch, 2008). Place-specific arrangements of technical artifacts and institutions urge humans to design, manage, and use technology following certain formal rules and informal norms. Gabrielle Hecht's work highlights the practical engagement of actors with institutions in creating and remaking technology as a way to explain how actors can organize technopolitics (Callon, 2009: xiii). Technopolitical power is shaped by the institutions and their interactions with other social and material dynamics, as well as the technopolitical practices of the actors who navigate these relationships. For Hecht (2009: 15), these interactions form "technopolitical regimes," which are "linked sets of people, engineering and industrial practices, technological artifacts, political programs, and institutional ideologies, which act together to govern technological development and pursue technopolitics." In these regimes, technical artifacts, that often stabilize certain ways of thinking and interacting by their material properties, are strategically maintained or reconfigured to pursue institutional interests.

Today, there is a nascent debate on "urban technopolitics" (Foley and Miller, 2020; Randle, 2021; for an early case, see Aibar and Bijker, 1997). This discourse emphasizes the significance of the city's seemingly inconspicuous technical artifacts as sites through which power and authority arise. Scholars reveal the tendency of technocratic urban management to overlook its inherently political nature and how urban technopolitical regimes can stabilize uneven power relations and unsustainable socio-technical orders of the city (Gopakumar, 2020). Focusing on water, scholars of urban technopolitics have illustrated how urban water networks are embroiled in technopolitical strategies aimed at governing citizens (von Schnitzler, 2008) or consolidating state power (Usher, 2019).

Researchers have also highlighted how incremental and small-scale technological interventions can contest the dominant technopolitics of urban infrastructures (Tiwale, 2019; Guma, 2020). While theoretical debates on technopolitics have benefitted greatly from research on the interplay between nature and technology (Carroll, 2012; Carse, 2012), the interface between urban technopolitics and urban environmental governance remains underexplored. This dissertation makes an intervention into this research gap. Mobilizing the theoretical debates outlined above, it develops an analytical framework that allows for the exploration of the political significance of technology in processes of circular urban water restructuring. By doing so, it aims to reveal the different proposals for governing urban nature and space that are involved in these processes.

1.3 The technopolitics of urban infrastructural change

> "Keeping the future open by refraining from making irrevocable decisions that one could eventually regret, requires vigilance, reflection, and sagacity at all times. Politics, as the art of preserving the possibility of choices and debate on those choices, is therefore at the heart of technological dynamics." (Callon, 2010: 220)

This section presents a theoretical framework for examining the politics of shifting urban infrastructures as a way to understand how circular urban water futures become contested. Generally, the notion of infrastructure offers a useful heuristic to explore how relations between social and material elements are organized in distinct ways to realize higher-order objectives (Star and Ruhleder, 1996). Social power rests in the capacity of actors to align diverse infrastructure elements that can stretch across geographical, institutional, and epistemic boundaries (Bowker, 1995; Hetherington, 2018). Only through the interplay of its diverse components infrastructure makes a difference in a given moment.

Here, we conceive of urban infrastructures as relational arrangements of social and material elements that can be relatively stable but whose capacity to enable particular objectives and outcomes can change as new combinations of practices and artifacts emerge. Infrastructure arrangements mature historically into "urban infrastructure regimes" (Monstadt, 2009) of closely intertwined artifacts, institutions, and practices. However, the artifacts and practices upon which urban infrastructures rely cannot be entirely controlled from a single center, which provides opportunities to contest and reconfigure infrastructure regimes. Infrastructural practices involve highly standardized, but also more incremental and sometimes improvised, technical, material, and knowledge interventions, which enable, contest, and transform urban infrastructures (Blok et al., 2016). Urban infrastructural change thus unfolds as a multi-layered and non-linear process marked by tensions and frictions (Moss, 2020). Moreover, such change occurs in a context that is itself dynamic. Aiming to "re-materialize" urban studies, scholars have framed the city as a socio-technical process that is embroiled with diverse meanings, shaped by distributed agencies, and escapes full control (Amin and Thrift, 2017). Urban and infrastructural change are thus mutually dependent. Urban infrastructures act as mediators of flows of resources, waste, money, and power that shape urban nature and space while themselves being products of urbanization processes (Kaika and Swyngedouw, 2000; Goh, 2020).

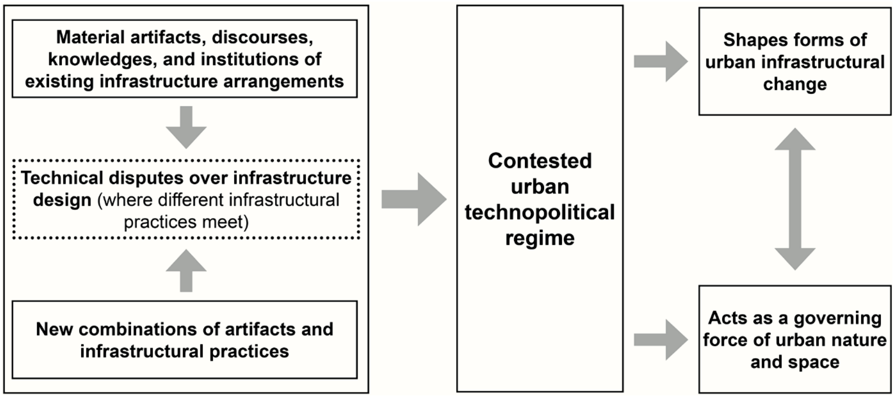

FIGURE 2 Technopolitics of urban infrastructural change (graphic produced by author)

Inspired by Hecht (2009), this study is centered on analyzing the forms of political power that emerge from the interplay of technical artifacts and social dynamics in processes of urban infrastructural change. To grasp these *technopolitics of urban infrastructural change*, analytical attention is drawn to how different infrastructural practices meet in *technical disputes over infrastructure design* (see Figure 2). This study analyzes *four dimensions of existing urban infrastructure arrangements* to explain the infrastructural practices of different actors in these disputes: material artifacts, discourses, knowledges, and institutions.

First, the materiality of infrastructure constrains possibilities of infrastructural change and structures the technopolitics that imbue evolving infrastructures with broader socio-political meaning. The physical properties of pipes or channels significantly influence the locations and technologies through which actors can reconfigure urban water flows. Inseparably from this, the lifestyles, ideologies, and political economies that are inscribed in existing infrastructure networks wield technopolitical power over urban water futures. For instance, when at the center of technical disputes over water circularity, legacy infrastructure artifacts unyieldingly make past ideas of service provision or safety vital concerns in present political debates. Nonetheless, practices of infrastructural adjustment and modification can introduce new artifacts into such disputes. Infrastructural practices can foreground certain artifacts and their entwined social relations in political debates about water circularity depending on their compatibility with existing material arrangements of infrastructure.

Second, discourses in urban water management shape what infrastructural practices prevail in technical disputes over water circularity and what technopolitical objectives actors can legitimately pursue through these practices. Here, discourses matter as Hajer (1995: 44) specifies, "as a specific ensemble of ideas, concepts, and categorizations [...] through which meaning is given to physical and social realities." These relatively stabilized ensembles develop over time and can thus structure social practices. Discourses of circular urban water management that are grounded in certain engineering ideas and ecological metaphors of a closed water cycle legitimize distinct infrastructural practices but disapprove others. This strongly depends on the assumptions inherent to these discourses about which infrastructural practices count as "sustainable," "efficient," or "reliable." Hegemonic discourses frame the practical negotiation of infrastructural change, bolstering the technopolitical strategies of actors who align their practices with these discourses while thwarting other technopolitics.

Third, the knowledge orders in urban infrastructure arrangements shape how actors reconfigure infrastructure artifacts in disputes over urban water circularity. How water is understood and managed in cities is still heavily influenced by specialized engineering knowledge that is codified in technical regulations and standards (Karvonen, 2011). Practices that correspond with the way water problems are framed by engineering knowledge tend to be privileged within infrastructure development. This gives rise to an "engineering governmentality" (Carroll, 2012: 510), where engineers reduce essentially political questions about how to realign water, technology, and urban space to mere questions of technical choice. For instance, infrastructural practices that rely on ecological or horticultural knowledge often remain marginalized. However, when novel infrastructure artifacts emerge with properties that disrupt entrenched ideas of infrastructure, they can challenge existing knowledge orders and require new knowledge and practices to be developed. The practices that ultimately prevail in disputes over infrastructure design depend on how actors get to portray distinct practices and knowledges as expert ways of doing things.

Finally, institutions permeate technical disputes over infrastructure design, thereby limiting options for urban infrastructural change. This is because institutions help to stabilize what is considered the "normal" functions, social promises, and ways of operating and using technology (Bijker, 1995). The codes, protocols, and standards that underly institutions, and which have co-evolved with technical systems, often give preference to inherited infrastructural practices over alternatives. This means that when circularity thinking is promoted in urban infrastructure arrangements that are organized by sectors, entrenched institutions often make boundary work necessary to coordinate the disparate systems (Monstadt and Coutard, 2019). These practices can reinforce shifting socio-technical relationships that serve the interest of existing institutions. However, the introduction of novel infrastructure artifacts can also provoke new forms of interaction that co-exist with or contradict inherited institutions. Actors can influence the technopolitics of urban infrastructural change depending on their capacity to establish new socio-technical interactions within institutional orders and on the flexibility of existing institutions.

In sum, urban infrastructural change can be studied as a technopolitical process by thinking through these four dimensions. Depending on the place-based constellations of discourses, material artifacts, knowledges, and institutions, certain practices may dominate in technical disputes over infrastructure design, while others may be hampered yet never fully displaced. To enact infrastructural change, actors continuously introduce new combinations of artifacts and practices into these disputes. The interplay of different infrastructural practices in these disputes brings about novel infrastructure arrangements. However, this does not yet fully capture the technopolitics involved in urban infrastructural change. A broader realm of power and authority arises from the discourses, political programs, and institutional ideologies linked to the multiple artifacts and practices at the heart of political debates about infrastructural change. Inspired by Hecht (2009), this realm of power can be called a *technopolitical regime of urban infrastructural change*. These regimes (i) shape the particular forms of urban infrastructural change and, in doing so, (ii) constitute a governing force of urban nature and space more broadly (see Figure 2). This perspective thus explains how the politics of technology shape the co-dependent development of infrastructure and cities. Essentially, technopolitical regimes of urban infrastructures are never fully stable. Rather, actors work the socio-technical relationships of these regimes through infrastructural practices and so influence how these regimes exert power. Depending on the technical and material artifacts that actors place at the center of political debates about urban infrastructural change, as well as the histories, cultural meanings, and urban geographies associated with these artifacts, particular technopolitics arise[2]. The distinct histories, cultural meanings, and urban geographies that are foregrounded through these practices powerfully frame the broader socio-political meaning of emerging infrastructure constellations and how they consequently govern urban nature and space. Hence, these technopolitics structure "possibilities of choices" (Callon, 2010: 2020) for infrastructural change. While existing infrastructure arrangements exert significant technopolitical power, new combinations of artifacts and practices that appear as infrastructures

2 The conceptual framework of this dissertation employs the term "technopolitics" rather than "material politics" to emphasize the political role of technology in processes of circular urban water restructuring and the governance of urban nature and space in the Anthropocene. However, inspired by ideas of material politics (see Chapter 3 and 4), this dissertation analyzed technical and other material artifacts in relation to social processes. Technological agency in governing urban nature through infrastructure is analyzed in relation to other human and nonhuman agencies.

evolve can challenge this power. The theoretical framework outlined here guides this dissertation in exploring the politics of technology in processes of circular urban water restructuring in Los Angeles.

1.4 Research focus

This dissertation investigates how circular urban water restructuring is contested and governed through technopolitical practices in response to water scarcity and pollution challenges in Los Angeles. The central research interest is to develop a more detailed and critical understanding of the contested governance of infrastructural change toward more circular urban water systems. The dissertation also analyzes how the politics of technology in processes of circular urban water restructuring reflect diverging proposals for governing urban nature and space. This inquiry responds to the dynamics of environmental governance in cities in the Anthropocene, where infrastructure renewal gains new importance as a means of realizing systemic remedies for environmental challenges (Derickson, 2018; Bulkeley, 2021). In the urban water sector, creating more circular water systems by combining diverse water management practices is seen as a promising way to enhance urban water sustainability and resilience (Bell, 2017). Against this backdrop, this study aims to:

> **explain the socio-technical change toward more circular urban water and wastewater infrastructures and the contested governance of this process.**

Urban infrastructural change is studied as a socio-technical process that takes place within an existing infrastructure regime context. Circular water restructuring in Los Angeles can be analyzed by tracing different actors' infrastructural practices in technical disputes over infrastructure design. The technopolitics of urban infrastructure restructuring, as reflected in these disputes, explain distinct forms of infrastructural change and the governance of this process. Here, the contested governance of infrastructural change captures how intertwined social and technical processes of circular water restructuring enable and obstruct particular choices that influence infrastructural change. Simultaneously, a technopolitical analysis that takes seriously the political entanglements between infrastructures and urban environments shows how circular water restructuring involves various and sometimes conflicting proposals for governing urban nature and space. This focus is intended to provide a deeper understanding of how different cultures of urban nature, ranging from technocratic to alternative, interact in the process of infrastructure restructuring and what implications these interactions have for urban nature. The following questions further specify the research interests of this dissertation.

> ***RQ 1:** How do water and wastewater infrastructures in Los Angeles change toward more circular water systems?*

This question highlights the changing relationships between centralized and decentralized water infrastructures in Los Angeles, the differences in implementing large-scale technological practices of water management (Chapter 2) and more landscape-centered practices (Chapter 4), and the emerging hybrid water infrastructure arrangements that combine diverse practices (Chapters 3 and 5). Revealing the contested nature of urban infrastructural change can help in critically interrogating the discourses surrounding circular urban water management, which often present infrastructure as a neutral tool to enhance urban sustainability. The inclusion of outdoor water conservation in private gardens in Chapter 4 offers a specific geographical lens that underscores how infrastructural change is contested in urban spaces where infrastructural dynamics intersect with broader processes of everyday urban life.

> ***RQ 2:** How do the intertwined social and technical processes of circular water restructuring in Los Angeles reflect and produce particular "technopolitics"?*

This question delves into the efforts of policymakers, water engineers, environmental groups, activists, and residents to reconfigure urban water infrastructures in order to achieve broader political objectives (Chapters 2–5). It is examined how place-based constellations of material artifacts, discourses, knowledges, and institutions explain why certain infrastructural practices dominate over others. By tracing the relations between practices, artifacts – and the diverse social processes linked to them – this study uncovers how actors pursue certain technopolitical strategies of circular water restructuring. This inquiry advances scholarship on urban technopolitics by revealing how technopolitical power that shapes urban infrastructural change emerges, is stabilized, and is contested.

> ***RQ 3:** How do technical disputes over circular urban water restructuring involve diverse and partly competing proposals for governing urban nature and space?*

This question explores the relations between the technopolitics of circular water restructuring and the broader dynamics of governing urban nature and space in Los Angeles. The central premise is that different cultures of managing urban nature meet in technical disputes over water circularity. As such, the important role of infrastructure renewal in urban environmental policymaking calls for a critical inquiry into the cultures of managing urban nature that have co-evolved with modern technology. The study investigates how actors, through their particular infrastructural practices, introduce, defend, and put to rule the ways of knowing and governing urban nature and space. Tracing how technocratic and alternative cultures of urban nature meet in infrastructural disputes reveals technology as a powerful force that shapes urban nature, but that is also ambivalent and contested. Chapters 2–5 discuss how the technopolitics of circular water restructuring in Los Angeles comprise distinct relations between public experts and users, labor relations, different ways of valuing urban nature, as well as particular forms of using water and urban space that influence urban environmental governance.

> ***RQ 4: What lessons can be drawn from the study of Los Angeles for a more sustainable and socially just water governance in cities in the Anthropocene?***

This research question aims to draw lessons on how to govern water and plan water infrastructures that promote urban sustainability, livability, and justice. Chapters 2–5 enhance current debates on urban water circularity by offering potential pathways for reforming the prevailing technocratic culture of urban water management, which upholds eco-modernist beliefs in large-scale technological solutions, disciplinary framings of environmental problems, and inherited logics of resource consumption. The aim of these chapters is to foreground the plural proposals for governing water and urban space that become articulated through the infrastructural practices of different actors. The chapters explore how this understanding can inform planning paradigms and political debates about infrastructure development, which acknowledge the diversity of cultures of urban nature and include nonhumans as constituents of urban environmental governance. Finally, they critically reflect on the institutional and political economic orders that enable such planning.

1.5 Research design and methodology

This study used qualitative research methods to explore circular water restructuring in Los Angeles. Qualitative research aims to gain a deeper understanding of a selected research object through an in-depth analysis of social processes and interactions. This approach combines both inductive and deductive approaches, guided by theoretical premises and choices for data selection while advancing the analysis by interpreting the collected information (Creswell and Creswell, 2018). This study adopted an open and flexible research process where insights from both inductive and deductive analytical steps were held in tension to develop a larger and critical understanding of the case of Los Angeles.

Inspired by STS and critical geographical thought, this study emphasizes how different actors construct meanings of, and knowledge about, social phenomena, urban space, and the material world by engaging with technology. This foregrounds the multiplicity of worldviews involved in processes of meaning-making. Alongside critically interrogating how dominant forms of representation are achieved, attention was also paid to the sites where counternarratives are forged (Guy and Karvonen, 2011; Pickett et al., 2020). Circular urban water restructuring is influenced by place-based infrastructure arrangements, urban politics, and the diverse practices of the actors involved. Here, infrastructure was used as a heuristic to grasp the situated entanglements of material artifacts and social practices from which one can develop a larger and critical understanding of Los Angeles as an emerging circular water city. By following practices in technical disputes over infrastructure design, this study considered that "the intersections between environments and infrastructures can only be experienced and known 'from the middle out'" (Blok et al., 2016: 13). Instead of assuming a priori knowledge of Los Angeles' shifting water and wastewater infrastructures, this study explored these infrastructures and their politics by tracing infrastructural practices in relation to the constellations of artifacts and social processes that surround them. Insights from debates in urban political ecology, urban infrastructure studies, and STS guided this analysis, which allowed speaking back to the theory from the specificities of the Los Angeles case. Despite the dominance of particular ideas of circularity in policy discourses, the technopolitics of circular urban water restructuring reveal a plurality of and, at times radically different, proposals for aligning water, technology, and urban space in circular cities.

1.5.1 Case study selection

To generate a thorough understanding of an empirical phenomenon and theorize its underlying dynamics, "the force of example" (Flvybjerg, 2006: 228) has proven highly valuable. Therefore, this research used case studies as its methodology. Prescribing detailed empirical inquiry, case study methodology allows researchers to create knowledge that reveals the context-specific dynamics explaining a phenomenon (Baxter, 2010; see also Yin, 2018). This is not to say that case studies impede generalization. Instead, case studies draw their broader explanatory value from the robust theoretical explanations they make possible. These case-specific theories – propositions and hypotheses rather than predictive theories – can be transferred to other contexts to test and further refine them (Flyvbjerg, 2006: 227). Here, theoretical generalization and transferability largely depend on the selection of the case study and on "creating useful theory that is neither too abstract nor too case-specific" (Baxter, 2010: 94).

This dissertation is based on a single case study of the socio-technical change toward more circular water and wastewater infrastructures in Los

Angeles, California. Los Angeles has evolved as an archetypical modern "infrastructural city" (Varnelis, 2009), where modernist beliefs in the technological mastery of nature to enable an urban life in comfort and prosperity were radically executed through the construction of centralized infrastructure networks. The intensifying water challenges in climate-changing cities worldwide expose the profound social and ecological contradictions of the modernist approach used to build them. Los Angeles' drought-stricken, constructed urban ecology serves as a vivid example of this. At the same time, policymakers and practitioners in Los Angeles have embraced ideas of water circularity to address water challenges. The severity of local water challenges, the ambitious political goals for urban water sustainability, and the significant practical efforts to achieve them, make Los Angeles a "paradigmatic case" (Flyvbjerg, 2006) that reflects essential characteristics of climate-changing cities that seek to realize circular water futures to enhance urban water sustainability and resilience. Los Angeles provides a valuable case for understanding and critically interrogating the technological and cultural foundations of circular water initiatives in urban areas, and for evaluating their potential achievements, contradictions, and injustices. The city's unique challenges and approaches make it possible to analyze the "deeper causes and consequences" (Flyvbjerg, 2006: 229) of infrastructural change toward circular urban water systems. Not least, STS scholars argue that case studies are vital to grasp how *theories* of science and technology work in *practice* and thereby become politically relevant (Law, 2016). In Los Angeles, actors reconfigure infrastructure following their particular ideas of nature and technology and theories of circularity.

To ensure a thorough understanding of the topic through detailed empirical observation, this study chose three technological arrangements of water circularity in Los Angeles as sub-cases: wastewater recycling (Chapter 2), stormwater capture (Chapter 3), and landscape water conservation in residential gardens (Chapter 4). These arrangements were chosen as sub-cases due to their significant focus in central policy and planning documents on circular water restructuring and also their relevance to scholarly debates on water and wastewater governance in Los Angeles (Section 1.2.2). The sub-cases further reflect the diversity of technical and material artifacts, actors, discourses, knowledge cultures, institutions, and urban spaces that shape circular water urban restructuring. The approach of holding diverse socio-technical processes in Los Angeles in tension with system-based ideas of urban water circularity in policymaking enables a critical reading of circular cities. By exploring the underlying practices of wastewater recycling, stormwater capture, and outdoor water conservation in Los Angeles, and the interrelations between these three technological arrangements in the process of circular water restructuring, this dissertation makes a broader argument about the technopolitics of urban water circularity. As such, the aim of Chapter 5 is to synthesize the specificities of two broader technopolitical arrangements of water circularity, highlighting the emergence of a more plural circular Los Angeles where different rationalities of aligning water, technology, and urban space coexist. The chapter contrasts this plural approach with the ambition to establish a singular "One Water" cycle around centralized infrastructures.

Together, the research design of a single case study with three sub-cases provides the necessary analytical depth to grasp the intricate and context-specific socio-technical interactions that shape circular water restructuring in Los Angeles. This dissertation builds on the particular explanations of technopolitical power in circular urban water restructuring that are derived from the Los Angeles case and engages in dialogue with debates in urban infrastructure studies, urban political ecology, and STS. This permits us to draw theoretical conclusions about how the social processes underlying technology matter politically for governing circular water restructuring and the shaping of urban environments produced in this process. Bringing these contextual explanations from Los Angeles to other cities, testing them, and modifying them can contribute to a larger understanding of the politics of technology shaping circular urban water restructuring.

1.5.2 Data collection and analysis

The empirical data for this study were primarily collected between 2018 and 2019 through two extended research stays in Los Angeles. This involved the study of secondary literature, document analysis, expert interviews, field observations, and historical source analysis.

Literature review

The analysis included an extensive review of academic literature discussing cities in the Anthropocene, urban water governance, urban political ecology, socio-technical change of infrastructures, and the politics of technology. Moreover, scholarship on Los Angeles was analyzed to situate this study within a rich debate on water and wastewater governance in Los Angeles. The literature review identified gaps in debates on urban water governance and the co-evolution of urban infrastructures and urban nature; this involved the political role of technology in attempts to govern urban ecologies as complex adaptive systems. Scholarly debates on urban infrastructures and technopolititcs were critically assessed in order to design a theoretical framework to analyze infrastructure as a governing force of urban nature and a technopolitical process shaped by its own logics. By foregrounding the politics of technology, this study offers a novel perspective on the relations between different cultures of urban nature and technology that influence urban environmental governance in times of proliferating visions of urban water circularity.

Document and policy analysis

By analyzing a range of documents – covering a period from the 1990s until today – including policies, plans, strategies, project and policy reports, public meetings minutes, technical manuals, legislation, and relevant newspaper articles, this study gained extensive information on environmental discourses and the development of water and wastewater infrastructures in Los Angeles. This date range was chosen because the first public utilities plans and strategies for integrated water management in Los Angeles were published in the 1990s. The One Water LA plan 2040 (LA Sanitation, 2018) as well as LADWP's (2010, 2015, 2020) Urban Water Management Plans were key sources used to understand how public utilities envision and attempt to achieve urban water circularity. To capture the diverse views on circular water restructuring, proposals from environmental organizations and activists in reports, technical documents, and presentations were also examined and compared to those presented in public utilities' plans. Discursive material such as articles from newspapers and magazines, websites, public outreach material, and brochures were also collected and analyzed. Triangulating interview data with information from analyzed documents helps avoid research biases and increases the validity of the analysis. This approach allowed for the identification of convergences and divergences between the discursive material and practices, making it possible to assess the degree to which actors translated their environmental discourses, institutional ideologies, and political agendas into specific infrastructural practices.

Historical Sources

Generally, online[3] historical sources were consulted to explore the history of water and wastewater management in Los Angeles, including a rich photographic documentation of the construction of the Los Angeles Aqueduct that provided historical context. For the study on landscape water conservation (Chapter 4), selected historical sources from the Huntington Library in San Marino, California on the environmental history of gardening and urban development in Los Angeles were used. This analysis contributed to a better understanding of Los Angeles' history as a garden city.

Interviews

Qualitative expert interviews were a key source of empirical material that helped to test, specify, and complement information derived from the document analysis. In 2016, nine interviews were conducted with public engineers, environmental organizations, researchers, and a neighborhood representative. These initial interviews provided valuable insights for shaping the research design and

3 Examples for this are the "Lost LA Curriculum" by KCET (https://www.kcet.org/lost-la-curriculum) as well as sources collected by Water & Power Associates, Inc. (https://www.waterandpower.org/).

questions, as well as for mapping out relevant stakeholders. The main bulk of 54 interviews was carried out during two research stays in in Los Angeles in 2018 and 2019, supplemented by one online interview in 2021 (see Appendix A for a list of interview participants). The interviewees selected for this study were experts in water and wastewater management and related areas of environmental policy in Los Angeles. They included public engineers and utility managers, engineering consultants, regulators, politicians, environmental organizations, community activists, and researchers. To understand the dynamics around landscape water conservation (Chapter 4), horticulturists, landscape architects, garden supply businesses, real estate developers, but also employees in specialized nurseries and garden supply businesses, were interviewed. Nursery consultations are a good example of how snowball sampling was used to recruit relevant informants by interviewee recommendation . Nurseries were contacted after it became clear in interviews that landscape change in Los Angeles, used to increase outdoor water conservation, would require a restructuring of the regional nursery industry. Geographically, the interviewees were primarily located in the city of Los Angeles or nearby in the region. Regional perspectives were particularly valuable in tracing how water politics in Los Angeles matter beyond city limits (Chapter 2).

The interviewees were asked open-ended questions following semi-structured interview guidelines. Interview guidelines design was inspired by theoretical considerations and by the document analysis. Generally, the guidelines contained questions on (i) technologies used or promoted by interviewees, (ii) ideas of circularity, (iii) actors' understandings of water and wastewater challenges in Los Angeles and sustainability objectives, as well as (iv) institutional and knowledge conditions influencing the actors' practices. The guidelines were tailored for each conversation, for instance, by mentioning specific infrastructure projects relevant to the particular interviewee. Overall, interview questions were designed to bring understanding around the different interests and the technical and nontechnical choices of actors in creating more circular water systems in Los Angeles. All interviews were audio-recorded and transcribed, and interview transcripts were analyzed and coded using the qualitative analysis software MAXQDA. Inspired by the theoretical framework of this study, actors' choices to reconfigure water flows were analyzed in relation to shifts and continuities of material arrangements, discourses, knowledge, and institutions of water governance. In an iterative analysis process, these categories were substantiated, and subcategories were created and synthesized to explain the socio-technical change of water and wastewater infrastructures and the wider implications for urban environmental governance. Coded categories of the empirical material were created in an interpretative way by comparing differences and similarities of meaning in the statements of interviewees (Strauss, 1987: 25). Furthermore, conditions, interactions, strategies, and tactics, as well as consequences were deployed as guiding principles to code the empirical material (ibid.: 27–28). This formed the basis for synthesizing contextual explanations of the Los Angeles case by defining causal relationships between the various codes compiled. The results were validated through various means, including presenting draft articles at academic conferences, engaging in conservations with local researchers from Los Angeles, and seeking feedback from interviewees on selected key statements and information.

Field observations and attendance at public events

The collection of empirical data was complemented through field observations and attendance at public events. Various infrastructure facilities across Los Angeles were visited, including flood control facilities, streets retrofitted for stormwater management, local stormwater management demonstration sites, wastewater treatment plants, and the Los Angeles River. Many of these visits were guided by local experts or as part of public outreach events organized by public utilities. In order to gain a better understanding of strategic decisions related to water infrastructure management, video streams of LADWP's Board of Commissioners meetings were also reviewed. For the study of landscape water conservation, several public and private model gardens were visited, and field observation of landscaping work was carried out. Finally, two guided visits at California native plant nurseries proved insightful for this research.

1.6 Thesis outline

This dissertation is a compilation of three published journal articles (Chapters 2–4) and one submitted article (Chapter 5) integrated into a coherent manuscript with a comprehensive introduction and conclusion. The introduction sketches out the study's key research focus on the politics of technology in processes of circular water restructuring in Los Angeles in response to the research gap on urban water governance and the political relations between urban infrastructures and urban environments. As a system-based approach to governing crisis-prone environments in cities in the Anthropocene, water circularity has raised high expectations for urban sustainability and resilience. Urban infrastructure renewal is often embraced as a straightforward lever to put circularity visions into practice. So far, critical urban researchers have not explicitly analyzed the politics of technology that shape the governance of circular urban water restructuring to uncover the ambivalences, contradictions, and power imbalances involved in this process. A critical analysis of the technopolitics of circular urban water restructuring enables a deeper understanding of the underlying cultures of urban nature and technology and their socio-technical dynamics, within which circularity thinking thrives. This perspective further reveals the plural proposals for governing urban nature and space in circular cities, which emerge in technical disputes over water circularity.

The next chapters bring these questions to Los Angeles. Chapter 2 analyzes the technopolitics of wastewater restructuring there and conceptually outlines how technopolitical regimes of urban infrastructures shape wastewater restructuring and its broader impacts on urban environments. Chapter 3 explores the politics of Los Angeles' increasingly hybrid stormwater system, where centralized stormwater practices of public utilities prevail but increasingly co-exist with more decentralized landscape-centered practices. Chapter 4 discusses competing approaches to retrofitting residential gardens in Los Angeles to increase water conservation. Developing the notion of "infrastructuring gardens," this demonstrates how public water engineers shape landscape change but also how practices of California native plant gardening highlight the political relationships between water, technology, and urban environments that challenge technocratic water governance. Chapter 5 draws a comprehensive picture of circular urban water restructuring in Los Angeles by revealing two broader technopolitical regimes. The study contrasts the aspirations to establish a singular "One Water" cycle around centralized infrastructures with the emergence of a more plural circular Los Angeles marked by increasingly hybrid infrastructures that combine diverse ways of aligning water, technology, and urban space. The conclusion integrates the main empirical findings of this study, reflects on its conceptual contributions to critical urban research, and provides recommendations for further research as well as policymaking and planning.

1.7 References

Abu-Lughod, J. L. 1999. New York, Chicago, Los Angeles. University of Minnesota Press, Minneapolis.

Aibar, E. and W. E. Bijker 1997. Constructing a city: The Cerdà Plan for the extension of Barcelona. *Science, Technology, & Human Values* 22(1): 3-30.

Amin, A. and N. Thrift 2016. Seeing like a city. Polity Press, Cambridge.

Amin, A. and N. Thrift 2002. Cities: Reimagining the urban. Polity Press, Cambridge.

Anand, N. 2017. Hydraulic city: Water and the infrastructures of citizenship in Mumbai. Duke University Press, Durham.

Bakker, K. 2010. Privatizing water: Governance failure and the world's urban water crisis. Cornell University Press, Ithaca.

Banham, R. 1971. Los Angeles: The architecture of four ecologies. Allen Lane, London.

Baxter, J. 2010. Case studies in qualitative research. In I. Hay (ed.), Qualitative research methods in human geography (3rd ed.). Oxford University Press, Oxford.

Bell, S. 2015. Renegotiating urban water. *Progress in planning* 96: 1-28.

Bell, S. 2017. Urban water sustainability: Constructing infrastructure for cities and nature. Routledge, London.

Bigger, P. and N. Millington 2020. Getting soaked? Climate crisis, adaptation finance, and racialized austerity. *Environment and Planning E: Nature and Space* 3(3): 601-623.

Bijker, W. E. 1995. Of Bicycles bakelites, and bulbs: Toward a theory of sociotechnical change. MIT Press, Cambridge.

Bijker, W. E. 2001. Understanding technological culture through a constructivist view of science, technology, and society. In S. H. Cutcliffe and Mitcham, C. (eds.), Visions of STS: Counterpoints in science, technology, and society studies. SUNY Press, New York. 19-34.

Bijker, W. E. 2007. Dikes and dams, thick with politics. *Isis* 98(1): 109-123.

Blok, A., M. Nakazora and B.R. Winthereik 2016. Infrastructuring environments. *Science as Culture* 25(1): 1-22.

Bowker, G. 1994. Science on the run: Information management and industrial geographics at Schlumberger, 1920–1940. MIT Press, Cambridge.

Braun, B. P. 2014. A new urban dispositif? Governing life in an age of climate change. *Environment and Planning D: Society and Space* 32(1): 49-64.

Brenner, N. 2014. Implosions/explosions. Towards a study of planetary urbanization. Jovis, Berlin.

Brown, R. R. and M. A. Farrelly 2009. Delivering sustainable urban water management: A review of the hurdles we face. *Water science and technology* 59(5): 839-846.

Brown, R, R., M. A. Farrelly and D. A. Loorbach 2013. Actors working the institutions in sustainability transitions: The case of Melbourne's stormwater management. *Global Environmental Change* 23: 701–718.

Brown, R. R., N. Keath and T. H. Wong 2009. Urban water management in cities: Historical, current and future regimes. *Water science and technology* 59(5): 847-855.

Bulkeley, H. 2021. Climate changed urban futures: environmental politics in the Anthropocene city. *Environmental Politics* 30(1-2): 266-284.

Bulkeley, H., V. Castán Broto and A. Maassen 2014. Low-carbon transitions and the reconfiguration of urban infrastructure. *Urban studies* 51(7): 1471-1486.

Butler, D., S. Ward, S., C. Sweetapple, et al. 2017. Reliable, resilient and sustainable water management: the Safe & SuRe approach. *Global Challenges* 1(1): 63-77.

Callon, M. 2009. Foreword. In G. Hecht, The radiance of France: Nuclear power and national identity after World War II. MIT Press, Cambridge.

Callon, M. 2010. Afterword. In A. Feenberg, Between reason and experience: Essays in technology and modernity. MIT Press, Cambridge.

Carroll, P. 2012. Water and technoscientific state formation in California. *Social Studies of Science* 42(4): 489-516.

Carse, A. 2012. Nature as infrastructure: Making and managing the Panama Canal watershed. *Social Studies of Science* 42(4): 539-563.

Carson, R. 2002. Silent spring. Houghton Mifflin Harcourt, Boston.

City of Los Angeles 2019. pLAn. LA's Green New Deal. Los Angeles.

Cousins, J. J. 2017. Of floods and droughts: The uneven politics of stormwater in Los Angeles. *Political Geography* 60: 34-46.

Cousins, J. J. 2020. Malleable infrastructures: crisis and the engineering of political ecologies in Southern California. *Environment and Planning E: Nature and Space* 3(3): 927–49.

Coutard, O. and J. Rutherford 2016. Beyond the networked city: An introduction. In O. Coutard and J. Rutherford (eds.), Beyond the networked city: infrastructure reconfigurations and urban change in the North and South. Studies in Urbanism and the City. Routledge, London. 1-25.

Coutard, O. and S. Guy 2007. STS and the city: Politics and practices of hope. *Science, Technology & Human Values* 32(6): 713–734.

Creswell, J. W. and J. D. Creswell 2018. Research design: qualitative, quantitative, and mixed methods approaches. Fifth edition. SAGE, Los Angeles.

Davis, M. 1998. Ecology of fear: Los Angeles and the imagination of disaster. Macmillan, New York.

Dear, M. and S. Flusty 1998. Postmodern urbanism. *Annals of the Association of American Geographers* 88(1): 50-72.

Derickson, K. D. 2018. Urban geography III: Anthropocene urbanism. *Progress in Human Geography* 42(3): 425-435.

Desfor, G. and R. Keil 2004. Nature and the city: making environmental policy in Toronto and Los Angeles. University of Arizona Press, Tucson.

Diep, L., P. Parikh, D. Dodman, et al. 2022. Problematizing infrastructural "fixes": critical perspectives on technocratic approaches to Green Infrastructure. *Urban Geography*: 1-22.

Dorst, H., A. van der Jagt, H. Toxopeus, et al. 2022. What's behind the barriers? Uncovering structural conditions working against urban nature-based solutions. *Landscape and Urban Plannin*g, 220, 104335

Driessen, P. P. J., D. L. Hegger, Z. W. Kundzewicz, et al. 2018. Governance strategies for improving flood resilience in the face of climate change. *Water* 10(11): 1595.

Edwards, P. N. and G. Hecht 2010. History and the technopolitics of identity: the case of apartheid South Africa. *Journal of Southern African Studies* 36(3): 619-639.

Erie, S.P. and H.D. Brackman 2006. Beyond Chinatown: the metropolitan water district, growth, and the environment in Southern California. Stanford University Press, Stanford.

Feenberg, A. 2010. Between reason and experience: essays in technology and modernity. MIT Press, Cambridge.
Finewood, M. H. 2016. Green infrastructure, grey epistemologies, and the urban political ecology of Pittsburgh's water governance. *Antipode* 48(4): 1000-1021.
Fishman, R. 1987. Bourgeois utopias: the rise and fall of suburbia. Basic books, New York.
Flyvbjerg, B. 2006. Five misunderstandings about case-study research. *Qualitative Inquiry* 12(2): 219-245.
Foley, R. and T. Miller 2020. Urban techno-politics: an introduction. *Science as Culture* 29(3): 309-318.
Furlong, K. 2011. Small technologies, big change: rethinking infrastructure through STS and geography. *Progress in Human Geography* 35(4): 460-482.
Furlong, KM. 2021. Full-cost recovery = debt recovery: How infrastructure financing models lead to overcapacity, debt, and disconnection. *WIREs Water* 8: 1503.
Gandy, M. 2002. Concrete and clay: reworking nature in New York City. MIT Press, Cambridge.
Gandy, M. 2005. Cyborg urbanization: complexity and monstrosity in the contemporary city. *International Journal of Urban and Regional Research* 29(1): 26–49.
Gandy, M. 2014. The fabric of space: water, modernity, and the urban imagination. MIT Press, Cambridge.
Gandy, M. 2022. Natura urbana: ecological constellations in urban space. MIT Press, Cambridge.
Ghisellini, P., C. Cialani and S. Ulgiati 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production* 114 (February), 11–32.
Goh, K. 2021. Form and flow: the spatial politics of urban resilience and climate justice. MIT Press, Cambridge.
Gopakumar, G. 2020. Installing automobility: emerging politics of mobility and streets in Indian cities. The MIT Press, Cambridge.
Graham, S. and S. Marvin 2001. Splintering urbanism: networked infrastructures, technological mobilities and the urban condition. Routledge, London.
Graham, S. and C. McFarlane 2014. Infrastructural lives: urban infrastructure in context, Routledge, London.
Green, A. and S. Bell 2019. Neo-hydraulic water management: an international comparison of idle desalination plants. *Urban Water Journal* 16(2): 125-135.
Guma, P. K. 2020. Incompleteness of urban infrastructures in transition: scenarios from the mobile age in Nairobi. *Social Studies of Science* 50(5): 728-750.

Guy, S., and A. Karvonen 2011. Using sociotechnical methods: researching human-technological dynamics in the city In: J. Mason and A. Dale (eds.), Understanding social research: thinking creatively about method. Sage, London. 120-133.

Hajer, M.A. 1995. The politics of environmental discourse: ecological modernization and the policy process. Oxford University Press, Oxford.

Hardin, G. 1968. The tragedy of the commons: the population problem has no technical solution; it requires a fundamental extension in morality. *Science* 162(3859): 1243-1248.

Harvey, D. 1996. Justice, nature and the geography of difference. Blackwell, Cambridge.

Hecht, G. 2009. The radiance of France: nuclear power and national identity after World War II. MIT Press, Cambridge.

Hetherington, K. 2018. Infrastructure, environment, and life in the Anthropocene. Duke University Press, Durham.

Heynen, N., M. Kaika and E. Swyngedouw 2006. In the nature of cities: urban political ecology and the politics of urban metabolism. Routledge, London.

Heynen, N. 2015. Urban political ecology II: the abolitionist century. *Progress in Human Geography* 40(6): 839-845.

Hughes, S., S. Pincetl and S. Boone 2013. Triple exposure: regulatory, climatic, and political drivers of water management changes in the city of Los Angeles. *Cities* 32 (June), 51–59.

Hughes, T. P. 1987. The evolution of large technological systems. In: W. E. Bijker,
T. P. Hughes and T. J. Pinch (eds.), The social construction of technological systems. MIT Press, Cambridge. 51–82.

Kahrl, W. L. 1982. Water and power: The conflict over Los Angeles' water supply in the Owens Valley. University of California Press, Berkeley.

Kaika, M. 2005. City of flows: modernity, nature, and the city. Routledge, New York.

Kaika, M. and E. Swyngedouw 2000. Fetishizing the modern city: the phantasmagoria of urban technological networks. *International Journal of Urban and Regional Research* 24(1): 120–138.

Karvonen, A. 2011. Politics of urban runoff: nature, technology, and the sustainable city. MIT Press Cambridge.

Kirkpatrick, L. and M. P. Smith 2011. The infrastructural limits to growth: rethinking the urban growth machine in times of fiscal crisis. *International Journal of Urban and Regional Research* 35(3): 477-503.

Kirshen, P., S. Aytur, J. Hecht, et al. 2018. Integrated urban water management applied to adaptation to climate change. *Urban Climate* 24: 247-263.

Koop, S. H. A., L. Koetsier, A. Doornhof, et al. 2017. Assessing the governance capacity of cities to address challenges of water, waste, and climate change. *Water resources management* 31(11): 3427-3443.

Kooy, M. and K. Bakker 2008. Technologies of government: constituting subjectivities, spaces, and infrastructures in colonial and contemporary Jakarta. *International Journal of Urban and Regional Research* 32(2): 375-391.

Krueger, E., P. S. C. Rao and D. Borchardt 2019. Quantifying urban water supply security under global change. *Global Environmental Change* 56: 66-74.

LADWP 2010. Urban water management plan. Los Angeles.

LADWP 2015. Urban water management plan. Los Angeles.

LADWP 2020. Urban water management plan. Los Angeles.

Latham, A. and D. P. McCormack 2004. Moving cities: rethinking the materialities of urban geographies. *Progress in Human Geography* 28(6): 701-724.

Law, J. 2016. STS as method. In U. Felt, Fouché, R., Miller, C. A., and Smith-Doerr, L. (eds.), The handbook of science and technology studies. MIT Press, Cambridge. 31-59.

Lawhon, M., H. Ernstson and J. Silver 2014. Provincializing urban political ecology: towards a situated UPE through African urbanism. *Antipode* 46(2): 497-516.

Lawhon, M. and J. T. Murphy 2012. Socio-technical regimes and sustainability transitions: insights from political ecology. *Progress in Human Geography* 36(3): 354-378.

Lee, K. and W. Jepson 2020. Drivers and barriers to urban water reuse: a systematic review. *Water Security* 11: 100073.

Liu, L. and M. B. Jensen 2018. Green infrastructure for sustainable urban water management: Practices of five forerunner cities. *Cities* 74: 126-133.

Loftus, A. 2012. Everyday environmentalism: creating an urban political ecology. University of Minnesota Press, Minneapolis.

Loftus, A. and H. March 2016. Financializing desalination: rethinking the returns of big infrastructure. *International Journal of Urban and Regional Research* 40(1): 46-61.

Loftus, A., H. March and T. F. Purcell 2019. The political economy of water infrastructure: an introduction to financialization. *Wiley Interdisciplinary Reviews: Water* 6(1), e1326.

LA Sanitation 2018. One Water LA 2040 Plan. Los Angeles.

Marx, K. and F. Engels 1975. Collected work, Volume 5, New York.

McDonald, D. A. 2018. Remunicipalization: the future of water services?. *Geoforum*, 91, 47-56.

MacKillop, F. and J.-A. Boudreau 2008. Water and power networks and urban fragmentation in Los Angeles: rethinking assumed mechanisms. *Geoforum* 39(6): 1833–1842.

McFarlane, C. and J. Rutherford 2008. Political infrastructures: governing and experiencing the fabric of the city. *International Journal of Urban and Regional Research* 32(2): 363–374.

McGuirk, P. M., H. Bulkeley, H. and R. Dowling 2016. Configuring urban carbon governance: insights from Sydney, Australia. *Annals of the American Association of Geographers* 106(1): 145-166.

McHarg, I. 1969. Design with nature. Doubleday/Natural History Press, Garden City, N.J..

Meerow, S. and J. P. Newell 2017. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landscape and Urban Planning* 159: 62-75.

Melosi, M. 2008. The sanitary city: environmental services in urban America from colonial times to the present. University of Pittsburgh Press, Pittsburgh.

Millington, N. and S. Scheba 2021. Day Zero and the infrastructures of climate change: water governance, inequality, and infrastructural politics in Cape Town's water crisis. *International Journal of Urban and Regional Research* 45(1): 116-132.

Mini, C., T.S. Hogue, and S. Pincetl 2014. Estimation of residential outdoor water use in Los Angeles, California. *Landscape and Urban Planning* 127: 124-135.

Mitchell, T. 2002. Rule of experts: Egypt, techno-politics, modernity. University of California Press, Berkeley.

Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A* 41(8): 1924–1942.

Monstadt, J. and O. Coutard 2019. Cities in an era of interfacing infrastructures: politics and spatialities of the urban nexus. *Urban Studies* 56(11), 2191-2206.

Monstadt, J. and S. Schramm 2017. Toward the networked city? Translating technological ideals and planning models in water and sanitation systems in Dar es Salaam. *International Journal of Urban and Regional Research* 41(1): 104-125.

Moss, T. 2020. Remaking Berlin: a history of the city through infrastructure, 1920-2020. MIT Press, Cambridge.

Nicholls, W. J. 2011. The Los Angeles School: difference, politics, city. *International Journal of Urban and Regional Research* 35(1): 189–206.

Nieuwenhuis, E., E. Cuppen, J. Langeveld, et al. 2021. Towards the integrated management of urban water systems: conceptualizing integration and its uncertainties. *Journal of Cleaner Production* 280: 124977.

Orsi, J. 2004. Hazardous metropolis: flooding and urban ecology in Los Angeles. University of California Press, Berkeley.

Pahl-Wostl, C. 2017. An evolutionary perspective on water governance: from understanding to transformation. *Water resources management* 31(10): 2917-2932.

Parés, M., H. March and D. Saurí 2013. Atlantic gardens in Mediterranean climates: understanding the production of suburban natures in Barcelona. *International Journal of Urban and Regional Research* 37 (1): 328-347.

Park, M.-H., M. Stenstrom and S. Pincetl 2009. Water quality improvement policies: lessons learned from the implementation of Proposition O in Los Angeles, California. *Environmental Management* 43 (3): 514–522.

Pickett, N. R., S. Henkin and S. O'Lear 2020. Science, technology, and society approaches to fieldwork in Geography. *The Professional Geographer* 72(2): 253-263.

Pilo', F. 2020. Material politics: utility documents, claims-making and construction of the "deserving citizen" in Rio de Janeiro. *City & Society* 32(1): 71-92.

Pincetl, S. 2010. From the sanitary city to the sustainable city: challenges to institutionalising biogenic (nature's services) infrastructure. *Local Environment* 15(1): 43–58.

Pincetl, S., E. Porse and D. Cheng 2016. Fragmented flows: water supply in Los Angeles County. *Environmental Management* 58.2, 208–22

Pincetl, S., E. Porse, K. B. Mika, et al. 2019. Adapting urban water systems to manage scarcity in the 21st century: the case of Los Angeles. *Environmental Management* 63(3), 293-308.

Pinch, T. 2008. Technology and institutions: living in a material world. *Theory and Society* 37(5): 461-483.

Porse, E. 2013. Stormwater governance and future cities. *Water* 5(1): 29-52.

Porse, E., K. B. Mika, E. Litvak, et al. 2017. Systems analysis and optimization of local water supplies in Los Angeles. *Journal of Water Resources Planning and Management* 143(9): 04017049.

Randle, S. 2021. Battling over bathwater: greywater technopolitics in Los Angeles. *City & Society* 33(3): 444-466

Ranganathan, M. 2015. Storm drains as assemblages: the political ecology of flood risk in post-colonial Bangalore. *Antipode* 47(5): 1300-1320.

Reisner, M. 1993. Cadillac desert: the American West and its disappearing water. Penguin, New York.

Robbins, P. 2007. Lawn people: How grasses, weeds, and chemicals make us who we are. Temple University Press. Philadelphia.

Rockström, J., W. Steffen, K. Noone, et al. 2009. A safe operating space for humanity. *Nature* 461(7263), 472-475.

Rutherford, J. 2020. Redeploying urban infrastructure: the politics of urban socio-technical futures. Pelgrave Macmillan, Cham.

Scott, A. J. and E. W. Soja 1996. City – Los Angeles and urban theory at the end of the twentieth century. University of California Press, Berkeley.

Sklar, A. 2008. Brown acres: An intimate history of the Los Angeles sewers. Angel City Press. Los Angeles.

Soja, E. W. 2014. My Los Angeles: From urban restructuring to regional urbanization. University of California Press, Berkeley.
Star, S. L. 1999. The ethnography of infrastructure. *American Behavioral Scientist* 43(3): 377–391.
Star, S. L. and K. Ruhleder 1996. Steps toward an ecology of infrastructure: design and access for large information spaces. *Information systems research* 7(1): 111-134.
Strauss, A. L. 1987. Qualitative analysis for social scientists. Cambridge University Press, Cambridge.
Sultana, F. 2020. Embodied intersectionalities of urban citizenship: water, infrastructure, and gender in the Global South. *Annals of the American Association of Geographers* 110(5): 1407-1424.
Swyngedouw, E. and M. Kaika 2014. Urban political ecology. Great promises, deadlock… and new beginnings? *Documents d'anàlisi geogràfica* 60(3): 459-481.
Swyngedouw, E. 2004. Social power and the urbanization of water: flows of power. Oxford University Press, Oxford.
Tiwale, S. 2019. Materiality matters: revealing how inequities are conceived and sustained in the networked water infrastructure-The case of Lilongwe, Malawi. *Geoforum* 107: 168-178.
Truelove, Y. 2019. Gray zones: the everyday practices and governance of water beyond the network. *Annals of the American Association of Geographers* 109(6): 1758-1774.
United States Census Bureau 2022. Quick facts. Los Angeles city, California. Accessed December 22, 2022. https: //www. census. gov/quickfacts/losange-lescitycalifornia
Usher, M. 2018. Conduct of conduits: engineering, desire and government through the enclosure and exposure of urban water. *International Journal of Urban and Regional Research* 42(2): 315-333.
Usher, M. 2019. Desali-nation: techno-diplomacy and hydraulic state restructuring through reverse osmosis membranes in Singapore. *Transactions of the Institute of British Geographers* 44(1): 110-124.
Varnelis, K. (ed.) 2009. The infrastructural city: networked ecologies in Los Angeles. Actar, Barcelona.
Von Schnitzler, A. 2008. Citizenship prepaid: water, calculability, and techno-politics in South Africa. *Journal of Southern African Studies* 34(4): 899-917.
Wakefield, S. 2018. Infrastructures of liberal life: from modernity and progress to resilience and ruins. *Geography Compass* 12(7).
Williams, J. 2022. Desalination in the 21st century: a critical review of trends and debates. *Water Alternatives* 15(2): 193-217.
Winner, L. 1986. The whale and the reactor: a search for limits in an age of high technology. University of Chicago Press, Chicago.

Wolch, J. R., M. Pastor and P. Dreier 2004. Up against the sprawl: public policy and the making of Southern California. University of Minnesota Press, Minneapolis.

World Trade Center Los Angeles 2022. Choose LA. Accessed December 22, 2022. https://www.wtcla.org/choose-la

Yin, R. K. 2018. Case study research and applications: design and methods (6th ed.). SAGE, Thousand Oaks.

2

FROM THE SANITARY CITY TO THE CIRCULAR CITY? TECHNOPOLITICS OF WASTEWATER RESTRUCTURING IN LOS ANGELES, CALIFORNIA

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ABSTRACT

This article follows the flow of wastewater in Los Angeles, California, from upstream treatment plants to the Pacific Ocean, to explore struggles over reconfigurations of urban wastewater flows for new policy ambitions in recycling and reuse. We show how ambitious infrastructure visions of circular urban resource management have gained force since California's most recent drought (2011–16) but clash with incumbent gravity-fed water and sewer systems, political economy, and urban geographies. Engineers navigate these path dependencies through incremental technical improvements of existing infrastructures to increase wastewater recycling. These interventions largely reproduce given infrastructure configurations and urban geographies of water and wastewater while marginalizing other voices in struggles over water circularity and stymying critical debate about more progressive change. We argue that novel infrastructural practices are deeply political and normative and can be explained by four dimensions of the "technopolitics" of wastewater restructuring in Los Angeles: materiality and inherited topologies of infrastructures; circularity discourses; entrenched knowledge cultures; and institutional orders of infrastructure management and public control mechanisms of infrastructure investments and tariffs. We conclude by discussing how these four dimensions of an emerging technopolitical regime of wastewater recycling expand concepts of power that explain urban metabolic change.

2.1 Introduction

The development of the city of Los Angeles into a modern metropolis features notoriously as a lively history of water infrastructure expansion realized by the Los Angeles Department of Water and Power (LADWP) and the Metropolitan Water District of Southern California (Reisner, 1993). The roll-out of gigantic water import systems has strongly shaped local and regional politics by catalyzing Los Angeles' growth into the largest city in California, despite the semi-arid climate. While much has been written on Los Angeles' notorious history of water grabs from distant sources, much less is known about how urbanization was co-constructed by the expansion of subterranean sewer networks, which are managed by the Los Angeles Bureau of Sanitation (LA Sanitation). Gravity-fed sewers have been designed to effectively treat and discharge increasing amounts of wastewater[4] into the Pacific Ocean at the Hyperion Water Reclamation Plant (Sklar, 2008). Neighboring an ensemble of Los Angeles' international airport, two power plants, an oil refinery, aerospace industrial sites as well as affluent beach communities, the treatment plant forms part of an iconographic landscape of twentieth-century Los Angeles (see Soja, 2014).

Today, the socio-technical regime of "sanitary Los Angeles" is being exposed to increasing pressures that arise from water import restrictions, environmental policies, and climate change (Hughes et al., 2013) and from the high costs of maintenance and renewal. In the aftermath of California's most recent drought (2011–16), Los Angeles mayor Eric Garcetti (2019) announced that there will be 100% recycling of the city's wastewater by 2035. Planned wastewater recycling projects are envisioned to pave the way toward a "circular Los Angeles" in which water circulates through a closed metabolic cycle of water use, wastewater treatment, and water reuse to supply the prospering city. Redefining wastewater as a local water resource, this shift toward circularity has sparked a suite of technopolitical reconfigurations of sanitary Los Angeles' modern infrastructures and their urban geographies.

An extensive scholarship has discussed the politics of water management, urban ecologies, and infrastructural growth in Los Angeles (e.g., Kahrl, 1983; Reisner, 1993; Erie and Brackman, 2006), and urban political ecologists have skillfully unveiled the socio-ecological ills and injustices of Los Angeles' modern urbanization (Davis 1998; 2006; Desfor and Keil, 2004; Gandy, 2014). Today, ambitious goals for circular urban water management are radically foregrounding infrastructure in urban politics. Circular economy discourses have made their way into engineering debates that present wastewater recycling as a promising technical fix for urban water scarcity (Bichai et al., 2018; Hoffman et al., 2020). As urban water policy is increasingly being shaped by technical concepts of water

4 This does not include stormwater, which is managed in a separate system.

circularity, there is a growing need to critically examine the underlying social processes of technology and its political entanglements with urban metabolic change.

In this article, we scrutinize the technopolitics of urban wastewater recycling and their broader urban political salience by examining three issues. Firstly, we trace how new infrastructural practices and power dynamics that explain infrastructural change arise from discourses mobilized by progressive engineers, environmentalists, and utility managers to promote wastewater recycling. Secondly, we explore the urban geographical and metabolic implications of infrastructural contestations about wastewater recycling. Finally, we demonstrate how hegemonic technopolitical regimes preclude alternative urban water practices.

We address these questions by drawing on the notion of "technopolitics" to describe "the strategic practice of designing or using technology to constitute, embody, or enact political goals" (Hecht, 2009: 56). To unveil Los Angeles' shifting technopolitics of wastewater, we pay close attention to the materiality of technology, to discourses and expert knowledge, and to institutional arrangements linked to technology (Mitchell, 2002; Hecht, 2009). Our focus on urban water and sewer systems is intended to expand recent work in urban studies on political actions through technology (Björkman and Harris, 2018; Cousins, 2020). We aim to study and explain interrelated urban and infrastructural change through technopolitical practices that emanate from the materiality of technical infrastructure, discourses on infrastructural renewal, and existing expert knowledge and institutional arrangements. This allows a materially grounded analysis of urban politics around infrastructure that links infrastructural practices with the power relations embedded in urban technopolitical regimes. Furthermore, the study of infrastructure technopolitics enhances critical scholarship in urban political ecology by foregrounding how technology matters for urban metabolic change (Monstadt, 2009).

We begin empirically, by portraying the context of wastewater recycling in Los Angeles: visions of circularity clash with inherited socio-technical orders. Next, we uncover how water agencies navigate path dependencies and declining wastewater flows to maximize wastewater recycling. Incremental engineering interventions focus on retrofitting existing treatment plants at the "end of the pipe", thereby marginalizing alternative practices and visions of a circular Los Angeles. These interventions conflict with revitalization plans for the Los Angeles River that take for granted that treated wastewater flows will continue to feed the river. A sustainability fix through technical retrofits leaves social orders of sanitary Los Angeles unchallenged. The discussion reveals how the interplay between given socio-technical orders and an emerging technopolitical regime of circular Los Angeles shapes path-dependent trajectories of change. Finally, we rethink the relations of power underlying urban metabolic change toward circular cities through infrastructure technopolitics.

We collected the empirical data for this article in three long research stays in Los Angeles between 2016 and 2019. Firstly, we qualitatively analyzed planning and policy documents, technical manuals, legislation, newspaper articles and official statistics. Then we conducted 54 semi-structured, qualitative interviews with engineers and managers of Los Angeles' water agencies as well as with politicians, environmental organizations, activists, private businesses and researchers. Our questions were intended to enable us to understand and explain the various actors' interests and the actors' technical or non-technical choices in their decisions on circular Los Angeles. In addition, we asked questions that examined connections between reconfigurations of wastewater flows and their distinct spatialities. Our qualitative content analysis centered on relating reconfigurations of wastewater flows to shifts and continuities in industrial structures, forms of expertise, governance structures of resource management, and concepts of technology and nature.

2.2 Recycling wastewater: from sanitary city to circular city

Contemporary practices of urban water and wastewater management can be seen as the historical product of a co-evolution of technology, scientific knowledge, shifting modes of economic production and reproduction, cultures of hygiene, and the organization of the state (Gandy, 2014). Melosi (2008) traces the rise of the "sanitary city" in nineteenth-century North America as the formation of a rationalized socio-technical regime of urban water, wastewater and solid waste management, designed to overcome limitations of urban development by preventing disease and ensuring pure drinking water.

Technically, the sanitary city's sewer networks collect wastewater across the urban area, treat it in centralized plants and discharge treated wastewater into open water bodies. Hydraulic pipe design and gravity ensure an effluent metabolism: clean water is brought in upstream and treated wastewater is discharged downstream. Since the late nineteenth century, urban sanitation has evolved into a comprehensive technoscientific project, managing pollution at the "end of the pipe" (Karvonen, 2011: 7–9). Instead of targeting high water consumption and wastewater production, innovation has focused on universalizing centralized sewer networks and improving treatment technologies. The sanitary city has cultivated a "professional bureaucracy" (Melosi, 2008: 75) of highly developed water and wastewater industries with taskspecific standards and regulations, budgeting practices, revenue models, and patterns of service. High public spending, far-reaching public regulation and public ownership turned the universalization of urban wastewater networks into a predominantly public endeavor (ibid.: 86). Over time, urban water and wastewater management have matured into distinct epistemic realms with specialized knowledge. In many cities, expertise, operational processes, and the governance of water and wastewater are organized in separate agencies with distinct institutional, financial, and political control mechanisms (Pincetl, 2010: 45–46).

Overall, the operational logic of the sanitary city is geared toward a safe disposal of wastewater. Technical networks mediate the social differentiation of water as consumable good and wastewater as disposable public bad, which facilitates processes of valorization and devalorization of resources. However, since the 1990s the sanitary city's regime of resource extraction and waste accumulation has come under increasing criticism. Apart from the high operational costs of centralized sewer networks and their limited adaptability to changing urban environments, the model of a sanitary city has been criticized because it "assumes a linear economy pattern [...] and fails to [...] take into account the exhaustible nature of natural resources" (Ghisellini et al., 2016: 16) and natural assimilation capacities of human waste (Arup et al., 2018). Sparked by discourses on a "circular economy" or "circular city", an abundant engineering literature has mobilized visions of circular urban wastewater systems targeting the recovery and revalorization of resources from wastewater (primarily water, energy, and nutrients) (e.g., Bichai et al., 2018; Hoffmann et al., 2020). Wastewater reuse and recycling, particularly in dry cities, has been portrayed as a promising solution for urban water scarcity (Arup et al., 2018). Different technologies are available: Non-potable reuse systems supply recycled water from the treatment plant via dedicated pipes for irrigation and industrial purposes. Indirect potable reuse is based on an environmental buffer such as a groundwater aquifer where recycled water is mixed with groundwater between the treatment plant and the reprocessing of the water for potable reuse. Direct potable reuse entails a fully engineered water metabolism in which the boundaries between wastewater treatment and water supply have been removed (Cotruvo, 2016). Other alternatives for resource recovery are the reuse of greywater from the laundry or the shower for garden irrigation, and more decentralized wastewater treatment and recycling facilities (see Hoffmann et al., 2020).

Critical urban scholarship has scrutinized the uptake of circular economy and circular city discourses in urban policies (Savini, 2019; Williams, 2019) that pursue a "technology-led dematerialization geared toward resolving the tension between the scarcity of resources and economic growth" (Kębłowski et al., 2020: 143). Technoscientific endeavors to revalorize waste informed by concepts in industrial ecology increasingly frame discourses and practices of urban and infrastructure development. Urban imaginaries of circularity through wastewater recycling are a case in point here. Nonetheless, scant attention has been paid to how those imaginaries materialize locally and how they are shaped by urban technopolitical regimes. Positioned at the interface of siloed water and wastewater institutions and industries, wastewater recycling implies conflictual reconfigurations of existing patterns of financing, resource management, and governance. Crucially, it turns the sanitary city's operational logic of rapid waste disposal inside out. Modern ideals of sanitation, progress, and control over nature are translated into a new – and fundamentally more complex – socio-technical form that is envisaged to supply growing cities with locally circulating water and other resources, to align water, wastewater, and energy systems (at least partially), and to fix urban resource scarcity and pollution.

2.3 The technopolitics of changing urban infrastructures

Research on urban political ecology has greatly contributed to a deeper understanding of urban metabolic change of water infrastructures as a contested process that intersects with reconfigurations of the city's urban nature, its social and technological fabric, and its cultural representations. Urban political ecologists have studied water infrastructures as an empirical entry to examining the politics of the urban metabolism that conceptualizes how social and biophysical processes co-produce urban nature in dialectic relationships (Gandy, 2004). Uncovering the uneven power relations underlying the production of urban nature is central to this scholarship (e.g., Swyngedouw, 2004; Heynen et al., 2006). Water infrastructures feature not only as objects of policymaking but also as bearers of social meaning and mediators of material flows (Kaika and Swyngedouw, 2000). Other studies have focused on (storm)water infrastructures to criticize technomanagerial expertise dominating urban environmental management (Karvonen, 2011) or to explain socio-spatial injustice as an outcome of global–local histories of urbanization (Goh, 2019). Although the hybrids of technology and institutions, governance structures, expertise, cultural meaning, and economic relations that constitute infrastructures are implicit in this work, they remain less explicitly analyzed and conceptualized (Monstadt, 2009).

Urban infrastructure scholars read infrastructures as aggregates of technical artifacts linked to "actors, skills, knowledges, practices, cultural meanings, and values, resources, money, and politics" (Coutard and Rutherford, 2016: 13). With Hecht (2009), we argue that these multiple social and material elements of water infrastructures condense into place-based technopolitical regimes. They form a configuration of heterogeneous elements, combining technical materialities, discourses, a knowledge base, institutional, and political components, etc., "which are rendered mutually interdependent and support one another" (Callon, 2009: xiii). Often, the tight linkages between regime elements create "a self-perpetuating cycle of enormous stability" (Gopakumar, 2020: 360) that is resistant to change beyond established development patterns, but is neither uncontested nor fixed (Monstadt, 2009). Thinking through the technopolitical regimes of a sanitary city reveals how current infrastructural decisions are linked to the engineering choices, values, knowledge and institutional arrangements prevailing when a sanitary city was constructed and consolidated, and how inherited configurations can compete with alternative visions of a circular city. We argue that the envisaged transformations from a sanitary to a circular city can be framed as a technopolitical process that is inextricably linked to urban metabolic change but is characterized by distinct social dynamics underlying technology and by the power relations technology enables. When the concept of technopolitics is applied to cities, it foregrounds the city's physical artifacts that "are constituted through arrangements of power and authority that embody or enact political goals" (Foley et al., 2020: 324). To demonstrate this, we highlight and describe four dimensions of technopolitics: the mere *materiality of technology* limits political choices; *discourses* form a political force influencing infrastructural practices; *expert knowledge* inscribed into technology influences how actors partake in decision making; and *institutional arrangements* linked to technology shape infrastructural practices.

Firstly, political objectives of redesigning urban infrastructures are contingent on the materiality of technology. The sheer bulk of installed pipes, pumps, treatment plants, etc., hampers a radical recomposing of urban water and sewer infrastructures. These technical artifacts do not determine a specific course of action, but rather modify the "field of possibilities" (Foucault, 1982: 221) for social operations and technical innovation in sewer systems, or what is perceived as "doable and not doable" (Tiwale, 2019: 169). In particular, sewer networks that collect wastewater from all urban residents and transport it to centralized treatment plants define corridors of infrastructural change that are difficult to ignore. The limited compatibility of these networks with alternative approaches (e.g., decentralized wastewater reuse) restricts political choices and obstructs proponents of disruptive technologies. When novel social demands such as circular flow management appear, technical artifacts matter politically because they shape the practices of urban and infrastructure reconfigurations.

Secondly, discourses around urban water and wastewater management have significant impacts on practices. Together with Hajer (1995: 44), we argue that discourses can be defined "as a specific ensemble of ideas, concepts, and categorizations [...] through which meaning is given to physical and social realities." Common storylines form the basis of "discourse coalitions" reflecting actors' shared understandings and definitions of a given problem (Hajer, 1995). Discourses result from practices of "likeminded" actors and, at the same time, produce, reproduce, and transform a particular set of practices. In technopolitical regimes, discourses essentially surround distinct technical designs. Accordingly, storylines and imaginaries of urban wastewater as a local water resource enabled by recycling technologies constitute a broader political discourse that frames how circular urban water management is negotiated in practice, promoting distinct technopolitics while marginalizing technopolitical alternatives.

Thirdly, expert knowledge powerfully mediates urban infrastructural change. Mitchell (2002) underscores that modern expertise is not a given but is accomplished in material practice. Hegemonic expert knowledge, he argues, is frequently legitimated through the functionality of technical artifacts that are portrayed as embodiments of pure reason, while their messy histories and ambivalent decisions taken in the past are downplayed (ibid.: 36). With the rise of the sanitary city, knowledge hierarchies have been consolidated and inscribed in technical designs, institutionalizing expertise on how to design, operate, use, and govern wastewater infrastructures. This hegemonic expertise, primarily of engineers and utility managers, can impede the deployment of alternative technologies and forms of knowledge required for these technologies, thereby constraining the political possibilities for urban technological change (Karvonen, 2011; Björkman and Harris, 2018). By delving into the relations between expert knowledge and technical artifacts, we can better understand how knowledge hierarchies are enacted and exert power.

Finally, the institutional embedding of urban infrastructures frames, and is itself altered by, the politics and practices of infrastructural change. Hughes (1983) famously illustrated how, throughout the evolution of large technical systems, distinct institutional arrangements arise together with technical designs. Taking this further, Hecht (2009: 16) understands technopolitical regimes as being "grounded" in institutions; power emanating from these heterogeneous regimes frequently serves distinct institutional interests. Equally, in cities, practices in infrastructure management and governance are profoundly shaped by institutional orders (Monstadt, 2009), and infrastructural innovation depends on the openness and flexibility to change and readjust the "overall rules of the game." For example, market rules, finance mechanisms, and shared beliefs guide and structure infrastructure investments and the delivery and use of water and wastewater services. Other examples are hegemonic assessment criteria and standards of technical designs which obscure these designs' inherent politics – that is, they can sustain distinct orders of rule and prevent technopolitical alternatives (Hecht, 2009: 323).

Altogether, we conceptualize urban infrastructural change as a technopolitical process shaped by materialities, discourses, knowledge, and institutions. These dimensions, we argue, help trace technopolitical practices and their significance for wider urban metabolic dynamics. Using this perspective, we seek to explain infrastructure shifts and continuities and to critically question the urban technopolitical context of water circularity ambitions. Highlighting the underlying social dynamics and politics of infrastructures adds to scholarship in urban political ecology that is otherwise well equipped to unearth the social, ecological and spatial unevenness of urban production of nature under capitalism. Next, we scrutinize reconfigurations of wastewater flows to forge a circular Los Angeles by foregrounding technology as an important realm of negotiating urban metabolic change that brings together various human and non-human agencies.

2.4 The rise of sanitary Los Angeles

The story of Los Angeles' twentieth-century urbanization prominently features a powerful urban growth machine. Vast available land, booming industries, a cheap labor force and the expansion of infrastructure networks have been cobbled together by a local business elite to realize the suburban dream on the Pacific Ocean. Besides oil, water has arguably been the most important fuel of this booming "infrastructural city" (Varnelis, 2009; see also Soja, 2014). The construction of modern water and sewer networks has turned Los Angeles into an urban machine of high water consumption and vast wastewater discharge: sanitary Los Angeles. Since the inauguration of the cityowned Los Angeles Aqueduct in 1913, large amounts of fresh water have been flowing by gravity into the Los Angeles Basin. Under rampant post-war urbanization, a culture of abundant consumption took root: booming industries required vast amounts of water, gardens became semi-tropical, and a hygienic culture emerged in the private bathrooms of Los Angeles' mushrooming single-family homes (Davis, 1998).

Since its foundation in 1902,[5] LADWP has ensured there is a reliable, abundant and affordable water supply for the city (Reisner, 1993). As one of Los Angeles' three proprietary departments (the others govern the harbor and the airport), LADWP operates as a quasi-independent public entity with its own board of commissioners. Water rates are subject to California's Proposition 218 (1996), which binds them to the per-unit costs of service. At the same time, due to drastically reduced public investments after California's infamous local property tax cut measure Proposition 13 (1978), the public utilities rely on revenues from water sales (see Kirkpatrick and Smith, 2011). Since 2011, LADWP's tariffs have been controlled by a "ratepayer advocate" (Hughes et al., 2013: 55). This institutional architecture makes increasing water rates a politically sensitive issue, complicates the introduction of progressive rates that stimulate conservation by the largest water users, and leaves LADWP with a tight budget for investments. Meanwhile, LADWP's energy revenues are channelled into the city budget, constituting a "profit center for the city", as an interviewed water policy expert put it, while granting LADWP political leverage in city council decisions (Interview 1, 2018).

Los Angeles' wastewater flows by gravity. Making use of the region's steep topography, a separate sewer system was steadily expanded throughout the twentieth century to discharge wastewater in compliance with the US Clean Water Act and to enable urban growth (Sklar, 2008). Today, Los Angeles' sewage disposal system intercepts some of the wastewater in two upstream treatment plants (Donald C. Tillman Water Reclamation Plant and Glendale Water Reclamation Plant) but

5 LADWP started to deliver electricity in 1917.

deals with most of it downstream. Here, the Hyperion Water Reclamation Plant [6] (formerly named the Hyperion Sewage Treatment Plant) treats about 80% of Los Angeles' sewage before channelling it into the Pacific Ocean (LADWP, 2016: 4–10). The Terminal Island Water Reclamation Plant uses advanced treatment to purify wastewater mostly from industries in a small collection area around Los Angeles' harbor. Throughout Los Angeles' modern history, sanitation engineers have struggled with recurring sewer overflows caused by rapidly increasing volumes of wastewater. LA Sanitation is exposed to the same stringent tax regime as LADWP but is even more closely tied to city politics: the agency reports directly to the city council, operates with a substantially smaller budget and pays significantly lower salaries than LADWP. Historically, sewer rate increases were only politically approved when urban growth was threatened and when, in the 1980s, environmental pollution in the Santa Monica Bay sparked a large environmental movement fighting to "Heal the Bay."[7] Only then was Hyperion upgraded with full secondary wastewater treatment to ensure a safer discharge of wastewater (Sklar, 2008: 196).

From a wastewater recycling perspective, however, the historical expansion of sanitary Los Angeles that was intended to solve the city's wastewater problem for decades to come appears to be far from satisfactory. In fact, since 1979, in the wake of a drought, wastewater has been recycled for non-potable purposes on a small scale at the Glendale plant. The Tillman plant came online in 1985, discharging its tertiary-treated effluent into the Los Angeles River. Today wastewater recycling is exclusively deployed to produce non-potable water for irrigation, indoor use (cooling, toilet flushing), and industrial purposes, and to block saltwater intrusion in groundwater basins around the Terminal Island plant. Despite the progressive discourse on wastewater recycling, the socio-technical structures of sanitary Los Angeles complicate a straightforward engineering of a circular water metabolism. Hitherto abstract concepts of circularity are taking shape in this environment, making visible the complex relationships between technology, water consumption, public policy, expert knowledge and urban space.

2.5 Assembling circular Los Angeles: from upstream treatment plants to the Pacific Ocean

Prior to 2014, when rules for indirect potable reuse came into force, wastewater recycling in California was restricted to non-potable reuse (LADWP, 2016: 4–8) and fragmented governance responsibilities stymied recycling in the state (Hughes,

6 The Donald C. Tillman Water Reclamation Plant and the Hyperion Water Reclamation Plant are hereafter referred to as 'Tillman' and 'Hyperion' respectively.

7 The name of the environmental non-profit organization that was leading this movement.

2013). However, following the most recent drought in California, municipalities have increasingly mobilized discourses on circular water management that reframe wastewater as a local water resource. California's water industry has been diligently improving direct potable reuse technology, and a legal framework for it is due by 2023 (California State Water Resources Control Board, 2019). As noted previously, in 2019 Los Angeles mayor Garcetti announced that the city would be recycling all its wastewater by 2035. Despite ambitious recycling goals, between 2013 and 2018 imported water still accounted for 86% of Los Angeles' average annual total water consumption of 646 million m^3 (City of Los Angeles, 2019). Currently, only about 10 million m^3 of wastewater are recycled annually (LADWP, 2019b: 19). To explore struggles to achieve a circular Los Angeles, we will now follow the flow of wastewater in Los Angeles from upstream treatment plants to the Pacific Ocean.

2.5.1 Maximizing "infrastructure assets" at Tillman

The Tillman plant was constructed to "scalp" wastewater flows upstream to prevent sewer overflows at Hyperion. Facing a severe drought in the early 1990s, LADWP instigated the East Valley Water Reclamation Project to maximize "infrastructure assets" at the plant for wastewater recycling (Interview 2, 2018).

The project envisaged groundwater replenishment on so-called spreading grounds north of Tillman. These vast water storage basins would be deployed to infiltrate recycled water into the San Fernando Groundwater Basin, where the city of Los Angeles owns substantial groundwater rights. This water would then be reused as a local resource and distributed by gravity through existing drinking water networks, thanks to the plant's high elevation (see Figure 3). The $55 million project ran only for a few days in 2001, until a secessionist movement that aimed to separate the San Fernando Valley from the city of Los Angeles rallied against it. Voicing mistrust in Los Angeles' water technocracy, the so-called toilet-to-tap campaign mobilized health concerns as a vehicle for its own political objectives and caused the project's failure.

Only since 2012 have Los Angeles' water agencies again embarked on a mission to improve the public perception of recycled water. Besides public education programs, treatment technologies came into focus as facilitators of the political success of wastewater recycling. Despite the better water quality at Tillman, the recycling plans for this plant mimicked "full advanced treatment" technology that had been used by the Orange County Water District since 2008. This technology physically removes salts, microplastics and pharmaceutical contaminants, but it has proven to be energy- and water-intensive, losing 20–25% of the treated water as a by-product of the treatment process.[8] Nonetheless, to reduce political risk,

8 The number is based on experiments at Tillman and taken from an interview with a treatment plant manager (LA Sanitation) conducted in Los Angeles on 21 February 2018 (Interview 2, 2018).

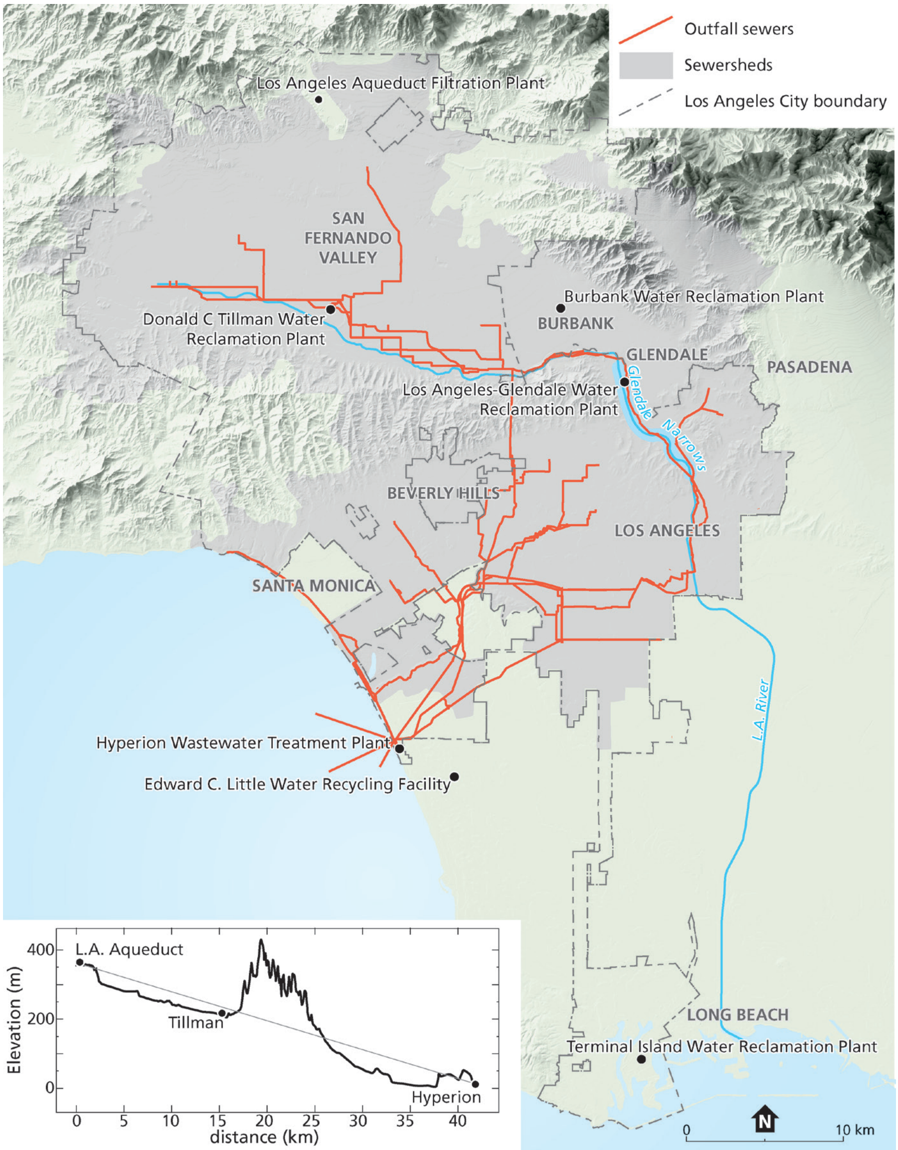

FIGURE 3 Los Angeles' gravity-fed sewer system (map produced by authors with cartography by Ton Markus)

managers opted for the technology to produce potable recycled water through groundwater replenishment at Tillman.

Meanwhile, non-potable wastewater recycling to supply golf course irrigation or industrial facilities through a separate pipe system has scarcely been expanded in recent years (LADWP, 2019b: 19). This is not only because new pipes are costly, but also because agencies fear economic risks and are wary of the health risks associated with non-potable recycled water (Interview 3, 2018). Furthermore, a decentralized wastewater recycling project in a San Fernando Valley brewery was opposed by LA Sanitation; as a local neighborhood council member reported, the agency anticipated less wastewater would be available for recycling at Tillman (Interview 4, 2016). Public engineers are thus redesigning infrastructures to ensure control over wastewater flows and the end use of recycled water.

Wastewater recycling projects are realized by an expert community trained to manage and plan for increasing wastewater flows. However, urban and metropolitan water efficiency policies, and particularly the mandatory water conservation during California's most recent drought, have, for an LA Sanitation manager, resulted in a "drastic reduction" of wastewater flows (Interview 2, 2018). These fell by 27%, from about 620 million m^3 in 2005 to 453 million m^3 in the peak drought year of 2016 (LA Sanitation, 2018: 2-4, 2-5). This is a major headache for water agencies. Not only do lower flows jeopardize recycling goals, but pollutants are more concentrated in the smaller volume of incoming wastewater, creating operational challenges. LA Sanitation finds itself in a financial trap: costs per unit of treated water are rising while infrastructure fixed costs remain relatively stable. As sewage fees were not adjusted, revenues have declined and investments must consequently be curtailed given the strict budgetary control of Los Angeles' water agencies. Lower flows thus invoke either politically sensitive rate increases or a decrease in investments.

Institutional arrangements require public servants to preserve a "normality" of designing, operating, and financing water and wastewater infrastructure in line with a supply-driven and growth-oriented management rationale established under Los Angeles' twentieth-century urban growth regime. In contradiction to this rationale, environmentalists push for further conservation of water to be achieved by raising water prices and by irrigating with greywater (laundry and shower water) to decrease flow in sewers (Interview 5, 2018). Hence, LA Sanitation engineers, who generally mistrust homeowners operating greywater systems, have never embraced this technology and are seeking to centralize wastewater flows instead (Interview 6, 2018). Besides efforts to increase the water efficiency of wastewater recycling technology, much has been done to reroute wastewater flows from other parts of the San Fernando Valley and dry-weather urban runoff that previously bypassed Tillman. That runoff is largely from Los Angeles' lush irrigated landscapes that environmentalists criticize as wasteful (Interview 7, 2019). Construction efforts and pumping against gravity to redirect wastewater flows risk building new material and energy inefficiencies into Los Angeles' emerging circular water metabolism.

Overall, by centralizing reduced wastewater flows at Tillman, water agencies seek to maximize infrastructure assets for the production of potable recycled water while minimizing political risk and ensuring managerial control over recycling. At the same time, this technopolitical strategy constrains decentralized wastewater recycling which redistributes responsibilities and could allow a more differentiated wastewater reuse tailored to local purposes. But rationalizing Tillman for wastewater recycling has even wider urban political ramifications. Los Angeles' water agencies are determined to hold back about 25 million cubic meters per annum (25 million m^3/a) of treated wastewater at Tillman that currently sustains the ecosystem of the Los Angeles River (LA Sanitation, 2018: 5–35), which clashes strikingly with revitalization visions for the river.

2.5.2 Circular Los Angeles' contested urban nature: the Los Angeles River

It is difficult to identify any characteristic of the contemporary Los Angeles River that evokes imaginaries of an unimpaired river ecosystem. To protect Los Angeles from flooding, the river channel was largely concretized in the 1930s. Gang activities and pop culture have created a lasting civic imaginary of the bleak flood-control channel as a space of danger and public neglect. Meanwhile, working-class and Latino communities neighboring the river share a long history of contesting this "health-threatening urban landscape" (Gandy, 2014: 177). Not until the mid-1990s did two master plans, one from the US Army Corps of Engineers for flood control and the other from Los Angeles County, bring the river back onto Los Angeles' environmental policy agenda, seeking to revalue the river as a community asset for labor reproduction (Desfor and Keil, 2004). Since 1986, the environmental organization Friends of the Los Angeles River has committed to transforming this "flood-control channel" into a "natural" river habitat (Interview 8, 2018).

Today, the river restoration group's activities are concentrated in the Glendale Narrows north of downtown Los Angeles (see Figure 4), one of the river's rare softbottom stretches that has made its way into the public imaginary: persons arriving at Los Angeles' airport are greeted by a poster of Mayor Garcetti kayaking through the Glendale Narrows and welcoming visitors to Los Angeles "where nature catches you by surprise." Plans by the City of Los Angeles (2007) and private engineering firms (Aecom, 2018) envision the Los Angeles River as a blue-green ribbon with ample flow and lush vegetation catalyzing urban development alongside its downtown riverbanks. Although the riverbed has not yet been touched, public debates have heated up. Neighborhood activists have struggled to fight rising land prices that are fueling neighborhood change in former working-class neighborhoods. Meanwhile, a long-awaited master plan from renowned Los Angeles architect Frank Gehry has sparked further fears – and hopes – of gentrification (Interview 9, 2018).

A view of the Los Angeles River through the lens of wastewater recycling highlights a socio-technical complexity that is glossed over in river revitalization visions. Since 1985, Tillman has been committed to providing 37 million m^3/a treated wastewater to the Los Angeles River, which accounts for a major share of treated wastewater from upstream treatment plants that discharge into the river (Interview 10, 2016). In total, an average of about 140 million m^3 of water currently ripples down the river each year (Mika et al., 2017: 76). Since the construction of Tillman, discharges of treated wastewater and increased urban runoff entering the river through urban development have changed the river's flow regime drastically; flows have more than tripled in volume (ibid.). Whereas prior to urbanization the Los Angeles River regularly dried up in summer, urban runoff and treated wastewater now uphold a continuous flow that has also led to invasive plant species colonizing the riverbed.

FIGURE 4 The Los Angeles River in the Glendale Narrows (photo by Valentin Meilinger, 2018)

Wastewater recycling plans at Tillman imply a radical transformation of this river ecology. Firstly, concentrating wastewater flows at Tillman for recycling strikingly contradicts river revitalization visions that take ample flows in the river for granted. Assuming widespread implementation of stormwater capture infrastructure (less urban runoff entering the river) and the reuse of 100% of the treated wastewater that currently feeds the river, Mika et al. (2017: 49) predict that flows in the river are likely to drop to zero. Los Angeles' neighboring municipalities have already filed petitions to reuse wastewater that currently sustains the river.[9] While protesting the city of Burbank's petition, LADWP managers opted to withdraw about 25 million m³/a wastewater from the river for use at Tillman (Interview 11, 2018). This technopolitical strategy threatens environmentalist desires for a "swimmable, boatable, fishable, bikeable river for all" (Friends of the Los Angeles River, 2020) and urban redevelopment interests that exploit such desires to increase land values. Secondly, wastewater recycling plans are intensifying the modernization of the Los Angeles River. Los Angeles' water agencies have proposed engineering solutions such as rubber dams to sustain the river's present-day ecosystem in some areas while maximizing recycling. But LADWP managers also link flow reductions to a vague narrative of restoring a pre-urbanization habitat: "native plants that *should* be in the river [...] want less water" (emphasis in original) (Interview 3, 2018). They are thus arguing, in line with specific nature conservationist viewpoints, that the "predevelopment condition is what defines the higher environmental use" (The Nature Conservancy, 2016: ES-3). Nonetheless, while environmentalists advocate expanding riparian wetlands for flood control and removing concrete banks (Interview 12, 2018), water agencies plan for a *highly engineered* flow reduction that is driven by the rationale to utilize Tillman's unused treatment capacities for wastewater recycling, but not by imaginaries of riparian ecosystems. In sum, we observe that with wastewater recycling ambitions, the Tillman plant has become a political force in contestations over the Los Angeles River. The collective call from engineers, non-profit organizations and politicians for a scientific study to determine "the proper flow regime for a healthy riparian ecosystem" can be read as an attempt to legitimize future interventions in the river (Interview 3, 2018). However, diverging epistemologies of urban nature obstruct the hopes for scientific truth about a "natural" river ecosystem and call for a political solution to coordinate plans for the river and circular Los Angeles.

2.5.3 Repurposing the Hyperion treatment plant, Los Angeles' "last collector"

Most of Los Angeles' wastewater flows and political debates about recycling gravitate toward the Hyperion treatment plant – sanitary Los Angeles' "last collector" (Interview 13, 2016). After a drought in 1991, LA Sanitation started to convey a small share of Hyperion's treated wastewater to the Edward C. Little Wastewater Recycling Facility in the West Basin Municipal Water District (see Figure 3). This

9 Taking water from open water bodies requires permission from the California State Water Resources Control Board. Glendale's public water utility has applied for permission to reduce discharges to the Los Angeles River by 2 million m³/a. Burbank has filed a petition to reduce discharges by over 4 million m³/a (California State Water Resources Control Board, 2017a; 2017b).

facility seized the early opportunity to buy 48 million m³/a of Hyperion's "surplus water" for an extraordinarily low price, to recycle it for non-potable reuse in nearby oil refineries (Interview 14, 2018).

Although Hyperion has not undergone any larger material changes since then, many environmental organizations, water agencies and politicians are now determined to tap the plant's "river of treated wastewater that pours into the Pacific Ocean" (Boxall, 2019). In early 2019, Mayor Garcetti announced bold plans to fully repurpose Hyperion as a *recycling* facility. Technical upgrades would equip Hyperion with advanced treatment technology for LADWP to use the highly purified water for recharging groundwater. In conversations with city-adjacent water agencies that hold pumping rights and own water distribution networks and groundwater injection wells in the region, selling and pricing mechanisms are negotiated for the retrieved potable water. In total, the estimated project costs amount to $8.1 billion over the next 25 years (LADWP, 2019a).

But sanitary Los Angeles' socio-technical regime holds many uncertainties for Hyperion's future. Firstly, existing gravity-fed sewers complicate change: the conveyance of recycled water to groundwater injection wells further inland from Hyperion entails not only heavy construction but also great pumping efforts and high energy costs due to Hyperion's location at sea level. Reconfiguring Hyperion is thus technically complex, requires huge financial investment and is hampered by the limited space available at the plant.

Secondly, groundwater recharge with recycled water engenders governance challenges due to regionally fragmented groundwater rights. In the 1960s, in response to unsustainable groundwater extraction, strictly restricted pumping rights were adjudicated to a plethora of historical pumpers, from private businesses to water districts (Ostrom, 1990). Complex governance structures that have co-evolved with the construction of a regional water import system (Pincetl et al., 2016) and the urban-political fragmentation of metropolitan Los Angeles (MacKillop and Boudreau, 2008) can only be redesigned in meticulous negotiations – and in parallel with socio-technical change.

Finally, the separate industrial and institutional structures of water and wastewater management in Los Angeles obstruct change. Local tax restrictions in California and strict public control of siloed water and wastewater revenues through Proposition 218 leave little leeway for financing wastewater recycling because the technology lies at the interface of water supply and sanitation financing. At Hyperion, this means that LA Sanitation has no institutional incentive to raise sewer service charges for investments in treatment or recycling technologies that exceed the requirements of the US Clean Water Act. Nonetheless, repurposing Hyperion involves technology managed by LA Sanitation and implies costs for the agency, although only LADWP benefits from selling more recycled water. But since LADWP neither operates the plant itself nor has the expertise to do so, heavy investments in Hyperion involve risks.

Under these conditions, and with most of Los Angeles' wastewater concentrating at the plant, Hyperion is simultaneously a huge barrier to and the key site for creating circular Los Angeles. Wastewater recycling pilot projects at Hyperion become crucial arenas in achieving a circular Los Angeles. An advanced wastewater treatment project to supply Los Angeles' airport with water for non-potable purposes is intended to be preparation for wider technical reconfigurations: "once we perfect that [pilot], we can just expand on that as we move along" (Interview 2, 2018). Despite the current political directive to replenish regional groundwater basins with Hyperion's treated effluent, purification technology is being tested and new regulations are under way to clear the path for direct potable reuse in California. To remove the salts accumulated at Hyperion, any wastewater recycling alternative at the plant will have to highly purify the incoming wastewater. Engineers thus consider it a "waste" to infiltrate recycled water into the ground before using it; once purified, the water could be sold immediately (Interview 3, 2018). Hence, once regulations are in place, LADWP managers are determined to deploy direct potable reuse at Hyperion (Boxall, 2019).

Evolving in parallel, technical and regulatory innovation and political debate about recycling continuously reshape possible wastewater recycling futures in Los Angeles. Although the pilot projects are addressing a negligible part of Hyperion's total operations, they are establishing new operational procedures as well as patterns of financing and selling recycled water. The ultimate goal is to bypass siloed industrial and governance structures and overcome technical challenges. The technical knowledge created allows water agencies to portray the repurposing of Hyperion as the preferable option for enhancing Los Angeles' local water supply, while decentralized wastewater recycling or institutional reforms are averted. The enormous economic and political costs water agencies have invested in Hyperion are the rationale for such a strict focus on the plant. Together with the city council's fear of antagonizing voters by raising rates, this material obduracy defines the parameters, scope, and objectives of realizing visions of wastewater recycling in Los Angeles.

2.6 Engineering circularity on sanitary foundations

Over the last 20 years, engineering and policy discourses on water and wastewater management in Los Angeles have changed fundamentally and presently center on visions of urban water circularity. Nonetheless, material orders of sanitary Los Angeles persist. The configuration of Hyperion as an ocean discharge plant, sewer infrastructures at Tillman and the Los Angeles River's hybrid nature – all massive and capital-intensive artifacts – need to be thoroughly redesigned to engineer a closed water loop. Furthermore, infrastructural change is contingent on existing social orders, especially on entrenched knowledge cultures, separate water and wastewater agencies, the public control of infrastructure tariffs and investments, and a culture of abundant water consumption. Struggles over wastewater recycling take place between the socio-technical orders of sanitary Los Angeles and an emerging technopolitical regime of circular Los Angeles (see Table 1).

TABLE 1 Dimensions of historic technopolitical changes of wastewater in Los Angeles

	Sanitary Los Angeles	Circular Los Angeles
Discourses	Ample water supply through water imports and safe wastewater management through "end-of-pipe" treatment and disposal	Safe wastewater management, local water supply and independence from purchased water imports through recycling of 100% of Los Angeles' wastewater
Technology	Centralized, gravity-fed wastewater disposal system with upstream scalping plants and Hyperion as "last collector"	Closed urban water loop with direct/indirect connections between water supply and treatment
Material flows	Effluent flow regime with neat separation between water and wastewater	Circular flow regime in highly engineered and integrated water metabolism
Epistemic structure	Rationalization of operational processes to manage wastewater flows between point of consumption (toilet flush) to point of centralized disposal	Blurring of epistemic boundaries between water supply and sanitation; new areas of knowledge (e.g., water "purification")
Industrial structure	Siloed regulations, management structures and procedures, revenue streams, and patterns of service provision for water supply (LADWP) and sanitation (LA Sanitation)	New interfaces between water supply and sanitation; painstaking renegotiation of tariffs for purified water and technical reworking of modern sanitary culture
Governance structure	Separate water supply and sanitation agencies: LA Sanitation controlled by city council, LADWP with own board of commissioners and powerful union	Project-by-project collaboration to preempt strong opposition to institutional integration of LA Sanitation and LADWP and lock-in by City Charter
Operational logic	End-of-pipe solution for disposal of wastewater as public bad and to accommodate urban growth	Vision of risk-free and inexhaustible recycling of wastewater as public good to sustain urban growth
Ideas of nature	Modernist separation between nature and society mediated by technology; external nature as resource and sink	Intensified modernization: new forms of separation between society and nature mediated by technology

Tracing ongoing reconfiguration of the gravitational flow of Los Angeles' wastewater, we identified four central technopolitical dimensions that explain how circularity visions materialize in Los Angeles: discourses on wastewater recycling; material obduracy and inherited topologies of water and wastewater infrastructures; local expert knowledge; and persistent institutional arrangements of sanitary Los Angeles.

Firstly, infrastructure reconfigurations are driven by a hegemonic discourse of water circularity that portrays recycled wastewater as Los Angeles' future prime local water supply, allowing the offsetting of purchased water imports. While accepted across the city as a general aspiration, this discourse sustains an emerging technopolitical regime of centralized wastewater recycling. At its heart, recycling pilot projects at the Hyperion plant nourish this discourse, rebranding Hyperion as the central site of circular Los Angeles where a river of unused wastewater can be "tapped." Furthermore, this vision entails a reframing and refutation of hygienic concerns with recycled wastewater in public discourse, achieved through improving recycling technology. At the same time, decentralized solutions for wastewater recycling or greywater reuse remain caught up with hygienic concerns and fail to become part of a rising circular Los Angeles discourse.

Secondly, circular water ambitions are faced with Los Angeles' urban context of centralized, gravity-fed water and sewer networks that were built to cope with a crisis of ocean pollution caused by explosive post-war urbanization. By design, these networks hamper a more distributed reuse of recycled wastewater or greywater in private homes and businesses or on industrial sites. But what also explains the centralized recycling regime is the focus of policies and infrastructural practices for circular Los Angeles on existing treatment plants. At Hyperion, utility managers and political leaders highlight vast unused capacities for wastewater recycling when outlining a future of direct potable water reuse *within* Los Angeles' city limits. While retrofitting Hyperion aims at minimizing the economic risks of regional groundwater recharge, it implies high energy costs for the advanced treatment of recycled water and its redistribution against gravity (Porse et al., 2020). More generally, the technopolitics of fixing water scarcity through wastewater recycling at the "end of the pipe" defer pressing questions about the way water is consumed, managed, and governed in Los Angeles. Water rate increases to finance retrofits of existing technology are justified with techno-economic reasoning: water from centralized recycling plants is expected to be cheaper than purchasing imported water. As a result, such strategies repel the calls of environmentalists for water rates that stimulate water conservation. In the San Fernando Valley, "infrastructure assets" at Tillman enable a technopolitical agenda of concentrating scarce wastewater flows in the plant to produce potable recycled water that creates future revenues for LADWP. Meanwhile, alternative circular water futures through greywater reuse and distributed wastewater recycling are discouraged or actively opposed by LA Sanitation. Equally significant, in the absence of a political initiative that lifts conflicts between wastewater recycling and river revitalization plans to the center of public debate, the shifting technopolitics of wastewater at Tillman become active agents in creating Los Angeles' urban nature.

Thirdly, managing water and wastewater in Los Angeles is organized in separate expert tasks of LADWP and LA Sanitation. In struggles over circular Los

Angeles, this hegemonic knowledge that is built into inherited infrastructure networks encounters other knowledges and diverging epistemologies of urban nature. Nonetheless, entrenched epistemic cultures centered on controllability, safety, and reliability, once established to provide sanitation and ample water for a booming twentieth-century metropolis, continue to guide the actions of Los Angeles' water agencies. Water managers follow those principles to justify their operations and investments to the public. In pilot projects at Hyperion, new technical expertise is also developed that is geared toward treating the water to the highest level to secure revenues. As a result, the political complexities of public infrastructure financing and regional politics are reduced to questions of engineering. Conversely, neither knowledge of decentralized recycling nor the expertise of greywater systems installers is generally being used when framing circular water policies. The technopolitics of incremental innovation thus actively reproduce hierarchies of knowledge that marginalize socio-technical alternatives. Furthermore, centralized recycling takes little account of environmentalists' expertise on the sources of wastewater production and these sources' entanglements with the built environment, lifestyles and economic activities across the city. Instead of preventing entry of certain materials at their source (e.g., micropollutants such as microplastics or pharmaceuticals) and separating highly polluted or toxic wastewater flows for treating them in decentralized plants, circularity initiatives prioritize the mitigation of water scarcity only. Sustaining incumbent expert knowledge in LA Sanitation in operating and retrofitting centralized systems leaves inherited urban geographies of wastewater in place. Finally, whereas since the 1990s revitalization discourses have "downplayed the artificiality of the […] river" (Gandy, 2014: 181), wastewater recycling ambitions strikingly expose this artificiality. But vague revitalization debates disregard the river's hybrid nature and many controversies over the river play out at the level of technical flow reconfigurations. Uncovering epistemological differences and digging into the river's artificiality thus help to critically analyze interventions of urban developers, environmental organizations, politicians, and LA's water agencies, all of which claim to act in the name of ecological restoration and the wider public interest.

Fourthly, practices of Los Angeles' water agencies to incrementally innovate wastewater recycling at the "end of the pipe" have become the dominant rationale and political force for realigning water, wastewater and urban life in a circular water metabolism. These particular practices are rooted in persisting institutional orders of sanitary Los Angeles. LADWP decides on investments and technical interventions according to cost-efficiency goals for a safe, abundant and affordable water supply. LA Sanitation has traditionally considered wastewater to be a cost item, not a potential source of revenue. Although wastewater recycling distorts the cost-benefit patterns of LADWP and LA Sanitation, both agencies and LADWP's labor union fiercely oppose any attempt at institutional integration, which would also require an amendment to Los Angeles' city charter (Interview 1, 2018). Nonetheless, as revenue-dependent industries and with a strict public control of tariffs, both agencies seek to minimize risks. Incremental innovation practices thus help secure revenue streams for Los Angeles' siloed water agencies in circular water futures, thereby sustaining an institutional set-up that seems increasingly dysfunctional in a circular city. Utility managers justify such incremental innovation solely with hegemonic techno-economic reasoning of mediating water scarcity. Yet this reasoning downplays an inherited consensus on low water prices and vested institutional interests that are inseparable from ongoing engineering interventions. Conversely, environmentalists' interests in the Los Angeles River or their demands for locally more differentiated wastewater recycling fail to be widely accepted as hegemonic infrastructural practices in an emerging circular Los Angeles.

2.7 Conclusion

Wastewater recycling in California has seen an immense advance since the state's most recent drought (2011–16). Aiming to repurpose its modern sewage plants for wastewater recycling, Los Angeles joins the ranks of many dry cities around the world that are mobilizing circular economy discourses and embracing large-scale engineering projects to enhance local water supplies. This article has analyzed struggles over reconfiguring wastewater flows to create a city in which water is reused in a locally more circular water metabolism – the envisioned circular Los Angeles. To expose the distributed agencies involved in this urban reconfiguration process, we have applied to the city the concept of technopolitics that locates power in hybrids of technology and political practice. In particular, the notion of urban technopolitical regimes, which we have applied here to circular Los Angeles, can bring attention to how the politics of the urban metabolism are co-constituted through infrastructural practices. Thus, technopolitical regimes form nodes of power in the urban metabolism that have their own inner workings that result from context-specific practices shaped by technical artifacts, discourses, institutions, and knowledge.

Public engineers in Los Angeles are retrofitting existing technology to promote wastewater recycling as a sustainability fix for urban water scarcity. Obdurate technical artifacts, together with entrenched expert cultures and a rigid public control of water and sewage tariffs, explain the creation of circular Los Angeles at the "end of the pipe." These technopolitics of incremental innovation reduce political questions about how water is consumed, managed, and publicly governed in Los Angeles to technical problems addressed by path-dependent engineering practices. As a result, other possibilities for urban metabolic transformation, such as water saving, decentralized wastewater recycling, greywater reuse or energy recovery from wastewater, are marginalized. Similarly, conflicts over flows in the Los Angeles River associated with shifting technopolitics of wastewater are rarely subjected to open political debate on how to better align plans for the river restoration and for circular Los Angeles. Overall, we argue that considerable socio-technical change toward wastewater recycling and reuse is taking place in Los Angeles. However, this change projects the inherited technopolitical orders and geographies of water supply and wastewater management into the future through additive technologies and institutional arrangements. Understanding how trajectories of infrastructure change are achieved through technopolitics and with what effects advances debates about urban technology and infrastructure, urban environmental politics and the politics of urban space in three ways.

Firstly, infrastructural artifacts act as urban metabolic mediators that both enable and are shaped by distinct technopolitical strategies. This article shows how the material obduracy of technical artifacts and political practices oriented toward these artifacts can narrow the political pathways of metabolic change despite radically altered imaginaries of the "circular city". Adding to concepts in urban political ecology, this finding underscores the political relevance of distinct technical characteristics of infrastructural artifacts that are foregrounded in political decisions about urban metabolic change. In this way, urban technopolitical regimes expand or secure influence over urban nature and space. In addition, centralized wastewater recycling in Los Angeles has geographically extensive energy and material footprints, which demonstrates how urban technopolitical regimes wield power over metabolic processes beyond city boundaries (Connolly, 2019).

Secondly, the Los Angeles case suggests that technopolitical power emanating from dynamic entanglements between expertise and technical artifacts shapes urban metabolic change. Here knowledge hierarchies are frequently rooted in technical artifacts of past urbanization. This might partly explain why hegemonic technomanagerial forms of urban environmental governance have persisted, as discussed by urban political ecologists (Karvonen, 2011). As inherited artifacts become key foci of novel environmental policy and infrastructural reconfigurations, alternative knowledges may rarely achieve the status of "expertise" in aspired urban circular futures. Thus, urban futures contingent on alternative knowledge are stymied. Technical concepts of circular resource management that are realized in entrenched knowledge regimes of urban infrastructures therefore need to be scrutinized as emerging forms of governing urban nature and space.

Finally, applying to the city Hecht's (2009) emphasis on technopolitical regimes as "grounded" in institutions can help politicize what is considered "normal" urban infrastructural and related urban metabolic change. This perspective can draw the focus to how institutionalized political economies of urban infrastructures come into being through political practices oriented toward technology. We have highlighted the fundamentally more complex form of an emerging circular Los Angeles through which institutional orders of a tax-constrained public infrastructure financing in California are preserved. Beyond Los Angeles, scrutinizing the technopolitics of large-scale engineering can thus enrich critical urban studies of political economies of urban infrastructure. Adding to a nascent critical scholarship on circular cities, we argue that an urban technopolitics lens helps reveal how circular city imaginaries and discourses matter politically and how they are actually translated into urban and infrastructural practices. Such a research agenda examines how a technology-led revalorization of waste to fix resource scarcity and environmental pollution gives rise to technopolitical regimes that become powerful governing forces of urban space.

2.8 References

Aecom 2018. LA River gateway. Accessed April 20, 2019. https://imagine.aecom.com/larivergateway/

Arup, Antea Group and Ellen MacArthur Foundation 2018. Water and circular economy: a white paper. Accessed April 10, 2020. https://nextgenwater.eu/wp-content/uploads/2018/10/Water_and_circular_economy-Co.Project_White_paper.pdf

Bichai, F., A.K. Grindle and S.L. Murthy 2018. Addressing barriers in the water-recycling innovation system to reach water security in arid countries. *Journal of Cleaner Production* 171 (January), 97–109.

Björkman, L. and A. Harris 2018. Engineering cities: mediating materialities, infrastructural imaginaries and shifting regimes of urban expertise. *International Journal of Urban and Regional Research* 42(2): 244–62.

Boxall, B. 2019. LA's ambitious goal: recycle all of the city's sewage into drinkable water. *Los Angeles Times*, 22 February. Accessed March 16, 2019. https://www.latimes.com/local/lanow/la-me-water-recycling-los-angeles-20190222-story.html

California State Water Resources Control Board 2017a. Notice of wastewater change petition WW0091. Accessed July 7, 2018. https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/petitions/2017/ww0091_not.pdf

California State Water Resources Control Board 2017b. Notice of wastewater change petition WW0097. Accessed July 5, 2018. https://www.waterboards.ca.gov/waterrights/water_issues/programs/applications/wastewater_petition_orders/docs/ww0097_order.pdf

California State Water Resources Control Board 2019. A proposed framework for regulating direct potable reuse in California. Second edition. Accessed April 20, 2020 https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/direct_potable_reuse/direct_potable_reuse.html

Callon, M. 2009. Foreword. In G. Hecht, The radiance of France: nuclear power and national identity after World War II. MIT Press, Cambridge.
City of Los Angeles 2007. Los Angeles River revitalization master plan. Accessed August 15, 2019. http://clkrep.lacity.org/onlinedocs/2006/06-0186_rpt_misc_4-23-07.pdf
City of Los Angeles 2019. LADWP water supply in acre feet. Accessed March 16, 2019. https://data.lacity.org/ALivable-and-Sustainable-City/LADWP-Water-Supply-in-Acre-Feet/qyvz-diiw/data
Connolly, C. 2019. Urban political ecology beyond methodological cityism. *International Journal of Urban and Regional Research* 43(1): 63–75.
Cotruvo, J.A. 2016. Potable water reuse history and a new framework for decision making. *International Journal of Water Resources Development* 32(4): 503–13.
Cousins, J.J. 2020. Malleable infrastructures: crisis and the engineering of political ecologies in Southern California. *Environment and Planning E: Nature and Space* 3.3: 927–49.
Coutard, O. and J. Rutherford 2016. Beyond the networked city: an introduction. In O. Coutard and J. Rutherford (eds.), Beyond the networked city: infrastructure reconfigurations and urban change in the North and South. Studies in Urbanism and the City. Routledge, London. 1-25.
Davis, M. 1998. Ecology of fear: Los Angeles and the imagination of disaster. Macmillan, New York.
Davis, M. 2006. City of quartz: excavating the future in Los Angeles. Verso, London.
Desfor, G. and R. Keil 2004. Nature and the city: making environmental policy in Toronto and Los Angeles. University of Arizona Press, Tucson.
Erie, S.P. and H.D. Brackman 2006. Beyond Chinatown: the metropolitan water district, growth, and the environment in Southern California. Stanford University Press, Stanford.
Foley, R., T. Kalinowski and I. Bennett 2020. From public engagement to research intervention: analyzing processes and exploring outcomes in urban technopolitics. *Science as Culture* 29(3): 319–44.
Foucault, M. 1982. The subject and power. In H.L. Dreyfus and P. Rabinow (eds.), Michel Foucault: beyond structuralism and hermeneutics, University of Chicago Press, Chicago.
Friends of the Los Angeles River 2020. The great LA River cleanup 2020. La gran limpieza. Accessed September 7, 2020. https://folar.org/wp-content/uploads/2020/02/CU2020-SponsorPacket.pdf
Gandy, M. 2004. Rethinking urban metabolism: water, space and the modern city. *City* 8(3): 363–79.
Gandy, M. 2014. The fabric of space: water, modernity, and the urban imagination. MIT Press, Cambridge.

Garcetti, E. 2019. Mayor Garcetti: Los Angeles will recycle 100% of city's wastewater by 2035. Accessed November 7, 2019. https://www.lamayor.org/mayor-garcettilos-angeles-will-recycle-100-city%E2%80%99swastewater-2035

Ghisellini, P., C. Cialani and S. Ulgiati 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production* 114 (February), 11–32.

Goh, K. 2019. Urban waterscapes: the hydro-politics of flooding in a sinking city. *International Journal of Urban and Regional Research* 43(2): 250–72.

Gopakumar, G. 2020. Regime of congestion: technopolitics of mobility and inequality in Bengaluru, India. *Science as Culture* 29(3): 345–64.

Hajer, M.A. 1995. The politics of environmental discourse: ecological modernization and the policy process. Oxford University Press, Oxford.

Hecht, G. 2009. The radiance of France: nuclear power and national identity after World War II. Foreword by Michel Callon and a new afterword by the author, MIT Press, Cambridge.

Heynen, N., M. Kaika and E. Swyngedouw 2006. In the nature of cities: urban political ecology and the politics of urban metabolism. Routledge, London.

Hoffmann, S., U. Feldmann, P.M. Bach, et al. 2020. A research agenda for the future of urban water management: exploring the potential of non-grid, small-grid, and hybrid solutions. *Environmental Science & Technology* 54(9): 5312–22.

Hughes, S. 2013. Authority structures and service reform in multilevel urban governance: the case of wastewater recycling in California and Australia. *Urban Affairs Review* 49(3): 381–407.

Hughes, S., S. Pincetl and S. Boone 2013. Triple exposure: regulatory, climatic, and political drivers of water management changes in the city of Los Angeles. *Cities* 32 (June), 51–59.

Hughes, T.P. 1983. Networks of power: electrification in Western society, 1880–1930. Johns Hopkins University Press, Baltimore.

Kahrl, W.L. 1983. Water and power: the conflict over Los Angeles' water supply in the Owens Valley. University of California Press, Berkeley.

Kaika, M. and E. Swyngedouw 2000. Fetishizing the modern city: the phantasmagoria of urban technological networks. *International Journal of Urban and Regional Research* 24(1): 120–38.

Karvonen, A. 2011. Politics of urban runoff: nature, technology, and the sustainable city. MIT Press, Cambridge.

Kębłowski, W., D. Lambert and D. Bassens 2020. Circular economy and the city: an urban political economy agenda. *Culture and Organization* 26(2): 142–58.

Kirkpatrick, L.O. and M.P. Smith 2011. The infrastructural limits to growth: rethinking the urban growth machine in times of fiscal crisis. *International Journal of Urban and Regional Research* 35(3): 477–503.

LADWP 2012. Recycled water master planning. Executive summary. Los Angeles.
LADWP 2015. Urban water management plan. Los Angeles.
LADWP 2019a. Hyperion reuse and groundwater development program. Presentation at LADWP Board of Commissioners, Los Angeles, 26 February 2019.
LADWP 2019b. Recycled water annual report 2018/19. Los Angeles.
LA Sanitation 2018. One Water LA 2040 plan: wastewater facilities plan. City of Los Angeles. Los Angeles.
MacKillop, F. and J-A. Boudreau 2008. Water and power networks and urban fragmentation in Los Angeles: rethinking assumed mechanisms. *Geoforum* 39(6): 1833–42.
Melosi, M. 2008. The sanitary city: environmental services in urban America from colonial times to the present. University of Pittsburgh Press, Pittsburgh.
Mika, K., E. Gallo, L. Read, R. Edgley, K. Truong, T. Hogue, S. Pincetl and M. Gold 2017. LA sustainable water project: Los Angeles River watershed. Accessed May 1, 2020. https://escholarship.org/content/qt42m433ps/qt42m433ps.pdf?t=owhdri
Mitchell, T. 2002. Rule of experts: Egypt, techno-politics, modernity. University of California Press, Berkeley.
Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A: Economy and* Space 41(8): 1924–42.
Ostrom, E. 1990. Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge.
Pincetl, S. 2010. From the sanitary city to the sustainable city: challenges to institutionalising biogenic (nature's services) infrastructure. *Local Environment* 15(1): 43–58.
Pincetl, S., E. Porse and D. Cheng 2016. Fragmented flows: water supply in Los Angeles County. *Environmental Management* 58(2): 208–22.
Porse, E., K.B. Mika, A. Escriva-Bou, et al. 2020. Energy use for urban water management by utilities and households in Los Angeles. *Environmental Research Communications* 2(1): 015003.
Reisner, M. 1993. Cadillac desert: the American West and its disappearing water. Penguin, New York.
Savini, F. 2019. The economy that runs on waste: accumulation in the circular city. *Journal of Environmental Policy & Planning* 21(6): 675–91.
Sklar, A. 2008. Brown acres: an intimate history of the Los Angeles sewers. Angel City Press, Los Angeles.
Soja, E. 2014. My Los Angeles: from urban restructuring to regional urbanization. University of California Press, Berkeley.
Swyngedouw, E. 2004. Social power and the urbanization of water: flows of power. Oxford University Press, Oxford.

The Nature Conservancy 2016. Water supply and habitat resiliency for a future Los Angeles River. Accessed March 2, 2020. https://www.scienceforconservation.org/assets/downloads/TNC-LARiver-Study-2016.pdf

Tiwale, S. 2019. Materiality matters: revealing how inequities are conceived and sustained in the networked water infrastructure: the case of Lilongwe, Malawi. *Geoforum* 107(December), 168–78.

Varnelis, K. (ed.) 2009. The infrastructural city: networked ecologies in Los Angeles. Actar, Barcelona.

Williams, J. 2019. Circular cities. *Urban Studies* 5(13): 2746–62.

2.9 Cited interviews

1. Water policy expert, University of California, Los Angeles, 2 March 2018.
2. Treatment plant manager, LA Sanitation, Los Angeles, 21 February 2018.
3. Wastewater recycling manager, LADWP, Los Angeles, 8 February 2018.
4. Member, Lake Balboa Neighborhood Council, Los Angeles, 30 March 2016.
5. Greywater reuse activist, Los Angeles, 5 March 2018.
6. Wastewater recycling manager, LA Sanitation, Los Angeles, 13 March 2018.
7. Environmental activist and horticultural expert, Los Angeles, 13 March 2019.
8. Environmental activist, Friends of the Los Angeles River, Los Angeles, 30 January 2018.
9. Social justice activist, Elysian Valley Neighborhood Council, Los Angeles, 2 April 2018.
10. Treatment plant manager, LA Sanitation, Los Angeles, 30 March 2016.
11. Wastewater recycling manager LADWP, Los Angeles, 2 March 2018.
12. Leader, environmental non-profit, Los Angeles, 7 February 2018.
13. Wastewater recycling manager, LADWP, Los Angeles, 22 March 2016.
14. Treatment plant manager, West Basin Municipal Water District, Los Angeles, 22 February 2018.

3

THE MATERIAL POLITICS OF INTEGRATED URBAN STORMWATER MANAGEMENT IN LOS ANGELES, CALIFORNIA

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ABSTRACT

Cities worldwide have embraced the idea of integrated stormwater management using more decentralized and green infrastructures to enhance urban sustainability. Los Angeles County has recently introduced a new stormwater tax that envisions achieving sustainable stormwater futures through far-reaching infrastructural change. While embracing such visions, however, different actors seek to use tax revenues for diverging infrastructure designs. Our paper therefore explores shifting stormwater politics in Los Angeles by highlighting the social relations underlying technology. Technical disputes that we frame as combinations of material artifacts, discourses, expertise and institutions provoke the specific "material politics" behind the emergence of a hybrid stormwater system in which centralized stormwater practices of incumbent public utilities predominate but increasingly co-exist with more decentralized landscape-centered practices and become interdependent on them. We argue that technical disputes reflect ambiguities about a future stormwater system and engender the renegotiation of responsibility, knowledge orders, and the overall rationale of stormwater management. An inherited focus on controlling stormwater volumes thwarts attempts to couple stormwater and urban greening improvements more tightly. We conclude by emphasizing that infrastructures are relational systems that carry many potential stormwater futures and by outlining ways to better align stormwater management with wider urban sustainability objectives.

3.1 Introduction

Stormwater pollution has been a longstanding environmental concern in Los Angeles and poses a major challenge for the city's Bureau of Sanitation (hereafter: LA Sanitation). During California's 2011–2016 drought, a large coalition of environmental policy stakeholders reframed stormwater as a new source of local water supply. In 2018, voters approved the Safe, Clean Water Program,[10] a parcel tax on stormwater that makes about $300 million available annually and has conjured up visions of combining stormwater improvements with changes in urban landscaping.

Stormwater management in US cities is shaped by a drainage efficiency approach that focuses on rapid stormwater discharge through centralized infrastructures but that experts agree needs drastic reform (Karvonen, 2011). Besides polluting open waters, modern drainage networks deprive cities of stormwater as a resource and have ecologically and imaginatively separated urban landscapes from stormwater. Integrated urban stormwater management aims to combine flood control with water conservation, pollution prevention and ecological restoration to foster urban sustainability (Brown, 2005). Environmental scholars argue that centralized and decentralized stormwater technologies can be fruitfully combined to realize integrated stormwater management (Wong and Brown, 2009). "Green infrastructures" are considered promising vehicles to achieve this. By utilizing and mimicking natural processes of the soil and vegetation, permeable surfaces, and specific forms of landscaping to promote stormwater infiltration, green stormwater infrastructures couple stormwater with urban ecosystem and health improvements (Keeley et al., 2013). While decentralized and green infrastructures are considered key solutions for tackling stormwater challenges, their slow diffusion is often attributed to institutional problems of fragmented responsibility and lack of knowledge and data (Brown et al., 2013). When explaining cities' sustainability shortcomings, urban political ecologists have emphasized the uneven power relations underlying urban stormwater. For instance, although environmental discourses frame stormwater as an opportunity for urban sustainability, bureaucratic strategies frequently make stormwater management an expert task to strengthen technocratic organizations (Finewood, 2016; Cousins, 2017). However, less attention has been paid to the social relations that underlie technology and influence the realization of integrated stormwater approaches and urban stormwater politics. We argue that to better understand the urban politics of sustainable stormwater management and the urban environment they create, it is vital to explore how policy visions and their implementation processes are shaped by technical disputes about infrastructure design, and vice versa.

10 Although the program was approved for Los Angeles County, this paper focuses on the city of Los Angeles, the largest city in the county and the program's main beneficiary.

In this paper, we trace how actors seek to use Safe, Clean Water Program funds to achieve their own visions of integrated stormwater management by connecting centralized and decentralized stormwater technologies in particular ways. To explain the "material politics" (Rutherford, 2020) of urban stormwater that result from infrastructural change, we analyze how certain infrastructural practices come to dominate technical disputes about stormwater restructuring. Technology is conceptualized as a contested site where actors pursue distinct political objectives of environmental governance. By framing infrastructure as a relational system of diverse social and material elements (Star and Ruhleder, 1996), we highlight how alternative stormwater politics emerge in the interstices of dominant infrastructural practices.

After outlining our conceptual framework, we introduce stormwater governance in US cities in section 3.3. Section 3.4 discusses the Safe, Clean Water Program within Los Angeles' history of public infrastructure provision. Section 3.5 analyses distinctive infrastructure reconfigurations at three sites. Firstly, we show how public utilities seek to create a centralized infrastructure system that rationalizes stormwater improvement. Secondly, we describe the plans and hurdles associated with repurposing streets into semi-centralized stormwater technologies. Thirdly, we explain why environmental groups' aspirations to use Safe, Clean Water Program funds for stormwater retrofits on private parcels are not meeting expectations. Section 3.6 portrays the interplay between dominant stormwater practices of public engineers and alternative practices. Beyond mere path dependency, Los Angeles' increasingly "hybrid" stormwater system is marked by the diversifying roles of actors, knowledge orders and systemic rationales of stormwater management. In conclusion, we suggest two areas of reform: firstly, specifying green infrastructure requirements in water quality regulation and water supply missions can enhance the sustainability of practices that focus on controlling large volumes of stormwater; secondly, notions of efficiency underlying volumetric stormwater management should be overhauled by including green infrastructure requirements in stormwater funding criteria. These reforms may help create a skilled landscape-oriented workforce and foster collaboration in stormwater governance. Conceptually, we argue that studying technical infrastructure controversies is a fruitful way to reveal ambiguities about urban stormwater politics.

This study draws from empirical research in Los Angeles in 2018 and 2019, during which we conducted 54 semi-structured interviews with public engineers, politicians, environmental groups, landscaping experts and other relevant actors. We also scrutinized relevant newspaper articles, policy documents and legal texts, as well as technical and planning documents. Following our theoretical framework, we analyzed nuances, conditions and causes of actors' technical choices to reconfigure urban stormwater in relation to shifts and continuities in material orders, discourses, knowledge and institutions of stormwater governance. We refined these categories in an iterative process, using qualitative content analysis. This allowed us to explain how particular stormwater practices have come to dominate stormwater restructuring by interrelating: (i) actors' strategies for using Safe, Clean Water Program funds for specific infrastructure designs, (ii) social and technical characteristics of different stormwater technologies, (iii) socio-technical orders of Los Angeles' stormwater regime, (iv) actor-specific visions of integrated stormwater management, and (v) stormwater policies and the design of the Safe, Clean Water Program.

3.2 Material politics and practices of infrastructural change

Although infrastructures are less explicitly addressed in debates on urban stormwater governance, social studies of technology consider them to be vital facilitators of modern life that are inherently political. Coutard and Rutherford (2016: 13) have framed urban infrastructures as relational systems of heterogeneous social and material elements which work together toward certain objectives and outcomes. Over time, social and material components condense into localized "urban configurations of institutions, techniques, and artifacts" that can be called "urban infrastructure regimes" (Monstadt, 2009: 1937). New infrastructure visions have to wrestle with closely intertwined regime elements and embedded social interests. Nonetheless, infrastructure is never thoroughly programmed but relies on often contingent interactions of multiple actors and artifacts (Star and Ruhleder, 1996). Moss (2020) has described historical infrastructure development as non-linear and multi-layered, marked by "conjunctions of continuity and change." The interplay of stability and change can also be examined by tracing how actors reconfigure infrastructure artifacts to influence change. Giving rise to powerful "material politics", artifacts form sites where the political possibilities for infrastructure development are disputed (Rutherford, 2020).

We argue that analyzing urban stormwater politics through technical infrastructure controversies is particularly relevant, given recent dynamics in environmental policy. Technical concepts such as "green infrastructures" or "circular cities" are increasingly shaping how cities are reimagined and modernized, which calls for critical study of the social processes underlying technology that influence policy visions and their implementation through infrastructural renewal. Inspired by research on political action through technology, we explore material politics of urban stormwater by tracing how actors engage with and appropriate infrastructure artifacts. Actors can transform the material environment by practices of engineering or design (Björkman and Harris, 2018). But practices of creating knowledge about material artifacts and inventing the stories attached to these artifacts can also influence infrastructure development (Bowker, 1994). Infrastructures rely on a multiplicity of such practices of engaging with their material artifacts, which here we call infrastructural practices. In this article we seek to understand urban stormwater politics through the interplay of dominant and alternative infrastructural practices in translating policy visions into new infrastructure constellations.

This interplay can be explained by four interdependent variables. Firstly, infrastructural practices shape infrastructure development via the material artifacts they address. The obduracy of *material artifacts* or their compatibility with other material arrangements can enable or constrain specific infrastructural practices, thereby narrowing the possibilities for realizing policy visions. But by tinkering with, expanding or upgrading infrastructure networks, non-experts can also introduce new rationales of service provision and environmental management (Truelove, 2019). Environmental discourses co-evolve with material change. Gandy (2014) has illustrated how a discourse on the technological mastery of nature has underpinned the installation of vast water infrastructures in modern cities. Powerful *environmental discourses* are thus a second dimension that explains why certain infrastructural practices become prevalent. Today, green infrastructures promote visions of sustainable urban stormwater management. Yet ideas of how such management might be implemented, and to what social and environmental ends, often strikingly diverge. Inherited infrastructural practices might simply be reframed as "green", thereby marginalizing alternatives (Finewood, 2016). Nonetheless, landscape-centered stormwater practices have given rise to a discourse on multi-benefit infrastructures that incumbent actors can no longer ignore. Thirdly, the weight of particular infrastructural practices in shaping stormwater futures hinges on *knowledge hierarchies*. Obdurate infrastructure artifacts often underpin a dominance of engineering expertise in stormwater governance. But whereas engineers draw much power from portraying their actions as particularly effective and reliable, highly engineered infrastructure often has a large material footprint and limited co-benefits. Meanwhile, green infrastructure and landscape engineering approaches mobilize plants or soil – that have their own histories of practice and knowledge – to develop infrastructures. Practically demonstrating the benefits of green infrastructures can help reform the knowledge hierarchies specific to engineering, ecological and horticultural practices. Finally, dominant infrastructural practices are closely aligned with entrenched *institutions* such as norms, regulations or standards. But when new technologies are introduced, the interactions between actors may shift, the vocabulary of interaction may change, or new routines may emerge (Bijker, 1995: 265). Green infrastructures establish new interfaces between material artifacts and social actors that can challenge existing institutional arrangements. We can thus uncover how infrastructural practices linked to artifacts that have hitherto played a passive role in stormwater management might provoke new institutional orders in environmental governance.

Overall, we argue that tracing the infrastructural practices through which environmental policy visions become realized will reveal technical and political contestations about urban stormwater futures. Certain combinations of material artifacts, discourses, knowledges, and institutions can explain how specific infrastructural practices become dominant and shape urban stormwater restructuring. Our conceptual framework thus foregrounds technology as an arena where urban environmental politics are negotiated, rather than reading technology as a passive vehicle of policy implementation. While underlining the usefulness of thinking in terms of dominant infrastructural practices, we also argue that such dominance can never be absolute since "infrastructures are shaped by, yet also exceed the intentions of their builders" (Carse, 2012: 543). Infrastructural development thus unfolds as a contingent and multi-layered process, and alternative infrastructural practices can harbor novel environmental politics.

3.3 Stormwater management in US cities

In the nineteenth century, engineers started to construct centralized sewer networks to sanitize industrializing US cities and to protect them from floods (Melosi, 2008). Public investments through Progressive Era reforms drove infrastructure expansion managed by powerful public bureaucracies. In the twentieth century, gravity-fed separate sewer systems for sewage and stormwater replaced combined systems. Simultaneously, water expertise became increasingly differentiated, with separate agencies emerging for flood control, water supply and wastewater. By framing water as a technological problem, engineers established themselves as key figures in water governance (Carroll, 2012). But although hydraulic engineering largely relegated stormwater to the background of land development, landscape design and everyday urban life, this approach was never uncontested or absolute (Karvonen, 2011).

The rapid urbanization and extension of stormwater networks after World War II caused a pollution crisis at the "end of the pipe." Flagged by nascent environmental sciences and environmental movements, the control of polluted urban runoff from dispersed "nonpoint sources" became a growing concern. In 1972, the US Clean Water Act, which defines surface water emission limits and quality standards, came into force. The National Pollutant Discharge Elimination System from 1987 set water quality standards for municipal stormwater programs (Karvonen, 2011: 9). Since then, pollution challenges and plans to use stormwater as a water resource have led to the emergence of diverse stormwater technologies. *Decentralized* bioswales, porous pavements or rain gardens, *semi-centralized* detention ponds and green streets, as well as centralized conveyance networks, spreading basins or wetlands can all be combined in "hybrid" stormwater infrastructures (Porse, 2013). *Centralized* stormwater infrastructure is the domain of public sanitation and flood control agencies that operate large technical facilities.

This frequently called “grey” infrastructure approach is applied by engineers and a workforce trained to manage pumps, pipes or concrete channels but not landscape ecosystems.

Integrated stormwater management concepts promote more decentralized and so-called “green” infrastructures. Such infrastructures utilize and mimic natural landscape functions to foster sustainability and livability, making significant changes to existing urban landscapes and environmental management practices. Cutting across sectoral tasks, these technologies call for more collaboration among the wastewater, planning, parks, environment and transportation departments that oversee green areas alongside streets. Furthermore, green infrastructure is “in full sight [...] and takes up real physical space” (Pincetl, 2010: 47), hence it demands spatially sensitive and landscape-oriented infrastructure planning. Lennon (2015) notes that the ecological benefits of green infrastructures need to be constantly articulated by a broad coalition of stakeholders in order to reform technocratic environmental management practices.

Green infrastructures may contain engineered components but compared to grey infrastructure they rely more on biological processes of the soil and vegetation and require combined expertise in engineering, ecology and landscape design. Good examples are the semi-centralized green streets in which street improvements capture runoff and infiltrate it through bioswales or planted depressions in the landscape. However, maintenance needs to be fairly frequent to avoid debris and dead planting material clogging up infiltration systems. While green infrastructures can perform well in stormwater retention and infiltration as well as in nutrient removal, their long-term removal of heavy metals remains uncertain and varies across catchment areas (Al-Ameri et al., 2018). Decentralized green infrastructures are particularly promoted by Low-Impact Development (LID) that aims to capture, infiltrate, and reuse stormwater at the source. Appropriate green infrastructure types need to be located and scaled, depending on factors such as land availability, infiltration options or pollutant sources, and this process requires careful analysis. US municipalities started to pilot LID in the early 1990s, also considering sharing responsibility for stormwater management with private property owners (Sedlak, 2014: 131). Technically, decentralized infrastructures are considered to complement centralized stormwater networks (Wong and Brown, 2009), but their combination raises complex socio-technical questions, and decentralization faces different impediments – for example, decision-making on land use and infrastructure investment is scattered across various public agencies which have “no authority to control stormwater from a private property” (Dhakal and Chevalier, 2016: 1115). Moreover, green infrastructures require skilled labor to design, build and maintain landscape ecosystems. Finally, faced with a lack of data on green infrastructure’s long-term pollutant removal benefits and given the challenges of monitoring and controlling emissions from distributed stormwater infrastructures, public agencies tend to be skeptical of these infrastructures’ worth. Several authors (Brown et al., 2013; Fitzgerald and Laufer, 2017) have suggested addressing institutional hurdles to integrated stormwater management through experimentation, stakeholder collaboration and institutional reform: for instance, through integrating accounting for multiple infrastructure benefits.

Below, we explore the implications of technical disputes over infrastructure reconfigurations for stormwater governance in Los Angeles.

3.4 A stormwater tax for Los Angeles

Los Angeles' urban growth history tells a vivid story of science and engineering endeavors to control stormwater. Founded in 1914, the Los Angeles County Flood Control District initiated an era of technocratic flood control by constructing large peri-urban dams, stormwater channels and spreading grounds to protect settlements (Orsi, 2004: 13). The decision to boost urban development through tax-financed infrastructure had rejected zoning and nature-based stormwater solutions (Gandy, 2014: 152).

In the post-war era, rapid stormwater discharge increasingly polluted the Santa Monica Bay, sparking a growing environmental movement. Los Angeles' first stormwater system permit in 1990 defined Total Maximum Daily Loads for pollutants, confronting LA Sanitation with daunting stormwater challenges. The urgency to reduce pollution rapidly and cost-efficiently drove centralized end-of-pipe solutions. A stormwater permit renewal in 2012 aimed to combine water quality, water supply, and flood control improvements. In new Enhanced Watershed Management Plans, pollution reduction scenarios for regulatory compliance were outlined. However, the total infrastructure investment costs for compliance in Los Angeles were estimated at $7.4 billion, causing the city to face a "dramatic" deficiency of public funds (LA Sanitation, 2018: ES-21, –25). Stricter pollution regulation since the 1990s has exacerbated stormwater funding requirements. But this dire financial situation also needs to be understood in the context of California's Proposition 13 (1978), which slashed municipal budgets through local property tax cuts. Moreover, Proposition 218 (1996) requires a majority voter approval when cities implement new or raise stormwater fees. This was specified in a far-reaching court decision (Howard Jarvis Taxpayers Association v. City of Salinas, 2002) on the previously vaguely defined term "sewer" in the legislation. Only in 2017, California's Senate Bill 231 revised the term "sewer" in the implementation act of Proposition 218 to exempt stormwater fees from the voter approval requirement, which had already applied to wastewater fees. Nonetheless, fearing expensive lawsuits, municipalities are hesitant to make use of this legal reform to raise stormwater fees. Furthermore, public stormwater investments might have been thwarted because stormwater was historically managed as a hazard, not as a commodifiable resource. The $500 million stormwater bond Proposition O (2004) could only provide temporary relief and included no funding for infrastructure maintenance (Park et al., 2009). In 2011, the city of Los Angeles enacted a Low-Impact Development Ordinance that prescribed stormwater improvements on private property for new development and substantial redevelopment.

In 2015, the Los Angeles Department of Water and Power (LADWP) released its first Stormwater Capture Master Plan, which proposes centralized and distributed infrastructure projects to increase stormwater capture for local water supply. Historically, water imports have diminished reliance on pumping local groundwater replenished by infiltrated stormwater. Urban development has significantly reduced infiltration, while in some aquifers, groundwater is polluted and requires treatment (Porse et al., 2016).

The approval of the Safe, Clean Water Program needs to be understood against this backdrop of scarce public funds and inherited twentieth-century infrastructure vis-à-vis bold political objectives and strong regulatory pressure. Voter approval has been fostered by a public discourse that reframes stormwater as a resource and as an opportunity for urban greening and environmental justice. Collecting taxes across Los Angeles County based upon a parcel's impermeable area, the Safe, Clean Water Program is divided into a Municipal Program and a Regional Program. Of the total annual revenue, 10% is used to administer the tax, 40% is directly returned to municipalities, and 50% goes to the Regional Program that redistributes revenue across Los Angeles County's nine watersheds in proportion to their contribution. A steering committee for each watershed selects stormwater projects. The project proposals are first assessed by a scoring committee, for whom the most important rating criterion is the volume of stormwater captured, but projects also receive better ratings by providing community benefits such as access to green space or habitat creation. Multi-benefit infrastructure is defined as providing both (i) a water quality benefit and (ii) a water supply or a community benefit (County of Los Angeles, 2019).

One interviewed non-profit leader criticized that "political appointments" of committee members influence public spending (Interview 6, 2019). LA Sanitation and LADWP occupy key positions in the Upper Los Angeles River and the Santa Monica Bay watershed steering committees to pursue their strategic goals. Los Angeles' environmental community has pushed for financing green infrastructure, particularly in disadvantaged communities. But technical contestations and existing plans for stormwater projects of public agencies also profoundly shape the politics of infrastructure development.

3.5 Building integrated stormwater infrastructure

LA Sanitation engineers envision that stormwater flows can be tackled along "three lines of defense" by aligning centralized, semi-centralized and decentralized stormwater technologies in a single system that rationalizes stormwater control (Interview 5, 2019). However, the diverse social interests and worldviews of the actors involved in Los Angeles' stormwater restructuring carry many potential stormwater futures. Below, we uncover how technical controversies reflect such ambiguities about shifting relationships between stormwater, technology and urban life.

3.5.1 Engineering watersheds through large-scale infrastructure

Entrenched infrastructural practices of public water agencies strongly impact stormwater restructuring in Los Angeles by interconnecting centralized facilities in a new infrastructure system. In the early 2000s, LADWP and the Los Angeles County Flood Control District started to deepen, interconnect and automate spreading grounds in the San Fernando Valley. Besides reducing flood risk, spreading grounds capture and infiltrate vast amounts of stormwater to replenish the San Fernando Valley groundwater basin. Owning exclusive pumping rights in the basin, LADWP is treating polluted groundwater and has retrofitted spreading grounds to reactivate underutilized groundwater resources. Some of the projects are producing potable water at $60 per acre-foot, while imported water from a regional wholesaler costs over $1,000 per acre-foot. An LADWP manager thus concluded: "when you look at it from a cost per acre-foot perspective, bigger is better" (Interview 1, 2018). LADWP is further retrofitting public parks with underground stormwater infiltration galleries fed from existing stormwater drains.

At the nexus of stormwater and new wastewater recycling infrastructures, LA Sanitation plans to divert more urban runoff into the sewer system for pollution mitigation, while also increasing wastewater recycling. A $30 million project in Ballona Creek (see Figure 5) that is co-financed with the Safe, Clean Water Regional Program aims to use the creek's entire average dry weather flow for wastewater recycling in Los Angeles' biggest wastewater treatment plant Hyperion. Because sewer flows dropped drastically after emergency state water conservation measures were imposed in 2014, water agencies have claimed that more water is needed to achieve the ambitious recycling plans (Interview 14, 2018). Reusing stormwater in centralized wastewater recycling demands spatial coordination with local stormwater infiltration. Overall, water agencies are creating a highly engineered urban water metabolism around centralized facilities to control large volumes of stormwater. Integrated stormwater management is being organized as a technical process that rationalizes flood control, water supply, and water quality tasks in a single infrastructure system, while relying on the practices and expertise of separate public agencies.

Public engineers underline that focusing on a small number of large-scale

FIGURE 5 Trash collection in the Ballona Creek (photo by Valentin Meilinger, 2019)

engineering projects facilitates agency collaboration to accelerate stormwater improvement in Los Angeles' urban landscape that can otherwise only be slowly transformed (Interview 1, 2018). For water agencies to comply with water quality targets in the Ballona Creek watershed has been estimated to take 57 years, which is far beyond compliance deadlines. In particular, high loads of heavy metals and bacteria continue to pose environmental and health hazards (Los Angeles Water Quality Resources Board, 2021: 25). LA Sanitation therefore prioritizes volumetric stormwater control in centralized infrastructures as the most effective and cost-efficient way to meet pollution reduction targets. Public agencies have also devised plans for decentralized stormwater control where large-scale projects are infeasible, but these plans still have to be fleshed out. Environmental groups criticize that stormwater improvements are all too often achieved through resource-intensive and costly technology rather than through ecological landscape functions that would expand green space. They have demanded stricter definitions and quantifications of community benefits such as biodiversity restoration for stormwater projects (Interview 3, 2019). Attempts to connect infrastructures at different scales show that stormwater is not reducible to an underutilized resource and a water quality liability but is inextricably linked with wider urban processes.

3.5.2 Green streets

Green streets capture street runoff, which then infiltrates into vegetated depressions or underground infiltration galleries. The pollution reduction scenarios developed for Los Angeles' 2012 stormwater permit generated a long list of proposed green streets that are considered Los Angeles' imperative "pathway toward [regulatory] compliance" (Interview 9, 2019).

This push for green streets, however, is complicated on at least three levels. Firstly, the responsibilities for green streets are fragmented among multiple city agencies and civil society actors. Although Los Angeles' Bureau of Engineering has produced a standard green street plan, green street projects typically involve onerous coordination between separate water agencies and the Bureau of Street Services. Moreover, maintenance is complex, since under the City Charter, city departments may only maintain the projects in their own portfolio. The Sustainable Street Ordinance proposed in 2015 to regulate maintenance has not yet been passed, as the redistribution of departmental responsibilities remains contested. Secondly, for public utilities, grey infrastructure remains the "common knowledge approach" based on a "longer history of testing and data" (LA Sanitation, 2018: ES-12). The project proposals for the Safe, Clean Water Regional Program must include much technical detail; this favors larger engineered projects because projects that have already received much funding to prepare them are rarely rejected, according to a policy expert (Interview 2, 2019). The third complication, voiced by another policy expert, is that LA Sanitation's green street plans were devised as "a pure [water quality] compliance effort" but focus less on enhancing multi-benefit infrastructure (Interview 7, 2018). To streamline infrastructure development for pollution control, the agency thwarted an attempt by environmentalists to make community investments a funding requirement for the Safe, Clean Water Regional Program.

Nonetheless, green street initiatives have increased in recent years, but they diverge from top-down public infrastructure development in three ways. Firstly, green streets were pioneered by environmental organizations and still rely heavily on their engagement to acquire project funding and organize community support for infrastructure maintenance. Collaborating in pilot projects with public utilities, environmental groups have demonstrated effective stormwater capture and have fostered community education in landscape care. Non-profits have also helped establish curb cuts, a low-cost design practice that conveys street runoff to landscaped parkways. Public engineers push for combining such landscaping interventions with engineered underground infiltration structures to enhance pollutant removal (Interview 5, 2019). Secondly, to implement green streets within fragmented institutional arrangements, city agencies are developing new organizational and technical standards. Los Angeles' One Water plan outlines opportunities to use synergies, such as mobilizing regular street retrofits for stormwater improvements (LA Sanitation, 2018). However, the plan makes no mention of a Green Street Committee founded in 2007 to promote interdepartmental collaboration. An environmental activist noted that although city agencies have enhanced collaboration for everyday project management, at the level of strategic management this is obstructed by narrow departmental remits (Interview 6, 2019). Thirdly, public agencies' cost-efficiency goals limit their contributions to green street projects. An LADWP manager explained that the utility "piggybacked" in some projects, bearing costs of up to $1,100 per acre-foot of stormwater that replenishes local groundwater basins (Interview 1, 2018). Financing green streets thus entails complicated agreements between different city agencies and contributing private actors.

Because multiple public service tasks intersect in streets, streets have been reframed as promising spaces of integrated stormwater management in environmental policy discourse. However, there is a discrepancy between the regulatory demands that have translated into a long – but abstract – list of green street projects and their practical realization, which relies greatly on opportunities for collaboration. Nevertheless, pilot projects have demonstrated the sustainability potential of street retrofits and have engendered small-scale technical and organizational innovations from which future infrastructure development can benefit.

3.5.3 Decentralized stormwater management

For over 20 years, environmental organizations have been advocating for single-family home plots in Los Angeles as the city's largest available area for stormwater management. So far, local stormwater capture and infiltration (or reuse) has barely reached a mature level of public infrastructure provision. Although Los Angeles' LID Ordinance to enhance stormwater source control at low cost was approved in 2011, staff shortages in LA Sanitation have hampered the inspection process, and maintenance poses an enormous challenge. Much of this uncertainty stems from public agencies' lack of experience – and trust – in collaborating with homeowners to operate and maintain infrastructure. This is why a recent proposal from environmental groups for a stormwater retrofit program on private parcels to be funded by the Safe, Clean Water Program was a "political non-starter" (Interview 3, 2019). The attempt was obstructed by public utilities that fear administrating multiple small-scale projects which require site-specific planning and whose performance is difficult to control. Instead, a tax exemption rule was enacted for those who manage stormwater on their property, but it has high bureaucratic hurdles. The requirements for project approval are very difficult to meet in a private backyard, and policy makers tweaked the exemption rule to curb business opposition to the Safe, Clean Water Program (Interview 4, 2019).

The realization of parcel retrofits and, through this, new infrastructural relationships between water agencies, property owners and environmental groups, is essentially shaped by technical controversy. There are three areas of contention. Firstly, local stormwater programs are contested at the level of measuring infrastructure benefits. LA Sanitation engineers only estimate stormwater volumes captured by LID, but these estimates do not count for water quality compliance. The engineers emphasize that it remains technically complex to quantify and monitor the pollution control and water supply benefits of LID (Interview 5, 2019). Meanwhile, a local environmental organization has declared its "fundamental crusade [...] to improve the LID Ordinance" (Interview 8, 2018) and to demonstrate the economic viability of nature-based parcel projects. Although ways to measure stormwater infrastructure benefits are becoming more diverse, environmentalists describe efforts to decentralize stormwater management as an "uphill battle" (Interview 10, 2019). Whereas larger agency projects are approved on the basis of stormwater models, non-profits have to provide monitoring data to receive agency co-funding.

Secondly, justifying green infrastructure in an environment where grey infrastructure practices predominate faces great obstacles. Living systems that need frequent maintenance contradict entrenched ideas of infrastructure reliability and endurance, and public engineers claim that there is little data about the long-term pollution reduction performance of different types of vegetation and soil media (Interview 5, 2019). Moreover, they have highlighted vector control as a challenge of green infrastructures. Climate change in California is likely to result in greater numbers of mosquitos that breed in stagnant water in green infrastructures and transmit diseases such as the West Nile virus (Bhattachan et al., 2021). More generally, diverging design practices reflect different objectives and epistemologies of nature and technology. Water agencies design technology for cost-efficient stormwater control. Meanwhile, environmental non-profits and progressive landscaping experts aim to restore landscape ecosystems and hydrological cycles, as well as to reduce resource and energy consumption through skilled landscape design and green infrastructure education (Interview 11, 2019). Although environmental actors recognize pollution challenges, public engineers foreground that options to decentralize stormwater management are limited by the structural deficits of green infrastructures in mitigating concentrated pollutants.

Thirdly, inherited infrastructure maintenance practices hamper decentralized green infrastructures. Besides mentioning public agencies' lack of skills, a non-profit leader noted that "there is no industry that can build nature-based solutions" (Interview 6, 2019). Established labor unions and the construction industry tend to oppose the broader proliferation of landscape-centered infrastructure (Interview 12, 2019). Meanwhile, environmentalists highlight parcel retrofit programs as an "education opportunity" (Interview 8, 2018) for homeowners. Nonetheless, policy makers have refrained from using Safe, Clean

Water Program funds for such retrofits, instead prioritizing landscaping incentives for water conservation “to encourage the behavior we want without touching the tax” (Interview 4, 2019).

Together, street retrofits and local stormwater practices shift the focus of infrastructure development to Los Angeles’ wider urban fabric as an environmental and health hazard. But to make a difference for stormwater improvement, decentralized practices need to be massively scaled up and strategically designed and located, as well as reliably maintained. For instance, regulatory compliance in the Ballona Creek watershed is estimated to require the construction of 71,000 bioretention units (Wolfand et al., 2018: 6376), but available space is scarce, and huge coordination efforts would be involved. Therefore, environmental groups highlight the growing evidence that combinations of green and larger grey infrastructure can produce safe water quality outcomes while reworking urban landscapes to create resilient and healthy communities (Interview 13, 2021). For the environmentalists, an exacerbating climate emergency and limited resources (money, space) rule out mere stormwater improvements as stipulated in the missions of public water agencies.

3.6 The material politics of hybrid stormwater infrastructures

The Safe, Clean Water Program alleviates a drastic underfunding of stormwater management and signals a major shift in public discourses. Since California’s 2011–2016 drought, stormwater has been reframed as a local resource and an opportunity for urban greening. This has coincided with the rise of integrated stormwater management paradigms and more diverse infrastructural practices, which has brought uncertainty about stormwater futures.

We found that Los Angeles’ shifting stormwater system accommodates diverging infrastructure designs that overlap, complement and partly conflict with each other. Public utilities deploy funding to interconnect centralized stormwater facilities in an effort of incremental adaptation that aims to rationalize flood control, water supply, and water quality management. As a still emerging infrastructure development, green street projects and local stormwater retrofits depend on opportunities for collaboration between siloed public agencies and civil society actors. We argue that the material politics shaping uneven stormwater restructuring in Los Angeles result from dominant infrastructural practices that sustain centralized facilities and entrenched institutions of water management. Nonetheless, new stormwater visions shared among policy stakeholders endorse combining stormwater infrastructures at different scales to advance their environmental and community benefits. While institutional objectives of public utilities largely influence the Safe, Clean Water Program, growing attempts to decentralize stormwater practices have resulted in landscape restoration and environmental education joining community health and resilience as prominent concerns in stormwater governance. Los Angeles' increasingly hybrid stormwater system thus shows promising potential for sustainability. But obdurate urban landscapes and governance challenges obstruct a rapid shift toward hybrid infrastructures. Designing, locating, and scaling stormwater technologies in order to minimize trade-offs between different objectives of infrastructure development is highly complex. At the same time, the responsibility for stormwater management is becoming more fragmented. While homeowners are emerging as infrastructure co-providers on their own properties, public engineers claim that it is difficult to control the water quality and supply outcomes of decentralized green infrastructures which lack standardization and exhibit structural deficits in pollutant removal. Together, frictions and synergies between centralized and decentralized infrastructural practices highlight the ambiguity about shifting stormwater politics, which is becoming particularly visible around material objects, knowledge orders, and institutions.

FIGURE 6 Spreading ground in San Fernando Valley (photo by Valentin Meilinger, 2019)

The dominant infrastructural practices of public engineers concentrate on existing stormwater channels, spreading grounds, public parks and wastewater treatment plants (see Figure 6). These artifacts are being interconnected to forge a centralized system within which stormwater can be captured for pollution mitigation and flood control and to be recycled or infiltrated into groundwater aquifers to augment local water supplies. Integrated stormwater management is thereby technically achieved, fulfilling the missions of LA Sanitation and LADWP most cost-efficiently. Safe, Clean Water Program funds are primarily channelled toward volumetric stormwater control to tackle pollution challenges as a key objective of environmental and health protection. The materiality of existing technology thus profoundly shapes the institutional orders and the objectives of stormwater governance. Nonetheless, green infrastructure projects pushed by environmental groups have broadened notions of "multi-benefit" infrastructure. Material change thus shows that environmental governance rationales inscribed in existing infrastructures are never either fully uniform or stable. Governing hybrid stormwater infrastructures involves planning for numerous (sometimes conflicting) objectives of infrastructure development that are linked to different systems of urban environmental management and new interfaces between these systems. Moreover, these objectives of infrastructure development come with distinct spatial demands that are difficult to coordinate in a densely populated urban fabric which is crisscrossed by existing infrastructure networks as well as political and biophysical boundaries. For instance, prioritizing technical solutions to mitigate stormwater pollution by retrofitting existing infrastructure facilities might limit opportunities to use stormwater investments for urban greening in the communities nearby these facilities.

Although still hierarchically organized, expertise is becoming more diverse in Los Angeles' stormwater transition. The focus of public utilities on centralized infrastructures sustains an "engineering governmentality" (Carroll, 2012: 510) that treats stormwater as a technical problem which can be solved by inherited environmental engineering practices. Decisions to re-valorize stormwater as a supply for centralized wastewater recycling while according less value to landscape restoration can partly be explained by LA Sanitation's specialization in wastewater. Liable for water quality protection, public engineers remain skeptical about decentralized green infrastructures developed and maintained by non-engineering communities. Also, the Safe, Clean Water Program frames stormwater retrofits of land parcels as voluntary efforts by engaged citizens that merit financial incentives, but less as public infrastructure development. Nonetheless, parkway retrofit projects have re-educated residents to be infrastructure co-providers, which shows that different user types co-exist and that knowledge hierarchies are malleable. Decentralized stormwater practices thus reform established ways of valuing expertise, as landscape design and horticultural expertise are slowly gaining more "infrastructural" relevance.

Inherited institutions of water management underpin centralized stormwater practices, while decentralized practices imply new forms of collaboration across institutional boundaries. Whereas LA Sanitation is pressured by water quality regulations, LADWP is mostly driven by a rigid public control of water prices. By influencing Safe, Clean Water Program funding criteria to reward a volumetric stormwater approach, the agencies sustain an institutional setup that favors centralized infrastructures to ensure reliable and cost-efficient services. Environmental groups criticize that better mobilizing urban landscapes for a hybrid stormwater management which links volume control with wider ecological and community health benefits lacks recognition and financial support. Consequently, inherited institutions become subject to political disputes about stormwater sustainability, as discussions arise about reorganizing institutional responsibilities within different water subsectors but also across water, street and landscape departments.

Overall, policy stakeholders in Los Angeles share a discourse of integrated stormwater management to foster urban sustainability. However, in disputes over infrastructure design, different actors align material artifacts, expertise and institutions to advance their own political objectives of stormwater governance. Yet actors converge around the issue of urban stormwater frequently retaining the practices and rationales of urban environmental and infrastructure management that evolved to tackle problems of industrializing cities in the twentieth century. Together, this provokes particular material politics of urban stormwater that reveal how the responsibility for infrastructure provision, the value of different forms of expertise and the overall rationale of stormwater infrastructures are contested.

3.7 Conclusion

Worldwide, there is growing criticism of urban drainage efficiency approaches, of which Los Angeles' modern stormwater networks are a prime example. This article has traced how actors in Los Angeles engage in disputes over infrastructure design to achieve their own visions of integrated stormwater management with revenues from a new stormwater tax. To do so, we studied dynamic constellations of material artifacts, discourses, expertise and institutions linked to stormwater infrastructures as sites where political possibilities for urban sustainability are contested.

By focusing on existing infrastructure facilities, the practices of Los Angeles' incumbent public water and sanitation engineers dominate stormwater restructuring. Accordingly, tax revenues are primarily used to interconnect centralized facilities to advance public water supply and water quality missions, which marginalizes decentralized green stormwater practices in top-down public infrastructure development. As a result, entrenched arrangements of power and knowledge shape urban stormwater sustainability (Cousins, 2017). However, the Los Angeles case provides a more differentiated story than one of mere path dependency. By exploring technology as a site of political controversy, we could highlight how discourses on multiple infrastructure benefits and struggles of environmental groups foster the slow diffusion of decentralized infrastructures in the interstices of centralized stormwater facilities. In Los Angeles' increasingly hybrid stormwater system, wider urban political and spatial dynamics such as urban greening shape stormwater management, which has traditionally relied on technocratic practices to control stormwater as a hazard. Citizens are becoming infrastructure co-providers and knowledge hierarchies are shifting, as public utilities can no longer ignore landscape design, ecology, and horticultural expertise. However, realizing the potential benefits of such infrastructures is thwarted by entrenched institutional arrangements and persistent water quality problems. Uncertainties about stormwater futures result from costs and benefits of stormwater management that are unevenly distributed among siloed public agencies and private actors. In addition, the various socio-political and biophysical dynamics that affect stormwater governance often have fragmented geographies, which complicates infrastructure planning. Disputes over designing hybrid infrastructures thus expose stormwater restructuring as inextricably linked to broader political questions about governing urban nature (Millington, 2021). For instance, limitations to investing in distributed green stormwater infrastructures due to persistent pollution challenges could be foregrounded to bring critical attention to the relations between pollution and urban life. But car mobility, construction or even the artificial turf used for water conservation as sources of pollution are hardly discussed in debates over stormwater infrastructure development. Central to this might be policy stakeholders' ambivalence about the understandings of urban nature and urban life that shape sustainability action. This is reflected in ongoing controversy about what "engineered" green infrastructures need to be in order to make cities livable. Hence, stormwater restructuring in Los Angeles exemplifies a broader dilemma in urban environmental governance where aspirations of a system-based urban environmental management clash with the plurality of agencies and perspectives underlying urban ecologies (Gandy, 2022).

Our findings suggest that urban stormwater sustainability can be enhanced by reforming two areas. Firstly, there is a need to better define green infrastructure planning requirements in stormwater regulation and public water supply missions. Changes to legislation, such as the Safe, Clean Water Program, have reframed stormwater as a resource but have fallen short of thoroughly reforming the entrenched volumetric stormwater approach. In the absence of technical rules for hybrid and more landscape-centered stormwater systems, the strict public control of investments and sectoral environmental regulations are driving utilities to prioritize centralized technologies. This volumetric stormwater approach is still considered to be more effective and cost-efficient for controlling pollution. Decentralizing and greening stormwater management requires the thorough reorganization of infrastructure planning, control and maintenance, which are currently being carried out in fragmented city departments. Moreover, spatial planning for stormwater systems is becoming more important. To foster distributed stormwater practices, the synergies between stormwater and land use regulation could be strengthened: for instance, by increasing capacity for LID inspection or by expanding green infrastructure education. Technical rules about the usefulness of different types of green infrastructure for pollution control and stormwater infiltration in disparate land use forms could support this.

Secondly, enhanced accounting and financing tools for landscape-centered stormwater practices that facilitate cost sharing between siloed city departments would broaden infrastructure benefits. Redistributing the costs and benefits of public infrastructure development could then help to overhaul the notions about providing efficient infrastructure via volumetric stormwater control inscribed in sectoral infrastructure planning rules and guidelines. Simultaneously, tools for financing green infrastructures could accord more value to ecological and landscape design practices. Such reworking of engineering in urban environmental management might offer a way to foster more collaborative and just forms of stormwater governance. Public financing criteria that support green infrastructure may help create a skilled landscape-oriented workforce or couple stormwater improvements with urban greening in disadvantaged communities. Studying technical disputes about stormwater infrastructure design and financing can thus enhance scholarship on uneven geographies of urban greening and environmental injustice.

Ultimately, the critical scrutiny of technical disputes offered in this article provides a fruitful approach for revealing the power dynamics that explain dominant forms of imagining, managing, and inhabiting the local environment of cities. This research agenda is becoming more important as visions of urban environmental policy are increasingly being shaped by technical concepts such as "green infrastructures" or "circular cities." Future research is needed to explore how the practical achievement of such concepts can produce disputes involving political questions of resource governance, the responsibility for infrastructure provision, and environmental justice.

3.8 References

Al-Ameri, M., B. Hatt, S. Le Coustumer, et al. 2018. Accumulation of heavy metals in stormwater bioretention media: a field study of temporal and spatial variation. *Journal of Hydrology* 567: 721–731.

Bhattachan, A., N. K. Skaff, A. M. Irish, et al. 2021. Outdoor residential water use restrictions during recent drought suppressed disease vector abundance in Southern California. *Environmental Science & Technology* 55(1): 478–487.

Bijker, W. E. 1995. Of bicycles, bakelites, and bulbs: toward a theory of sociotechnical change. MIT Press, Cambridge.

Björkman, L. and A. Harris 2018. Engineering cities: mediating materialities, infrastructural imaginaries and shifting regimes of urban expertise. *International Journal of Urban and Regional Research* 42(2): 244–62.

Bowker, G. 1994. Science on the run: information management and industrial geographics at Schlumberger, 1920–1940. MIT Press, Cambridge.

Brown, R. R. 2005. Impediments to integrated urban stormwater management: the need for institutional reform. *Environmental Management* 36(3): 455–468.

Brown, R, R., M. A. Farrelly, and D. A. Loorbach 2013. Actors working the institutions in sustainability transitions: the case of Melbourne's stormwater management. *Global Environmental Change* 23: 701–718.

Carroll, P. 2012. Water and technoscientific state formation in California. *Social Studies of Science* 42(4): 489–516.

Carse, A. 2012. Nature as infrastructure: making and managing the Panama Canal watershed. *Social Studies of Science* 42(4): 539-563.

County of Los Angeles 2019. Los Angeles Region Safe, Clean Water Program implementation ordinance. Accessed July 3, 2020. https://safecleanwaterla.org/wp-content/uploads/2019/08/SCW-July-30-2019-Board-Package.pdf.

Cousins, J. J. 2017. Of floods and droughts: the uneven politics of stormwater in Los Angeles. *Political Geography* 60: 34–46.

Coutard, O. and J. Rutherford 2016. Beyond the networked city: an introduction. In O. Coutard and J. Rutherford (eds.), Beyond the networked city: infrastructure reconfigurations and urban change in the North and South. Studies in Urbanism and the City. Routledge, London. 1-25.

Dhakal, K. P., and L.R. Chevalier 2016. Urban stormwater governance: the need for a paradigm shift. *Environmental Management* 57(5): 1112–1124.

Finewood, M. H. 2016. Green infrastructure, grey epistemologies, and the urban political ecology of Pittsburgh's water governance. *Antipode* 48(4): 1000-1021.

Fitzgerald, J. and J. Laufer 2017. Governing green stormwater infrastructure: the Philadelphia experience. *Local Environment* 22(2): 256–268.

Gandy, M. 2014. The fabric of space: water, modernity, and the urban imagination. MIT Press, Cambridge.

Gandy, M. 2022. Natura urbana: ecological constellations in urban space. MIT Press, Cambridge.

Karvonen, A. 2011. Politics of urban runoff: nature, technology, and the sustainable City. MIT Press, Cambridge.

Keeley, M., A. Koburger, D. P. Dolowitz, et al. 2013. Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. *Environmental Management* 51(6): 1093–1108.

LA Sanitation 2018. One Water LA 2040 Plan. Stormwater facilities plan. City of Los Angeles. Los Angeles.

Lennon, M. 2015. Green infrastructure and planning policy: a critical assessment. *Local Environment* 20(8): 957– 980.

Los Angeles Water Quality Resources Board 2021. Consideration of extension of final TMDL implementation deadlines for certain TMDLs in the Los Angeles Region. Accessed December 2, 2021. https://www.waterboards.

ca.gov/losangeles/board_decisions/basin_plan_amendments/technical_documents/137_new/StaffReportFinal_w_EOCrLtr.pdf.

Melosi, M. 2008. The sanitary city: environmental services in urban America from colonial times to the present. University of Pittsburgh Press. Pittsburgh.

Millington, N. 2021. Stormwater politics: flooding, infrastructure, and urban political ecology in São Paulo, Brazil. *Water Alternatives* 14(3): 866–885.

Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A: Economy and Space* 41(8): 1924–1942.

Moss, T. 2020. Remaking Berlin: a history of the city through infrastructure, 1920-2020, MIT Press, Cambridge.

Orsi, J. 2004. Hazardous metropolis: flooding and urban ecology in Los Angeles. University of California Press, Berkeley.

Park, M.-H., M. Stenstrom, and S. Pincetl 2009. Water quality improvement policies: lessons learned from the implementation of Proposition O in Los Angeles, California. *Environmental Management* 43 (3): 514–522.

Pincetl, S. 2010. From the sanitary city to the sustainable city: challenges to institutionalising biogenic (nature's services) infrastructure. *Local Environment* 15(1): 43–58.

Porse, E. 2013. Stormwater governance and future cities. *Water* 5(1): 29–52.

Porse, Eric, M. Glickfeld, K. Mertan, et al. 2016. Pumping for the masses: evolution of groundwater management in Metropolitan Los Angeles. *GeoJourna*l 81: 793–809.

Rutherford, J. 2020. Redeploying urban infrastructure. The politics of urban socio-technical futures. Palgrave Macmillan, Cham.

Sedlak, D. 2014. Water 4.0: the past, present, and future of the world's most vital resource. Yale University Press, New Haven.

Star, S. L. and K. Ruhleder 1996. Steps toward an ecology of infrastructure: design and access for large information spaces. *Information Systems Research* 7(1): 111–134.

Truelove, Y. 2019. Gray zones: the everyday practices and governance of water beyond the network. *Annals of the American Association of Geographers* 109(6): 1758-1774.

Wolfand, J. M., C. D. Bell, A. B. Boehm, et al. 2018. Multiple pathways to bacterial load reduction by stormwater best management practices: trade-offs in performance, volume, and treated area. *Environmental Science & Technology* 52: 6370–6379.

Wong, T. H. and R. R. Brown 2009. The water sensitive city: principles for practice. *Water Science and Technology* 60 (3): 673–682.

3.9 Cited interviews

1. Stormwater manager, LADWP, Los Angeles, 2 February 2018.
2. Water policy expert, University of California, Los Angeles, 12 April 2019.
3. Leader, water quality protection non-profit, Los Angeles, 12 April 2019.
4. Policy officer, County of Los Angeles, Los Angeles, 11 April 2019.
5. Stormwater manager, LA Sanitation, Los Angeles 10 April 2019.
6. Leader, environmental non-profit, Los Angeles, 29 March 2019.
7. Policy officer, County of Los Angeles, Los Angeles, 6 February 2018.
8. Leader, environmental non-profit, Los Angeles, 7 February 2018.
9. Stormwater policy consultant, Los Angeles, 20 Mach 2019.
10. Stormwater expert, water quality protection non-profit, Los Angeles, 19 March 2019.
11. California native plant landscape professional, Los Angeles, 13 March 2019.
12. Water quality expert, environmental non-profit, Los Angeles, 7 December 2021.
13. Wastewater manager, LA Sanitation, Los Angeles, 13 March 2018.

4

INFRASTRUCTURING GARDENS: THE MATERIAL POLITICS OF OUTDOOR WATER CONSERVATION IN LOS ANGELES

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ABSTRACT

Historically, urban developers, politicians, and public water utilities have invented Los Angeles as a semitropical oasis in a dry climate. During the California drought of 2011 through 2016, however, the city's residential gardens became a new frontier of water conservation policy. Water agencies started to subsidize the replacement of lushly irrigated lawns with California Friendly® landscapes, thereby endorsing a technology-centered "infrastructuring" of gardens to increase water conservation. This approach contrasts with California native plant gardening promoted by nature conservationists, which uses vernacular horticultural techniques to restore native plant biodiversity and reduce irrigation. The article shows that each approach has important political implications for urban space and water use, the value accorded to nature and gardening work, and relations between citizens and experts. Analyzing the differences between these approaches, we critically interrogate Los Angeles' modern infrastructure regime that shapes water conservation policy. Particular attention is paid to how new material objects, knowledges, and practices in gardening recompose relationships between water, plants, technology, humans, and urban space. We argue that the notion of infrastructuring gardens offers a fruitful lens for ascertaining how expert cultures shape urban environmental change and how alternative gardening practices (re)produce urban nature differently.

4.1 Introduction

This article studies endeavors of public water utilities and California native plant advocates to relandscape the thirsty residential gardens of Los Angeles for water conservation. Modern lawned gardens in North American cities have been fetishized as symbols of the human domestication of nature and as markers of cultural belonging. This, however, obfuscates the urban political ecologies of lawn gardens in which considerable labor, technology, and resource inputs produce highly uneven socio-ecological relations (Robbins, 2007). In arid climates worldwide, the suburban desire for lush gardens has nourished urban sprawl and exacerbated urban water scarcity (Askew and McGuirk 2004; Parés et al., 2013). Cities in the southwestern United States are prime examples (Larson et al., 2017). Although the expansion of water networks has facilitated the proliferation of thirsty gardens, these gardens have rarely been actively managed as infrastructure components. We argue that relandscaping endeavors for water conservation reveal not only the power relations that shape urban environmental governance through infrastructure, but also the opportunities for alternative forms for aligning infrastructures with urban nature.

The California drought between 2011 and 2016 brought these dynamics to the fore, and the current drought emergency underscores the urgency to change inherited landscaping practices. In Los Angeles, landscape irrigation represents 54% of single-family water use (Mini et al., 2014). Although water utilities in California largely depend on revenues from water sales, in 2014, the Los Angeles Department of Water and Power (LADWP) and the Metropolitan Water District of Southern California (MWD) turned to residential gardens as their new frontier of water conservation. The agencies set up a joint California Friendly® landscaping program that has subsidized the replacement of lawns with drought-tolerant plants from all over the world and has introduced more efficient irrigation systems. Meanwhile, a small but established California native plant restoration movement of conservationists, horticulturists, and landscape designers has promoted California native plant gardens, viewed as skillfully curated and largely self-sustaining ecologies that require minimal irrigation. Both approaches imply interrelated social, technical, and material changes to Los Angeles' modern gardens, yet these have attracted little attention. Even less attention has been paid to the shifting relationships between technocratic infrastructure management and gardens as complex spaces of everyday human and nonhuman urban life.

In this article we explore and compare the material politics of retrofitting Los Angeles' residential gardens through California Friendly® landscaping and California native plant gardening. This provides a promising case study for examining conflicts over urban environmental management shaped by technology and different forms of expertise (Cousins, 2017). Although being mindful of the relationships between aesthetics, the transformation of nature, and social power embodied in landscapes (Cosgrove, 1998), we uncover the politics of relandscaping through the lens of technology. We frame gardens as "technonatures" (White and Wilbert, 2009) to analyze the socio-technical entanglements linking residential gardens with water infrastructures. Inspired by Rutherford (2020), we trace how those entanglements become "material politics." This entails studying how actors reconfigure material objects to achieve political objectives of relandscaping Los Angeles, which rework substantive relationships between water, plants, technology, humans, and urban space.

Drawing from Blok et al. (2016), we conceptualize garden retrofits as processes of "infrastructuring" gardens to analyze the contested practices and projects of recombining technical and other material artifacts and knowledges in gardening through which actors seek to facilitate particular infrastructure development. Consequently, dynamics in gardening become part of more enduring patterns of organizing environments that can expand over broader spatial and temporal horizons. Reading gardens as sites of infrastructuring can enrich the critical study of technology in urban environmental governance by highlighting how infrastructure is shaped by technological agency in relation to other human and nonhuman agencies. This perspective reveals the power differentials and the instances of alternative politics of urban nature that occur when technocratic environmental management encounters the "ecological pluriverse" (Gandy, 2022) of contemporary cities where technology, culture, and nonhuman life intersect.

The analysis starts by discussing the historical coevolution of water network expansion and residential gardens in arid southwestern U.S. cities. Then, building on work on technonatures and urban infrastructures, we construct a conceptual framework for understanding the material politics of infrastructuring gardens. We next outline the emergence of Los Angeles as a semitropical garden city and analyze California Friendly® landscaping and California native plant gardening. We show that strict public control of water pricing, technoeconomic imperatives of enhancing local water supplies, and an inherited engineering culture in water management favor a technology-centered infrastructuring of gardens through California Friendly® landscaping to maximize water conservation. In contrast, California native plant gardening focuses on restoring autochthonous biodiversity that includes native or endemic species[11] and foregrounds alternative horticultural techniques. Comparing these landscaping approaches allows us to critically review the politics of water management in Los Angeles. The diverging choices of material objects, knowledges, and gardening practices have implications for urban space and water use, the value accorded to nature and gardening work, and the relationship between water agencies and citizens. The article concludes by highlighting how analyzing practices of infrastructuring gardens can be a useful

11 Conservationists focus on plant biodiversity but always see the latter in relation to faunal biodiversity.

way of exposing how expert cultures shape urban environmental change and developing alternative politics of urban infrastructure and nature.

For our research, we analyzed planning and policy documents, technical manuals, legislation, and relevant newspaper articles. The data were collected between 2018 and 2019 in 54 semi-structured qualitative interviews.[12] Inspired by our theoretical framework, the interviews focused on four analytical dimensions: (i) plants, technologies, forms of expertise, and practices involved in water-efficient gardening; (ii) the politics of water management in Los Angeles; (iii) actors' ideas of technology and nature; and (iv) the organization, knowledge, and practices of the landscaping industry. In an iterative process, these dimensions structured the qualitative content analysis of the empirical material, but they were also refined during the study and specified through subcategories. We constructed the argument around infrastructuring gardens by interrelating these four categories to explain relandscaping endeavors and their political implications in Los Angeles. The analysis was supplemented by field observation of gardening work, visits to nurseries and model gardens, and participation in a California Friendly® landscaping workshop. To better understand the history of Los Angeles as a garden city, we studied sources from the Huntington Library on the environmental history of gardening and urban development in Los Angeles.

4.2 Thirsty gardens in arid U.S. cities

In the twentieth century, U.S. suburbs saw the widespread proliferation of English-style lawn gardens, epitomizing a modern suburban lifestyle. After World War II, lawn gardens thrived as part of the Fordist "auto-house-electrical appliance complex" (Roobeek, 1987: 133), with a mix of natural resources, plants, labor, and technology deployed in pursuit of recreation and economic prosperity (Fishman, 1987). Maintaining neat lawn aesthetics through constant input of fertilizers, pesticides, and machine-aided labor, Robbins (2007) argued, became a moral obligation of U.S. homeowners. Pursuit of this aspiration sustains a multibillion-dollar garden industry that causes substantial ecological and health damage through watershed pollution, greenhouse gas emissions, and exposure to chemicals (Robbins, 2007: 66). More recently, the quest for a "'good' lawn – green, uniform and neat" (Brooks and Francis, 2019: 560) has led to artificial lawns

12 We interviewed environmental activists (five), community representatives (two), environmental consultants (three), environmental nonprofits (eight), garden supply businesses (two), home developers (one), landscape architects and consultants (four), landscape practitioners (one), lobby organizations (one), native plant horticulturists (three), nurseries (two), public policy officers (six), public water managers (twelve), and researchers (four). Interviewees were selected to widely cover the network of stakeholders involved in landscaping and water management in Los Angeles and by snowball sampling.

being embraced. Although garden supply companies and water utilities promote artificial lawns for water conservation, these lawns engender new conflicts about plastic waste production, biodiversity loss, and urban heat islands. Appearing at first sight to be a banal appendage to the modern home, lawn gardens imply conflictual decisions about the environments we live in – how we design and sustain them, for what purposes, and at what social and environmental costs.

Technology is deeply interwoven with the politics of residential landscaping in at least two ways. First, in nineteenth-century England and more humid regions of the United States, lawn care emerged as a matter of inputting labor and technology for weeding and mowing (Robbins, 2007: 45–46). Today, industry's pursuit of profits and an entrenched consumption culture result in households acquiring equipment such as mowers, edging shears, and leaf blowers. Second, in arid and semiarid climates, irrigation has been indispensable for the rise of lawn gardens and their associated cultures of suburban living. The creation of cities in the southwestern United States as green oases relied on garden irrigation enabled by the geographical expansion of water import networks (Reisner, 1993; Gober and Trapido- Lurie, 2006). Since the late nineteenth century, significant public infrastructure investments and the rationalization of service provision through territorial monopolies have fueled urbanization. In the early twentieth century, the centralization and frequent municipalization of water networks ensured universal water supply, which became the domain of expert cultures of engineering and applied economics (Melosi, 2008: 82ff). Simultaneously, dwelling in their networked homes, citizens became passive recipients of water services.

Although public investments in infrastructures have declined in U.S. cities since the 1970s, responsibility for ensuring cheap and abundant water supply often still remains in the public sector (Pincetl, 2010: 46). The revenue-dependent financing models of utilities continue to favor volumetric water sales and a focus on securing reliable supply for growing cities. Although largely technologically enabled, the water footprint of residential gardens is also embedded in a web of cultural norms. The settler colonial ideology of turning the desert into a flourishing empire formed a critical cultural underpinning of land development in the southwestern United States (Worster, 1985). Suburbanization processes nourished by this imaginary drove a socially produced water scarcity, exacerbated by the aesthetic norms of lawn cultures and social conventions of comfort (Robbins, 2007; Larson et al., 2017). Meanwhile, Mustafa et al. (2010) showed how water-saving landscapes can feature as markers of environmental consciousness and privilege. Watering a garden thus cannot be reduced to simply using a resource. Instead, gardens feature as arenas of social and cultural differentiation, symbolizing distinct lifestyles and value systems (Head and Atchison, 2009) and reflecting persistent colonial power structures (Ballard and Jones, 2011).

The diverse histories of infrastructure-fueled urbanization reveal gardens as highly political entanglements where there is convergence of labor relations, cultural meaning, relationships between water agencies and users, and resource and public infrastructure politics. Residential garden retrofits deployed to achieve a particular infrastructure development reconfigure these complex socio-technical and political relations.

4.3 The material politics of infrastructuring urban gardens

The notion of "technonatures" (White and Wilbert, 2009) can be used to explain the complex relationships between gardens and technology. It underscores the central role of technology in creating, maintaining, and experiencing natures. White and Wilbert (2009) argued that ideas of technological change are increasingly shaping political interventions that transform environments. Although the technological features of modern suburban gardens have been "buried beneath swathes of lawn" (Davison, 2009: 174), these features are becoming increasingly visible through practices of local water harvesting or food production. At its heart, the technonatures concept draws attention to locally contingent interactions between actors, technologies, and nature that give rise to distinct environments. Analyzing socio-technical practices that produce technonatures can thus reveal the distributed power relations underlying (urban) environments (see also Giglioli and Swyngedouw, 2008; Sultana, 2013). Accordingly, tracing the practices of retrofitting gardens for water conservation is a promising approach for exploring the emerging relationships between gardens and water infrastructures.

Urban water infrastructures are complex systems, however, that mediate flows of resources and power in producing urban technonatures (Monstadt, 2009). Infrastructure scholars have conceptualized urban infrastructures as socio-technical systems within which technical artifacts are tightly interlinked with institutions, governance structures, actors, practices, knowledges, and flows of materials and money (Coutard and Rutherford, 2016). Thus, technical artifacts' particular qualities and arrangements shape infrastructure development and the social interests embedded in infrastructures. Reconfiguring these artifacts provokes distinct "material politics" (Rutherford, 2020) of socio-technical change that exert power over interrelated infrastructure and urban development. Thereby, infrastructural objects constitute "the disparate settings and arenas in and through which policy discourse and goals are actively translated into actual concrete actions and political interventions" (Rutherford, 2020: 24). In a given urban infrastructure context, infrastructural practices follow systemic rationales and seek to align heterogeneous infrastructure elements accordingly. Consequently, infrastructure constitutes a powerful ordering mechanism (Star and Ruhleder, 1996). Although infrastructure rationales are embedded in material orders, institutions, standards, and hegemonic conventions of practice, infrastructures also "come into being, persist, and fail in relation to the practices of the diverse communities that accrete around them" (Carse, 2012: 544).

Drawing on the debates just presented, we can explore and explain how emerging relationships between gardens and water infrastructures are negotiated through material practices and are shaped by infrastructure as an ordering mechanism. Blok et al.'s (2016: 5) notion of "infrastructuring" brings into focus the "contested practices and projects whereby human groups seek to organize their environment via technical, material, and knowledge interventions." This builds on the idea that at a particular moment, artifacts become infrastructure within a broader set of relationships (Star and Ruhleder, 1996). Accordingly, we can describe landscape retrofits for water conservation as a process of infrastructuring gardens whereby gardens are rendered part of relatively enduring patterns of organizing environments through infrastructure. We argue that infrastructuring gardens describes the contested projects and practices of recombining technical and other material artifacts and knowledges in gardening, through which actors seek to facilitate particular infrastructure development. When gardens are infrastructured, specific plants or technologies are strategically recomposed according to a given infrastructure rationale or to change this rationale. Practices of infrastructuring gardens thereby engender distinct material politics that modify politically significant relationships between water, plants, technology, humans, and urban space.

Practices of infrastructuring gardens and their political effects depend on material objects and distinct forms of knowledge of how material objects work and interrelate. Infrastructuring practices reconfigure and are shaped by the material composition of gardens. For urban water infrastructure to function smoothly, system builders need to connect many technical objects whose physical properties codetermine how this can be achieved (Tiwale, 2019). Infrastructuring gardens for water conservation entails changing irrigation systems, plants, or ground cover, thereby sparking novel socio-technical relations. For instance, water utilities' decisions about investments and infrastructure planning can be influenced by the water and maintenance requirements of plants in gardens, and, conversely, these decisions can influence which plants are grown in gardens. Plants' requirements, however, mean that these issues cannot be separated from aspects such as biodiversity or aesthetics. Critical scholars of urban biodiversity have presented accounts of ecological practices that became growing scientific and political concerns and resulted in alternative politics of urban nature (Lachmund, 2013; Gandy, 2022). Similarly, through garden retrofits, plant-associated technonatural relations become new concerns of infrastructure management, which could lead to new ecological practices being adopted, thereby advancing infrastructure management. We argue that infrastructure development therefore largely depends on which biotic or abiotic features of urban gardens actors select and foreground through practices of infrastructuring.

The different forms of knowledge involved in garden retrofits shape how actors select and foreground biotic and abiotic features of urban gardens.

Practices of infrastructuring gardens draw together hitherto largely separate knowledge cultures of governing urban nature. Water management is dominated by engineering knowledge that focuses on abiotic aspects of the city while having less experience with managing plant ecosystems (Finewood et al., 2019). Water managers are more likely to deploy technical devices to create controllable technonatures that align with existing cost-efficiency and reliability principles. By contrast, landscape design and horticultural knowledge concentrate on the biological processes of plants and the interrelationships between biotic and abiotic elements of landscape ecosystems that serve as templates for practice (McHarg, 1969). When gardens are rendered functional elements of water infrastructures, infrastructure depends on homeowners' gardening techniques and skills, landscaping workers, or specialized horticulturists. "Saturated with technologies and techniques" (Davison, 2009: 181), residential gardens thus provide opportunities to develop new ideas of water infrastructures as systems that rely on different forms of expertise. Which ideas of infrastructure and related forms of governing urban nature ultimately prevail largely depends on how actors portray distinct practices and knowledges as expert ways of doing landscape water conservation.

Altogether, the notion of infrastructuring gardens provides a fruitful way to study the diverse agencies at work and the possibilities of future politics of urban nature at stake when residential gardens are transformed from a given backdrop to public urban life to a systemic component of urban infrastructure. Gardens thereby form sites where existing urban infrastructure regimes might become reconstituted and where these regimes can be challenged and reworked. This conceptual lens expands scholarship on technonatures by discussing infrastructures as both historically layered and continuously contested systems of (re) ordering urban gardens. At the same time, the technonatures concept emphasizes technology as a crucial element of infrastructuring gardens that is itself contested. Consequently, technology forms a particular mode of experiencing and producing gardens through technical interventions dominated by science and engineering rationality. Infrastructuring gardens also involves everyday urban practices that are not technological and that harbor alternative rationales of organizing environments. This perspective allows understanding conflicts over urban environmental management through the instability of different cultures of knowing and managing nature that clash in material disputes over infrastructure design. Drawing on Gandy (2022: 246), infrastructured gardens can further be read as distinctly urban ecological constellations that reflect broader tensions between cities as "generators of new cultures of urban nature" and drivers of global environmental change. Efforts to reconcile the technological, biological, and cultural dynamics in urban gardens to pursue more livable urban futures might point to alternative modernities and spark new ideas for governing urbanization in the Anthropocene.

In what follows, to unpack the material politics of outdoor water conservation in Los Angeles, we describe garden retrofits in terms of outdoor water conservation policies versus the restoration of autochthonous biodiversity. To do so, we scrutinize the distinct material orders, forms of expertise, and practices inherent to these diverging landscaping approaches; explore their particular political configurations of governing urban nature and space; and discuss what their differences reveal about the politics ingrained in socio-technical arrangements that shape outdoor water conservation in Los Angeles. The analysis is prefaced by a brief discussion of Los Angeles' combined history of modern water infrastructure and garden city development.

4.4 Semitropical Los Angeles facing the 2011 through 2016 drought

> "It's harder to have a garden than to have a yard. A lawn is very, very easy. As long as it's greenish and flat and it's mowed and it's green, you've won. You've won. You know, you did it. You succeed." (Interview 1, 2018)

Spanish missionaries founded Los Angeles in the Los Angeles Basin, where a Mediterranean climate and fresh water from the Los Angeles River were conducive for settlement and agriculture. In the twentieth century, expanding water networks turned the relationship between Los Angeles and its water resources inside out – through water imports, water was sourced from distant water catchment basins rather than locally. The construction of the 233-mile Los Angeles Aqueduct in 1913 famously unlocked the "invention" of modern Los Angeles as a semitropical garden city (Sackman, 2005). Lawned gardens proliferated in the affluent foothills, and autochthonous plants were replaced by "garden tolerant" (Green, 2017) species from Europe or tropical colonies that thrived in irrigated gardens. Simultaneously, land developers disseminated a powerful "from desert to garden" (Imperial Land Company, 1902) vision of Southern California that not only boosted urban growth but also established an imaginary rift between a city oasis and its allegedly hostile and worthless "desert" environment (see Figure 7). Lush green flourished predominantly on private property after real estate lobbyists had successfully thwarted the creation of a regional public park system in the 1930s (Hise and Deverell, 2000).

After World War II, water, tools, irrigation systems, and cheap immigrant labor rendered semitropical gardens the norm for middle- and upper-class neighborhoods. The MWD provided additional imported water from the Colorado River and California's State Water Project, which kept Los Angeles booming and blooming. Since its foundation in 1928, the MWD has been controlled by its member agencies (i.e., Southern California's public and private water utilities) but

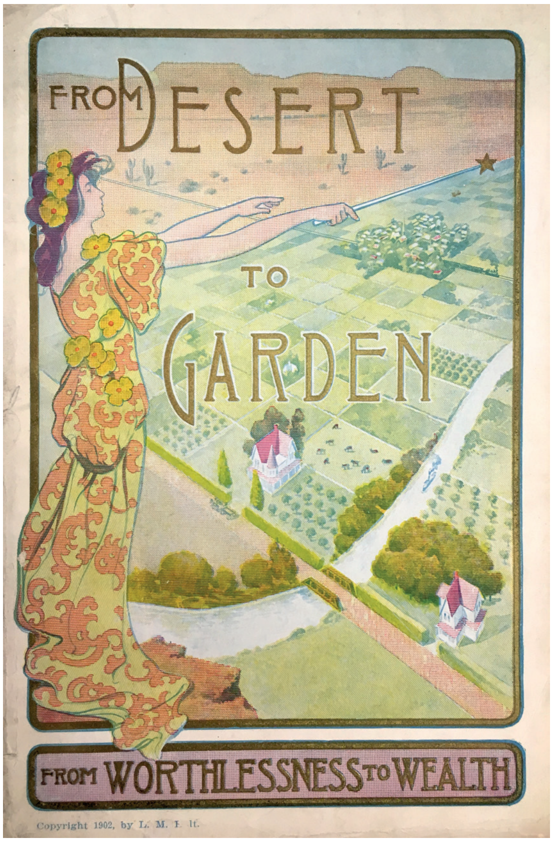

FIGURE 7 From Desert to Garden book cover (Imperial Land Company 1902; The Huntington Library, San Marino, California)

has operated as a revenue-driven business. Infrastructure investments in a vast system of dams and aqueducts have historically been made to expand the water supply. Similarly, the public LADWP incorporated an expansionist approach to water provision to keep water prices low and revenues flourishing. The strict control of water pricing through the votes of City Council members on unpopular water rate increases and a rigid regime of local taxes and fees in California[13] restrict LADWP's investment decisions. Throughout the twentieth century, technomanagerial efficiency propelled regional urban growth in a concerted effort of network expansion and urban development (MacKillop and Boudreau, 2008) and stimulated lock-ins into high consumption patterns. Only since the 1990s has LADWP more strongly embraced indoor water conservation (e.g., through promoting efficient showerheads) and a (somewhat tentative) conservation-

13 California's Proposition 13 (1978) cut local property taxes extensively and requires a two-thirds voter majority for tax increases. Proposition 218 (1996) regulates public service fees, limiting conservation-oriented water rate structures.

oriented rate structure, which has left high-consuming customers with a slightly higher per-unit price. Conservation strategies have been deployed to ensure unfettered growth in the face of finite resources and increasingly unreliable water imports (Hughes et al., 2013: 54–55).

Los Angeles' semitropical gardens are sustained by infrastructure and specific technonatural relations. Near-ubiquitous irrigation systems constantly water a cosmopolitan variety of plants. Typically, ground sprinklers are connected to underground piping, a pump, a pressure regulator, and a controller. Lawns, palm trees, and the city's floral emblem, the South African Bird of Paradise (*Strelitzia reginae*), require continuous irrigation throughout the year, especially during the long dry period from April until October. Repetitive irrigation cycles – typically watering "10 min, three times a week" (Interview 2, 2019) – flatten seasonal variation in rainfall and normalize high water consumption. What would otherwise require expert knowledge about sprinkler type, soil characteristics, and plant species is left to this standardized popular program formula. Meanwhile, the visual appearance of lawns functions as a proxy for plant health, and gardeners tend to water more to ensure lush green and prevent client complaints. Continuous irrigation and a balmy climate turn semitropical gardens into fast-paced technonatures, with landscape irrigation on average accounting for more than half of single-family water use (Mini et al., 2014).

Specific landscaping practices have been developed to curb rapid plant growth. Typically, gardening work in Los Angeles is contracted out to a low-wage, immigrant workforce. Until the 1970s, Japanese gardeners used hand clippers as iconic symbols of their skilled labor, but nowadays the mostly Mexican gardeners rely on power tools (Ramirez and Hondagneu-Sotelo, 2009: 74). These air-polluting devices standardize gardening work, thereby marginalizing horticulturally skilled gardening techniques. In weekly efforts, "mow-blow-and-go guys" (Interview 3, 2018) mow grass, blow dead plant material off the garden, apply chemicals, prune plants, and remove vast amounts of green waste to keep semitropical gardens in a static form, satisfying modernist aesthetic desires for domesticated nature. At the same time, the livelihoods of undocumented workers depend on frequent labor input, with one job in a suburban residential garden typically taking "30 to 60 min" (Ramirez and Hondagneu-Sotelo, 2009: 74). An abundance of garden products fuels this thirsty "treadmill" (Interview 4, 2019) ecology of semitropical Los Angeles.

Since the 1980s, xeriscaping, a form of adaptive landscaping in dry climates that strongly promotes efficient irrigation technology and uses drought-tolerant plants, has been adopted by water agencies in the southwestern United States (Sovocool et al., 2006). Finding that 66% of water savings in xeriscapes are realized through irrigation efficiency, Hilaire et al. (2008: 2086) underlined that the "emphasis must be placed on irrigation systems." Not until California's drought between 2011 and 2016, though, was massive public attention directed at Los Angeles' semitropical gardens, which were portrayed as the new frontier of water conservation. In May 2015, Governor Jerry Brown (2015) mandated a statewide reduction of urban water use by 25% compared to 2013 levels. The order imposed large-scale turf-removal programs and reformed California's Model Water Landscaping Ordinance to combine water-efficient landscaping with stormwater improvements in landscapes. These endeavors enrolled private gardens in technocratic efforts to maximize water conservation while increasing local water supplies through stormwater reuse (Cousins, 2017). The Executive Order Making Water Conservation a California Way of Life, signed in 2016, established a mechanism to determine and monitor local water conservation targets and resulted in new legislation promoting the reduction of outdoor water use (California Department of Water Resources, 2018). In this context, LADWP and the MWD initiated a joint California Friendly® landscaping program to tap into the enormous conservation potential of private gardens. This trademarked and specially developed drought-tolerant landscaping scheme was tied to a rebate program for turf removal: Through a $350 million investment from the MWD's emergency fund[14] and additional LADWP incentives, customers could receive a $3.75 subsidy per square foot of replaced lawn, which sparked "astronomical participation" (Interview 5, 2018).

The core elements of California Friendly® landscapes are a global plant palette of drought-tolerant, low-maintenance species and drip irrigation systems – perforated underground plastic tubes that apply irrigation water directly to the roots (Kent, 2017). Mulch, rocks, or gravel are required as permeable ground cover. In particular, improvements in irrigation systems mobilize a technology-centered conservation approach that sustains LADWP's strategy to ensure a cost-efficient and reliable water supply for a growing city under increasing uncertainty.

The attractive rebates led to the emergence of specialized turf-removal businesses. One company, called Turf Terminators, became notorious for installing what was perceived as bare landscapes predominantly of gravel and rocks or artificial grass, with minimal plant cover (see Figure 8). Offering to remove turf for customers for precisely the rebate amount, the business received "roughly 12%" (Scott, 2016) of the MWD's total rebate fund. Turf Terminators were heavily criticized by Los Angeles' environmental community and the broader public for creating landscapes that increase plastic waste (for artificial turf), reduce biodiversity, and exacerbate urban heat island effects. The company closed down in 2015, and since 2016 water agencies have stopped subsidizing artificial turf.

The MWD's $350 million fund was exhausted within a year, and by 2015, Los Angeles residents were receiving only $1.75 from LADWP per square foot of replaced lawn (Luskin Center for Innovation, 2017: 1). The MWD (2019: 1) resumed

14 This equates to approximately 20% of the MWD's 2018–2019 budget (MWD 2018, 29). Before then, the agency spent $20 million annually on water conservation (Interview 6, 2018).

FIGURE 8 A landscape retrofit by Turf Terminators (photo by Ewan Telford, 2016)

the program in April 2018 with a drastically reduced annual budget of $17 million. As participation after the drought remained low, the subsidy was raised again in February 2019 from $1 to $2 per square foot, and plant coverage requirements were relaxed (MWD, 2019: 2). Generally, however, the MWD strategically refrained from heavily funded turf-removal subsidies. Having only replaced approximately 3% of the lawns in the district's service area by investing $350 million (Interview 6, 2018), water managers opted instead to promote a paradigm shift in gardening through marketing and education.

A second alternative response to the drought emerged through a niche movement of California native plant conservationists. Since the 1980s, native plant gardening for water conservation has been advocated across the southwestern United States (Mee et al., 2003). Rather than being an overarching paradigm, though, native plant advocates see water conservation as a consequence of restoring autochthonous biodiversity. Schmidt's (1980: 1) early "case for native plants" foregrounded habitat preservation as the prime objective of California conservationists. Today, a network of growers and experts – including specialized landscape architects, contractors, and nurseries – promote a holistic idea of landscaping as facilitating and reestablishing native plant ecologies as "living systems" (Interview 7, 2019) that have been "lost" to urbanization. The emphasis is on the horticultural value of autochthonous plants and their symbiotic relationship with the local fauna and climate and their role as aesthetic markers of a distinct Californian cultural history (Bornstein et al., 2005; see Figure 9). The conservationists emphasize skilled techniques as a form of interaction with landscapes: Detailed plant knowledge, careful plant selection, and vernacular planting and cultivation practices are considered vital to create largely self-sustaining native plant ecologies that minimize technology and resource input.

4.5 The material politics of reworking residential gardens in Los Angeles

Drought-tolerant landscaping means different things to different communities and is shaped by environmental values. Environmental action might be based on diverging worldviews such as modernist approaches of sustainability or conservationist thinking to restore nature inspired by ideas of wilderness (Davison, 2009). Although water conservation managers and California native plant advocates in Los Angeles both problematize resource-intensive semitropical gardens, they propose competing landscape ecologies to reinvent this modern urban nature. In this section, we carve out the particular technonatural characteristics and unpack the material politics of the California Friendly® landscaping and California native plant gardening approaches by focusing on three themes (see Table 2 for an overview). We first discuss contested views of the interplay between technologies, plants, and material objects in garden retrofits. Second, we analyze the differing landscaping practices and related forms of expertise and labor. Third, we critically reflect on the socio-technical context of water conservation policy in Los Angeles and relations between LADWP and citizens as inferred from the city's gardens.

4.5.1 Technologies, plants, and material objects

Aside from behavioral change, water agencies' conservation policies have often been promoted as a matter of technological improvement. Refining irrigation technology is central to cutting water use through California Friendly® landscaping. Drip irrigation reduces the amount of water applied to a landscape, and "smart" weather-based irrigation controllers promise to correct the inefficiencies of a "set it and forget it" (Interview 8, 2019) logic dominating garden irrigation. Algorithms are envisioned to automate the background of irrigation, and control apps will enable complex ecosystems to be managed conveniently via a smartphone (Interview 9, 2019).

By contrast, California native plant conservationists frame landscape water needs primarily as ecosystem design. Native plants are cultivated as slow-growing but dynamic elements of urban ecosystems adapted to local soil and climate conditions, thereby minimizing water needs and human and technological input (Interview 2, 2019). The plants themselves are at the forefront

FIGURE 9 California native plant demonstration garden at the Natural History Museum of Los Angeles County (photo by Valentin Meilinger, 2019)

and center of any intervention. They are mobilized as water conservation tools by selecting locally adapted species that require little or no extra water, designing landscapes that divert rainwater to plants, and facilitating deep root establishment during the wetter winter months (Interview 10, 2019). Summer dormancy – when the metabolic activity of native plants is reduced to a minimum – challenges the idea that year-round irrigation is a prerequisite for landscaping in Los Angeles. In general, proponents of native plants seek to create interconnected habitat "corridors" (Interview 11, 2019) of autochthonous biodiversity that also serve as a carbon sink and can moderate heat island effects while keeping dynamic water needs low.

Also, a global plant palette for California Friendly® landscapes has been carefully assembled, including many species from South Africa, Australia, the Canary Islands, and California native plants (Kent, 2017). To ensure effective long-term water conservation, the plants selected have low water needs, require little maintenance, are resilient to external disturbances (including harmful gardening practices), and are commercially available. Their use of specific materials also distinguishes California Friendly® landscapes. The rebate requirements for plant coverage have recently been loosened – rocks and gravel thus remain important low-maintenance ground covers, and organic mulch is required in a three-inchdeep ring around all plants (MWD, 2019: 2). Similarly, California's Model Water Efficient Landscape Ordinance, which sets a maximum for outdoor water use for new development and substantial redevelopment, excludes unplanted backyards from its water budget rating. A sustainability manager of a prominent housing developer explained that developers frequently take advantage of this loophole to provide customers with more choices if they prefer hardscapes, such as a patio or a swimming pool in their backyard (Interview 12, 2019). By so doing, regulators prioritized effective water conservation above increasing the use of adaptive plant ecosystems.

The design choices made for California Friendly® landscapes and California native plant gardens reveal divergent ideas on the use of urban water and space, as well as different epistemologies of nature and technology. California Friendly® landscapes are devised as scalable technonatures to ensure effective water conservation. Planting drought-resistant plants undeniably introduces ideas of water sufficiency by reducing the water footprint through gardening practices (see Princen, 2003). A focus on irrigation efficiency, however, limits further exploration of plant-driven water sufficiency. At the heart of California Friendly® landscaping is the transformation of gardens to maximize water conservation at minimum cost to ensure that a growing city will be reliably supplied with water in a future of reduced water imports (see Table 2). By assembling robust, low-water plants and enhanced irrigation technology, gardens are infrastructured to contribute to the durability of an inherited system under pressure and to "place the future [of water scarcity] further away" (T. Mitchell, 2020). Via such infrastructuring, water agencies redefine the use of water and private urban space following abstract ideas of water conservation, and this is hardly publicly debated as a political question. The long-term social and environmental costs of highly engineered outdoor water conservation, however, could perpetuate biologically less prolific urban landscapes and smart irrigation technologies that rely on pumps, sensors, servers, and so on, building increasing energy demand into landscapes.

TABLE 2 Comparing technonatural characteristics and politics of California Friendly® landscaping and California native plant gardening

	California Friendly® landscaping	**California native plant gardening**
Role of technology	Smart, automated irrigation systems as prime tools to control watering practices and landscape water needs	Irrigation technology as "last resort"; gardens as self-sustaining ecosystems with technology input
Role of plants	A global plant palette of drought-tolerant, robust, and low-care plants as rather static elements of landscapes	Locally adapted California native plants as dynamic co-agents of outdoor water conservation in gardens
Gardening practices	"Installing" and maintaining gardens through technology-led and highly standardized landscaping practices	"Growing" and maintaining gardens through horticultural techniques as skilled, seasonal gardening practices

Expertise	Focus on technical irrigation expertise; standardized knowledge on California Friendly® plants and their maintenance	Expertise in California native plants, their individual biological relations, and their seasonal maintenance needs
Labor relations	Standardized, technology-oriented landscaping work; infrequent interventions in highly engineered landscapes	Highly skilled and knowledge-intensive gardening work with infrequent but better paid landscape interventions
Ideas of nature and technology	Human control of static and highly engineered landscapes through technology	Gardens as dynamic ecosystems, ideally with no technology input; human co-habitation with these ecosystems
Overall rationale	Highly engineered, standardized, and scalable landscapes that enable cost-efficient and reliable water conservation as a new "source" of local water supply	Urban residential gardens as native plant sanctuaries, coupling water sufficiency with the creation of native plant biodiversity corridors

Coupling water conservation with creating autochthonous biodiversity while reducing technology input, California native plant gardening can leverage political debates about the broader (non-monetized) social and ecological values of residential gardens beyond water conservation. In particular, the local character of landscape water conservation – as opposed to importing water, which has externalized environmental costs – provides an opportunity for a progressive rethinking of urban landscapes. Contested practices of infrastructuring gardens reveal political relations between the use of urban space and infrastructural relations that mobilize spaces further away to sustain urban life. California native plant gardening foregrounds plants as co-agents in governing water and urban space. The low water requirements of autochthonous biodiversity challenge the inevitability of deploying irrigation technology that originated as an agricultural innovation to improve crop productivity. The promotion of urban native plant biodiversity can thus not only enrich public discourse about urban landscapes and outdoor water use. It can also rework the city-nature dualism inherent in conservation thinking. As an alternative way of infrastructuring gardens, California native plant landscaping allows plants to be thought of as active elements of infrastructure provision. Urban water management increasingly becomes a question of dealing with urban biomass, which provides an opportunity to recast entrenched knowledge hierarchies and to critically rethink the wider urban environmental politics of water conservation policies (see Table 2).

4.5.2 Practices, expertise, and labor

Drought-tolerant landscapes involve distinct gardening practices and forms of expertise. Watering California Friendly® landscapes mostly revolves around enhancing irrigation technology. Nonetheless, landscaping experts agree that advanced irrigation faces many challenges in practice. Broken pipes are frequently unnoticed, making drip irrigation prone to failure, increasing material waste. Furthermore, by assessing plant health from the visual appearance of plants and incorrectly calibrating smart irrigation systems, both homeowners and commissioned landscapers continuously disrupt the smooth functioning of irrigation (Interview 1, 2018). The actual water use of these systems and their dynamic relationship with plant needs is frequently misunderstood, and "overwatering" (Interview 10, 2019) remains a prime cause of plant (and water) loss. Although smart irrigation algorithms do away with uncertainty about how to water, they can also prevent a more profound practical engagement with landscapes.

Proponents of California native plants place techniques – skilled gardening practices derived from the scientific and practical exploration of vernacular ecosystems – center stage in landscaping. Correct watering is considered a matter of closely observing plants and soils as well as of laboriously "growing" living ecologies instead of quickly "installing" a static landscape (Interview 1, 2018). The growing entails propagating native California species in pots and ensuring that plants establish deep root systems by planting small plants in the fall. Native plant horticulturists deem irrigation technology a "last resort" (Interview 10, 2019) rather than an inherent element of a garden landscape. They criticize that modern societies grant technology an elevated role in landscape care:

> "The whole idea of landscaping, it's also diminished in value because when it really comes down to it, it's not about tech[nology], it's about technique."
> (Interview 10, 2019)

Water conservation is thus viewed as a consequence of meticulous plant care that does not lend itself to the economy of scale principles. Once established, California native plant landscapes demand infrequent but horticulturally skilled "long-term inputs" (Interview 11, 2019) following the fundamental principles of seasonality, plant life cycles (root growth, strategic pruning), and local material cycles (dead organic material is left in place).

Highly engineered and favoring sturdy plants, California Friendly® landscapes are designed for robustness and low maintenance. The approach is applied in an environment in which landscaping maintenance is a highly standardized and machine-aided practice, and specialized horticultural expertise is frequently absent or not used. Hence, irrigation failure, inadequate pruning, and acidic urban soils are still expected to result in moribund California Friendly® landscape planting (Interview 3, 2018). More important, however, experts predict landscaping workers will continue their usual ingrained maintenance practices to secure a constant income (Interview 2, 2019). This social context of landscaping work puts into perspective visions of rationalizing outdoor water conservation through mere material changes:

> "If we devaluate our landscapes from the get-go, we're also devaluating the labor force and therefore we're setting unrealistic expectations as to how we're hiring to maintain […] the most complex ecological systems that we've devised." (Interview 4, 2019)

With landscapes and their upkeep work remaining culturally undervalued and given the high competition among landscapers, wages for gardeners are low. The average monthly rates for garden maintenance in a single-family home in Los Angeles dropped from between $75 and $100 in the 1980s to as low as $50 by the end of the 1990s. More recently, informal gardeners in Los Angeles earned between $50 and $75 per day (Huerta and Morales, 2014: 69). Self-employed landscapers and small businesses, predominantly run by Mexican immigrants and often undeclared labor, have tailored their business models to the frequent maintenance requirements of semitropical gardens. Successful landscape "worker-entrepreneurs" (Ramirez and Hondagneu-Sotelo, 2009: 74) are deemed to manage a maximum number of gardens with minimal time expenditure per garden (see also Hondagneu-Sotelo, 2014).

After significant budget cuts for water conservation in 2015, water agencies embraced landscaping education – a "recognized challenge" (Interview 5, 2018). Free California Friendly® gardening workshops for homeowners addressed irrigation control, California Friendly® plants, soil characteristics, climate zones, and garden design templates to standardize turf-removal projects and simplify landscape maintenance. The California Friendly® landscaping manual starts with a detailed section on irrigation control before introducing the watering, fertilizing, and pruning needs of California Friendly® plants (Kent, 2017).

Although the MWD is collaborating with the California Landscape Contractors Associations on a certification program for professional landscapers, the undocumented status of many landscaping workers limits the outreach of such programs. An expert horticulturist who trains homeowners and professionals criticized water agency-sponsored classes for being "irrigation-centric" (Interview 10, 2019). Although there are some overlaps between California Friendly® landscaping and California native plant gardening, their qualitative differences raise important questions about the value assigned to landscape ecologies and landscaping work. Designed for cost-efficient and reliable water conservation according to institutionalized engineering principles of water management, California Friendly® landscapes contrive labor worlds of reduced maintenance work. Water agencies' budget cuts for water conservation, together with cost-efficiency standards and low water prices, leave little room for well-resourced landscaping industry transformation programs. As carefully selected new infrastructure components, plants enable what Ernwein (2020: 3) called "eco-managerialist" forms of urban environmental management that perpetuate uneven labor relations and an existing skill set of landscaping work. Hence, to facilitate the desired infrastructure development, practices of infrastructuring gardens can, at times, incorporate existing injustices into an emerging infrastructure arrangement. Adding to D. Mitchell's (1996) idea of "dead labor" materialized in landscapes, the nonhuman work performed by California Friendly® plants constitutes a – socially uneven – backdrop of urban water management. Additionally, a huge power differential between immigrant landscaping workers and a multibillion-dollar garden supply industry that benefits from semitropical gardens and high technology input into gardens – two sides of the same coin – obstructs the reinvention of this industry. Although urban green is increasingly portrayed in policy discourses as something universally "good" (Angelo, 2020), its sustaining technonatural relations frequently remain pervaded by power imbalances. Tracing practices of infrastructuring gardens can reveal how the interplay of technical, human, and nonhuman agencies in local disputes over environmental management is bound up with labor relations or global discourses of urban sustainability.

California native plant gardens are still curated mostly by enthusiastic conservationists or designed as high-end gardens professionally horticulturally maintained for wealthy homeowners. Scaling up these ecologies requires significant shifts in the interplay of technology, plants, knowledge, and labor, and thus a radical transformation of the incumbent political ecology of landscaping. The idea of revaluing skilled horticultural practices through more widespread practical engagement with native plants as infrastructure components implies a powerful critique of low-wage landscaping work and technology-centered garden retrofits. Furthermore, if California native plants are to be grown, the nursery industry needs to shift toward local geographies and seasonal business models of raising and supplying autochthonous plants in big-box stores. Such a move challenges the industry of raising and selling perennial plants that coevolved with irrigation technology. Not least, infrastructuring gardens using native plants blurs the boundaries between public infrastructure and economic development policy. To promote a local Green New Deal, Los Angeles has launched the LA Cleantech Incubator, providing workspaces and funding for technology companies in clean energy. A native plant horticulturist, however, noted that a "landscape incubator" lies beyond the realm of contemporary sustainability policy (Interview 10, 2019). Rethinking water conservation through California native plants reveals this absence of a public policy that promotes sufficiency-oriented economic and infrastructure development in which plants – rather than technofixes – are center stage.

4.5.3 Gardens, water regimes, and citizens

Garden retrofits in Los Angeles need to be viewed against the backdrop of the city's current regime of water provision, which becomes renegotiated through practices of infrastructuring gardens.

LADWP and the MWD generate revenue from water sales. Hence, water conservation remains contested within both agencies, where environmentalists argue with proponents of business: "it's walking a fine line [...], the more conservation we do, the less water we sell" (Interview 6, 2018). Coupled with the high infrastructure fixed costs and traditionally low and strictly controlled water rates in Los Angeles, revenues that depend on volumetric water sales structurally disincentivize water conservation (Interview 13, 2018). In this context, the curtailing of turf-removal funds after the MDW's $350 million drought emergency investment signals a return to a less radical water conservation agenda. A technoeconomic rationale of offsetting increasingly costly and energy-intensive water imports from the Colorado River and the California State Water Project is what drives water conservation strategies in Los Angeles. Landscape water conservation can reduce the city's carbon footprint (Cousins and Newell, 2015). Moreover, turf removal is considered one of the cheapest new water sources for Southern California's growing cities compared to other efficiency technologies and new supplies from wastewater recycling or desalination. Cooley and Phurisambam (2016: 3) estimated that conserving one acre-foot of water annually through creating cheap water conservation landscapes can save up to $4,500 because lower landscape maintenance costs outweigh investment costs. Investing in high-end conservation landscapes would cost $1,400 per acre-foot of water conserved annually.

Despite the excellent potential for water conservation, the mobilization of private gardens for water conservation presents a complex challenge for water agencies. An interviewed horticulturist noted that unlike roads, electricity lines, or water pipes, residential landscaping has never "risen to a level of [public] health, safety, and welfare" (Interview 10, 2019). In fact, modern urban infrastructures have created an apparent rift between public service providers and passive consumers. Furthermore, Los Angeles' water agencies are adept in the financing, planning, and operating large technical infrastructures, whereas profound ecological and horticultural knowledge has historically been beyond their realm of expertise. Operating on unfamiliar terrain and with strict public control of water rates, LADWP engineers thus deploy irrigation systems to control thirsty plant ecologies and unsustainable watering practices. Technology companies envision automated irrigation as part of a smart home's "distributed infrastructure" that promises cost-efficient water conservation by allowing water utilities "to prescribe better behavior" based on monitored user data (Interview 14, 2019).

Smart irrigation undeniably increases water conservation: The U.S. Environmental Protection Agency (2017) estimated that replacing clock timers with smart irrigation controllers results in annual savings of 7,600 gallons of water for an average home. Infrastructuring gardens via such devices drives up electricity consumption, tying gardens closer to energy systems, data centers, and greenhouse gas emissions. Although promoting ideas of creating harmonious urban natures in a climate-changing world, such infrastructured gardens bring about new collectives that accelerate the extractive "logics of circuits, chips, and capital" (Gabrys, 2022: 2). A spokesperson for a smart irrigation business explained that as a "consumer-driven" development, automating irrigation aims "to put the homeowner back into the driver seat" (Interview 14, 2019) by granting homeowners more control over irrigation and their water bills. Horticulturists are skeptical about such visions and underline the risk that automation further distances homeowners from a practical engagement with the dynamic ecosystems in their gardens (Interview 4, 2019).

In general, water conservation policies in Los Angeles have traditionally preferred user education – frequently about individual cost savings – and economic incentives for technical retrofitting over conservation-oriented water rates. Acting as "ratepayer advocate," Los Angeles' city controller Ron Galperin closely oversees LADWP's spending in the interest of cheap, abundant, and safe water. Galperin (2015: 2) criticized the cost efficiency of turf-removal rebates between 2014 and 2015; replacing the existing 2.5 million acres of California lawns with a rebate of $3 per square foot would amount to a stunning cost of $403 billion (Galperin, 2015: 4). Instead, he suggested encouraging voluntary conservation through subsidizing smart water meters and rewarding individual water savers. Water supply reliability, he argued, should primarily be ensured through investments in wastewater recycling. Expanding supply, instead of investing in conservation, increases the asset value of water utilities (Bell, 2015: 19). Meanwhile, to foster a culture of individual action, water agencies give out free rain barrels as symbols of water use efficiency: "landscaping is the water efficiency you can see [...]. It's like having a Prius in your driveway" (Interview 6, 2019). In turn, excessive garden watering, notoriously in upmarket West Los Angeles neighborhoods, is increasingly being publicly denounced.

Infrastructuring gardens through California Friendly® landscapes reconstitutes relationships between water agencies and users. Turf-removal programs reeducate homeowners as "California Friendly" subjects who visibly perform environmental responsibility while realizing individual cost savings. This, however, is socially uneven: Whereas all rate payers fund turf-removal subsidies, the beneficiaries tend to be middle- and high-income homeowners with gardens (Pincetl et al., 2017). At the same time, endeavors to fix a culture of abundant outdoor water consumption through California Friendly® landscaping do not impinge on politically delicate debates about more progressive water pricing. Users continue to consume an abstract resource and to strictly oversee water rates and their water bills, even as advanced irrigation controls watering inefficiencies. This illustrates how plants and, in particular, technological fixes in California Friendly® landscapes such as “smart” irrigation stabilize existing political orders of water governance. In contrast, California native plant gardening reimagines homeowners as civic experts who contribute to a larger public good through informed gardening choices and practices. Being a good homeowner means doing more than conserving water, but curating gardens through skilled practice. Instead of granting agency to automated irrigation technology, a focus on practice lifts gardens as dynamic ecologies into the foreground of everyday urban life and water governance. The infrastructured garden can become an important site where identity is tied to more ecological practices and where novel technonatural imaginaries of the city are created that recast inherited boundaries between public infrastructure provision and the private realm of the city.

4.6 Conclusion

Although historically relegated to the margins of public urban life, residential gardens form complex technonatures with profound social and environmental implications for urban development. Infrastructural practices of retrofitting gardens to conserve water render these relationships visible and raise critical questions about the dominant technologically mediated management of urban nature. Furthermore, infrastructural disputes over relandscaping illustrate a crucial dynamic of governing urban nature in the Anthropocene: Systemic endeavors to make the urban fabric at large an infrastructure for climate resilience or resource efficiency goals increasingly clash with alternative approaches to urban nature such as biodiversity restoration or urban rewilding.

This article has explored the material politics of remaking the semitropical residential gardens in Los Angeles through California Friendly® landscaping and California native plant gardening. Developed for a subsidized turf-removal program from Los Angeles’ water agencies, California Friendly® landscaping translates a rationale of maximizing water conservation into gardens. Meanwhile, California native plant gardening that is advocated by conservationists couples water sufficiency with enhancing autochthonous biodiversity. This approach also promotes skilled horticultural techniques, challenging an inequitable landscaping industry in which the high profits of equipment suppliers contrast with underpaid labor. California Friendly® landscaping aims to control watering practices by improving irrigation, which has normalized technology-centered environmental management that has culturally undervalued biology and landscaping work. Water agencies further encourage voluntary garden retrofits by emphasizing individual monetary savings. These retrofits, however, result in money from all ratepayers being redistributed to (relatively well-off) garden owners and stymie debates about more progressive water rates that are more socially just and could encourage alternative gardening techniques. Policymakers need to address such injustices caused by public infrastructure investments, but this raises issues of institutional and governance reform to change the constraints and incentives under which public water managers operate – their revenue largely depends on selling large volumes of cheap water.

Our article illustrates how the politics of Los Angeles' inherited water infrastructure regime profoundly shape garden retrofits. Confronted with the complexity of urban landscapes, this regime also becomes renegotiated in residential gardens. We have developed the notion of infrastructuring gardens to foreground practices and projects of reconfiguring technical and other material artifacts and knowledges in gardening as political forces that shape new ways of organizing urban nature and space through infrastructure. Practices of infrastructuring gardens reveal power differentials and the instances of emerging alternative politics of urban nature. This perspective can advance geographical debates about urban infrastructure and environmental politics in three distinct ways.

First, as plants, technical artifacts, and other material objects in gardens become reconfigured through novel infrastructural practices, they become agents in governing urban nature and space. As a result, geographies of infrastructural contestations are extended into residential gardens. Adding to urban scholarship on political practices through technology (e.g., Sultana, 2013), we have shown how plants are rendered mediating components of infrastructure development. Tracing the practices of infrastructuring gardens can highlight rationales of sufficiency or alternative purposes of water use that are embedded in landscape ecosystems. These rationales from the margins can be related to the technomanagerial logics at the center of urban water regimes, advancing geographical work on the malleability of urban infrastructures (Furlong, 2011; Tiwale, 2019). Thinking in terms of infrastructuring gardens thus allows us to critically interrogate abstract ideas of relationships between water, technology, and urbanization underlying entrenched urban lifestyles, patterns of urban development, and forms of urban water management. The concept further offers a heuristic to analyze politically significant relations between technology, humans, and nonhumans, which can enrich debates on more-than-human geographies with a more robust conceptualization of technology.

Second, processes of infrastructuring gardens convene different forms of expertise. In many cities, modernist approaches to managing urban nature through technology and engineering remain hegemonic. The practices of remaking semitropical Los Angeles, however, reveal urban gardens as objects of ecological and technical knowledge and formalized and practical knowledge. The political lesson to draw is the need for hitherto separate knowledge cultures to be integrated to create multi-benefit urban infrastructures. Analytically, an infrastructure perspective can help foreground the importance of previously undervalued knowledge in urban environmental management. For instance, the mutual dependence of water supply policies and plant ecologies that rely on skilled maintenance can provoke new articulations of valuing urban nature and ecological work that could be seedbeds of more progressive politics of urban nature.

Finally, the notion of infrastructuring gardens outlines a specific take on the clash between the technocratic management of urban nature and gardens as spaces of everyday human and nonhuman urban life. This allows political conflicts over urban environmental management to be understood through exploring the instability of different cultures of knowing and managing nature that clash in technical disputes over infrastructure development. Geographical research on how marginalized cultures of urban nature gain infrastructural relevance alongside technocratic practices can benefit from, and inform, critical studies of technology that examine technology not as "a servant of some predefined social purpose," but as "an environment within which a way of life is elaborated" (Feenberg, 2010: 15). Exploring moments of infrastructure formation offers a more open-ended lens on conflicts over environmental management shaped by expertise as scrutinized by urban political ecologists (Cousins, 2017). Similarly, urban infrastructural change can be explained by tracing how – and at what moments – actors incorporate particular artifacts into infrastructure to realize a particular infrastructure development. Although relying on specific practices, infrastructure consequently constitutes a powerful ordering mechanism of urban processes. Concepts of urban technonatures can be fruitfully expanded by taking account of this ordering power of infrastructure, thereby bringing attention to infrastructural practices and discourses that reconfigure urban technonatural relationships.

Empirically, the expansion of smart technologies from homes into gardens needs to be critically scrutinized concerning the social organization of public goods and inequitable economic relations. Smart gardening further highlights how urban subjectivities are contested at the intersection of ecological and smart city practices, which can inform nascent geographical scholarship on digital urban natures (Moss et al., 2021). Furthermore, an infrastructure lens on urban technonatures can reveal how technically constituted power might pervade uneven political economies of ecological labor (Ernwein, 2020) or interfere with meaning-making processes through human–plant interactions as debated by cultural geographers (Gandy, 2022). We argue that studying how gardens become components of urban infrastructures is politically relevant. It provides an opportunity to rework a cultural dominance of technology underlying institutionalized forms of urban environmental governance. Tracing technological agency in relation to other human and nonhuman agencies in practices of infrastructuring gardens can clarify the role of technology in the "ecological pluriverse" (Gandy, 2022) of contemporary cities. This can advance a critical study of system-based approaches to urban environmental governance. Urban gardens provide a rich repository for such an agenda. They blur the boundaries between technology and nature, public and private, and their complex biophysical and social dynamics evade complete technical control.

4.7 References

Angelo, H. 2020. How green became good. Urbanized nature and the making of cities and citizens. University of Chicago Press, Chicago.

Askew, L.E. and P.M. McGuirk 2004. Watering the suburbs: distinction, conformity and the suburban garden. *Australian Geographer* 35(1): 17-37.

Ballard, R. and G.A. Jones 2011. Natural neighbors: indigenous landscapes and eco-estates in Durban, South Africa. *Annals of the Association of American Geographers* 101(1): 131-148.

Bell, S. 2015. Renegotiating urban water. *Progress in planning* 96: 1-28.

Blok, A., M. Nakazora and B.R. Winthereik 2016. Infrastructuring environments. *Science as Culture* 25(1): 1-22.

Bornstein, C., D. Fross and B. O'Brien 2005. California native plants for the garden. Cachuma Press, Los Olivos.

Brooks, A. and R.A. Francis 2019. Artificial lawn people. *Environment and Planning E: Nature and Space* 2(3): 548–564.

Brown, E. 2015. Executive Order B-29-15. Accessed 19 July, 2021. https://www.ca.gov/archive/gov39/wp-content/uploads/2017/09/4.1.15_Executive_Order.pdf

California Department of Water Resources 2018. Making water conservation a California way of life. Sacramento.

Carse, A. 2012. Nature as infrastructure: making and managing the Panama Canal watershed. *Social Studies of Science* 42(4): 539-563.

Cooley, H. and R. Phurisambam 2016. The cost of alternative water supply and efficiency options in California. Executive summary. Pacific Institute. Oakland.

Cosgrove, D. 1998. Social formation and symbolic landscape. University of Wisconsin Press, Madison.

Cousins, J. J. 2017. Structuring hydrosocial relations in urban water governance. *Annals of the American Association of Geographers* 107(5): 1144-1161.

Cousins, J. J. and J.P. Newell 2015. A political–industrial ecology of water supply infrastructure for Los Angeles. *Geoforum* 58: 38-50.

Coutard, O. and J. Rutherford 2016. Beyond the networked city: an introduction. In O. Coutard and J. Rutherford (eds.), Beyond the networked city: infrastructure reconfigurations and urban change in the North and South. Studies in Urbanism and the City. Routledge, London. 1-25.

Davison, A. 2009. Living between nature and technology: the suburban constitution of environmentalism in Australia. In D.F. White and C. Wilbert C (eds.), Technonatures: environments, technologies, spaces, and places in the twenty-first century. Wilfrid Laurier University Press, Waterloo. 167-189.

Ernwein, M. 2020. Bringing urban parks to life: the more-than-human politics of urban ecological work. *Annals of the American Association of Geographers* Advance online publication. 111(2): 559-576.

Feenberg, A. 2010. Between reason and experience: essays in technology and modernity. MIT Press, Cambridge.

Finewood, M.H., A.M. Matsler and J. Zivkovich 2019. Green infrastructure and the hidden politics of urban stormwater governance in a postindustrial city. *Annals of the American Association of Geographers* 109: 909-925.

Fishman, R. 1987. Bourgeois utopias: the rise and fall of suburbia. Basic books, New York.

Furlong, K. 2011. Small technologies, big change: rethinking infrastructure through STS and geography. *Progress in Human Geography* 35(4), 460-482.

Gabrys, J. 2022. Programming nature as infrastructure in the smart forest city. *Journal of Urban Technology* 1-7.

Galperin, R. 2015. Audit of DWP customer-based water conservation programs. Cover letter. Los Angeles.

Gandy, M. 2022. Natura urbana: ecological constellations in urban space. MIT Press, Cambridge.

Giglioli, I. and E. Swyngedouw 2008. Let's drink to the great thirst! Water and the politics of fractured techno-natures in Sicily. *International Journal of Urban and Regional Research* 32 (2), 392-414.

Gober, P. and B. Trapido-Lurie 2006. Metropolitan Phoenix: place making and community building in the desert. University of Pennsylvania Press, Philadelphia.

Green, E. 2017. Water, native plants, and Southern California's long history of unsustainable gardening. Accessed 1 July, 2019. https://www.kcet.org/shows/lost-la/water-native-plants-and-southern-californias-long-history-of-unsustainable-gardening

Head, L. and J. Atchison 2009. Cultural ecology: emerging human-plant geographies. *Progress in Human Geography* 33(2): 236-245.

Hilaire, R.S., M.A., Arnold MA, D.C. Wilkerson, et al. 2008. Efficient water use in residential urban landscapes. *HortScience* 43(7): 2081-2092.

Hise, G. and W.F. Deverell 2000. Eden by design: the 1930 Olmsted-Bartholomew plan for the Los Angeles region. University of California Press, Berkeley.

Hondagneu-Sotelo, P. 2014. Paradise transplanted: migration and the making of California gardens. University of California Press, Oakland.

Huerta, A. and A. Morales 2014. Formation of a Latino grassroots movement: the Association of Latin American Gardeners of Los Angeles challenges City Hall. *Aztlán: A Journal of Chicano Studies* 39(2): 65-93.

Hughes, S., S. Pincetl and C. Boone 2013. Triple exposure: regulatory, climatic, and political drivers of water management changes in the city of Los Angeles. *Cities* 32(1): 51–59.

Imperial Land Company 1902. From desert to garden: from worthlessness to wealth. Times-Mirror Printing and Binding House, Los Angeles.

Kent, D. 2017. California Friendly®. A maintenance guide for landscapers, gardeners and landscape managers. Los Angeles.

Lachmund, J. 2013. Greening Berlin: the co-production of science, politics, and urban nature. MIT Pres, Cambridge.

Larson, K. L., J. Hoffman and J. Ripplinger 2017. Legacy effects and landscape choices in a desert city. *Landscape and Urban Planning* 165: 22-29.

Luskin Center for Innovation 2017. Turf replacement program impacts on households and ratepayers: an analysis for the City of Los Angeles. University of California, Los Angeles.

MacKillop, F. and J.-A. Boudreau 2008. Water and power networks and urban fragmentation in Los Angeles: rethinking assumed mechanisms. *Geoforum* 39 (6): 1833–1842.

McHarg, I. 1969. Design with nature. Doubleday/Natural History Press, Garden City, N.J.

Mee, W., J. Barnes, R. Kjelgren, et al. 2003. Water wise: native plants for intermountain landscapes. Utah University Press, Colorado.

Melosi, M. 2008. The sanitary city: environmental services in urban America from colonial times to the present. University of Pittsburgh Press, Pittsburgh.

Mini, C., T.S. Hogue and S. Pincetl 2014. Estimation of residential outdoor water use in Los Angeles, California. *Landscape and Urban Planning* 127: 124-135.

Mitchell, D. 1996. The lie of the land: migrant workers and the California landscape. University of Minnesota Press, Minneapolis.

Mitchell, T. 2020. Infrastructures work on time. Accessed 3 July, 2021. https://www.e-flux.com/architecture/new-silk-roads/312596/infrastructures-work-on-time/

Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A: Economy and Space* 41(8): 1924–1942.

Moss, T., F. Voigt and S. Becker 2021. Digital urban nature. *City* 25(3-4): 255-276.

Mustafa, D., T.A. Smucker, F. Ginn, et al. 2010. Xeriscape people and the cultural politics of turfgrass transformation. *Environment and Planning D: Society and Space* 28(4): 600-617.

MWD 2019. Board of directors water planning and stewardship committee board action 8-4. Board Meeting of 12 February, 2019. Los Angeles.

MWD 2018. Biennial budget fiscal years 2018/19 and 2019/20. Realizing the benefit of sound investments. Los Angeles.

Parés, M., H. March and D. Saurí 2013. Atlantic gardens in mediterranean climates: understanding the production of suburban natures in Barcelona. *International Journal of Urban and Regional Research* 37(1): 328-347.

Pincetl, S. 2010. From the sanitary city to the sustainable city: challenges to institutionalising biogenic (nature's services) infrastructure. *Local Environment* 15(1): 43–58.

Pincetl, S., T.W. Gillespie, D. Pataki, et al. 2017. Evaluating the effects of turf-replacement programs in Los Angeles County. UCLA Institute of the Environment and Sustainability. Los Angeles.

Princen, T. 2003. Principles for sustainability: from cooperation and efficiency to sufficiency. *Global Environmental Politics* 3(1): 33-50.

Ramirez, H. and P. Hondagneu-Sotelo 2009. Mexican immigrant gardeners: entrepreneurs or exploited workers? *Social Problems* 56(1): 70-88.

Reisner, M. 1993. Cadillac desert: the American West and its disappearing water. Penguin, New York.

Robbins, P. 2007. Lawn people: how grasses, weeds, and chemicals make us who we are. Temple University Press, Philadelphia.

Roobeek, A.J. 1987. The crisis in Fordism and the rise of a new technological paradigm. *Futures* 19(2): 129-154.

Rutherford, J. 2020. Redeploying urban infrastructure: the politics of urban socio-technical futures. Pelgrave Macmillan, Cham.

Sackman, D. 2005. A garden of worldly delights. In G. Hise and W.F. Deverell (eds.), Land of sunshine: the environmental history of Greater Los Angeles. University of Pittsburgh Press, Pittsburgh. 245-266.

Schmidt, M.G. 1980 Growing California native plants. University of California Press, Berkeley.

Scott, A. 2016. Grass Warfare in L.A. Some well-intentioned Angelenos traded grass for gravel on their front lawns. It got ugly. *Bloomberg Businessweek online*. Accessed 8 July, 2019. https://www.bloomberg.com/features/2016-turf-terminators-grass-war

Sovocool, K.A., M. Morgan and D. Bennett 2006. An in-depth investigation of Xeriscape as a water conservation measure. *Journal-American Water Works Association* 98(2): 82-93.

Star, S. L. and K. Ruhleder 1996. Steps toward an ecology of infrastructure: design and access for large information spaces. *Information Systems Research*, 7(1): 111-134.

Sultana, F. 2013. Water, technology, and development: transformations of development technonatures in changing waterscapes. *Environment and Planning D: Society and Space* 31(2): 337-353.

Tiwale, S. 2019. Materiality matters: revealing how inequities are conceived and sustained in the networked water infrastructure-The case of Lilongwe, Malawi. *Geoforum* 107, 168-178.

US Environmental Protection Agency 2017. WaterSense® labeled irrigation controllers. Accessed 7 January, 2020. https://www.epa.gov/sites/production/files/2017-01/documents/ws-products-factsheet-irrigation-controllers.pdf.

White, D.F. and C. Wilbert 2009. Technonatures: environments, technologies, spaces, and places in the twenty-first century. Wilfrid Laurier University Press, Waterloo.

Worster, D. 1985. Rivers of empire: water, aridity, and the growth of the American West. Oxford University Press, New York.

4.8 Cited interviews

1. Expert in water-efficient landscaping, Los Angeles, 21 February 2018
2. California native plant horticulturist, Los Angeles, 14 March 2019.
3. Expert in water-efficient landscaping, Los Angeles, 13 March 2018.
4. Sustainable landscape manager, City of Santa Monica, Los Angeles, 10 April 2019.
5. Water conservation managers, LADWP, Los Angeles, 16 March 2018.
6. Water conservation manager, MWD, Los Angeles, 26 February 2018.
7. California native plant landscape architect, Los Angeles, 14 March 2019.
8. California native plant landscape professional, Los Angeles, 13 March 2019.
9. Manager, leading lawn and garden supply business, Los Angeles, 2 March 2019.
10. Consultant in water-efficient landscaping, Los Angeles, 13 March 2019.
11. California native plant horticulturist, Los Angeles, 11 April 2019.
12. Sustainability manager, housing development business, Los Angeles, 15 March 2019.
13. Los Angeles water policy expert, Los Angeles, 2 March 2018.
14. Manager, irrigation technology business, Los Angeles, 10 July 2019.

5

One Water in Los Angeles? Contesting the circular city through infrastructural practices

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ABSTRACT

Los Angeles is a paradigmatic modern metropolis under water stress, exacerbated by climate change and severe droughts. To enhance urban water sustainability, city authorities strive to integrate water management tasks by closing urban water cycles. However, the ways which visions of water circularity materialize and influence the politics of urban nature are subject to controversy. This article investigates the forms and political implications of technical disputes over water circularity in Los Angeles, where actors seek to reconfigure water flows through infrastructural practices. We argue that these disputes reflect how actors pursue "technopolitics" of urban water circularity by placing the histories, cultural meanings, and urban geographies linked to certain infrastructure artifacts at the center of political debates about circularity. Public engineers combine centralized infrastructures in an artificial "One Water" loop to decouple urban growth from water imports and pollution while ensuring revenues through water sales. The endeavor to mobilize homes and gardens for technocratic water management underpins this approach. Yet, infrastructure decentralization also involves activists' and homeowners' practices that illustrate plural ways of governing urban nature. We unpack the tensions between these contrasting infrastructure configurations by highlighting their differing rationales for using water and urban space, as well as the relations between users and state experts.

5.1 Introduction

As a semi-tropical garden city constructed in Southern California's Mediterranean climate, Los Angeles represents a paradigmatic example of a modern metropolis facing daunting water challenges. This article takes as a starting point that urbanization and water infrastructure expansion in Los Angeles have resulted in a linear water metabolism, characterized by abundant water imports and rapid stormwater and wastewater discharge following treatment.

Today, droughts are intensifying, and as a result, less water will be able for import in a climate-changing future, even as urban growth remains unabated. In order to enhance water sustainability and climate resilience, the "One Water LA 2040 plan" aims to integrate water management more tightly into a closed urban water cycle, with three strategies (LA Sanitation, 2018). The Los Angeles Bureau of Sanitation (LA Sanitation) and the Los Angeles Department of Water and Power (LADWP) aim to expand wastewater recycling and increase stormwater capture, and offer LADWP subsidies for garden retrofits to promote water conservation. Meanwhile, environmentalists and enthusiastic homeowners advocate for more decentralized, user-driven, and landscape-centric infrastructural practices that link water circularity with broader urban greening ambitions.

Los Angeles offers a valuable case to explore how infrastructure disputes over water circularity reveal diverging proposals for organizing water in urban environments. This focus brings critical attention to different technological cultures of managing urban nature at a time when "circular city" visions proliferate. Studying circular city initiatives as arenas of remaking urban nature in the Anthropocene shaped by multiple human and non-human agencies allows us to critically review approaches to govern urban ecologies as complex adaptive systems (Derickson, 2018; Gandy, 2022). Furthermore, foregrounding the social relations underlying technology in infrastructure disputes can enhance scholarship on power relations in urban environmental governance (Swyngedouw, 2004; Williams et al., 2019).

Circular city visions are inspired by the circular economy, which is an economic model focused on extending resource productivity in a closed loop of material and energy flows (Ghisellini et al., 2016). Urban scholars have shown how creating circular cities involves the renewal of cities as complex socio-ecological systems (Williams, 2019). More critical accounts have also highlighted the uneven power relations that shape circular cities, and have pointed out injustices and unsustainable outcomes resulting from these approaches (Savini, 2019; Keblowski et al., 2020). We argue that studying current dynamics in urban water management allows for the analysis of the still-scantly explored political role of technology in endeavors to remake urban nature following circular city visions. Over the past two decades, the idea of managing urban water as a "total water cycle" (Brown and Farrelly, 2009: 839) has gained traction, while water management technologies have become increasingly diverse, ranging from large-scale wastewater recycling to decentralized and landscape-centric practices for stormwater capture stormwater or water conservation. As such, how the social relations underlying different technologies shape environmental governance in circular water cities becomes a pressing question.

In this article, we explore the “technopolitics” of circular water and wastewater restructuring in Los Angeles by tracing infrastructure disputes over wastewater recycling, stormwater capture, and landscape water conservation. Technopolitics describes how actors pursue political goals by strategically mobilizing the material aspects of technology and their claimed social implications in political controversies (Hecht, 2009). Here, infrastructures are viewed as relational achievements of artifacts and practices that actors can reconfigure depending on their particular knowledge about infrastructure artifacts (Carse, 2012; Blok et al., 2016). In the infrastructure disputes over water circularity in Los Angeles, different technopolitical arrangements arise. These constellations involve diverging proposals for governing urban nature and space that are grounded in actors’ particular understandings of nature and technology, which otherwise often remain obscured by vague circularity discourses. To specify the technopolitics of urban water circularity, we draw on work on infrastructure’s relevance to political economies of urban resource use and development (Kirkpatrick and Smith, 2011; Millington and Sheba, 2021) as well as on infrastructural relations between state experts and users (Meehan, 2014; Truelove, 2021).

The following section explores circularity as a systemic water management concept vis à vis diverse water management practices that bear diverging rationales of aligning water, technology, and urban space. Section 5.3 outlines how and why we use debates in science and technology studies and urban infrastructure studies to analyze the technopolitics of urban water circularity. In Section 5.4, we introduce the current “One Water” ambitions of circular water restructuring in Los Angeles. The discussion reveals two distinct technopolitical arrangements of water circularity. Firstly, infrastructure restructuring by public water utilities, which concentrates water in a One Water loop to promote institutional water management interests. Programs of infrastructure decentralization that underpin this strategy advance a more hybrid water system wherein different technologies co-exist, and actors’ roles diversify. Secondly, this hybridization is increased by practices of environmental groups and enthusiastic homeowners, which display more plural possibilities of governing circular Los Angeles. We explore the different technopolitics by examining forms of water and urban space use, as well as relations between the state and users in circularity endeavors. In the conclusion, we reflect on how studying the technopolitics of urban water circularity can enhance critical geographical research on circular cities.

This article is based on empirical research on shifting water infrastructures in Los Angeles, which was conducted between 2018 and 2021. The research draws from three in-depth case studies on technological arrangements in wastewater recycling, stormwater capture, and landscape water conservation to develop a broader argument about the technopolitics of urban water circularity (Meilinger and Monstadt, 2022a; 2022b; 2023). We used qualitative content analysis to scrutinize selected planning documents, laws, newspaper articles, historical sources, and technical manuals. Additionally, we conducted 54 qualitative expert interviews, and, following our theoretical framework, we analyzed the empirical material according to the categories of: material artifacts and forms of knowledge linked to infrastructural practices. In an iterative analysis process, we refined these categories to explain how technical disputes over circular water restructuring constitute particular forms of urban environmental governance.

5.2 Water and the circular city

The construction of aqueducts and centralized sewers in industrializing cities in Europe and the US has placed resource bases and sinks into urban hinterlands (Melosi, 2008). Vast public spending and the development of public bureaucracies with separate water supply, flood control, and wastewater management tasks have enhanced the efficiency of this "end of the pipe" approach (Karvonen, 2011). Meanwhile, a private culture of water abundance materialized in the piped homes of the modern city, and lawned landscapes were reduced to an ornamental background of everyday life (Robbins, 2007).

Since the 1970s, neoliberal reforms engendered state retrenchment and a stronger profit orientation in urban water management (Bakker, 2010), while stricter environmental regulation raised the burden on local governments. Society's "complex, sometimes schizophrenic" (Melosi, 2008: 178) relationship with science and technology became more visible. Whereas the environmental sciences improved the understanding of environmental problems, progress in science and technology also accelerated an excessive consumption culture. Today, disinvestment and aging infrastructures paired with unfettered urban growth and exacerbating consequences of climate change have provoked a water crisis in many cities. Although the sanitary city has tremendously improved hygienic and environmental conditions, scholars consider it unsustainable due to its linear metabolism of high water use and wastewater disposal (Brown et al., 2009; Pincetl et al., 2019).

Circular economy thinking promises systemic solutions to enhance sustainability by extending resource productivity. The Ellen McArthur Foundation (2013: 14) established an influential definition of the circular economy as "an industrial economy that is restorative or regenerative by intention and design." Central to this model is the idea of decoupling economic growth from resource consumption, which is fiercely debated. Critics underline that circular economy models assume that value creation and continuous growth occur in a human-controlled industrial system separate from nature, downplaying the necessity of nature's limited sink functions to counterbalance continuous resource use (Hofmeister, 2013; Giampietro, 2019). Nonetheless, alternative narratives of the circular economy exist. Early conservationists focused on protecting and restoring nature's productivity to create circular flows of resources and energy (Blomsma and Brennan, 2017). Degrowth advocates reject a capitalist impetus of surpassing scarcity to fuel growth, instead promoting ideas of sufficiency and care, and reciprocity (Kallis, 2021; Savini, 2021). Overall, critics emphasize the need for social, normative, and institutional change to align economic activity, technology, and knowledge creation with the capacity of the earth's biosphere (Giampietro, 2019; Kallis, 2021).

Circular city discourses that promote recycling and reuse practices or ecosystem restoration as opportunities for urban sustainability and livability increasingly shape urban policymaking (Williams, 2019). In the urban water sector, managing water as a "total water cycle" (Brown and Farrelly, 2009: 839) to integrate water management tasks is envisioned to enhance sustainability. Influential policy frameworks for circular water cities have arisen (World Bank, 2021). While these frameworks foresee infrastructure development that designs out waste externalities, keeps resources in use, and regenerates natural capital, more radical ideas to prioritize sufficiency over growth remain unaddressed. Critical geographers suggest that, in practice, synergies and contradictions of system-based approaches to urban nature play out depending on local histories and dynamics of environmental governance (Gandy, 2022). Hence, circular city initiatives shaped by uneven power dynamics can fail to reform excessive consumption (Savini, 2019) or marginalize practices that promote alternatives to market-based values such as sufficiency (Keblowski et al., 2020; Savini, 2021). While there is some critical research on circular cities and urban degrowth, the political role of technology in circular city-making is understudied. How technology enables particular forms of governing urban nature hinges on the norms, values, and worldviews of the actors involved in circular water restructuring and the environments in which they act.

A growing diversity of technologies can be combined to realize urban water circularity. Large-scale engineering solutions have rapidly developed over recent years. Alongside desalination, wastewater recycling is now a widely pursued option to address water scarcity. Green and Bell (2019: 125) describe such "capital-intensive, supply-side solutions in response to uncertainty" as a "neo-hydraulic" approach focused on large-scale technology. Also, decentralized landscape and urban design and technological interventions proliferate in urban water management. Green infrastructures that use ecological processes of the soil and vegetation are increasingly deployed to restore local hydrological cycles and ecosystem functions of landscapes (Li and Jensen, 2018). Depending on their design through different actors, green infrastructures can contribute to diverging goals of environmental governance, while scholars highlight that professional maintenance and public control of decentralized, user-driven infrastructures remains challenging (Cousins, 2018).

Although visions of urban water circularity often assume a smooth combination of diverse technologies, the different social relations underlying technology bear particular arrangements of water, technology, and urban space. We can reveal emerging forms of governing urban nature and space in circular water cities by exploring disputes over infrastructure design, through which actors aim to translate models of water circularity into actual urban practices.

5.3 Technopolitics of urban water circularity

To realize their particular visions of urban water circularity, actors combine different water technologies into new infrastructure arrangements. Research in social studies of infrastructure helps capture the nature and the political relevance of these practices (Carse, 2012). Inspired by Blok et al. (2016), we understand infrastructural practices as the technical, material, and knowledge interventions through which actors combine heterogeneous infrastructure elements to facilitate broader objectives and outcomes. In technical disputes over urban water circularity, different infrastructural practices meet and come into conflict with each other. Urban scholarship helps to understand the context of such disputes that play out in existing infrastructure arrangements of closely intertwined material artifacts, discourses, institutions, rules, money flows, and knowledge orders (Monstadt, 2009; Millington and Sheba, 2021). While these arrangements structure the disputes over infrastructure design, they also evolve as new combinations of infrastructural artifacts and practices emerge. We argue that circularity visions drive such re-combinations by activating new actors, artifacts, and spaces in governing urban nature through infrastructure.

Focusing on the relations between infrastructures and urban nature, we can trace how actors pursue political goals in governing environments by participating in infrastructure disputes over water circularity. These relations can be understood in terms of "technopolitics," which captures how strategic practices of designing and using technology "constitute, embody, or enact political goals" (Hecht, 2009: 15). We analyze the technopolitics of urban water circularity in Los Angeles by exploring how actors place the histories, cultural meanings, and urban geographies linked to particular infrastructure artifacts at the center of political debates about circularity. These ensembles of practices, cultural meaning, and artifacts frame what circularity means in practice and how it governs urban environments. Often, technopolitical power is grounded in existing infrastructure arrangements managed by experts who displace political questions into technical design choices (Gopakumar, 2020). However, by introducing novel, and sometimes ostensibly inconspicuous, material artifacts or non-human beings into infrastructure disputes over circularity, actors can contest predominant technopolitics (Tozzi et al., 2022). For instance, plants and animals with particular histories and ecological relations can form unruly infrastructure elements that urge humans to act in new ways (Barua, 2021).

This article focuses on how different actors' technopolitical strategies of urban water circularity entail their forms and mechanisms of governing urban nature and space. Scholars have discussed two political dimensions of urban infrastructure through which we can understand these relationships

First, infrastructural practices guided by circularity visions can stabilize and contest political economies of urban development by implying different forms of utilizing using water and urban space. Centralized water infrastructures that tap abundant resources and control hazards form essential pillars of urban growth regimes. The investments in such networks are often sought to be recovered through rising property prices and taxes ignited by infrastructure-driven urban development (Kirkpatrick and Smith, 2011). Such political economic orders can influence how cities aim to reuse wastewater and stormwater to overcome water scarcity (Millington and Sheba, 2021). However, depending on the technologies they promote, actors can foreground different ways of valorizing reused water and associated norms of water use in political debates about water circularity. For instance, proponents of advanced wastewater treatment technologies in centralized facilities often envision urban futures where potable water reuse is prioritized (Ormerod, 2019). Other scholars have shown how directly capturing stormwater in homes (Meehan, 2014) or local greywater reuse can challenge established patterns and norms of water use in homes and gardens (Randle, 2021). A resource-sensitive lens on infrastructural practices allows for critically interrogating the political economies behind circular city-making processes. Examining the particular logics of resource valorization, the forms of land use, and the institutionalized urban political economies linked to infrastructural practices helps grasp how technopolitics of circular water restructuring shape urban environmental governance. In particular, this lens explores how actors promote different ways of framing water reuse and aligning it with particular urban development pathways in technical disputes over infrastructure design.

Second, infrastructural practices enable distinct roles of users and state experts in governing urban nature and space in circular cities. Scholars have demonstrated how large-scale water infrastructures often pair technocratic urban environmental management with particular cultures of water consumption and user roles (Kooy and Bakker, 2008). Modern infrastructure networks grant public experts centralized control over water flows to fulfill their institutionalized missions in compliance with sectoral regulation and under task-specific financing mechanisms. This approach has relegated water to the background of urban life, leaving users as passive service recipients (Karvonen, 2011). Today, "neosanitarian" (Ormerod, 2019) wastewater reuse practices arise in the context of urban sanitation and water supply services provided by experts, while users' relations with water are mostly through paying – and contesting – service fees. Meanwhile, infrastructure decentralization seems to generate ambiguous roles of users and public experts. Authors have argued that promoting decentralized infrastructural practices as symbols of environmentally friendly behavior can be used to shift responsibility for infrastructure provision to users (Usher, 2018). However, users that locally rework urban water networks according to their own experiences and worldviews can also curb the authority of state experts in environmental governance. While user-driven infrastructure interventions can challenge unsustainable or unjust infrastructure arrangements (Karvonen, 2011; Trulove, 2021), they can also undermine principles of solidarity in centralized infrastructure systems (Millington and Sheba, 2021) or complicate control by regulatory authorities. Analyzing how state experts and users aim to gain authority over – or delegate responsibility for – urban nature by foregrounding certain technologies in debates about water circularity can advance our understanding of the technopolitics of urban water circularity.

Together, we suggest that in technical disputes over infrastructure design, different actors' technopolitical strategies of urban water circularity become visible. Tracing the distinct rationales of resource use, user roles, and state authority linked to infrastructural practices offers a way to reveal how technopolitics of urban water circularity influence urban nature and space. We understand the capacities of actors to pursue technopolitical goals in infrastructure disputes in terms of actors' knowledge about infrastructure artifacts and these artifacts' material characteristics. Stable ways of thinking and fixed patterns of interactions in given infrastructure arrangements may thwart alternative practices. Yet, diversifying circular urban water technologies can advance novel infrastructural arrangements.

5.4 "One Water" in Los Angeles

Water imports since the twentieth century fueled the rise of modern Los Angeles. A local elite of land developers, business owners, politicians, and public bureaucracies coordinated urban and water network expansion to advance their political and profit interests. Critical scholars of Los Angeles highlighted the staggering power of capital interests after post-Fordist restructuring to explain a socially uneven and ecologically destructive urban expansion (Davis, 1998). Meanwhile, Erie and MacKenzie (2009: 546) underlined that, rather than being "monolithic and subservient to the economic system," the local state mobilized large public investments to influence urban development according to its agenda.

LADWP operates the 233-mile Los Angeles Aqueduct, which has delivered water by gravity since 1913 and remains the agency's main asset until today. The agency greatly influences city politics by cross-subsidizing the city of Los Angeles' general budget from its electricity revenues. Overseen by its board of supervisors, LADWP sells water following a business rationale to finance operations and maintenance, infrastructure investments, and the high salaries of its unionized employees. A "ratepayer advocate" controls traditionally low prices of water supplies in customers' interest (Hughes et al., 2013). As a regional wholesaler, the Metropolitan Water District of Southern California (MWD) delivers water from the California State Water Project and the Colorado River at considerably higher energy costs through a far-reaching import network. Also, Los Angeles' centralized sewers were historically expanded when urban growth was impeded to avoid paying fines for violating the US Clean Water Act. Sewer networks are managed by LA Sanitation which is separate from LADWP and directly controlled by the City Council. The agency is financed through wastewater fees, while its historically underfunded stormwater services have benefitted since 2020 from a regional stormwater tax.

Today, Los Angeles' linear water flow regime of abundant water imports, high water use, and rapid discharge of stormwater and treated wastewater is under enormous pressure. While water pollution challenges are ongoing, climate change has rendered water imports increasingly unreliable. To ensure water supply for the expected 500,000 new residents by 2035, the City of Los Angeles (2019) has announced that, by then, it will source 70% of its water locally.[15] Public water agencies have presented the "One Water LA 2040 plan" (One Water plan), which envisages a future of integrating water supply, water quality, and flood control tasks by managing water in a seamless loop. This vision has emerged from LA Sanitation's infrastructure facilities plan that explores synergies between existing infrastructure development strategies of separate public water agencies. The One Water plan outlines a radical move away from water imports toward reusing wastewater and stormwater, supported by ambitious water conservation. But the infrastructural practices through which circularity visions become realized are shaped by separate utilities with their own investment plans, regulatory structures, governing boards, and management cultures – together, leaving the One Water plan without a coherent governance structure.

This article synthesizes the insights from three articles on wastewater recycling (Meilinger and Monstadt, 2022a), stormwater capture (Meilinger and Monstadt, 2022b), and outdoor water conservation (Meilinger and Monstadt, 2023) to achieve a coherent analysis of the technopolitics of circular water restructuring in Los Angeles that arise from One Water endeavors (see Table 3).

15 Compared to an average 11% of local water supply between 2016 and 2020 (LADWP, 2020: ES-19).

TABLE 3 Technological arrangements of circular water restructuring in Los Angeles

	Wastewater recycling	Stormwater capture	Outdoor water conservation
Public policy goals by 2035 (City of Los Angeles, 2019)	Source 70% of water supply locally. Activate local groundwater aquifers to store infiltrated stormwater and recycled wastewater. Ensure compliance with US Clean Water Act		
	Recycle 100% of Los Angeles' wastewater	Capture 150.000 acre feet of stormwater locally (equates to 22% of expected water use in 2035)	Reduce potable water use per capita by 25% (compared to 2014)
Public infrastructure programs	Operation NEXT to retrofit the Hyperion Wastewater Treatment Plant for wastewater recycling (LADWP and LA Sanitation, planning phase since 2019)	Low Impact Development Ordinance (2011) Safe, Clean Water Program (parcel tax on stormwater in Los Angeles County since 2021)	Subsidies for turf-removal through California Friendly® landscaping program (LADWP and MWD since 2015)
Activities of non-state actors	Environmental activists, homeowners, and small businesses promoting local greywater reuse	City-wide coalition of environmental organizations promoting decentralized, nature-based stormwater practices	California native plant movement promoting autochthonous plant ecologies

Eric Garcetti has announced that Los Angeles' entire wastewater will be recycled by 2035, placing wastewater recycling at the heart of water circularity ambitions. This development flourished on the public reframing of wastewater and stormwater as local resources during the 2011-2016 drought. However, in 2000, a technically fully developed wastewater recycling project was stopped due to a political "Toilet to tap" campaign. Also, recycled water distribution networks for non-potable uses have been sparingly expanded, and LA Sanitation engineers remain skeptical about the reuse of greywater by homeowners. Consequently, wastewater reuse only represented 2% of Los Angeles' water supply in 2020 (LADWP, 2020: ES-19). Current recycling ambitions focus on the Hyperion Wastewater Treatment Plant, where 80% of Los Angeles' wastewater accumulates by gravity. Through the so-called Operation NEXT, LADWP and LA Sanitation jointly pursue solutions to satisfy up to half of Los Angeles' potable water demand with recycled water from Hyperion (LADWP, 2022). However, LADWP owns few rights in regional groundwater basins nearby to store the recycled water before reuse. Repurposing Hyperion relies on massive technical change and complex negotiations about groundwater rights, pricing and compensation schemes for water exchanges, and water distribution between the city of Los Angeles and a plethora of regional stakeholders.

While emphasizing that stormwater pollution remains a pressing problem, the One Water plan aims to transform stormwater into a water supply source. Environmental groups promote urban greening through landscape-centered stormwater practices. These developments have supported the approval of the Safe, Clean Water Program in Los Angeles County, a new parcel tax on stormwater. Tax revenues provide funding for LA Sanitation's stormwater services and support eligible stormwater projects of other public and private actors. Debates about project funding criteria reflect the different priorities of public water agencies and environmentalists. Budgeting more money for projects that provide water quality improvements and water supply or community benefits (e.g., urban greening), the funding criteria prioritize controlling large stormwater volumes for pollution mitigation – LA Sanitation's core institutional interest. LADWP retrofits centralized drainage networks and flood control basins to infiltrate stormwater into groundwater aquifers. Los Angeles' Low-Impact Development Ordinance (LID) from 2011 mandates stormwater retrofits for new development and larger redevelopment on private parcels. Although environmental groups have a long history of demonstrating the feasibility and cost-efficiency of stormwater retrofits on private parcels or street parkways, they criticize that "distributed scales of water management or infrastructure remain [...] treated as something that's a pilot rather than something that should be taken seriously" (Interview 1, 2019).

The One Water plan further depicts intensified water conservation as critical to realizing water supply goals in a more circular Los Angeles. In the 1990s, LADWP established a water conservation program to reduce reliance on expensive MWD sources. However, the drought year 2016 marked a landmark event when LADWP managers targeted semi-tropical gardens as a largely untapped frontier of water conservation. On average, more than half of all single-family water use in Los Angeles is outdoors (Mini et al., 2014). Therefore, LADWP and the MWD started to subsidize homeowners and businesses with $3.75 per square foot of replacing lawns with so-called California Friendly® landscaping. This landscaping approach promotes efficient irrigation technology and drought-tolerant plants from all over the world. Yet, alternative proposals for aligning water and urban landscapes in a circular Los Angeles exist. Pioneered by the English horticulturist Theodore Payne who opened Los Angeles' first public native plant garden at Exposition Park in 1916 (Guerrini, 2021), California native plant gardening has proliferated in recent years. Since a drought in the 1970s, a small movement of horticulturists, landscape architects, landscape professionals, and enthusiastic garden owners has advocated for combining water conservation with restoring California native plant biodiversity.

Together, developments in wastewater recycling, stormwater capture, and outdoor water conservation illustrate the complexity of circular water restructuring in Los Angeles. Ideas of a seamless integration of water management through One Water planning clash with the diversifying actors, infrastructure artifacts, and urban spaces involved in this process. In particular, disputes over water circularity include increasingly variegated technologies which are entangled with certain discourses, institutions, and knowledge orders. Infrastructural change toward water circularity and its political repercussions for governing urban nature and space depend on the socio-technical constellations that prevail in these disputes. To understand the technopolitics of a circular Los Angeles, we analyze how different actors participate in infrastructure disputes over circular water restructuring.

5.5 Technopolitics of circular Los Angeles

Circular water restructuring in Los Angeles occurs in an infrastructure regime designed to manage stormwater and wastewater as environmental hazards and developed under the assumption that cheap water can be imported indefinitely (Pincetl et al., 2019). In this context, public water agencies, enthusiastic homeowners, activists, and environmental groups pursue their visions of water circularity. Shaped by those stakeholders' particular social interests and worldviews, their infrastructural practices provoke diverging forms of resource use and roles of users and state experts. We argue that two technopolitical arrangements are emerging in a circular Los Angeles (see Table 4).

First, public water managers pursue the One Water vision by interconnecting centralized infrastructure facilities in a singular system that allows centralized control of large volumes of water. Programs of infrastructure decentralization aim to mobilize homeowners and private parcels for volumetric water management via technology, incentives, and rules, which, however, remains a challenge for the utilities. This technopolitical strategy reshapes broader relations between water and urban space and between public utilities and users according to institutional water supply and water quality interests. A second technopolitical constellation emerges through decentralized infrastructural practices of users and environmental groups that extend, modify, and challenge One Water's aspirations. These practices articulate more plural ways of governing a circular Los Angeles, for instance, by introducing sufficiency and biodiversity ideas into debates about circularity. Simultaneously, these practices reflect ambiguities of environmental governance arising from the complexity of governing increasingly hybrid water infrastructures.

TABLE 4 Technopolitics of water circularity in Los Angeles

	One Water cycle	Plural water cycle
Infrastructure typology and urban geographies	Creation of an artificial One Water system around centralized facilities linked to local groundwater basins. Standardized retrofits of private parcels to sustain the system's functionality	Creation of a more hybrid infrastructure system through distributed, landscape-centered water circularity practices in private homes and gardens, and on streets
Principles of infrastructure provision	Reliable and cost-efficient local water supply and pollution control through volumetric water management	Coupling water improvements with resource sufficiency, biodiversity restoration, climate change adaptation, and community greening
Political economic logics	Supply-driven approach of remaking wastewater and stormwater as potable water resources to offset expensive water imports and ensure revenues Valorizing urban landscapes as frontier for water conservation while balancing investments in conservation with revenue-dependency from water sales	Revaluing more differentiated forms of water reuse (e.g., greywater reuse). Small market of high-end distributed water reuse technologies Valorization of landscape ecosystems and landscape and horticultural expertise. Demands for retraining a low-wage landscaping workforce
Rationales of land use	Rationalization of private gardens for volumetric water conservation and stormwater pollution control Provision of reliable water supply for urban development Instances of water and resource sufficiency in California Friendly® landscapes. Focus on irrigation technology for effective water conservation	Tension between visions of redesigning private gardens as water-saving biodiversity sanctuaries and resource land (e.g., food production) and stormwater pollution control Linking of water management with protection of native biodiversity from urban growth Landscapes as co-designed ecologies with human and non-human benefits (e.g., sufficiency, biodiversity) that broaden rationales of infrastructure provision
Rationales of water and resource use	Priority for the *potable reuse* of recycled wastewater due to hygienic culture and interest in water sales. Higher energy input in circular water infrastructures	More *differentiated forms of non-potable water reuse* through greywater reuse in homes and gardens and stormwater reuse in landscapes. Mixture of highly engineered practices and low-tech and low-energy practices
Relationship between state experts and users	Users as service recipients interested in cost savings and service reliability. Mobilization of users as supporters of volumetric water management dominated by public engineers	Users as infrastructure co-providers that modify and contest technocratic water management of public experts according to their own environmental values and experiences

5.5.1 Building One Water cycle

Los Angeles' extensive water reservoirs and aqueducts are increasingly seen as remnants of a declining water management approach. Water agencies highlight large-scale *local* facilities as "infrastructural assets" (Interview 2, 2018) of water circularity. LADWP retrofits vast flood control structures built in the 1930s for stormwater infiltration to refill the San Fernando Valley Groundwater Basin in northern Los Angeles. Simultaneously, LA Sanitation upgrades a smaller treatment plant to recycle wastewater that will be pumped to these spreading basins for infiltration. Increasingly, the agency diverts stormwater into the sewer system, which is used as a supply to expand wastewater recycling. Sewer flows mainly concentrate at the Hyperion treatment plant, where LADWP explores options to store recycled wastewater in regional groundwater basins before potable reuse. This depends on reactivating groundwater basins, whose importance has diminished since the 1950s due to pollution and cheap water imports. Decades-long neglect has impeded the reform of fragmented groundwater rights (Pincetl et al., 2016). Crucially, LADWP plans for the *direct* potable reuse of up to 75% of Hyperion's water (LADWP, 2022). The recycled water would be pumped to the San Fernando Valley for direct distribution after additional treatment. While this involves higher energy expenses, an interviewed engineering consultant highlighted LADWP's interest in controlling water flows within city boundaries, which reduces dependency on regional groundwater basins (Interview 3, 2018). A vast sewage spill at Hyperion in 2021 exposed the technical complexity of this vision, showing how limitations of existing infrastructures and unresolved pollution problems shape investments in water circularity.

Centralized infrastructure restructuring aligns with institutionalized expertise in large-scale engineering and the principles of cost-efficiency, safety, and service reliability in water agencies. Nonetheless, discourses of urban greening and opportunities to locally conserve water and capture stormwater drive agencies to adopt programs for distributed infrastructures.

California Friendly® landscaping subsidies are designed to foster outdoor water conservation. California Friendly® plants were selected for their low water needs and their resilience to poorly skilled irrigation and gardening practices. LADWP engineers emphasize efficiency gains through "smart" irrigation systems that rationalize irrigation based on plant, soil, and live weather data (Interview 4, 2018). By continuing to offer free California Friendly® landscaping classes for homeowners and landscaping workers, MWD has significantly reduced turf-removal subsidies after 2016 (Interview 5, 2018). This indicates a shift toward investments in local water supply expansion through centralized wastewater recycling, which is more aligned with inherited water management practices. Stormwater restructuring reflects a similar logic. LA Sanitation promoted the LID Ordinance to mobilize property owners in locally managing stormwater at their own expense. However, the agency lacks the capacity to oversee a large number of decentralized infrastructures for pollution control. Hence, from a water quality perspective, linking water flows more closely with everyday urban life implies significant regulatory uncertainty. Therefore, LA Sanitation opposed environmental groups' proposal to fund stormwater retrofits on private parcels with tax revenues to secure money for investments in centralized infrastructures.

Public water utilities pursue particular technopolitical objectives by combining centralized infrastructure restructuring with rules and incentives for more distributed practices. First, One Water infrastructure reconfigurations promote institutional goals to remake stormwater and wastewater into resources for reliable water supply while effectively controlling pollution. This occurs in an inherited context of urban growth politics. Local property tax cuts through Proposition 13 have left Californian municipalities in a "race for growth," whereby public infrastructure investments serve to increase local sales taxes by enabling urban development (Kirkpatrick and Smith, 2011). California's Proposition 218 further regulates that public service fees cannot exceed the cost-of-service provision. Therefore, Los Angeles' water agencies are bound to recover the costs of debt-financed infrastructure investments through service fees revenues. Despite its comparatively high costs, the agencies favor centralized wastewater recycling that promises direct control over wastewater flows to align water supply reliability and pollution mitigation goals with the need to secure revenues. Although conservation is structurally disincentivized in LADWP whose revenues depend on abundant water sales, it remains the cheapest new water supply for urban development. Thus, California Friendly® landscapes are designed to tap this supply source. To promote conservation, LADWP further increased the per-unit price of water for customers with excessive consumption in 2022. High costs for wastewater recycling will likely intensify political struggles about volumetric water prices. Nonetheless, imperatives of municipal finance propel a logic whereby public utilities mobilize water scarcity to justify a supply-driven water management approach through large-scale technology. The institutionally separate LADWP and LA Sanitation additionally favor centralized projects to facilitate collaboration and avoid costs of overseeing numerous smaller infrastructures. While the One Water plan lacks institutional support, these technopolitical interventions reduce management and regulatory uncertainty provoked by circularity ambitions.

We argue that public utilities accommodate inherited political economies and institutions of water and wastewater management in a circular Los Angeles through a technology-led approach to concentrate water flows in a One Water system. While this approach provokes broader political repercussions on environmental governance, these are often downplayed or mainly addressed as issues of large-scale engineering. For instance, by diverting stormwater into sewers and concentrating wastewater flows at centralized treatment plants, public utilities establish a culture focused on the potable reuse of recycled water.

Environmental groups criticize that directing stormwater into sewers can thwart attempts to retain stormwater in landscapes to enhance urban greening (Interview 1, 2019). Efforts to concentrate One Water flows also impinge on urban political debates about the Los Angeles River. The river's current ecosystem relies almost entirely on flows of treated wastewater, which LAWDP aims to reserve for recycling after sewer flows have declined due to recurring droughts. LADWP's plan to remake the river into a water supply for the growing city clashes with large-scale river redevelopment plans. Through engineering interventions to reserve the river's flow for wastewater recycling, public engineers structure the conditions within which spatial visions of urban growth through green, postindustrial urban redevelopment can evolve. Not least, California Friendly® landscape subsidies exemplify how technological interventions for One Water advance water-related objectives while downplaying their broader political repercussions. A focus on smart irrigation normalizes energy-intensive irrigation in gardens and sustains a "digital urban growth machine" (Rosen and Alvarez León, 2022). Garden supply businesses that sell irrigation systems benefit from this development, while irrigation-centric landscaping disregards the poorly skilled and underpaid landscaping practices of a predominantly immigrant workforce.

Second, One Water endeavors underpin the authority of state experts in circular water management while activating users as supporters of their volumetric approach. But different technological interventions also reveal a growing ambiguity about the role of users in circular Los Angeles. On one hand, centralized infrastructure restructuring reproduces a social contract whereby public utilities exclusively control water flows but are strictly overseen by collectively organized users. While principles of service reliability and centralized control have historically evolved to improve public health and environmental protection, in contemporary Los Angeles, a discourse of water resilience strengthens water management by public experts. Utilities prominently portray facilities such as the Hyperion treatment plant as guarantors of water security in an uncertain future. They consider large-scale engineering as the best option for "getting our ratepayer's money worth" (Interview 6, 2018) by ensuring cost-efficiency and leveraging state grants for infrastructure development. Here, public water managers frame citizens as a homogenous group of consumers who are unified around shared interests of individual cost savings and uninterrupted service (Interview 4, 2018).

On the other hand, programs of infrastructure decentralization form technopolitical attempts to mobilize users and private space for volumetric water management. The irrigation-focused California Friendly® landscaping advances objectives to control water use practices. One landscape architect lauded that "the beauty of [smart irrigation] is, there's no button on the machine. You can't mess with it" (Interview 7, 2019). While efficiency is associated with enhanced technology, users are framed as causes of inefficiency. Public engineers further emphasize that homeowners can reduce their water bills through California

Friendly® landscaping. By design, these landscapes link a logic of individual cost savings with a moral discourse of water conservation by "California Friendly" homeowners. The LID Ordinance formally shifts responsibility for local stormwater to property owners. While public engineers acknowledge the large stormwater potential of private properties, they avoid leaving pollution mitigation tasks with users. Highlighting the difficulty and high costs of controlling users, a policy expert underlined that to manage pollution, "command and control sometimes are incredibly justified" (Interview 8, 2019). Hence, there remains a friction between objectives to activate homeowners for stormwater control and practical priorities to concentrate stormwater in sewers to ensure reliable public service. For one non-profit representative, managing stormwater on private property is "not a public service" (Interview 9, 2018) but a question of rethinking building or landscape preferences and associated ideas of homes and gardens. Utility-led infrastructure decentralization programs thus raise novel political questions about the blurring boundaries between consumer choice and public service provision. However, technological interventions of public engineers are primarily made to advance their institutional mandates. These interventions tend to prescribe user roles by technological design instead of stimulating a critical debate about consumer choice in circular Los Angeles, where new spaces, actors, and artifacts gain infrastructural relevance.

5.5.2 Pluralizing circular Los Angeles

Alternative proposals of water circularity in Los Angeles by environmental groups, activists, and enthusiastic homeowners arise in the interstices of centralized networks, frequently at the intersection of water flows and urban landscapes. Together with the infrastructure decentralization programs of public utilities, these interventions produce a hybrid infrastructure system in which different technologies co-exist, actor roles diversify, and water management tasks overlap. This user-driven development reveals more plural ways of using water and space, which diverge from the technopolitics of One Water ambitions.

Through longstanding advocacy work, environmental groups have prominently placed nature-based stormwater practices on private parcels and in streets in discourses about water circularity. The goal is to restore natural watershed functions to mitigate flooding, improve water quality, and increase groundwater infiltration while greening communities to provide habitat, cooling, and healthy amenities. For one non-profit leader, climate change constitutes a new "leverage in Los Angeles on stormwater issues," reframing stormwater as an essential resource for climate change adaptation rather than a pollution control liability (Interview 10, 2018). Through the Safe, Clean Water Program, community greening can no longer be dismissed in stormwater decisions. Nonetheless, rolling out landscape-centered stormwater practices remains complicated. Scaling up distributed practices for water quality compliance would overburden the financial and organizational capacities of public utilities and community organizations. Moreover, a policy expert flagged that homeowners often poorly maintain stormwater infrastructures, except for enthusiasts that "are proud of it [...] and usually have money" (Interview 8, 2019).

In addition, advocates of greywater reuse link circularity visions with particular practices. So-called laundry-to-landscape systems divert used laundry water to gardens through simple piping. Proponents of this practice emphasize the benefits of greywater-irrigated gardens that typically harbor fruit trees and thus produce crops, shade, and cooling. Yet, this reduces sewer flows and thus competes with public utilities' centralized wastewater recycling ambitions that underline the public health risks of greywater reuse. There is also a growing market for high-end greywater reuse technologies that raise aspirations of sustaining lifestyles of abundance through water self-sufficiency. Installers often view greywater systems as "sort of a luxury item. It's kind of like: solar panels, Tesla, greywater system" (Interview 11, 2018). Here, private consumption preferences risk undermining public service provision goals concerned with ensuring affordable and reliable drinking water supply.

Not least, California native plant gardening practices bear distinct proposals for a more plural circular Los Angeles. Critical conservationists denounce that, for decades, water utilities have exploited water conservation as

> "the cheapest source of water in California [...], so we can keep our economy running, and we can grow it three to four percent every year, we can mow over native landscapes, which you're supposedly trying to protect" (Interview 12, 2018).

When retrofitting urban landscapes, native plant gardeners see water conservation as inseparable from restoring landscapes' resources, biodiversity, and sink functions. Accordingly, a municipal horticulturist called for primarily reforming the "expectations to landscapes" (Interview 13, 2019), by moving away from seeing landscapes as an aesthetic background of urban life that is cheap and easily controlled by technology. But California native plants are frequently planted in the sophisticated gardens of wealthy homeowners that require training for homeowners or expensive – for many unaffordable – professional care. Ideas of scaling up these ecologies belie Los Angeles' uneven socio-economic realities and are complicated by contaminated urban soils where weeds might grow better than native species.

New combinations of artifacts, practices, and knowledges in these distributed infrastructure interventions reflect technopolitics that co-exist with, and partly contradict, One Water ambitions. First, distributed infrastructural practices introduce rationalities of using water and urban space in circular Los Angeles, which diverge from volumetric water management. These practices flesh out circularity visions by linking them to a wider range of norms and patterns of water use. For instance, greywater systems to flush toilets irrigate landscapes challenge a modernist hygienic culture of potable water (re)use. This culture is closely entwined with the financial logics that shape circular water restructuring by public utilities that aim to secure future revenues through investments in centralized wastewater recycling. In contrast, a tax-financed water management that alleviates this fee-dependency might grant more room for alternative reuse practices. The calls of greywater activists for more sufficiency in water management imply such political demands, while potentially contradicting the public health paradigms of public experts. Uncovering the plural value sets in technical disputes over water circularity – from institutionalized finance logics to ideas of sufficiency – offers a way to problematize economic value relations that shape how circularity visions materialize. Inseparably from this, new political possibilities for using urban space become articulated in these disputes. Advocates for greywater-irrigated and California native plant gardening reimagine urban gardens as water-saving biodiversity sanctuaries and as a land resource that both produces crops and benefits urban cooling. These practices question abstract ideas of urban landscapes as frontiers of water conservation which can be tapped to enable urban development that downplay other aspects of landscapes. However, techno-optimistic visions of enhancing sustainability through greywater reuse or native plant gardening risk obscuring the socio-technical relations that sustain the resource-intensive lifestyles of many affluent homeowners that embrace these technologies. Moreover, environmentalists' demands for financing more nature-based stormwater practices to remake streets as resources for climate change adaptation broaden possibilities of using urban space. But realizing such demands remains hampered by splintered responsibilities for governing streets within the city of Los Angeles and often hinges on community organizations.

In general, putting user-driven practices of water circularity in relation with One Water efforts allows rethinking implicit assumptions about urban life and nature underlying technocratic water management. For instance, California native plant gardening exposes how landscaping expertise has previously remained undervalued in Los Angeles. Native plant gardening can evoke radical demands for retraining and better pay for a low-wage immigrant workforce that maintains most of Los Angeles' gardens (Hondagneu-Sotelo, 2014). Exploring the histories and cultural meanings linked to circular water technologies offers a starting point for critically revising the value sets which define emerging economic relations in circular cities. This perspective also reveals the ambiguities involved in circular water restructuring. In particular, the diversifying technologies, spaces, and rationalities of environmental management in more hybrid water infrastructures clash with strictly regulated public services missions for human health and environmental protection, together increasing the complexity of governing circular Los Angeles.

Second, alternative infrastructural practices of water circularity in Los Angeles reimagine users as infrastructure co-providers that modify and challenge water governance led by public experts. These practices imply more plural user roles and highlight a "porosity" (Anand, 2017) of state authority in circular Los Angeles' increasingly hybrid infrastructure. Detailed knowledge of water technologies is an important precondition for users acting as infrastructure co-providers. California native plant advocates reject a "command-and-control relationship" with landscapes and object to the technical control of homeowners' gardening practices (Interview 12, 2018). Instead, homeowners' understanding of the ecological relations underlying their gardens is in focus. As these relations transcend the private sphere, native plant advocates reframe gardens as infrastructural elements of a shared urban nature in circular Los Angeles. While this proposal unsettles public experts' modernist orders of single-purpose infrastructure provision, it shifts responsibilities for complex environmental management to users. Also, greywater advocates highlight that greywater reuse practices can reconnect users with the environmental effects of their lifestyles, urging them to rethink consumption habits. Foregrounding such embodied infrastructure experiences in debates about water circularity discloses political possibilities for sufficiency or biodiversity while showing that exploring these possibilities requires carefully rethinking knowledge orders and responsibilities.

Circular water restructuring in Los Angeles further highlights how decentralized infrastructure interventions can leave users and public engineers with uncertainty. With the approval of the Safe, Clean Water Program, the majority of voters in Los Angeles have embraced narratives of more local stormwater management, and the LID Ordinance mandates stormwater practices on private parcels. Nonetheless, many homeowners are overburdened with maintaining stormwater technologies that can get clogged or overgrown by vegetation, and community-based organizations often lack sufficient funding to take on responsibility for distributed stormwater practices. These practices thus also increase governance complexity for public utilities, which remain responsible for meeting public service provision goals and regulatory requirements. Not least, decentralized water technologies privilege some users and thereby undermine public service provision goals. Smart irrigation or high-end greywater reuse systems might be deployed to rationalize the resource-intensive lifestyles of wealthy homeowners. This can preserve semi-disconnected islands of privilege in a circular Los Angeles while users overall will have to pay higher water prices and consume less water. Moreover, these technologies can strengthen beliefs in ecological modernization, thwarting a critical public debate about unsustainable water use rooted in entrenched ideas of upper-class (sub)urban living in Los Angeles.

Together, user-driven infrastructure decentralization places novel rationalities of water and urban space use into political debates about circular Los Angeles, which urges incumbent experts to engage with these new rationalities and the cultures of nature and technology they represent. However, the technopolitics of circular Los Angeles' increasingly hybrid infrastructures remain ambiguous. More plural proposals for governing urban nature through water circularity partly contradict public service provision goals and remain in tension with inherited governance and institutional orders of water and wastewater management.

5.6 Conclusion

The circular city is a proliferating paradigm in urban environmental governance in a world of rapidly growing cities. Yet, the political role of technology in circular city-making is underexplored. This article argues that the social processes underlying technologies that come into focus of agendas of urban water circularity shape broader regimes of urban environmental governance. By examining the participation of various actors in infrastructure disputes over water restructuring in Los Angeles, we can better understand these "technopolitics" of urban water circularity.

Los Angeles' water agencies pursue water circularity by interconnecting centralized infrastructures in a One Water loop to control large volumes of water. This system includes new "geographies of storage" (Randle, 2022) in groundwater basins while re-engineering private gardens as spaces of water conservation. Behind this is a technopolitical strategy to align circularity with institutional missions of public water utilities influenced by inherited urban growth politics. Through infrastructure restructuring, the utilities remake stormwater and wastewater into potable water resources to reduce reliance on water imports while advancing pollution mitigation. But agency programs of infrastructure decentralization and user-driven infrastructural practices also provoke a more hybrid water system in which diverse technologies co-exist. Especially at the nexus of water networks and private homes and gardens, more plural political possibilities of governing nature and urban space in circular Los Angeles arise. By promoting greywater systems or nature-based water practices, environmental groups and enthusiastic homeowners render resource sufficiency, climate change adaptation, and biodiversity restoration vital political concerns of urban water circularity. But user-driven practices can also sustain abundant consumption of privileged homeowners and leave public agencies with regulatory uncertainty in mitigating pollution.

Conceptually, our analysis advances critical geographical research on circular cities, urban environmental politics, and on urban infrastructures in three distinct ways. First, circular water restructuring in Los Angeles challenges eco-modernist ideas that aim to enhance technocratic control over urban nature while increasing sustainability. Circular city-making is still often pursued as a matter of closing material cycles through technology (Williams, 2019). However, infrastructure disputes over circular Los Angeles unsettle ideas of straightforward technological solutions. In Los Angeles, centralized infrastructure restructuring coincides with a centrifugal expansion of infrastructure arrangements that integrate new artifacts, actors, and urban spaces to enhance sustainability. The diverse and partly opposing social processes underlying Los Angeles' hybrid infrastructure system reveal how circular water restructuring can increase governance complexity and uncertainty. This development calls for a more radical reworking of the social orders within which eco-modernists propose environmental solutions. Exploring the hybrid infrastructures of circular cities allows for critically reviewing inherited institutional and epistemological orders of urban environmental governance. This can inform ways of governing that acknowledge the emerging and often indeterminate nature of inclusive solutions to contemporary urban environmental problems (Bulkeley, 2021)

Second, this article highlights dimensions of technopolitics that matter for analyzing environmental governance in circular cities. Research on circular cities can benefit from exploring the financial and institutional logics that influence urban infrastructure politics (Kirkpatrick and Smith, 2011; Millington and Sheba, 2021) and the political relations between public experts and users in infrastructure provision (Usher, 2018) that shape – and are shaped by – infrastructural practices of circularity. In Los Angeles, a logic of cost recovery for debt-financed infrastructure investments explains a supply-driven approach to water circularity. However, the value relations that shape circular city-making cannot be separated from the institutional orders and cultures of infrastructure provision and use rooted in modernist ideas of universal service provision, service reliability, expert knowledge, and consumer choice. In Los Angeles, these entanglements create a situation where the shift toward more decentralized, user-driven infrastructures increases regulatory uncertainty. By exploring these technopolitical relations, we can inform emerging work on infrastructural resource ecologies and help to uncover the politics of infrastructural attempts at urban degrowth.

Finally, tracing infrastructural practices in struggles over water circularity enhances critical work on approaches to manage urban nature in the Anthropocene as complex adaptive systems. Authors assert that the dominant epistemologies of specific actors that structure such approaches explain these approaches' often uneven politics (Derickson, 2018; Gandy, 2022). We argue that studying the social relations that underly technology in circular city-making can reveal how the worldviews of particular actors shape systemic attempts to govern environments and how this is contested. Actors reconfigure infrastructures depending on their knowledge of specific artifacts and their material properties. The concept of technopolitics of urban water circularity captures how the histories, cultural meanings, and urban geographies tied to infrastructure artifacts frame political debates about circularity. But novel technical artifacts or non-human elements in emerging infrastructure constellations can exceed the control of technocratic cultures of urban nature that organize environments through technological interventions informed by science and engineering rationality. Analyzing how alternative technological cultures of urban nature influence the technopolitics of circular water restructuring can reveal plural rationales of governing urban nature. For instance, foregrounding living infrastructure components and thereby highlighting "the intrinsic value of integrated ecosystems" (Jarvis, 2019: 264) offers new ways to critically revise abstract ideas about urban life and development in technocratic environmental management.

5.7 References

Bakker, K. 2010. Privatizing water: governance failure and the world's urban water crisis, Cornell University Press, Ithaca.

Barua, M. 2021. Infrastructure and non-human life: a wider ontology. *Progress in Human Geography* 45(6): 1467-1489.

Blok, A., M. Nakazora, B. R. Winthereik 2016. Infrastructuring environments. *Science as Culture* 25(1): 1-22.

Blomsma, F. and G. Brennan 2017. The emergence of circular economy: a new framing around prolonging resource productivity. *Journal of Industrial Ecology* 21(3): 603-614.

Brown, R. R. and M. A. Farrelly 2009. Delivering sustainable urban water management: a review of the hurdles we face. *Water science and technology* 59(5): 839-846.

Bulkeley, H. 2021. Climate changed urban futures: environmental politics in the Anthropocene city. *Environmental Politics* 30:1-2, 266-284.

Carse, A. 2012. Nature as infrastructure: making and managing the Panama Canal watershed. *Social Studies of Science* 42(4): 539-563.

City of Los Angeles 2019. pLAn. LA's Green New Deal. Los Angeles.

Cousins, J. J. 2018. Remaking stormwater as a resource: technology, law, and citizenship. *Wiley Interdisciplinary Reviews: Water* 5(5), e1300.

Davis, M. 1998. Ecology of fear: Los Angeles and the imagination of disaster. Macmillan, New York.

Derickson, K. D. 2018. Urban geography III: Anthropocene urbanism. *Progress in Human Geography* 42(3): 425-435.

Erie, S.P. and H.D. Brackman 2006. Beyond Chinatown: the metropolitan water district, growth, and the environment in Southern California. Stanford University Press, Stanford.

Gandy, M. 2022. Natura urbana: ecological constellations in urban space. MIT Press, Cambridge.

Giampietro, M. 2019. On the circular bioeconomy and decoupling: implications for sustainable growth. *Ecological economics* 162, 143-156.

Ghisellini, P., C. Cialani and S. Ulgiati 2016, A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production* 114 (February), 11–32.

Gopakumar, G. 2020. Installing automobility: emerging politics of mobility and streets in Indian Cities. MIT Press, Cambridge.

Green, A. and S. Bell 2019. Neo-hydraulic water management: an international comparison of idle desalination plants. *Urban Water Journal* 16(2): 125-135.

Hecht, G. 2009. The radiance of France: nuclear power and national identity after World War II. MIT press, Cambridge.

Hofmeister, S. 2013. Von der Abfallwirtschaft zur ökologischen Stoffwirtschaft: Wege zu einer Ökonomie der Reproduktion. Springer-Verlag, Wiesbaden.

Hondagneu-Sotelo, P. 2014. Paradise transplanted: migration and the making of California gardens. University of California Press, Berkeley.

Hughes, S., S. Pincetl and C. Boone 2013. Triple exposure: regulatory, climatic, and political drivers of water management changes in the city of Los Angeles. *Cities* 32, 51–59.

Jarvis, H. 2019. Sharing, togetherness and intentional degrowth. *Progress in Human Geography* 43(2): 256-275.

Kallis, G. 2021. Limits, ecomodernism and degrowth. *Political Geography* 87, 102367.

Kębłowski, W., D. Lambert, D. and D. Bassens 2020. Circular economy and the city: an urban political economy agenda. *Culture and Organization* 26(2): 142-158.

Kirkpatrick, L. O. and M. P. Smith 2011. The infrastructural limits to growth: rethinking the urban growth machine in times of fiscal crisis. *International Journal of Urban and Regional Research* 35(3): 477-503.

Kooy, M. and K. Bakker 2008. Technologies of government: constituting subjectivities, spaces, and infrastructures in colonial and contemporary Jakarta. *International Journal of Urban and Regional Research* 32(2): 375-391.

LA Sanitation 2018. One Water LA 2040 Plan. Los Angeles.

LADWP 2022. Operation NEXT water supply program. Presentation. Accessed 22 July, 2022. https://www.ladwp.com/cs/idcplg?IdcService=GET_FILE&dDocName=OPLADWPCCB731558&RevisionSelectionMethod=LatestReleased

LADWP 2020. Urban water management plan 2020. Los Angeles.

Liu, L. and M.B. Jensen 2018. Green infrastructure for sustainable urban water management: Practices of five forerunner cities. *Cities* 74, 126-133.

Meehan, K. M. 2014. Tool-power: Water infrastructure as wellsprings of state power. *Geoforum* 57, 215-224.

Meilinger, V. and J. Monstadt 2022a. From the sanitary city to the circular city? Technopolitics of wastewater restructuring in Los Angeles, California. *International Journal of Urban and Regional Research* 46(2): 182-201.

Meilinger, V. and J. Monstadt 2022b. The material politics of integrated urban stormwater management in Los Angeles, California. *Local Environment* 27(7): 847-862.

Meilinger V. and J. Monstadt 2023. Infrastructuring gardens: the material politics of outdoor water conservation in Los Angeles. *Annals of the American Association of Geographers* 113(1): 206-224.

Millington, N. and S. Scheba 2021. Day zero and the infrastructures of climate change: water governance, inequality, and infrastructural politics in Cape Town's water crisis. *International Journal of Urban and Regional Research* 45(1): 116-132.

Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A: Economy and Space* 41 (8): 1924–1942.

Ormerod, K. J. 2019. Toilet power: potable water reuse and the situated meaning of sustainability in the southwestern United States. *Journal of Political Ecology* 26(1): 633-651.

Pincetl, S., E. Porse, K. B. Mika, et al. 2019. Adapting urban water systems to manage scarcity in the 21st century: the Case of Los Angeles. *Environmental Management* 63(3): 293-308.

Pincetl, S., E. Porse and D. Cheng 2016. Fragmented flows: water supply in Los Angeles county. *Environmental Management* 58(2): 208-222.

Randle, S. 2021. Battling over bathwater: greywater technopolitics in Los Angeles. *City & Society* 33(3): 444-466

Randle, S. 2022. Holding water for the city: emergent geographies of storage and the urbanization of nature. *Environment and Planning E: Nature and Space* 5(4): 2283-2306.

Robbins, P. 2007. Lawn people: how grasses, weeds, and chemicals make us who we are. Temple University Press, Philadelphia.

Rosen, J. and L. F. Alvarez León 2022. The digital growth machine: urban change and the ideology of technology. *Annals of the American Association of Geographers*, 1-18.

Savini, F. 2019. The economy that runs on waste: accumulation in the circular city. *Journal of Environmental Policy & Planning* 21(6): 675-691.

Savini, F. 2021. Toward an urban degrowth: habitability, finity and polycentric autonomism. *Environment and Planning A: Economy and Space* 53(5): 1076-1095.

Swyngedouw, E. 2004. Social power and the urbanization of water: flows of power. University Press Oxford, Oxford.

Tozzi, A., S. Bouzarovski, S. and C. Henry 2022. Colonizing the rains: disentangling more-than-human technopolitics of drought protection in the archive. *Geoforum*, 135, 12-24.

Truelove, Y. 2021. Who is the state? Infrastructural power and everyday water governance in Delhi. *Environment and Planning C: Politics and Space* 39(2): 282-299.

Usher, M. 2018. Conduct of conduits: engineering, desire and government through the enclosure and exposure of urban water. *International Journal of Urban and Regional Research* 42(2): 315-333.

Williams, J. 2019. Circular cities. *Urban Studies* 56(13): 2746-2762.

Williams, J., S. Bouzarovski, S and E. Swyngedouw 2019. The urban resource nexus: on the politics of relationality, water–energy infrastructure and the fallacy of integration. *Environment and Planning C: Politics and Space* 37(4): 652-669.

World Bank 2021. Water in circular economy and resilience. Accessed April 3, 2022. https://openknowledge.worldbank.org/bitstream/handle/10986/36254/163924.pdf?sequence=1&isAllowed=y

5.8 Cited interviews

1. Stormwater expert, water quality protection non-profit, Los Angeles, 19 March 2019.
2. Stormwater manager, LADWP, Los Angeles, 2 February 2018.
3. Wastewater recycling engineering consultant, Los Angeles, 9 February 2018.
4. Water conservation managers, LADWP, Los Angeles, 16 March 2018.
5. Water conservation manager, MWD, Los Angeles, 26 February 2018.
6. Manager, LADWP, Los Angeles, 3 February 2018.
7. Water-efficient landscaping consultant, Los Angeles, 14 March 2019.
8. Stormwater policy consultant, Los Angeles, 2 March 2019.
9. Manger and policy officer, environmental non-profit, 14 February 2018.
10. Leader, environmental non-profit, 7 February 2018.
11. Greywater business owner, 5 March 2018.
12. Water-efficient landscaping consultant, 13 March 2018.
13. Municipal landscaping expert, 10 April 2019.

6

CONCLUSION

In cities worldwide, climate change, paired with ongoing urban growth, puts water systems under enormous pressure. Water scarcity and floods intensify while pollution remains a pressing problem. Scholars agree that contemporary urban water challenges are historically constructed through interdependent social and biophysical dynamics (Bell, 2017; Pincetl et al., 2019). The pursuit of what Graham and Marvin (2001) called the "modern infrastructure ideal", which involved the construction of centralized water and wastewater networks, has facilitated immense urban growth and lifestyles of bountiful water use in dry climates (Gober and Trapido-Lurie, 2006; Parés et al., 2013). However, the linear water metabolism marked by the rapid discharge of stormwater and treated wastewater without reuse that enabled this urban development now faces an unprecedented crisis. The growing tension between inherited cultures of water abundance and new climatic conditions of prolonged droughts increases the unsustainability of urban water systems and aggravates existing injustices (Millington and Scheba, 2021). Against the backdrop of growing urban water challenges, concepts of urban water circularity have gained momentum in urban policymaking and practice. These concepts promise to tackle challenges of water scarcity, flooding, and pollution by managing water in a closed cycle (Arup and Ellen MacArthur Foundation, 2018; World Bank, 2021). Stakeholders are placing high hopes for water sustainability and resilience on the combination of different water management technologies in new infrastructure arrangements that facilitate water circularity.

Urban water crises are emblematic of environmental challenges in the Anthropocene where societies face the increasingly incalculable and, at times, life-threatening ecologies they have themselves created. This condition raises broader questions: How do modern societies practically respond to the self-induced deterioration of the ecologies that sustain them? To what extent are they equipped with the right concepts and methods to tackle this crisis? This dissertation connected with these questions by examining urban infrastructural practices and concepts of urban water circularity. The study analyzed the political relationships between visions of urban water circularity and the socio-technical change of water and wastewater infrastructures that are emerging to tackle water challenges in Los Angeles.

This focus addresses a gap in academic debates on urban water governance and the political relations between urban infrastructures and urban nature. To explain the sustainability shortcomings of urban water systems, scholars highlight governance failure and ill-suited institutions that thwart alternative water management practices (Section 1.2.2). Urban political ecologists foreground uneven power relations in capitalist urbanization processes as the main drivers of water crises (Section 1.2.3). Scholarship on cities in the Anthropocene underlines that proliferating approaches to governing urban ecologies as complex adaptive systems obscure power dynamics that marginalize sustainability alternatives (Section 1.2.1). Similarly, urban water circularity visions often imply that urban environments can be made more sustainable by knowing and governing them as complex adaptive systems. Enhancing sustainability becomes a matter of smoothly combining diverse technologies to create more circular urban water systems – as if there was an unambiguous understanding of what circularity includes. However, urban water management technologies have strongly diversified, and involve a wide range of actors, knowledges, institutions, and urban spaces.

So far, the current body of critical urban scholarship has not explicitly studied the political role of technology in processes of circular urban water restructuring, leaving a gap in understanding the contested governance of these processes. The premise explored in this dissertation is that an analysis of the politics of technology can reveal ambivalences, contradictions, and power imbalances involved in making circular water futures that otherwise remain obscured by vague circularity discourses. In this study, the technopolitics of circular urban water restructuring were uncovered by tracing how actors in Los Angeles pursued their own visions of water circularity through infrastructural practices. Behind this is the idea, prevalent in STS, that the political relevance of social concepts such as circularity becomes visible in practice (Law, 2016).

The city of Los Angeles, which faces the crisis of a modern water regime of linear flow, provides an insightful case to investigate these questions. In particular, this study drew attention to the relationships between a powerful discourse of water circularity that shapes water management and policy in Los Angeles, the political and socio-technical orders of Los Angeles' inherited water infrastructure regime, and the diverse infrastructural practices of public water utilities, environmental groups, and enthusiastic homeowners in pursuing water circularity. Four research questions guided the analysis:

RQ 1: How do water and wastewater infrastructures in Los Angeles change toward more circular water systems?

RQ 2: How do the intertwined social and technical processes of circular water restructuring in Los Angeles reflect and produce particular "technopolitics"?

RQ 3: How do technical disputes over circular urban water restructuring involve diverse and partly competing proposals for governing urban nature and space?

RQ 4: What lessons can be drawn from the study of Los Angeles for a more sustainable and socially just water governance in cities in the Anthropocene?

Overall, this dissertation reveals that the socio-technical change of urban water and wastewater infrastructures toward more circular water cities is a highly ambivalent and contested process. In Los Angeles, place-specific constellations of material artifacts, discourses, knowledge, and institutions explain the predominance of centralized infrastructural practices by public engineers who advocate for a singular "One Water" system and how they prevail in infrastructural disputes. Although they remain marginalized, more decentralized and landscape-centered water circularity practices of non-profit groups, activists, and homeowners can no longer be ignored. This development produces an increasingly hybrid water system wherein diverse infrastructural practices that articulate plural and partly competing proposals for governing urban nature co-exist.

A critical conceptual argument of this study is that circular urban water restructuring is a technopolitical process whereby political relations between water, technology, and urban nature become practically negotiated through infrastructure renewal. In this process, urban technopolitical regimes arise as governing forces of urban nature and space and become contested through infrastructural practices. This technopolitical lens highlights the instability of the different technological cultures of urban nature through which urban ecologies become known and differently managed. Another key insight was that technopolitical power that arises from infrastructural attempts to create a more circular water flow frames the broader socio-political meaning of evolving urban infrastructures. This can explain how existing urban infrastructure arrangements become stabilized, modified, and contested. Together, the insights gained from this study expand our understanding of infrastructural change toward circular urban water futures and the political role of technology in governing urban nature and space in accordance with the principles of circularity.

The next section outlines the main empirical findings of this study in exploring these questions in Los Angeles. The remainder of this conclusion then reflects on the broader meaning of the Los Angeles case for theoretical debates in critical urban research, as well as for further research and policymaking.

6.1 Main findings

6.1.1 Infrastructural change toward a more circular Los Angeles

This dissertation has found that an inherent tension marks circular water restructuring in Los Angeles. Practices of public engineers to incrementally adapt existing infrastructures that concentrate circularity debates at a handful of centralized facilities predominate. However, these practices increasingly coexist with a variety of decentralized infrastructural practices, which together create a more hybrid infrastructure system. Nonetheless, the twentieth-century infrastructure regime of sanitary Los Angeles continues to exert a powerful influence on the socio-technical change of water and wastewater infrastructures. Meanwhile, the increasingly unreliable water imports, coupled with the impacts of a changing climate, environmental regulations for water quality and usage, and political aims to "green" Los Angeles, are putting this regime under pressure to adapt and transform. There is a broad consensus among policy stakeholders that enhancing water sustainability and resilience in Los Angeles requires the creation of a more circular and local water system. This study showed that such discursive convergence, actors aim to reconfigure water and wastewater systems differently, which produces particular forms of infrastructural change.

Circular water restructuring in Los Angeles is dominated by large-scale engineering practices of incumbent experts in public utilities. Chapters 2 and 5 demonstrated how public experts seek to forge an aspired One Water system mainly by retrofitting existing, centralized infrastructure facilities and by interconnecting previously separate water supply, sewer, and stormwater networks at these acclaimed "infrastructural assets" of water circularity. This *dominant process of incremental adaptation* drives the creation of a circular Los Angeles at the "end of the pipe" of existing networks. As a result, water circularity partly materializes in highly engineered One Water system around increasingly interconnected centralized facilities, with local and regional groundwater basins strategically integrated as storage spaces for infiltrated stormwater and recycled wastewater.

This study also revealed how the public reframing of wastewater and stormwater as resources, and discourses of urban greening linked to circularity visions, also drive infrastructure decentralization. First, Chapters 3, 4, and 5 documented how public utility programs of infrastructure decentralization deploy specific technologies, incentives, and rules to promote distributed water management as part of a *centrifugal expansion of existing infrastructure networks*. Public parks, streets, and private parcels are activated for circular water management, requiring the collaboration of water utilities with other city departments (e.g., street services), environmental non-profits, and private property owners. This utility-led development underpins One Water aspirations by increasing stormwater capture and outdoor efficiency beyond centralized networks.

Second, this study revealed that distributed infrastructural practices of environmental groups, activists, and homeowners cannot be neglected in circular water restructuring after longstanding advocacy work for local stormwater capture, greywater reuse, and landscape water conservation. Although to some extent thwarted by the dominant practices of public engineers, this *user-driven infrastructure decentralization develops in the interstices of centralized networks*. Through a stronger focus on landscape-centered practices and site-specific solutions for water circularity, this development extends, modifies, and, at times, contradicts utility-led water circularity efforts.

Overall, this study illustrates how the process of circular water restructuring in Los Angeles is complex and dynamic, reflecting Timothy Moss' (2020) observation that urban infrastructural change is a non-linear and multi-layered process that exhibits "conjunctions of continuity and change." The persistence of sanitary Los Angeles' infrastructure regime orders is actively fabricated through a combined approach of incremental adaptation and the centrifugal expansion of existing infrastructure networks. Together with user-led infrastructure decentralization, this development engenders *more hybrid water systems*. Whereas the large-scale engineering practices of public experts remain dominant and concentrate efforts to create a more circular Los Angeles at "the end of the pipe" of existing water networks, diverging infrastructure designs increasingly overlap and become interdependent. As a result, the scales and urban spaces, the actors, the forms of knowledge, and the infrastructure artifacts of water management become more diverse, which in turn increases governance complexity. Technically diverse and spatially dispersed infrastructures complicate the monitoring and control of water and pollution flows by public experts. In addition, entrenched water management institutions imply considerable coordination efforts among the multiple actors. Simultaneously, frictions arise between dominant endeavors to create a more circular Los Angeles through the incremental adaptation of centralized infrastructure facilities and the diverse decentralization initiatives. For instance, contested ambitions to re-landscape private gardens for water conservation and disputes over greywater reuse testify to how circular water restructuring stretches across different spaces, communities, and cultural realms of the city, with distinct politics that act back on infrastructural change. Local greywater reuse practices, used to increase the water efficiency of wealthy homeowners' resource-intensive lifestyles, can undermine paradigms of universal service provision in Los Angeles' hybrid water systems. The multiple infrastructure artifacts, and the social processes and urban geographies linked to them, complicate the teleological ideas of creating a circular Los Angeles through One Water visions. Consequently, there is considerable ambivalence and uncertainty about the infrastructure arrangements through which water circularity will eventually materialize in Los Angeles.

6.1.2 The technopolitics of circular water restructuring in Los Angeles

This study revealed a dominant technopolitical regime that frames circular water restructuring in Los Angeles mainly as a problem of incrementally adapting existing infrastructures. The political power wielded by this regime evokes a future where large volumes of circular water can be centrally controlled through technology. However, this regime is more heterogeneous than initially apparent and is contested by the infrastructural practices of environmental groups, activists, and homeowners.

The dominant technopolitical regime of water circularity is rooted in the inherited socio-technical orders of sanitary Los Angeles. Chapters 2–5 showed how this regime arises from the dynamic relations between existing centralized infrastructure facilities, the infrastructural practices of public experts, as well as inherited political economies, institutions, and knowledge hierarchies in water management. Public water utilities are under high financial pressure as their revenues depend on strictly controlled volumetric service fees. To fulfill their institutional missions most cost-efficiently, LADWP and LA Sanitation seek to create a One Water system in Los Angeles around centralized infrastructures where water flows concentrate by gravity. This end-of-pipe approach is consistent with the agencies' expertise in managing large-scale infrastructure projects and entrenched service reliability, controllability, and safety principles. Together, this generates powerful technopolitics through which water circularity becomes understood and framed as a problem of the volumetric control of large water flows. Epistemologically, these technopolitics downplay broader social and ecological relationships of urban water flows in order to streamline volumetric water management. On a discursive level, they portray centralized wastewater treatment plants and other acclaimed "infrastructure assets" as the lynchpins of water sustainability and resilience in circular Los Angeles. This promotes a rationale for achieving water circularity through the technical integration of separate infrastructure networks while preserving entrenched institutions and knowledge hierarchies.

The study further uncovered how dominant technopolitics of incremental adaptation are strengthened by utility-led infrastructure decentralization to expand existing water networks into the urban fabric. Chapter 3 illustrated how this is pursued through a combination of mandating and standardizing stormwater management practices on private property to increase control over stormwater flows. Chapter 4 documented the public utilities' strategy to improve cost-efficient water conservation in private gardens. This works by subsidizing "smart" irrigation technologies and by linking California Friendly® landscape designs with a discourse of water conservation as the moral responsibility of environmentally-friendly citizens. Instead of separating circular water flows from their broader social and ecological entanglements, these technopolitical interventions strategically organize these relationships to promote water circularity as a matter of volumetric water management.

This dissertation also closely analyzed how the dominant technopolitics of pursuing One Water aspirations through incremental adaptation and the volumetric control of water flows become contested in technical disputes. Technopolitical contestation occurs when actors introduce novel infrastructure artifacts with particular histories, cultural meanings, and urban geographies into political debates about water circularity in order to differently frame the meaning of circularity in practice. Three relevant ways of such contestation were identified.

First, Chapters 2 and 5 highlighted how actors could subvert the dominant technopolitics of circular water restructuring by diverting stormwater and wastewater flows beyond centralized networks. For instance, the porous control of public engineers over wastewater flows is exposed through greywater reuse practices. *Technological interventions to locally intersect water flows* challenge the political promises of realizing a One Water system through incremental adaptation and infrastructure decentralization led by public utilities.

Second, infrastructural practices can contest the dominant technopolitics of circular water restructuring on an epistemological level. Chapters 3 and 4 showed how technical disputes over water circularity reveal the instability of a dominant culture of water management that relies on expertise in large-scale engineering. For instance, infrastructural practices whose multiple benefits cannot simply be measured in terms of captured stormwater volumes or which include living beings (e.g., plants) as infrastructure components can disrupt entrenched ways of knowing and managing water. By introducing alternative *epistemologies of water flow* in processes of circular water restructuring, actors dispute political claims about water circularity based on hegemonic expertise in large-scale engineering.

Third, technological interventions that bring broader environmental discourses to the forefront of infrastructural concerns in circular water restructuring can counteract dominant technopolitics. For example, instead of reducing water circularity to a problem of volume control, environmental groups in Los Angeles frame circularity as a matter of climate adaptation and community greening by using nature-based stormwater practices (Chapter 3). Once specific *meanings and abstractions* are established in political debates about circularity, or even institutionalized in new governance arrangements of water management, they shape the political possibilities (and necessities) of infrastructural change.

In summary, this study demonstrates how a dominant technopolitical regime of water circularity in Los Angeles is sustained through two key strategies: (i) the incremental adaptation of existing infrastructures by public engineers and (ii) their attempts to organize broader urban social and ecological relations through the centrifugal expansion of infrastructure networks. By employing these strategies, the creation of a circular Los Angeles is primarily framed as a problem of volumetric control of water flows, achievable mainly by technological reconfigurations. These technopolitics simultaneously sustain the political interests of public water utilities and marginalize infrastructural proposals by "non-experts." Yet, attempts to control water flows beyond centralized networks also increase the complexity of water management. Moreover, dominant technopolitics become contested by the infrastructural practices of environmental groups, activists, and homeowners. More plural political possibilities of urban water circularity manifest through practices that (i) locally intercept water flows and expose the difficulty of centrally organizing them in more hybrid water infrastructures, (ii) introduce new epistemologies of water circularity, and (iii) broaden the meaning of water circularity by linking it with other abstractions and environmental discourses.

6.1.3 Governing urban nature and space in circular Los Angeles

A central objective of this study was to develop a more nuanced understanding of the political relations between urban infrastructures and urban nature in processes of circular water city-making. The analysis revealed three dimensions that illustrate how the technopolitics of circular water restructuring in Los Angeles reflect different proposals for governing urban nature and space.

First, the technopolitics of circular water restructuring in Los Angeles involve *diverging and partly competing rationales for using water and urban space*. Chapters 2 and 5 showed how public utilities in Los Angeles seek to achieve water circularity through the incremental adaptation of centralized facilities by remaking large volumes of wastewater and stormwater as resources for potable water supply while simultaneously mitigating pollution. The utilities' dependency on revenues from volumetric water sales stymies more radical water conservation. Instead, incremental infrastructure adaptation sustains an eco-modernist logic whereby the utilities mobilize water scarcity to justify a supply-driven water management approach through large-scale technology. Inseparable from this, centralized wastewater recycling endeavors preserve a dominant culture focused on potable water use in circular futures, which hinders alternatives approaches to non-potable water reuse. For public engineers, centralized wastewater recycling avoids considerable governance challenges that stem from the complexity of controlling the sustainability performance of distributed non-potable water reuse practices and their compliance with public health regulations. At the same time, dominant technopolitics that concentrate water flows in a centralized water cycle tailored for drinking water provision shape urban space. Chapter 2 illustrated how plans for centralized wastewater recycling would result in less water flow in the Los Angeles River. Here, technology-led water circularity endeavors wield political power over spatial discourses of revitalizing the Los Angeles River to support inner-city redevelopment.

Other political proposals for utilizing water and urban space in circular Los Angeles are articulated in the infrastructural practices of environmental groups, activists, and enthusiastic homeowners. Chapter 3 described how disputes around measuring the benefits of landscape-centered stormwater practices reflect different forms of conceptualizing water and urban space use. Proposals to assess the cost-efficiency and effectiveness of stormwater practices based on broader community benefits (e.g., green space, urban cooling, etc.) in addition to volumetric stormwater improvement envision urban futures where parks, streets, and private property are more radically transformed into landscape-centered infrastructures. However, implementing such decentralized nature-based practices, especially on private property, presents new challenges for public engineers responsible for stormwater pollution abatement, as they must ensure these practices' reliable environmental performance and professional maintenance. Chapter 4 illustrated how California native plant horticulturists promote autochthonous gardens to link discourses of water circularity with ideas of biodiversity restoration, resource sufficiency, and a co-habitation of humans with nonhuman urban life. This challenges the dominant water conservation regime, which that assesses possibilities of urban development in terms of saved volumes of water and produces more standardized landscape ecologies rationalized for cost-effective and reliable water conservation.

Second, the technopolitics of urban water circularity in Los Angeles reorganize the *roles of public experts and users in governing urban nature and space through infrastructure*. One of the key findings of the study is that actors' roles in the water management system are becoming more diverse and more ambiguous, with inherited roles increasingly overlapping with new forms of user mobilization and emancipation. These novel actor constellations emerge as a result of more diverse infrastructure designs co-existing in Los Angeles' increasingly hybrid water system. Chapter 2 showed how of public engineers maintain their authority as expert infrastructure providers through strategies that aim to assemble a circular Los Angeles through centralized infrastructure restructuring. Notions of resilience, service reliability, and public safety are foregrounded to legitimize public experts' exclusive control over water flows. At the same time, users are framed as a homogeneous group of consumers unified around a shared interest in individual cost savings and uninterrupted service. Moreover, utility-led infrastructure decentralization vacillates between shifting responsibility for volumetric water management to users and attempts to control user practices through technology. Chapter 3 highlighted how Los Angeles' LID Ordinance mandates stormwater capture on private parcels, while homeowners are often overburdened with properly managing stormwater. This causes uncertainty among public engineers who are charged with controlling pollution effectively. Chapter 4 documented how California Friendly® landscapes are advertised as symbols of a Californian water conservation ethos so that homeowners embrace them, while a focus on enhanced irrigation aims to control users' watering practices. Finally, the study showed that practices such as local greywater reuse or California native plant gardening evoke more plural user roles. Users that adopt these practices act as infrastructure co-providers who modify and challenge water governance led by public experts according to their political interests, worldviews, and environmental experiences.

Finally, the technopolitics of urban water circularity in Los Angeles reflect *different ways of valuing urban nature, environmental knowledge, and labor*. Public engineers' efforts to create a circular Los Angeles at the end of the pipe frame circularity as a problem of volume control, thereby maintaining modernist ideas of nature and technology as separate. These practices aim to strip off water flows from urban social and ecological relations that obstruct the remaking of stormwater and wastewater into water supply resources. As a result, these practices devalue other aspects of the urban ecologies linked to circular water flows, such as recreation or biodiversity enhancement (see Chapter 3). Chapter 4 illustrated how the technopolitics of California Friendly® landscapes, which prioritize irrigation technology, normalize a low-wage immigrant workforce tasked with highly standardized landscaping work. But processes of circular water restructuring also reveal the artificiality of circular Los Angeles' environments where boundaries between nature, technology, and society become blurred. This study found that new ways of valuing nature and environmental knowledge become articulated through infrastructural practices that introduce understandings of water circularity as inseparable from broader urban social and ecological relations. For instance, Chapter 4 revealed that California native plant gardening emphasizes the importance of horticulture and landscape design expertise to realize synergies between water circularity and the broader objectives of sustainability and environmental justice. The reliance of water systems on practices that care for fragile plant ecosystems evokes a radical critique of entrenched knowledge hierarchies and forms of valuing knowledge in urban environmental governance.

6.1.4 Lessons from Los Angeles for a more sustainable and socially just water governance in cities of the Anthropocene

This dissertation builds on urban water governance research which emphasizes the need to rework the cognitive, normative, and regulatory conditions of water management – as well as material change – to enhance urban water sustainability (Section 1.2.2). Urban political ecologists underline the importance of grassroots movements in challenging uneven power relations that contribute to unsustainability and injustices in urban water governance (Section 1.2.3). Adopting a technopolitical lens, this study suggests that foregrounding and bringing into conversation the diverse proposals for governing water and urban space articulated by different actors and their infrastructural practices can open up new possibilities for urban water sustainability and justice. This approach involves revealing the distinct political ideas about governing urban water that are codified in expert knowledge and making the synergies and trade-offs between diverging infrastructural practices subject to informed and open decision-making. For policymakers and urban and infrastructure planners, this comes down to creating the institutional and incentive structures, knowledge base, forms of collaboration, and planning procedures that enable more integrated development of water infrastructures beyond rationalizing volumetric water management. This study has identified key ways to support these efforts.

Chapters 2–5 indicate how the political economies and institutions of urban water management in Los Angeles, which have evolved during the twentieth century, are increasingly ill-suited to address today's water challenges. Exposing institutional misalignment and reworking these conditions is a prerequisite for developing more sustainable and socially just urban water systems. To advance sustainable urban water management, it is vital to reorganize the separate water agencies that act according to their distinct regulatory embedding, economic incentives, and historically evolved missions and knowledge repertoires. On a regulatory level, improving regulations for the direct potable reuse of recycled wastewater and onsite systems for non-potable reuse in California can support agency collaboration in wastewater recycling. Additionally, revising the funding criteria of public water bonds to incentivize multi-benefit projects and agency collaboration can make a difference.

Within Los Angeles' city politics, better agency collaboration on integrated water management is promoted at the mayor's level but requires stronger institutional support. To advance this, beyond the implementation of a city-wide database for multi-benefit water projects, revenue-sharing agreements, technical norms and standards for nature-based practices, and interdepartmental workforce development programs can be developed. A political challenge will be to reform inherited water pricing and revenue schemes of water utilities that depend on selling large volumes of water, which disincentivize conservation. Chapter 4 showed that the social justice aspects of subsidies for water conservation through landscape change, from which predominantly middle-class and upper-middle-class homeowners with gardens benefit, need to receive more attention. A more just reform could be increasing per-unit water prices for homeowners with higher consumption as well as advertising free landscaping education programs more broadly. Meanwhile, water affordability programs for low-income residents, who often have little extra room to conserve more water through efficiency technology given their low levels of consumption, should be strengthened. This could require reforming California's Proposition 218. The regulation stipulates that water rates cannot exceed the costs of service provision for individual customers, which complicates the implementation of tiered pricing schemes with lifeline rates for low-income customers. In general, policymakers must better balance the economic imperatives that incentivize investments in expanding local water supply with the ecological goals of conserving water.

A vital lesson of this dissertation is that enhancing the sustainability and justice of circular urban water systems requires a more productive engagement with increasingly hybrid water infrastructures. The Los Angeles case shows that planning strategies must better coordinate diverse practices, actors, knowledges, scales, and institutionalized environmental management tasks in hybrid water infrastructures. Chapter 3 demonstrated that so far, fragmented planning processes to realize landscape-centered stormwater infrastructures on streets or in public parks require reform. Developing better accounting and financing tools for landscape-centered stormwater practices can facilitate cost sharing between city departments and revamp obsolete notions of water management efficiency based on ideas of volumetric control. To minimize trade-offs, spatial planning must also do a better job of reflecting and coordinating the spatial requirements of landscape-centered stormwater practices at different scales. One way to do so is to incorporate more comprehensive data on the soil and infiltration conditions at a sub-watershed level into spatial planning decisions. Furthermore, in order to learn from hybrid water infrastructures, planning processes should better incorporate diverse forms of knowledge. As discussed in Chapter 4, the remaking of private gardens as elements of water infrastructures requires a more substantial uptake of horticultural and ecological knowledge in water management. A more general lesson is that overhauling the dominance of engineering knowledge in urban environmental management offers opportunities for urban water sustainability and justice. Strategies for circular urban water management need to better value the labor of those who care for landscape-centered infrastructures. Finally, homeowners should be more effectively mobilized as informed co-providers of infrastructure. Environmental education aimed at promoting the potential of sustainable water management on private properties can be a useful strategy. However, homeowner participation must be carefully balanced with public responsibilities for water pollution control compliance, especially in the context of stormwater management. In addition to improving agency capacities to inspect distributed stormwater practices and standardizing these practices, spatially sensitive public infrastructure interventions based on detailed geographical pollution and groundwater data can foster this balancing. As a result, pollution abatement through centralized infrastructures can improve heavily polluted areas. In addition, dialogue processes can help build trust between water management experts and citizens, clarifying heir distinct roles in water management.

6.2 Theoretical reflections

6.2.1 Studying urban infrastructural change as a contested process

This study built on debates in urban water governance and on critical studies of urban infrastructures to better understand the contested governance of shifting urban water and wastewater infrastructures as cities pursue water circularity goals. Governance scholars have underlined governance failure as an impediment to more sustainable urban water systems, which has unsettled the primacy of the teleological trajectory toward urban water sustainability is the outcome of progress in science and technology (Section 1.2.2). This dissertation's analysis of the technopolitics of circular urban water restructuring extends an understanding of the contested governance of urban infrastructural change. Essentially, this was achieved by drawing attention to two entangled techno-political dynamics that shape urban infrastructural change. The prevailing infrastructural practices in technical disputes over infrastructure restructuring depend on place-specific constellations of material artifacts, discourses, knowledge, and institutions, specific infrastructural practices. Simultaneously, actors organize the technopolitics of urban water circularity through these practices. Depending on their particular organization, technopolitical constellations frame the socio-political meaning of evolving infrastructures in specific ways and thereby structure political possibilities of change.

From this conceptual perspective, this dissertation utilized and refined academic debates on the co-evolution of cities and infrastructures by scrutinizing Los Angeles as an archetypical modern constructed according to the "modern infrastructure ideal" (Graham and Marvin, 2001). The analysis allows making an explicit contribution because, in Los Angeles, ambitions to advance water circularity and to decentralize water management occur in a linear water system of centralized infrastructure networks. The study not only examined the interrelations between centralized and more distributed infrastructural practices in implementing circularity visions, but also explored the particularities of endeavors to roll out large-scale technological solutions compared to more landscape-centered water management practices. This analytical focus connects to broader questions in critical studies of urban infrastructural change. Scholars have developed a rich analytical repertoire to understand urban infrastructures as relatively stable regimes of artifacts, institutions, and practices that resist change (Monstadt, 2009; Tiwale, 2019) and as more malleable socio-technical constellations that become reproduced, extended, and modified through situated practices (Furlong, 2011; Rutherford, 2020; Guma, 2020).

This study enhanced this research by uncovering how the technopolitical relations between water circularity visions, existing infrastructure arrangements, and the infrastructural practices through which actors pursue water circularity shape urban infrastructural change. Three contributions were made.

First, this study improved theories on the *obduracy of urban infrastructure regimes*. Chapter 2 has demonstrated that the efforts to incrementally adapt existing infrastructure networks for advancing water circularity in Los Angeles conjure up a powerful discourse that tightly links water circularity futures with centralized wastewater recycling. The dominant vision of centralized wastewater recycling marginalizes more distributed forms of wastewater reuse that diverge from this perspective. Hence, the obduracy of urban infrastructure regimes can, in part, be explained by tracing how infrastructural practices of incumbent actors mobilize circularity concepts as a technopolitical force that limits political possibilities of change. This occurs as infrastructural interventions concentrate political debates about water circularity on certain existing infrastructure artifacts by highlighting their technical effectiveness and reliability. Consequently, the cultural meanings and institutional ideologies inscribed in these artifacts largely influence what emerging circular infrastructure constellations ought to look like.

Secondly, this dissertation sharpened conceptualizations of *urban infrastructure stability and malleability as intertwined processes*. This interplay can be understood through the notion of "infrastructuring gardens" as developed in Chapter 4 and which brings debates from anthropology (Blok et al., 2016) into conversation with studies of urban infrastructures. Infrastructuring can stabilize a given infrastructure regime by incorporating new artifacts into the regime and aligning these artifacts and their underlying social processes with existing socio-technical regime orders. At the same time, infrastructuring can modify and contest an existing infrastructure regime from its margins. This perspective examines how actors render specific artifacts new infrastructure components whose associated practices, knowledges, and discourses alter the broader meaning of an evolving infrastructure regime. Infrastructuring allows a multi-sited study of infrastructural change that places the rationales located at the center of a given infrastructure regime against the situated practices and histories of different urban spaces. This perspective advances work on the malleability of urban infrastructures (Furlong, 2011; Tiwale, 2019).

Third, this study enhanced research on the contested governance of urban infrastructural change by specifying the *technopolitics of hybrid urban infrastructure systems*. The empirical analysis showed that water circularity endeavors drive infrastructural hybridity. This complicates ideas of achieving water circularity by smoothly integrating different technologies in novel infrastructure arrangements. One of the key findings of this study is that political power over infrastructural change in hybrid systems is contingent upon the actors' ability to combine the incremental adaptation of centralized infrastructures restructuring with the centrifugal expansion of infrastructure networks. Chapter 5 highlighted how public engineers aim to conduct broader urban social and ecological relations linked to hybrid infrastructures by establishing an overarching technopolitical framing of water circularity as a problem of volumetric water control through technology. Chapters 3 and 4 documented the limits of this approach, which result from the multiple human and nonhuman agencies involved in circular water restructuring that permeate institutional, epistemological, and spatial boundaries. Attending to the interplay of technopolitical conduct and the distributed agencies in hybrid infrastructures enhances the understanding of urban infrastructural change as a contested and ambivalent process.

Overall, the Los Angeles case repudiates techno-optimistic narratives that suggest urban water challenges can be fixed by creating more closed urban water cycles through technical infrastructure restructuring. This dissertation shows how actors attempt to organize the technopolitics that shape urban infrastructural change toward more circular urban water futures by (i) concentrating political debates about urban water circularity at particular artifacts, (ii) and the centrifugal expansion of infrastructure networks or the contestation of existing infrastructure arrangements from the margins. These dynamics overlap in hybrid urban infrastructure systems where distributed agencies permeate centralized technopolitical control.

6.2.2 The techonopolitics and rationalities of governing urban nature and space

An essential contribution of this dissertation to critical urban research is refining conceptualizations of the political relations between urban infrastructures and urban nature. Theoretical reflections in this dissertation have built upon the study of circular urban water restructuring to explore broader implications for governing urban nature and space, with technology at the center of the analysis. Inspired by STS, this dissertation explored technology as “an environment within which a way of life is elaborated” (Feenberg 2010, 15), recognizing that in modern societies, the creation of technology is a highly unequal process dominated by experts. Debates in urban political ecology are another important conceptual point of departure of this study. Central here is the idea that infrastructures form powerful mediators in the production of urban nature while themselves emerging through capitalist urbanization processes (Section 1.2.3). Yet, this dissertation has engaged in a productive critique of debates about urban infrastructures in urban political ecology. The hybrids of technology, institutions, expertise, cultural meaning, and economic relations that constitute infrastructures remain less explicitly analyzed and conceptualized in these debates. Furthermore, urban political ecologists attend less to the diverse practices of actors with diverging worldviews who contribute to the creation of environment-shaping infrastructures (Section 1.2.3). An exception is more recent work in urban political ecology that investigates the “socio-technical aspects of everyday urban life” (Gandy, 2022a: 28), mainly in cities of the Global South. Prior research placed particular emphasis on analyzing infrastructures as a structural force in urbanization processes.

This dissertation enriched debates in urban political ecology and urban water governance by offering an explanation of technopolitical power in circular water restructuring as shaped by existing infrastructure arrangements and by the infrastructural practices of diverse actors. This was achieved by equipping nascent debates on urban technopolitics (Foley and Miller, 2020; Randle, 2021) with a dedicated analytical framework to study the technopolitics of circular urban water restructuring. Essentially, this perspective explores infrastructural change as a technopolitical process that has its own inner workings but impinges on urban nature more broadly. This analysis highlights how the political economic, ideological, institutional, and knowledge conditions within which urban environmental management is carried out are co-constructed by technology. Along these lines, three distinct contributions were made.

First, this dissertation explains the *dominance of technological experts’ rationalities of governing urban nature and space* through technopolitical regimes that develop in circular urban water restructuring processes. In Los Angeles, the pursuit of circular water restructuring is primarily carried out through retrofits and the interconnection of centralized infrastructure artifacts by public engineers, with centralized wastewater recycling at the heart of this dynamic. These technopolitics of incremental infrastructural adjustment in Los Angeles sustain political economies of supply-driven water management and a modernist hygienic culture focused on highly purified potable water. Meanwhile, the socio-political possibilities of the non-potable reuse of wastewater in homes, urban landscapes, and artificial urban ecosystems are constrained. Together, this dissertation has shown how technopolitical regimes that emerge through the technology-led revalorization of wastewater to fix urban water scarcity and pollution problems become powerful governing forces of urban development. Research on the political economies of urban water scarcity (Millington and Scheba, 2021) can benefit from this technopolitical account to explain structural power in governing urban environments in the context of climate change.

Second, this study revealed that *political ambivalence and complexity in governing urban environments* arise from the diverse technologies that actors deploy to pursue sustainability visions. Chapters 3 and 5 documented how the technopolitics of circular water restructuring in Los Angeles reflect plural and partly diverging proposals for governing urban environments and provoke more ambivalent actor roles in infrastructure provision. This occurs as urban infrastructure systems become more hybrid. For instance, the political demands of climate change adaptation and community greening, as articulated through nature-based infrastructural practices, should be addressed in urban water restructuring. This challenges entrenched knowledge hierarchies in water management. In terms of managing stormwater pollution, nature-based infrastructures can also significantly increase governance complexity and public expert uncertainty as they are responsible for ensuring water quality standards. Expertise in large-scale engineering and paradigms of volumetric water management are crucial towards addressing water pollution. Together, exploring infrastructural hybridity can inform research on the broader political dynamics linked to urban water flows (Goh, 2021; Millington, 2021) by highlighting an extended field of political possibilities and governance complexity embedded in evolving infrastructures.

Finally, this study shows how *dominant rationalities of governing urban environments become contested at the margins of urban technopolitical regimes*. Chapter 4 discussed how public engineers rework private gardens to pursue institutional interests of urban water management; it also shows how the gardening practices of specialized horticulturists modify and contest these technopolitics. By incorporating specific plants as infrastructure components in the process of "infrastructuring gardens," horticulturists shape more enduring patterns of environmental organization. The idea that infrastructure is shaped by technological agency – in relation to other human and nonhuman agencies made explicit here – equips debates in urban political ecology and on more-than-human geographies with a better conceptualization of technology. The notion of infrastructuring gardens has a key conceptual value in drawing attention to the specific moments and places in which different technological cultures of urban nature converge. Political conflicts over urban environmental management can be better understood by exploring the *instability of different cultures of urban nature* in disputes over infrastructure development. This open-ended perspective on the making and remaking of urban environments through infrastructure can advance research in urban political ecology that examines conflicts over environmental management shaped by expertise (Finewood, 2016).

Together, this dissertation enhances research on political power and different rationalities in governing urban environments by specifying the political role of technology in circular city-making. Understanding how urban technopolitical regimes emerge and become contested in processes of circular water restructuring advances debates in urban political ecology on political power in producing urban nature. Research in urban water governance can benefit from this study by understanding that the social orders (e.g., institutions, knowledge) within which water management takes place, are co-produced through technopolitics. This perspective can direct the attention of governance scholars to the political entanglements between institutional reform efforts and the diversifying technologies of urban water management.

6.2.3 A critical technopolitics perspective on circular cities

This dissertation's analysis of practical attempts to create a more circular water system in Los Angeles can inform theoretical reflections on circular cities as a phenomenon of urbanization in the Anthropocene. These reflections connect with geographical debates around concepts of "smart cities" or "urban resilience," which promise to govern cities as complex adaptive systems, but which also demand critical examination as governance idioms of urban development (Braun, 2014; Derickson, 2018; Ernstson and Swyngedouw, 2018). It is crucial here that actors strategically deploy these concepts to pursue particular goals in urban governance that are presented as if there was a general consensus around them. Gandy (2022b) further argued that framings of cities as complex adaptive systems, that can be managed as a whole, have become predominant in urban environmental management. Yet, the historical and political dimensions of urbanization that explain how certain framings of environmental problems are produced and contested are obscured by such system-based approaches.

Taking these debates further, this dissertation problematizes the circular city as a vaguely defined but widely adopted concept among urban policymakers and practitioners to enhance urban sustainability by governing urban ecologies as complex adaptive systems. This critical analysis of circularity concepts as a mode of governing urban environments was conducted by examining the diverse technological cultures of urban nature that shape how ideas of urban water circularity become realized through infrastructure renewal. The study demonstrated that technopolitical power largely influences how circularity ideas become a political force in the remaking of urban nature in the Anthropocene, where policymakers seek systemic remedies for exacerbating socio-ecological crises. This works in two ways.

First, urban technopolitical regimes exert *structural power that explains the hegemony of certain systemic representations of urban ecologies*. This matters since these representations guide politically-relevant interventions in urban environments. Chapters 2 and 5 documented the rise of a powerful technopolitical regime of circular Los Angeles around centralized infrastructure facilities managed by public experts. Those chapters have shown how the volumetric epistemologies of water inscribed in these facilities downplay other social and ecological aspects of urban water flow. Urban technopolitical regimes can thus profoundly influence the epistemological foundations upon which understandings of cities as complex adaptive systems are grounded. Moreover, the technopolitics of circular urban water restructuring can frame distinct social phenomena as “normal” elements of urban ecologies, neglecting their often-conflict-ridden histories. For instance, Chapter 4 reveals how focusing on irrigation technology in California Friendly® landscapes maintains the social realities of a poorly skilled and underpaid landscaping workforce.

Second, a technopolitics lens highlights the *constructed and contested nature of representations of cities as complex adaptive systems*. This study showed how circular urban water restructuring provokes increasingly hybrid infrastructures. The diverse technologies that co-exist in hybrid infrastructures exhibit the ambivalences and contradictions in circular city-making that might otherwise be obscured in predominant circularity discourses. More generally, an analysis of the technopolitics of circular urban water restructuring foregrounds the plurality of agencies and perspectives underlying urban ecologies. For instance, disputes about greywater reuse in Los Angeles show how social categories of “hazards” and “resources” in circular city-making are fluid and can be used for diverging technopolitical objectives.

In sum, this dissertation proposes an approach for a critical technopolitical analysis of circular (water) cities as a concept that shapes urban environmental governance practices by introducing particular understandings of cities as complex adaptive systems. First, a focus on technology can reveal the often messy and unaccomplished place-based realities of circular cities, which contrast with globally circulating policy visions of circular cities and the hegemonic ways in which circularity is represented in a given city. This helps to foreground the lasting (and at times exacerbating) unsustainability of cities in the Anthropocene vis à vis political promises of sustainability. Second, a technopolitics perspective is a useful means to explore how dominant technocratic cultures of urban nature envision circular cities and aim to realize their visions compared to alternative cultures of urban nature. Tracing how these cultures encounter each other in circular city-making disputes reveals power differences in this process. Third, and related to this, exploring the technopolitics of circular water restructuring contributes to the re-politicization of technocratic governance idioms of cities in the Anthropocene that obscure their inherited politics. Foregrounding the plural ways of knowing and managing urban nature through technology that co-exist in circular cities allows critically interrogating the specific and historically produced representations of urban ecologies in hegemonic framings of circularity.

6.3 Recommendations

6.3.1 Recommendations for future research

A general limitation of this dissertation stems from its case study design. While providing a solid contextual explanation of the Los Angeles case, this study cannot claim to present a full-range analysis of the broader politics of technology in shaping circular urban water restructuring. Nonetheless, insights from this study can be refined by testing and modifying this theory from Los Angeles in other geographical contexts. Beyond this, the analysis identified several avenues for further research that link a technopolitical inquiry of circular urban water restructuring with broader debates in urban geography and planning.

First, future research can investigate the technopolitics of water circularity through the relations between cities and their surrounding region. Los Angeles, often described as a poster child of "regional urbanization" (Soja, 2014), has profoundly influenced debates on suburbanization (Keil, 2017; Tzaninis et al., 2020). Likewise, water management in Los Angeles is inextricably linked with regional dynamics (McKillop and Boudreau, 2008). Therefore, future research can delve into how promises of local water supply through water reuse impinge on and are shaped by the political relations in the highly fragmented Los Angeles region. How are local initiatives to increase water self-sufficiency through infrastructure renewal and regional water infrastructure reconfigurations intertwined? How do such entangled infrastructure interventions reconstitute the political region of greater Los Angeles? An urban-regional inquiry can explore the technopolitics that emerge from the fragmented "geographies of storage" (Randle, 2022) in regional groundwater basins, the diverse community responses to circular water restructuring across the region, or infrastructural imaginaries of regional water circularity. By examining the technopolitics of circular water restructuring in the Los Angeles region and other urban regions, research can specify the political role of technology in a nascent debate on "infrastructural regionalism" (Addie et al., 2020).

Second, another insightful research strand is to better include the socio-economic, cultural, and ethical diversity of Los Angeles' communities in an analysis of circular water restructuring. This can bring into dialogue the study of technopolitics of water circularity with a rich body of literature on socio-spatial differences and environmental injustice in Los Angeles (Nicholls, 2011; Carter, 2016; Rigolon, 2019). Key assumptions of urban socio-spatial difference of the Los Angeles School of Urbanism (Nicholls, 2011; Soja, 2014) can be reassessed against the backdrop of infrastructural responses to water challenges in Los Angeles that have their own spatial politics. For instance, studying the links between circular water restructuring and the revitalization of the Los Angeles River can advance our understanding of technology's political role in green gentrification processes (Anguelovski et al., 2019). It was also beyond the scope of this dissertation to examine how nature-based solutions for water circularity are adopted, contested, and modified in different communities. Researchers can study which technopolitical strategies actors in working-class or ethnic communities adopt in response to threats of green gentrification through water circularity. A broader question that arises is how everyday experiences of urban "technonatures" (White and Wilbert, 2009) that vary across socio-culturally and economically different communities and have specific histories contrast with expert visions of circular water cities. Tracing these differences allows for a historically grounded and critical assessment of system-based ideas of urban water circularity. Exploring the socio-spatial differences in circular urban water restructuring in Los Angeles and other cities can both fertilize and benefit from recent debates on "intra-urban comparison of infrastructure" (McFarlane et al., 2017; see also Koepke et al., 2021).

Third, this dissertation provoked larger and previously underexplored questions about the diffusion of water circularity concepts across different urban contexts worldwide. Scholars have discussed the emergence of a "neo-hydraulic" water management approach that promotes centralized supply-side responses to urban water challenges (Green and Bell, 2019). This study investigated how the technology-led realization of circular city visions gives rise to urban technopolitical regimes. Future research can explore how global communities of technological experts, who promote water circularity as a matter of large-scale engineering, structure the processes of circular water restructuring in cities worldwide (Goh, 2021). In global comparison, Los Angeles forms a rather specific case of a publicly owned water system. Meanwhile, large-scale technological fixes to urban water problems are increasingly rolled out under conditions of the advancing commercialization of infrastructure services (Furlong, 2021; Millington and Scheba, 2021). Therefore, it is worth further investigating processes of circular urban water restructuring in the context of infrastructure commercialization. However, this dissertation also showed that technopolitical regimes of urban water circularity are contested as different cultures of urban nature clash in technical disputes over water circularity. Therefore, global technocratic cultures of urban water circularity need to be explored vis à vis locally specific articulations of circularity shaped by situated cultures of urban nature and technology (Monstadt and Schramm, 2017). For example: How do expert communities mobilize concepts of urban water circularity and transfer them into new contexts? What logics of urban environmental governance become promoted in this way, and what different logics emerge as expert circularity ideas become locally adapted and contested? Adopting this global-local lens on the technopolitics of water circularity can enrich a critical engagement with hegemonic approaches to manage urban ecologies as complex adaptive systems.

Fourth, this study touched upon the relationship between circular urban water restructuring and ideas of degrowth. Especially efforts to conserve water through landscape renewal made such relations visible. Researchers can further examine how the rationalities of water and resource use that are inscribed in different infrastructural practices reflect particular ideas of economic value creation. More generally, this study of the technopolitics of circular water restructuring can inspire a research agenda that explores technology as a political site where processes of resource commodification and efficiency paradigms co-exist with degrowth and resource use principles and practices including sufficiency, care, sharing, and reciprocity (Savini, 2021; Kallis 2021). This inquiry can help us to critically rethink the abstract ideas of often resource-intensive urban lifestyles and landscapes as well as development in technocratic urban environmental management. One concrete question that emerges from this study is how digital metering technologies in circular urban water infrastructures promote particular resource management paradigms and forms of commodification.

The last line of future inquiry guided by this study's findings is an analysis of the politics of pollution and the epidemiological dimensions associated with urban water circularity. Researchers could more critically interrogate techno-optimistic promises of tackling stormwater challenges through nature-based solutions in cities where urban lifestyles remain sources of water pollution. How can we critically examine the ways in which policy discourses of nature-based solutions for urban water circularity based on morphological conceptions of the city obscure the toxic realities of urbanization as a geographically extended process? Moreover, threats of vector-borne diseases related to nature-based solutions come to mind here. Future studies can pay critical attention to the epidemiological dimensions and potential adverse effects of human-centered infrastructure paradigms through which circularity is pursued in "zoonotic cities" (Gandy, 2022c) where urban development, biodiversity loss, and the spread of zoonotic diseases are closely entwined. A related question is how urban wastewater recycling ambitions that concentrate water flows in an artificial water cycle designed for human water use might jeopardize urban ecosystems that sustain multispecies health.

6.3.2 Recommendations for policy and practice

From this study, central recommendations can be drawn to help policymakers and urban practitioners advance sustainability and justice objectives in realizing urban water circularity. A strong advantage of this dissertation is that it thoroughly examined the social relations underlying the diverse technologies through which actors seek to create more circular water systems. This revealed opportunities for reworking the inherited socio-technical urban water and wastewater management orders that are increasingly ill-suited to tackle contemporary challenges. As a result, three key points can be highlighted.

First, in order to enhance more circular and integrated urban water management, there is a need for a stronger institutional framework. This dissertation shows that fragmented institutions remain a significant obstacle to urban water circularity and cities must move from a laborious project-by-project approach to finding new institutional arrangements that foster collaboration and alignment. One major opportunity is to bundle infrastructure investments better to balance the costs and benefits of infrastructure development among separate water and wastewater utilities. To facilitate such bundling, it is necessary to rewrite the budgetary rules of utilities to grant more value to integrated water management and to revise accounting practices. Another possibility is to establish dedicated funds for shared infrastructure projects which can help overcome a persistent logic of assessing the cost-efficiency of infrastructure investments in terms of the return on investments from volume-based fees for water supply or water quality services. Implementing nature-based solutions with multiple social and ecological advantages can especially benefit from overhauling ideas of providing efficient infrastructure through volumetric water management.

In addition, designing new technical rules and standards can facilitate better integrated urban water management. In Los Angeles, new standard plans for green streets help to mainstream nature-based water management practices on streets. Cities can establish technical working groups that convene representatives of water and wastewater utilities as well as construction, recreation, and street departments to develop new technical standards that acknowledge ecosystem functions and regulate ecosystem responsibilities.

Furthermore, institutional reform for circular water management can be supported by integrated spatial planning. There is a need to better coordinate water-related interventions in urban space on a watershed or sub-watershed scale. While formal spatial planning instruments do not explicitly target these scales, considering watershed layers and consulting area-based water committees in planning processes can advance more water-sensitive spatial planning. Through targeted siting and coordination with other land uses, landscape-centered infrastructures can realize synergies between stormwater pollution mitigation and stormwater infiltration goals that often have diverging geographies. This study further shows that planning on a sub-watershed or neighborhood scale has community advantages. As such, areas-based community representatives should be strategically involved in land-related water management decisions to align water management with community development. This approach can improve environmental justice by prioritizing disadvantaged communities in water infrastructure investments with urban greening benefits. Moreover, it can prevent the risks of green gentrification by carefully weighing infrastructure development with broader community needs and transformations.

Second, reworking the inherited relationships between infrastructure service providers and users is an essential precondition for more sustainable and just circular water cities. This dissertation has revealed the plurality of technologies, discourses, knowledges, values, and actors that matter in circular water restructuring. The strategies for achieving urban water circularity need to better utilize this distributed intelligence, while also addressing ambiguities and clarifying the roles of various actors. In particular, governance challenges are reflected in distributed stormwater management. Ordinances that mandate stormwater capture on private property must be strengthened by improving public agencies' inspection and monitoring of distributed infrastructures. Environmental education in schools, community centers, or provided by utilities to raise awareness for the ecological relationships pervading homes and gardens can help educate homeowners as infrastructure co-providers. However, and especially in terms of pollution control, policymakers need to be cautious when shifting responsibility for public services to users. In cases where pollutants are concentrated in a particular area, it is recommended that stormwater facilities serving a sub-watershed should remain on public ground and be professionally maintained. Additionally, regular training and compliance reporting for property owners who seek exemption from stormwater taxes by managing stormwater locally can improve decentralized stormwater management. Training and reporting schemes could also be established for local greywater reuse, while clearly defined criteria for greywater reuse permits can reduce regulatory uncertainty among public agencies. Both measures require building up institutional capacity within public agencies. Not least, the study shows that it is imperative to maintain principles of justice when involving users in infrastructure provision. Public subsidies for local water conservation should not redistribute money from all ratepayers to those – often wealthy – ratepayers with high conservation potentials without considering justice aspects (see also Section 6.1.4).

Finally, advancing more sustainable and just urban water systems relies on aligning water circularity endeavors with other sectoral policies and forms of community engagement. Mainstreaming nature-based practices requires policy intervention beyond water and wastewater management institutions. These institutions have historically evolved with advances in engineering science and technology yet still lack a profound knowledge base for nature-based practices.

There is a need therefore to develop new knowledge repertoires that not only document experiences in operating nature-based water management practices but also collect robust monitoring data on these practices (Tozer et al., 2022). Public utilities can draw on the often-longstanding experience of local environmental groups when co-creating new technical ways of measuring the multiple benefits of nature-based infrastructures. Moreover, local economic development policies can strengthen nature-based water circularity practices. For instance, within the framework of Green Deals, cities can support innovation and knowledge development in infrastructural practices that rely on horticultural and ecological knowledge. This can be bolstered by the efforts of labor unions and professional associations to grant more public attention and economic value to landscape-related forms of work that remain undervalued. Justice in circular water restructuring can be improved by fostering community engagement in infrastructure investment decisions. The Safe, Clean Water Program, which finances stormwater practices in Los Angeles, is an excellent example of how a wider range of stakeholders can be involved in investment decisions through steering committees for different watersheds. Not least, efforts to maintain nature-based infrastructures by community organizations or environmental non-profits should receive long-term financing. This is particularly the case in municipal governments where budget cuts have slashed the capacities of public utilities (Pincetl, 2010).

Overall, this study focused on infrastructural practices in making circular water cities. This followed the classic idea in STS to explore how science and technology matter politically for societies while being embedded in society (Felt et al., 2016). The recommendations for policy and practice above were derived from research findings that were achieved by following this analytical paradigm. Technology was used as a lens to help policymakers and practitioners critically reflect on the institutional orders, disciplinary landscapes, management paradigms, and the knowledge hierarchies within which they operate; to raise awareness for distributed intelligence in the city that can improve water management; to highlight interrelations of water circularity endeavors with other relevant policy fields; and to underline the need to search for sustainability synergies while also acknowledging the trade-offs in remaking contemporary urban ecologies through technology.

6.4 References

Addie, J. P. D., M. R. Glass, M. R., et al. 2020. Regionalizing the infrastructure turn: a research agenda. *Regional studies, Regional science* 7(1): 10-26.

Anguelovski, I., J. J. Connolly, M. Garcia-Lamarca, et al. 2019. New scholarly pathways on green gentrification: what does the urban 'green turn' mean and where is it going?. *Progress in human geography* 43(6): 1064-1086.

Arup, Antea Group and Ellen MacArthur Foundation 2018. Water and circular economy: a white paper. Accessed April 10, 2020. https: //nextgenwater.eu/wp-content/uploads/2018/10/Water_and_circular_economy-Co.Project_White_paper.pdf

Bell, S. 2017. Urban water sustainability: constructing infrastructure for cities and nature, Routledge London.

Blok, A., M. Nakazora, and B.R. Winthereik 2016. Infrastructuring environments. *Science as Culture* 25(1): 1-22.

Braun, B. P. 2014. A new urban dispositif? Governing life in an age of climate change. *Environment and Planning D: Society and Space* 32(1): 49-64

Carter, E. D. 2016. Environmental Justice 2.0: new Latino environmentalism in Los Angeles. *Local Environment* 21(1): 3-23.

Derickson, K. D. 2018. Urban geography III: Anthropocene urbanism. *Progress in Human* Geography 42(3): 425-435.

Ernstson, H. and E. Swyngedouw 2018. Urban political ecology in the Anthropo-obscene: interruptions and possibilities. Routledge, London.

Feenberg, A. 2010. Between reason and experience: essays in technology and modernity, MIT Press, Cambridge.

Felt, U., R. F. Clark, A. Miller, et al. 2016. Handbook of science and technology studies. MIT Press, Cambridge.

Finewood, M. H. 2016. Green infrastructure, grey epistemologies, and the urban political ecology of Pittsburgh's water governance. *Antipode* 48(4): 1000-1021.

Foley, R. and T. Miller 2020. Urban techno-politics: an introduction. *Science as Culture* 29(3): 309-318.

Furlong, K. 2011. Small technologies, big change: rethinking infrastructure through STS and geography. *Progress in Human Geography* 35(4): 460-482.

Furlong, KM. 2021. Full-cost recovery = debt recovery: how infrastructure financing models lead to overcapacity, debt, and disconnection. *WIREs Water* 8:1503.

Gandy, M. 2022a. Urban political ecology: a critical reconfiguration. *Progress in Human Geography* 46(1): 21-43.

Gandy, M. 2022b. Natura urbana: ecological constellations in urban space. MIT Press, Cambridge.

Gandy, M. 2022c. The zoonotic city: urban political ecology and the pandemic imaginary. *International Journal of Urban and Regional Research* 46(2): 202-219.

Gober, P. and B. Trapido-Lurie 2006. Metropolitan Phoenix: place making and community building in the desert. University of Pennsylvania Press, Philadelphia.

Goh, K. 2021. Form and flow: the spatial politics of urban resilience and climate justice, MIT Press. Cambridge.

Graham, S. and S. Marvin 2001. Splintering urbanism: networked infrastructures, technological mobilities and the urban condition. Routledge, London.

Green, A. and S. Bell 2019. Neo-hydraulic water management: an international comparison of idle desalination plants. *Urban Water Journal* 16(2): 125-135.
Guma, P. K. 2020. Incompleteness of urban infrastructures in transition: scenarios from the mobile age in Nairobi. *Social Studies of Science* 50(5), 728-750.
Kallis, G. 2021. Limits, ecomodernism and degrowth. *Political Geography* 87: 102367.
Keil, R. 2017. Suburban planet: making the world urban from the outside in. Polity, Cambridge.
Koepke, M., J. Monstadt, J. and K. Otsuki 2021. Rethinking energy transitions in Southern cities: urban and infrastructural heterogeneity in Dar es Salaam. *Energy Research & Social Science*, 74, 101937.
Law, J. 2016. STS as Method. In U. Felt, Fouché, R., Miller, C. A., & Smith-Doerr, L. (eds.), The handbook of science and technology studies. MIT Press, Cambridge. 31-59.
McFarlane, C., J. Silver and Y. Truelove 2017. Cities within cities: intra-urban comparison of infrastructure in Mumbai, Delhi and Cape Town. *Urban Geography* 38(9): 1393-1417.
Millington, N. 2021. Stormwater politics: flooding, infrastructure, and urban political ecology in São Paulo, Brazil. *Water Alternatives* 14(3): 866-885.
Millington, N. and S. Scheba 2021. Day Zero and the infrastructures of climate change: water governance, inequality, and infrastructural politics in Cape Town's water crisis. *International Journal of Urban and Regional Research* 45(1): 116-132.
Monstadt, J. 2009. Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. *Environment and Planning A: Economy and Space* 41 (8): 1924–1942.
Monstadt, J. and S. Schramm 2017. Toward the networked city? Translating technological ideals and planning models in water and sanitation systems in Dar es Salaam. *International Journal of Urban and Regional Research* 41(1): 104-125.
Nicholls, W. J. 2011. The Los Angeles School: difference, politics, city. *International Journal of Urban and Regional Research* 35(1): 189–206.
Parés, M., H. March, and D. Saurí 2013. Atlantic gardens in mediterranean climates: understanding the production of suburban natures in Barcelona. *International Journal of Urban and Regional Research* 37 (1): 328-347.
Pincetl, S. 2010. From the sanitary city to the sustainable city: challenges to institutionalising biogenic (nature's services) infrastructure. *Local Environment* 15(1): 43–58.
Pincetl, S., E. Porse, K. B. Mika, et al. 2019. Adapting urban water systems to manage scarcity in the 21st century: the case of Los Angeles. *Environmental Management* 63(3), 293-308.

Randle, S. 2021. Battling over bathwater: greywater technopolitics in Los Angeles. *City & Society* 33(3): 444-466.

Randle, S. 2022. Holding water for the city: emergent geographies of storage and the urbanization of nature. *Environment and Planning E: Nature and Space*, 5(4), 2283–2306

Rigolon, A. 2019. Nonprofits and park equity in Los Angeles: a promising way forward for environmental justice. *Urban Geography* 40(7): 984-1009.

Rutherford, J. 2020. Redeploying urban infrastructure: the politics of urban socio-technical futures. Pelgrave Macmillan, Cham.

Savini, F. 2021. Towards an urban degrowth: habitability, finity and polycentric autonomism. *Environment and Planning A: Economy and Space* 53(5): 1076-1095.

Soja, E. W. 2014. My Los Angeles: from urban restructuring to regional urbanization. University of California Press, Berkeley.

Tiwale, S. 2019. Materiality matters: revealing how inequities are conceived and sustained in the networked water infrastructure-The case of Lilongwe, Malawi. *Geoforum* 107: 168-178.

Tozer, L., H. Bulkeley, A. van der Jagt, et al. 2022. Catalyzing sustainability pathways: Navigating urban nature based solutions in Europe. *Global Environmental Change*, 74, 102521.

Tzaninis, Y., T. Mandler, M. Kaika and R. Keil 2021. Moving urban political ecology beyond the 'urbanization of nature'. *Progress in Human Geography* 45(2): 229-252.

White, D.F. and C. Wilbert 2009. Technonatures: environments, technologies, spaces, and places in the twenty-first century. Wilfrid Laurier University Press, Waterloo.

World Bank 2021. Water in circular economy and resilience. Accessed April 3, 2022. https://openknowledge.worldbank.org/bitstream/handle/10986/36254/163924.pdf?sequence=1&isAllowed=y

Annex A – Overview of interviews

No.	Position	Organization	Date
1	Social justice activist	Elysian Valley Neighborhood Council	February 4, 2018
2	Board member	Los Angeles Regional Water Resources Control Board	January 29, 2018
3	Policy officer	Friends of the Los Angeles River	January 30, 2018
4	Senior water manager	Los Angeles Department of Water and Power	February 2, 2018
5	Executive director	The River Project	February 7, 2018
6	Wastewater recycling planner	Los Angeles Department of Water and Power	February 8, 2018
7	Two senior consultants	RMC Engineering Consultants	February 9, 2018
8	Senior associate and researcher	Natural Resources Defense Council	February 14, 2018
9	Senior manager	Los Angeles Building Owners and Managers Association	February 16, 2018
10	Executive director	Theodore Payne Foundation for California Native Plants	February 20, 2018
11	Senior wastewater manager	City of Los Angeles Bureau of Sanitation	February 21, 2018
12	Wastewater manager	West Basin Municipal Water District	February 22, 2018
13	Policy officer	Office of Los Angeles County Supervisor Sheila Kuehl	February 26, 2018
14	Senior water conservation manager	Metropolitan Water District of Southern California	February 26, 2018
15	Senior power systems manager	Los Angeles Department of Water and Power	February 28, 2018
16	Two senior policy officers	City of Los Angeles Sustainability Office	February 28, 2018
17	Board member	Metropolitan Water District of Southern California Board of Directors	March 1, 2018
18	Senior wastewater recycling manager	Los Angeles Department of Water and Power	March 2, 2018
19	Waste manager	City of Los Angeles Bureau of Sanitation	March 2, 2018
20	Executive director	Greywater Corps	March 5, 2018
21	Senior associate	Global Green USA	March 5, 2018
22	Senior associate	TreePeople	March 7, 2018
23	Senior stormwater manager	City of Los Angeles Bureau of Sanitation	March 12, 2018
24	Adjunct professor	Cal Poly Pomona, John Lyle Center for Regenerative Studies	March 13, 2018
25	Adjunct assistant professor	UCLA, Institute of the Environment and Sustainability	March 14, 2018

26	Three water conservation managers	Los Angeles Department of Water and Power	March 16, 2018
27	Senior associate	Los Angeles Initiative for a New Economy	April 5, 2019
28	Senior public affairs manager	Water Replenishment District of Southern California	March 7, 2019
29	Founder	Los Angeles Neighborhood Council Sustainability Alliance	March 8, 2019
30	Member	Los Angeles Eco-Village	March 9, 2019
31	Council member	Lake Balboa Neighborhood Council	March 11, 2019
32	Assistant director	UCLA, Mildred E. Mathias Botanical Garden	March 11, 2019
33	Founders and directors	The Urban Water Group	March 12, 2019
34	Contractor	Selva International	March 13, 2019
35	Founder and director	The Green Gardens Group	March 13, 2019
36	Founder	Ecotone Studios Landscape Architecture	March 14, 2019
37	Founder and director	Tree of Life Nursery	March 14, 2019
38	Executive director	LA City Plants	March 15, 2019
39	Senior sustainability manager	KB Home Real Estate	March 15, 2019
40	Researcher	LA Waterkeeper	March 19, 2019
41	Principal	EW Consulting Inc.	March 20, 2019
42	Director and senior manager	RCS - Consulting Groundwater Geologists	March 21, 2019
43	Senior manager	ScottsMiracle-Gro	March 22, 2019
44	Director	Nature Gardens at the Natural History Museum of Los Angeles County	March 26, 2019
45	Executive director	The River Project	March 29, 2019
46	Senior manager	City of Santa Monica Sustainability Office	April 10, 2019
47	Senior stormwater manager	City of Los Angeles Bureau of Sanitation	April 10, 2019
48	Policy officer	Office of Los Angeles County Supervisor Sheila Kuehl	April 11, 2019
49	Executive director	LA Waterkeeper	April 12, 2019
50	Board member	Metropolitan Water District of Southern California Board of Directors	April 12, 2019
51	Senior associate	Los Angeles Initiative for a New Economy	April 16, 2019
52	Senior manager	Rachio Inc.	July 10, 2019
53	Cofounder	Greywater Action	March 21, 2019
54	Senior scientist	Heal the Bay	December 7, 2021

Summary

Globally, cities face exacerbating water crises. The consequences of climate change and ongoing urban growth result in more intense water scarcity and flooding, while water pollution remains a pressing problem. Urban policymakers and practitioners have widely endorsed urban water circularity as a new paradigm to tackle these challenges. They pin high hopes for urban water sustainability and resilience on visions to combine diverse water management technologies in new infrastructure arrangements that enable a more circular water flow. This development reflects the broader dynamics of urban environmental governance in the Anthropocene, where urban environmental challenges are met with attempts to govern cities as complex adaptive systems.

This dissertation undertakes a critical inquiry into urban water circularity in practice. The main objective is to develop a more detailed and critical understanding of the political relationships between the visions of urban water circularity and the socio-technical changes in urban water infrastructures emerging in efforts to tackle urban water crises. The study aims to explore the contested governance of circular water restructuring in cities and its broader political entanglements with urban nature. To grasp the complex and situated socio-technical interactions that shape circular urban water restructuring, the study focuses on the case of Los Angeles. Three sub-cases are examined in detail: wastewater recycling (Chapter 2), stormwater capture (Chapter 3), and landscape water conservation in residential gardens (Chapter 4).

The main conceptual focus of this dissertation is on the political role of technology in endeavors to realize ideas of urban water circularity. The study employs and refines critical debates on urban infrastructures and in science and technology studies to analyze the technopolitics of infrastructural change in emerging circular water cities. This focus highlights how actors pursue political goals in processes of infrastructural change through technology. Depending on the particular technical artifacts that actors place at the center of political debates about water circularity, the histories, cultural meanings, and urban geographies linked to these artifacts powerfully frame the meaning of novel infrastructure constellations and thereby structure possibilities of change. Moreover, the study draws on debates in urban water governance and urban political ecology to examine the diverse political proposals for governing urban nature and space articulated in technical disputes over water circularity. Overall, tracing the social relationships underlying technology that matter politically in processes of circular urban water restructuring is a timely and fruitful analytical approach. It reveals the ambiguities, contradictions, and power imbalances inherent in circular city-making, which broad discourses of circularity may otherwise obscure. This perspective also enables a critical assessment of the socio-technical arrangements and technological cultures of urban nature within which circularity thinking thrives.

Empirical findings

Chapter 2 discusses the efforts of wastewater restructuring in Los Angeles. This chapter explores how ambitious policy visions of wastewater recycling and reuse, which gained momentum during California's drought between 2011 and 2016, clash with incumbent gravity-fed water and sewer systems, political economy, and urban geographies. The chapter demonstrates how public engineers navigate these path dependencies by making incremental technical improvements to existing infrastructure to increase wastewater recycling. However, these interventions primarily reproduce given infrastructure configurations and urban geographies of water and wastewater while marginalizing other voices in struggles over water circularity and stymying critical debate about more progressive change. The chapter reveals how a dominant technopolitical regime of centralized wastewater recycling emerges as a powerful governing force in infrastructural and broader urban environmental change.

Chapter 3 analyzes stormwater restructuring in Los Angeles, where stakeholders have embraced ideas of integrated stormwater management using decentralized and green infrastructures to enhance urban sustainability. The chapter reviews how, despite this shared vision, different actors seek to use the revenues from a new stormwater tax in Los Angeles County for diverging infrastructure designs. This leads to the emergence of a more hybrid infrastructure system, where centralized stormwater practices of incumbent public utilities continue to dominate but increasingly coexist with more decentralized landscape-centered practices and become interdependent on them. Technical disputes over infrastructure design reflect ambiguities about the future of stormwater management and engender renegotiations of responsibility, knowledge orders, and the overall rationale of stormwater management. The chapter demonstrates how infrastructures as relational systems carry many potential stormwater futures, and that infrastructural disputes form a political site where stormwater objectives and broader environmental goals can be aligned or pitted against each other.

Chapter 4 explores how private gardens in Los Angeles became a new frontier of water conservation policy after the California drought of 2011 through 2016 and thus a site of circular urban water restructuring. Public water agencies initiated a subsidy program to replace water-hungry lawns with specially developed California Friendly® landscapes that enhance irrigation. The chapter compares this approach with California native plant gardening promoted by nature conservationists, which uses vernacular horticultural techniques to restore native plant biodiversity and reduce irrigation. Each approach has important political implications for urban space and water use, the value accorded to nature and gardening work, and the relationships between citizens and experts. The chapter develops the concept of "infrastructuring" gardens to ascertain how expert cultures shape urban environmental change and how alternative gardening practices (re) produce urban nature differently.

Chapter 5 provides a comprehensive overview of circular urban water restructuring in Los Angeles by presenting two emerging technopolitical constellations. First, the chapter reviews how public engineers combine centralized infrastructure artifacts in an artificial "One Water" loop to decouple urban growth from water imports and water pollution while ensuring future revenues through volumetric water sales. This approach relies on efforts to activate homes and gardens for technocratic water management. Second, the chapter highlights how infrastructure decentralization involves practices of activists and homeowners, whereby more plural ways of governing urban nature and space in circular Los Angeles become articulated. The chapter unpacks the tensions between these contrasting infrastructure configurations by highlighting their differing rationales for using water and urban space, and relationships between users and state experts.

Conclusions and reflections

In sum, the findings of this study suggest that the socio-technical change of urban water and wastewater infrastructures toward more circular cities is highly ambivalent and contested. In Los Angeles, the established socio-technical orders of water and wastewater management, which emerged through modern urbanization, result in infrastructural path dependencies. Infrastructural change is dominated by incumbent experts' practices of incremental adaptation of inherited centralized infrastructure networks and centrifugal expansion of these networks. However, these practices increasingly coexist with decentralized and more landscape-centered infrastructural practices driven by environmental groups, activists, and users. As a result, water circularity endeavors produce a more hybrid water system, within which diverse infrastructural practices overlap and become interdependent. This leads to increased diversity in the scales, urban spaces, actors, forms of knowledge, and infrastructure artifacts of water management, which increases governance complexity.

In contrast to the singular visions of water circularity that prevail in the public debate, infrastructural disputes in Los Angeles reflect power imbalances and instances of political alternatives for creating a more circular water flow. This dissertation thus argues that emerging circular water cities can be examined as a technopolitical process, whereby novel political relations between water, technology, and urban nature become practically negotiated through infrastructure renewal. In particular, this study reveals three dimensions of these political relationships which exhibit plural and partly competing proposals for governing urban nature and space through technology.

- *First, the technopolitics of circular water restructuring in Los Angeles involve different rationalities for using water and urban space*. The dominant infrastructural practices of public experts aim to remake wastewater and stormwater into potable water supply resources and to control water pollution through technology. This coincides with interventions to promote non-potable and environmental water uses that link water circularity with goals related to biodiversity, nature-based climate adaptation, and community greening. Both developments occur in and produce particular urban spaces.

- *Second, the technopolitics of circular water restructuring in Los Angeles involve increasingly diverse and ambivalent actor roles in infrastructure provision*. Incumbent public experts remain key agents, while users and non-profit organizations become mobilized as infrastructure co-providers. As such, these users and non-profits partly sustain technocratic environmental management and act according to their interests and worldviews. The shifting actor roles in Los Angeles' more hybrid water systems raise new governance challenges, including the professional maintenance of (especially local, nature-based) infrastructures, the reliable control of their environmental performance, and the coordination among multiple stakeholders across institutional boundaries.

- *Third, the technopolitics of urban water circularity in Los Angeles reflect different ways of valuing urban nature, environmental knowledge, and labor*. Inherited engineering paradigms based on modernist ideas of nature and technology dominate how environmental knowledge and labor are valued. Yet, ecological and horticultural knowledge and forms of labor that rely on this knowledge are gaining more "infrastructural relevance." This development challenges existing knowledge hierarchies and value systems, creating ambiguity in knowing and managing urban nature in circular Los Angeles.

With regard to advancing conceptual debates in critical research on urban infrastructures and urban nature, the study makes three significant contributions:

- *First, the dissertation enhances the critical inquiry of urban infrastructural change by explaining infrastructure stability and malleability as intertwined dynamics in a technopolitical process of circular urban water restructuring*. Depending on place-specific constellations of material artifacts, discourses, knowledge, and institutions, specific infrastructural practices prevail in technical disputes over infrastructure restructuring. Through these practices, actors organize the technopolitics of urban water circularity, which frames the socio-political meaning of evolving infrastructures in particular ways. Consequently, the technopolitics of urban water circularity can stabilize, modify, or contest existing infrastructure arrangements.

- *Second, the dissertation refines conceptualizations of the political relations between urban infrastructures and urban nature*. Central to this is the discussion of how urban technopolitical regimes arise as a governing force of urban nature and space and become contested in processes of circular urban water restructuring. This equips debates in urban political ecology and urban environmental governance with a better conceptualization of structural power enabled by technology. Simultaneously, a focus on the diverse infrastructural artifacts and practices underlying urban techno-political regimes supports an open-ended inquiry into political power constituted by technology.

- *Third, the dissertation specifies a technopolitical approach to examine concepts of urban water circularity as inherently political modes of governing urban nature in cities in the Anthropocene*. A technopolitics lens highlights the instability of different technological cultures of urban nature through which cities become known and managed as complex adaptive systems. The study shows how technopolitical power shapes how certain systemic representations of cities that include particular system boundaries, fixed ideas of "normal" social phenomena, or normative categories become dominant. However, the technopolitics of circular urban water restructuring also reflect the plurality of agencies and perspectives underlying urban ecologies, revealing hegemonic framings of circularity as historically produced and political.

This dissertation further outlines critical recommendations to help policymakers and urban practitioners advance sustainability and justice objectives in realizing urban water circularity, including the following:

- Circular urban water management requires a better institutional underpinning, for instance, advancing collaboration and cost-sharing between fragmented water and wastewater agencies.

- Cities need more integrated spatial planning that coordinates water-related interventions into urban space on a (sub-)watershed scale with other land uses.

- Area-based community representatives should be involved in water management decisions to align circular urban water management with locally specific community needs and development.

- Attempts to decentralize urban water management need to carefully weigh measures that mobilize users as infrastructure co-providers with the necessity to leave the responsibility for infrastructure provision and compliance with environmental standards with (public) experts (environmental risks through stormwater pollution are a case in point).

- Governance complexity in more hybrid urban water systems can be reduced by more clearly defining infrastructural responsibilities, building up institutional capacity to oversee decentralized infrastructures, and improving environmental education for users.

- Water and wastewater policies need to be better coordinated with other sectoral policies and forms of community engagement in urban environmental management, for instance, by improving nature-based water management through economic development policies that foster ecological knowledge and innovation.

Finally, this dissertation reveals fruitful avenues for further research that link a technopolitical inquiry into urban water circularity with broader debates in urban geography and planning. These avenues include: (i) the technopolitical relations between water circularity and regional urbanization, (ii) socio-spatial differences in circular water cities, (iii) the politics of the global diffusion and local adaptation of ideas of urban water circularity in different cities, (iv) the relationships between urban water circularity and urban degrowth, and (v) the politics of pollution and the epidemiological dimensions associated with urban water circularity.

Samenvatting

Wereldwijd worden steden geconfronteerd met verergerende watercrises. De gevolgen van de klimaatverandering en de aanhoudende stedelijke groei leiden tot meer intense waterschaarste en overstromingen, terwijl watervervuiling een urgent probleem blijft. Stedelijke beleidsmakers en praktijkmensen hebben de circulaire waterhuishouding in steden breed onderschreven als een nieuw paradigma om deze uitdagingen aan te pakken. Ze vestigen hoge verwachtingen voor stedelijke waterduurzaamheid en veerkracht op visies om verschillende waterbeheertechnologieën te combineren in nieuwe infrastructuurarrangementen die een meer circulaire waterstroom mogelijk maken. Deze ontwikkeling weerspiegelt een bredere dynamiek in stedelijk milieubeheer in het Antropoceen, waar stedelijke milieu-uitdagingen worden geconfronteerd met pogingen om steden te besturen als complexe adaptieve systemen.

Dit proefschrift onderneemt een kritisch onderzoek naar de circulaire waterhuishouding in steden in de praktijk. Het belangrijkste doel is om een gedetailleerder en kritischer begrip te ontwikkelen van de politieke relaties tussen visies op stedelijke watercirculariteit en de sociaal-technische verandering van stedelijke waterinfrastructuren die opduiken in de inspanningen om stedelijke watercrises aan te pakken. Dit dient om de betwiste governance van circulaire waterherstructurering in steden en de bredere politieke verwikkelingen met de stedelijke natuur te verkennen. Om de complexe en gesitueerde sociaal-technische interacties te begrijpen die de herstructurering van circulair stedelijk water vormgeven, is het proefschrift gebaseerd op de zaak van Los Angeles. Drie subgevallen worden onderzocht: afvalwaterrecycling (hoofdstuk 2), opvang van regenwater (hoofdstuk 3) en landschapswaterbehoud in residentiële tuinen (hoofdstuk 4).

De belangrijkste conceptuele focus van dit proefschrift is op de politieke rol van technologie bij het realiseren van ideeën over stedelijke watercirculariteit. De studie gebruikt en verfijnt kritische debatten over stedelijke infrastructuren en in wetenschappelijke en technologische studies om de technopolitiek van infrastructurele verandering in opkomende circulaire watersteden te analyseren. Deze focus benadrukt hoe actoren politieke doelen nastreven in processen van infrastructurele verandering door middel van technologie. Afhankelijk van de specifieke technische artefacten die actoren plaatsen in het centrum van de politieke debatten over water circulariteit, de geschiedenis, culturele betekenissen en stedelijke geografieën gekoppeld aan deze artefacten krachtig kader de betekenis van nieuwe infrastructuur constellaties en daardoor de structuur mogelijkheden van verandering. Bovendien is de studie gebaseerd op debatten over stedelijk waterbeheer en stedelijke politieke ecologie om de verschillende politieke voorstellen te onderzoeken voor het regelen van stedelijke natuur en ruimte die zijn gearticuleerd in technische geschillen over watercirculariteit. Over het algemeen is het traceren van de sociale relaties die ten grondslag liggen aan technologie die politiek van belang is in processen van herstructurering van circulair stedelijk water een tijdige en vruchtbare analytische zet. Het maakt het mogelijk om de ambivalenties, tegenstrijdigheden en machtsonevenwichtigheden in het maken van circulaire steden te onthullen die vage discoursen van circulariteit anders zouden kunnen verdoezelen. Dit perspectief stelt ons verder in staat om kritisch te kijken naar de stedelijke sociaal-technische regelingen en de technologische culturen van de stedelijke natuur waarbinnen het circulaire denken gedijt.

Empirische bevindingen

In hoofdstuk 2 wordt ingegaan op de herstructurering van afvalwater in Los Angeles. Ambitieuze beleidsvisies van afvalwaterrecycling en hergebruik die populariteit hebben verworven sinds de droogte in Californië tussen 2011 en 2016 botsen met bestaande door zwaartekracht gevoede water- en rioleringssystemen, politieke economie en stedelijke geografieën. Het hoofdstuk laat zien hoe openbare ingenieurs deze padafhankelijkheden navigeren door incrementele technische verbeteringen van bestaande infrastructuren om de recycling van afvalwater te vergroten. Deze interventies reproduceren voornamelijk bepaalde infrastructuurconfiguraties en stedelijke geografieën van water en afvalwater, terwijl andere stemmen worden gemarginaliseerd in de strijd om watercirculariteit en het kritische debat over meer progressieve verandering wordt belemmerd. Het hoofdstuk synthetiseert hoe een dominant technopolitiek regime van gecentraliseerde afvalwaterrecycling ontstaat als een krachtige regerende kracht van infrastructurele en bredere stedelijke milieuverandering.

In hoofdstuk 3 wordt de herstructurering van regenwater in Los Angeles geanalyseerd, waar belanghebbenden ideeën hebben omarmd over geïntegreerd regenwaterbeheer met behulp van meer gedecentraliseerde en groene infrastructuren om de stedelijke duurzaamheid te verbeteren. Het hoofdstuk bespreekt hoe ondanks deze gedeelde visie, verschillende actoren proberen de inkomsten uit een nieuwe stormwaterbelasting in Los Angeles County te gebruiken voor uiteenlopende infrastructuurontwerpen. Dit veroorzaakt een meer hybride infrastructuursysteem waarin gecentraliseerde stormwaterpraktijken van gevestigde openbare nutsbedrijven overheersen, maar steeds meer samengaan met meer gedecentraliseerde landschapsgerichte praktijken en er onderling afhankelijk van worden. Technische geschillen over infrastructuurontwerp weerspiegelen onduidelijkheden over een toekomstig regenwatersysteem en leiden tot heronderhandeling van verantwoordelijkheid, kennisorders en de algemene redenering van stormwaterbeheer. Het hoofdstuk laat zien hoe infrastructuren als relationele systemen veel potentiële stormwatertoekomsten met zich meebrengen en dat infrastructurele geschillen een politieke plek vormen waar stormwaterdoelstellingen en bredere milieudoelstellingen op elkaar kunnen worden afgestemd of tegen elkaar kunnen worden opgezet.

Hoofdstuk 4 onderzoekt hoe de privétuinen van Los Angeles na de droogte van Californië van 2011 tot 2016 een nieuwe grens van waterbehoudsbeleid werden en dus een site van herstructurering van circulair stedelijk water. Openbare wateragentschappen zijn een subsidieprogramma gestart om waterhongerige gazons te vervangen door speciaal ontwikkelde California Friendly® -landschappen die de irrigatie verbeteren. Het hoofdstuk vergelijkt deze aanpak met inheemse plantentuinen in Californië die worden gepromoot door natuurbeschermers, die gebruik maken van inheemse tuinbouwtechnieken om de biodiversiteit van inheemse planten te herstellen en irrigatie te verminderen. Elke benadering heeft belangrijke politieke implicaties voor stedelijke ruimte en watergebruik; de waarde die wordt toegekend aan natuur- en tuinwerkzaamheden; en de relaties tussen burgers en experts. Het hoofdstuk ontwikkelt het concept van 'infrastructurele' tuinen om vast te stellen hoe expertculturen stedelijke milieuverandering vormgeven en hoe alternatieve tuinbouwpraktijken de stedelijke natuur anders (her)produceren.

In hoofdstuk 5 wordt een uitgebreid beeld gesynthetiseerd van de herstructurering van circulair stedelijk water in Los Angeles door twee bredere technopolitieke constellaties te onthullen die momenteel in opkomst zijn. Ten eerste bespreekt het hoofdstuk hoe openbare ingenieurs gecentraliseerde infrastructuurartefacten combineren in een kunstmatige "One Water"-lus om stedelijke groei te ontkoppelen van waterinvoer en watervervuiling, terwijl toekomstige inkomsten worden gegarandeerd door volumetrische waterverkoop. Inspanningen om huizen en tuinen te activeren voor technocratisch waterbeheer ondersteunen deze aanpak. Ten tweede benadrukt het hoofdstuk hoe decentralisatie van infrastructuur praktijken van activisten en huiseigenaren omvat, waarbij meer meervoudige manieren om de natuur en stedelijke ruimte in circulair Los Angeles te besturen, worden gearticuleerd. Het hoofdstuk ontrafelt de spanningen tussen deze contrasterende infrastructuurconfiguraties door hun verschillende onderbouwingen voor het gebruik van water en stedelijke ruimte en relaties tussen gebruikers en staatsexperts te benadrukken.

Conclusies en reflecties

Kortom, de bevindingen van deze studie suggereren dat de sociaal-technische verandering van stedelijke water- en afvalwaterinfrastructuren naar meer circulaire steden zeer ambivalent en omstreden is. In Los Angeles, geërfde socio-technische ordes van water- en afvalwaterbeheer die is ontstaan door middel van moderne verstedelijking resulteren in infrastructurele padafhankelijkheden. Infrastructuurverandering wordt gedomineerd door de praktijken van gevestigde experts van een incrementele aanpassing van overgeërfde gecentraliseerde infrastructuurnetwerken en een centrifugale uitbreiding van deze netwerken. Deze praktijken bestaan echter steeds meer samen met gedecentraliseerde en meer landschapsgerichte infrastructurele praktijken die worden aangestuurd door milieugroepen, activisten en gebruikers. Watercirculariteit levert dus een meer hybride watersysteem op waarin verschillende infrastructurele praktijken elkaar overlappen en onderling afhankelijk worden. Als gevolg hiervan worden de schalen, de stedelijke ruimtes, de actoren, de vormen van kennis en de infrastructuurartefacten van waterbeheer diverser, wat de bestuurlijke complexiteit vergroot.

In tegenstelling tot enkele visies op watercirculariteit die de overhand hebben in het publieke debat, weerspiegelen infrastructurele geschillen in Los Angeles machtsonevenwichtigheden en voorbeelden van politieke alternatieven bij het creëren van een meer circulaire waterstroom. Dit proefschrift stelt dus dat opkomende circulaire watersteden kunnen worden verkend als een technopolitiek proces waarbij nieuwe politieke relaties tussen water, technologie en stedelijke natuur praktisch worden onderhandeld door middel van infrastructuurvernieuwing. Met name deze studie onthult drie dimensies van deze politieke relaties die meervoudige en gedeeltelijk concurrerende voorstellen vertonen om stedelijke natuur en ruimte te regelen door middel van technologie.

- *Ten eerste omvat de technopolitiek van circulaire waterherstructurering in Los Angeles verschillende onderbouwingen voor het gebruik van water en stedelijke ruimte*. Dominante infrastructurele praktijken van publieke experts zijn gericht op het opnieuw maken van afvalwater en regenwater als drinkwaterbronnen en het beheersen van watervervuiling door middel van technologie. Dit valt samen met interventies om niet-drinkbaar en milieuvriendelijk watergebruik te bevorderen dat watercirculariteit verbindt met biodiversiteit, op de natuur gebaseerde klimaatadaptatie en gemeenschapsvergroeningsdoelen. Beide ontwikkelingen vinden plaats in, en produceren, bepaalde stedelijke ruimtes.

- *Ten tweede omvat de technopolitiek van circulaire waterherstructurering in Los Angeles een steeds diversere en ambivalente rol van actoren bij de infrastructuurvoorziening*. Bestaande publieke experts blijven belangrijke agenten, terwijl gebruikers en non-profitorganisaties worden gemobiliseerd als co-providers van infrastructuur. Als zodanig ondersteunen deze gebruikers en non-profit-organisaties gedeeltelijk technocratisch milieubeheer en handelen ze volgens hun belangen en wereldbeelden. De verschuivende rol van actoren in de meer hybride watersystemen van Los Angeles brengt nieuwe bestuurlijke uitdagingen met zich mee, waaronder het professionele onderhoud van (vooral lokale, op de natuur gebaseerde) infrastructuren, de betrouwbare controle van hun milieuprestaties en de coördinatie tussen meerdere belanghebbenden over institutionele grenzen heen.

- *Ten derde weerspiegelt de technopolitiek van stedelijke watercirculariteit in Los Angeles verschillende manieren om de stedelijke natuur, milieukennis en arbeid te waarderen*. Erfelijke technische paradigma's gebaseerd op modernistische ideeën over natuur en technologie domineren hoe milieukennis en arbeid worden gewaardeerd. Toch krijgen ecologische en tuinbouwkundige kennis en vormen van arbeid die afhankelijk zijn van deze kennis meer "infrastructurele relevantie". Deze ontwikkeling daagt bestaande kennishiërarchieën en waardenreeksen uit, waardoor dubbelzinnigheid ontstaat in het kennen en beheren van stedelijke natuur in circulair Los Angeles.

Met betrekking tot het bevorderen van conceptuele debatten in kritisch onderzoek naar stedelijke infrastructuren en stedelijke natuur, levert de studie drie belangrijke bijdragen:

- *Ten eerste verbetert het proefschrift het kritische onderzoek naar stedelijke infrastructurele verandering door infrastructuurstabiliteit en kneedbaarheid uit te leggen als verweven dynamiek in een technopolitiek proces van herstructurering van circulair stedelijk water*. Afhankelijk van plaats-specifieke constellaties van materiële artefacten, discoursen, kennis en instellingen, prevaleren specifieke infrastructurele praktijken in technische geschillen over infrastructuurherstructurering. Door deze praktijken organiseren actoren de technopolitiek van stedelijke watercirculariteit die de sociaal-politieke betekenis van evoluerende infrastructuren op bepaalde manieren kadert. Hierdoor kan de technopolitiek van stedelijke watercirculariteit bestaande infrastructuurregelingen stabiliseren, wijzigen of betwisten.

- *Ten tweede verfijnt het proefschrift conceptualisaties van de politieke relaties tussen stedelijke infrastructuren en stedelijke natuur*. Centraal staat hier de discussie over hoe stedelijke technopolitieke regimes ontstaan als een regerende kracht van stedelijke natuur en ruimte en worden betwist in processen van herstructurering van circulair stedelijk water. Dit onderbouwt debatten in stedelijke politieke ecologie en stedelijk milieubeheer met een betere conceptualisering van structurele macht mogelijk gemaakt door technologie. Tegelijkertijd ondersteunt een focus op de verschillende infrastructurele artefacten en praktijken die ten grondslag liggen aan stedelijke technopolitieke regimes, een open onderzoek naar politieke macht gevormd door technologie.

- *Ten derde specificeert het proefschrift een technopolitieke benadering om concepten van stedelijke (water)circulariteit te onderzoeken als inherent politieke manieren om de stedelijke natuur in steden in het Antropoceen te beheersen*. Een technopolitieke lens benadrukt de instabiliteit van verschillende technologische culturen van de stedelijke natuur waardoor steden bekend worden en worden beheerd als complexe adaptieve systemen. De studie laat zien hoe technopolitieke macht bepaalt hoe bepaalde systemische representaties van steden met bepaalde systeemgrenzen, vaste ideeën van 'normale' sociale verschijnselen of normatieve categorieën dominant worden. Maar de technopolitiek van de herstructurering van circulair stedelijk water weerspiegelt ook de pluraliteit van agentschappen en perspectieven die ten grondslag liggen aan stedelijke ecologieën, en onthult hegemonische kaders van circulariteit als historisch geproduceerd en politiek.

Dit proefschrift schetst verder kritische aanbevelingen om beleidsmakers en stedelijke beoefenaars te helpen bij het bevorderen van duurzaamheids- en rechtvaardigheidsdoelstellingen bij het realiseren van stedelijke watercirculariteit.

- Circulair stedelijk waterbeheer vereist een betere institutionele onderbouwing, bijvoorbeeld door het bevorderen van samenwerking en kostendeling tussen gefragmenteerde water- en afvalwateragentschappen.

- Steden hebben behoefte aan een meer geïntegreerde ruimtelijke ordening die watergerelateerde interventies in de stedelijke ruimte op (sub) stroomgebiedsschaal coördineert met ander landgebruik.

- Gebiedsgebonden vertegenwoordigers van de gemeenschap moeten worden betrokken bij beslissingen over waterbeheer om het beheer van circulair stedelijk water in overeenstemming te brengen met lokale specifieke behoeften en ontwikkeling van de gemeenschap.

- Pogingen om stedelijk waterbeheer te decentraliseren moeten maatregelen die gebruikers mobiliseren als co-providers van infrastructuur zorgvuldig afwegen tegen de noodzaak om de verantwoordelijkheid voor de infrastructuurvoorziening en naleving van milieunormen over te laten aan (publieke) experts (milieurisico's door regenwaterverontreiniging zijn hier een voorbeeld van).

- De complexiteit van de governance in meer hybride stedelijke watersystemen kan worden verminderd door de infrastructuurverantwoordelijkheden duidelijker te definiëren, institutionele capaciteit op te bouwen om toezicht te houden op gedecentraliseerde infrastructuren en de milieueducatie voor gebruikers te verbeteren.

- Het water- en afvalwaterbeleid moet beter worden gecoördineerd met ander sectoraal beleid en vormen van maatschappelijke betrokkenheid bij stedelijk milieubeheer, bijvoorbeeld door het verbeteren van op de natuur gebaseerd waterbeheer door middel van economisch ontwikkelingsbeleid dat ecologische kennis en innovatie bevordert.

Ten slotte onthult dit proefschrift vruchtbare wegen voor verder onderzoek dat een technopolitiek onderzoek naar de circulaire waterhuishouding in steden verbindt met bredere debatten in stedelijke geografie en planning. Deze wegen omvatten: (i) de technopolitieke relaties tussen watercirculariteit en regionale verstedelijking, (ii) sociaal-ruimtelijke verschillen in circulaire (water)steden, (iii) de politiek van de wereldwijde verspreiding en lokale aanpassing van ideeën over stedelijke watercirculariteit in verschillende steden, (iv) de relaties tussen stedelijke watercirculariteit en stedelijke ontgroei, en (v) de politiek van vervuiling en de epidemiologische dimensies geassocieerd met stedelijke watercirculariteit.

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