The limits to large scale supply augmentation: Exploring the crossroads of conflicting urban water system development pathways

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Abstract. Managers of urban water systems constantly make decisions to guarantee water services by overcoming problems related to supply-demand imbalances. A preferred strategy has been supply augmentation through hydraulic infrastructure development. However, despite considerable investments, many systems seem to be trapped in lackluster development pathways making some problems seem like an enduring, almost stubborn, characteristic of the systems: over-exploitation and pollution of water sources, distribution networks overwhelmed by leakages and non-revenue water, and unequal water insecurity. Because of these strategies and persistent problems, water conflicts have emerged, whereby social actors oppose these strategies and propose alternative technologies and strategies. This can create development pathways crossroads of the urban water system. To study this development pathway crossroads, we selected the Zapotillo conflict in Mexico where a large supply augmentation project for two cities experiencing water shortages is at stake. The paper concludes that urban water systems that are engaged in a trajectory characterized by supply-side strategies may experience a temporal relief but neglect equally pressing issues that stymie the human right to water in the medium and long run. However, there is not a straightforward, self-evident development pathway to choose from, only a range of multiple alternatives with multiple trade-offs that need to be thoroughly discussed and negotiated between the stakeholders. We argue that this development pathway crossroads can cross-fertilize technical disciplines such as socio-hydrology, and social disciplines based on hydrosocial studies, which both ambition to make their knowledge actionable and relevant.

1 Introduction

Urban water systems, understood as the managerial, technological, and infrastructural configuration of water supply in a city interlinked with its diverse water resources, have become vulnerable in the face of climate change and uncontrolled urban growth (Flörke et al., 2018). This alarming situation poses a risk that may sever water security for billions of people (WWAP, 2019; UNESCO, UNWater, 2020). Historically, water managers have uncritically implemented large supply augmentation projects as their main strategy (Allan, 2003; Molle, 2008; McCulligh & Tetreault, 2017; Boelens et al., 2019), despite the piling evidence of its shortfalls (Gupta & Van der Zaag, 2008; Gohari et al., 2013; Rinaudo & Barraqué, 2015; Purvis & Dinar, 2020). However, affected communities have constituted grassroots movements and a strong opposition against the

implementation of these projects. In some cases, these movements have been effective in delaying or even cancelling these projects (Ahlers et al., 2017; Godinez-Madrigal et al., 2020).

Hundreds of water conflicts have emerged in the past decades, many of which are related to the implementation of large water
35   infrastructure development (EJOLT, 2021). The importance of these conflicts is that they have played a key role in redefining the decision space of cities and basins to address pressing problems like water shortages and poor water quality (Rodriguez-Labajos & Martinez-Alier, 2015; Ochoa-García & Rist, 2018). The decision space in such conflicts is characterized by competing approaches either based on business-as-usual pathways like large-scale infrastructure or transitioning to alternative pathways (Godinez Madrigal et al., 2018a; 2020). This has generated an impasse, whereby large infrastructure projects are
40   stalled due to the conflict, but alternatives remain untested. We call this situation characterized by conflict and indecisiveness in troubled urban water systems a development pathway crossroads, in which the actors in conflict will either define a new pathway or reinforce the current one.

Overcoming this crossroads is of extreme importance since it will imprint long-lasting consequences for the water security and water justice expressed in institutional arrangements and infrastructural configurations of the urban water system in question.
45   For instance, in business-as-usual scenarios based on large infrastructure, Kallis (2010) observed a recurring phenomenon in the co-evolution of cities and water systems dubbed the 'supply-demand cycle', in which additional sources of water supply fostered a societal response that increased water demand. Thus, a larger water demand warranted developing new sources of water supply, fuelling the cycle, externalizing social and environmental costs to rural populations (Kallis, 2010), and exacerbating uneven water access in urban and sub-urban populations (Savelli et al., 2021). Moreover, a high dependence on
50   reservoirs may render cities more vulnerable to hydro-climatic variations (Kuil et al., 2016; Di Baldassarre et al., 2018). Therefore, if water conflicts and grassroots movements can redefine the decision space of urban water systems, they will also interfere with the socio-economic, political and hydroclimatic dynamics that reproduce the supply-demand cycle.

To understand the origins, extent, and possible consequences of this development pathway crossroads, it is necessary to study both the interdependent relationship between the coupled human and water systems, and the power dynamics that configure
55   the decision space within the urban water system. To test this approach, we draw on empirical work on the Mexican urban heartlands of León and Guadalajara suffering from water shortages and overexploited water resources, and their water security strategy of increasing water supply through an intra-basin water transfer. This infrastructure project has caused a 15 years-old intractable water conflict between the cities and three villages within the projected reservoir's site who have fought not to be relocated. The villagers formed a grassroots movement that has been successful in stalling the implementation of the
60   infrastructure project and lobbying for the implementation of alternatives strategies in the two recipient urban water systems. In this paper, we aim to explore the concept of development pathway crossroads to visualize the role of water conflicts and grassroots movements as a heterogeneous social response in coupled human-water systems characterized by the supply-demand cycle. We first ask what hydrological, technical, and socio-economic and political factors are triggering the supply-demand cycle in León and Guadalajara. Then, we describe and analyse how grassroots movements can redefine the decision

65 space of urban water systems to address water shortages, and act as a feedback mechanism that could disrupt the supply-demand cycle of urban water systems.

The paper is organized as follows. First, we discuss the relevant literature to develop our concept of development pathway crossroads in urban water systems. Second, we describe the methodology, which involved ethnographic techniques and conducting participatory modelling. Then, we present the results, and finally discuss the relevance of the case to the
70 understanding of development pathway crossroads.

2 Development pathway crossroads in urban water systems

With habitual news headlines of cities reaching tipping points and 'day zero´s' in urban water systems (Maxmen, 2018), academic articles and reports calculating future billions of people without access to water (Vörösmarty et al., 2010; Schlosser et al., 2014; Mekonnen & Hoekstra, 2016; WWAP, 2019), and the incorporation of water in the investments of commodities
75 of futures due to the growing fears for its scarcity (Bloomberg, 2020), water managers keep implementing a limited number of tried-and-tested strategies based on large infrastructure that no longer respond to emerging drivers of change (Leach et al., 2010; Larsen et al., 2016). In contrast, water managers underestimate the potential of alternatives and trivialize negative social and environmental effects of large infrastructure (GWP, 2012; Godinez Madrigal et al., 2020). This phenomenon is relevant because this decision-making pattern often triggers unintended consequences in urban water systems such as contributing to a
80 more pronounced water scarcity in the future (Gohari et al., 2013; Kuil et al., 2016; Li et al., 2019).

With a systems approach, Kallis (2010) conceptualised this phenomenon as the supply-demand cycle, which describes locked-in urban systems engaged in a constant dynamic of supply augmentation strategies followed by an increased water demand in different economic sectors that overshoots again water availability. Moreover, Di Baldassarre et al. (2018) further developed this concept by describing the reservoir effect, in which urban water systems become more vulnerable by increasing their
85 dependence on external water sources that can be affected by future droughts.

This systems approach has been the foundation of socio-hydrological scholarship, which has mostly intended to understand what is happening with coupled human-water systems and why, instead of focusing on what should be done (Sivapalan & Blöschl, 2015). As a result, socio-hydrology has advanced the understanding of the prevalence of this large supply augmentation strategy in terms of co-evolution of human and water systems, infrastructure path-dependence, locked-in
90 systems, and feedback mechanisms of coupled human-water systems (Kallis 2010; Gohari et al., 2013; Di Baldassarre et al., 2018; Li et al., 2019). However, there is a paucity of literature that has focused on case studies where the status quo has changed, especially through the emergence of grassroots movements (Rodriguez-Labajos & Martinez-Alier, 2015), and the emergence of water conflicts, a research topic that remains underresearched (Di Baldassarre et al., 2019).

Kallis (2010: 807) glimpsed the potential to break the supply-demand cycle through "environmental changes, social and
95 technical experiments, social movements and coalitions and innovations." However, few studies have analyzed cases of social movements and water conflicts that have exerted a crucial change to a water system by widening the decision space to

implement alternatives and interfere with pernicious supply-demand cycles (i.e., Platt, 1995, is a good example). A challenge to analysing complex cases involving water systems and human agency is that it requires a sound interdisciplinary integration (Wesselink et al., 2017; Rusca & Di Baldassarre, 2019; Di Baldassarre et al., 2019). For instance, Savelli et al. (2021) addressed

100 how the lack of understanding of power relations and heterogeneity in socio-hydrology may lead to overlooking differentiated responses and distribution of risks for diverse social groups in the case of Cape Town during the Day Zero drought. Societal responses and agency in contexts of power asymmetry need to be unpacked to better capture the diverse feedback mechanisms of coupled human-water systems.

To fill this gap in the natural sciences, critical studies developed the concept of the hydrosocial cycle (Swyngedouw 1997;

105 2004; 2009, Boelens, 2014, Linton & Budds, 2014, Schmidt 2014), which internalizes the interplay of water and social power as a dialectic inherent to the cycle (Linton & Budds, 2014). Specifically, this approach has investigated how different distributions of water, authority, and knowledge in each society (re)produce several forms of exclusion and asymmetrical risks in different groups of society (Zwarteveen et al., 2017). In the case of the recurring decision-making pattern of large infrastructure implementation, critical studies have mobilised diverse approaches to understand how sanctioned discourses

110 align the practices of decision makers, political economy of water management favouring the interests of prominent economic and political actors, psychological biases in decision making and power embedded in knowledge asymmetries (Allan, 2003, Lach et al., 2005; Molle, 2008; Molle et al., 2009, Budds 2008; Flyvbjerg et al., 2003: Flyvbjerg, 2009; 2014; Hommes et al 2016; 2019; Hommes & Boelens 2017; Boelens et al., 2019). However, few critical studies engage in interdisciplinary research, which limits their transformative potential (Rusca & Di Baldassarre, 2019).

115 This is an important gap that needs to be addressed, because, as discussed by Castree et al. (2014), Zeitoun et al. (2019) and Rusca & Di Baldassarre (2019), scientists have a moral obligation to change (not only to interpret) the world. Moreover, Lave et al. (2014) consider it imperative that more scientists "combine critical attention to relations of social power with deep knowledge of a particular field of biophysical science or technology in the service of social and environmental transformation". Therefore, innovative frameworks and methods are needed to engage socio-environmental transformation by addressing the

120 interplay between a diversity of actors that frame differently how to address the many challenges facing urban water systems and hydrological flows. Leach et al. (2010) offers a promising approach based on the concept of development pathways, understood as: "particular directions in which interacting social, technological and environmental systems co-evolve over time." Key elements of this approach are acknowledging the power dynamics and feedback mechanisms behind a current development pathway of a coupled nature-human system and unearthing marginalized alternative narratives. This is critical

125 since it highlights the possibility of change by emphasizing a need to widen the decision space to include these marginalized alternatives into negotiation and decision-making processes. A key question is to find which tools are appropriate to support unearthing and supporting alternative narratives that can compete with dominant development pathways.

3 Methodology

Considering the two research questions driving this paper regarding the multiple factors behind the supply-demand cycle in
León and Guadalajara and investigating the role of water conflicts and grassroots movement in interfering with this cycle by
showcasing alternative pathways, we conducted an inter and transdisciplinary approach. First, we employed socio-hydrological
and political ecology perspectives to analyse the long-term interplay of qualitative and quantitative factors that steer the co-
evolution of the urban water systems of León and Guadalajara. We took inspiration from similar works that accounted for the
political and socio-technical history behind these developments, such as Kallis (2008) on the co-evolution of water resources
development in Athens, Molle & Wester (2009) on the longitudinal in-depth historic analysis of specific basins known as River
Basin Trajectories, Hommes & Boelens (2017) on the role of imaginaries of modernity and progress in justifying rural-urban
water transfers, and Savelli et al. (2021) on the interplay of society and hydrological flows of Cape Town. In the context of the
Zapotillo conflict, we conducted 29 semi-structured interviews with key stakeholders and decision makers of León and
Guadalajara between 2017 and 2020. During that time, we also conducted participatory observation in meetings, forums, and
other workshops to which the first author was invited until the end of 2021. We chronicled those meetings in fieldnotes which
were commonly shared with the authors. We complemented these perspectives with official statistical data of both cities and
requested unpublished information to both water utilities to understand the co-evolution of their infrastructural configuration
and socio-political dynamics.

Second, as a method to showcase marginalized alternative narratives and their role in exerting a development pathway
crossroads, we tested participatory modelling during a stakeholder workshop with the most important actors in the conflict in
Jalisco during December 2018. Several studies have analysed the role of participatory modelling as an empowering design
(Stirling et al., 2007) in contributing not only to our understanding of coupled human-water systems, but also to benefit social
processes like conflict resolution (Basco-Carrera et al., 2017; 2018, Van Cauwenbergh et al., 2018). Nevertheless, participatory
modelling remains largely unexplored by socio-hydrology and hydrosocial studies to account for diverse social values in water
systems and unveil power and knowledge asymmetries between actors (Melsen et al., 2018; Srinivasan et al., 2018). To the
best of our knowledge, in the context of supply-demand cycle and the emergence of water conflicts and grassroots movements,
this tool has not been used yet. We invited representatives in favour of the of the supply augmentation project of El Zapotillo
— Conagua (National Water Commission), IMTA (Mexican Institute of Water Technology, the technical branch of Conagua),
Jalisco´s government, the college of civil engineers —, actors of the grassroots movement — community members of
Temacapulín and affected communities downstream, IMDEC (Mexican Institute of Community Development, a prominent
NGO working with the dam-affected communities of Temacapulín, Acasico and Palmarejo), Tómala (a civil society group
involved in facilitating dialogue around important societal challenges in Jalisco), and academics of local universities.
Supplementary material of this paper describes in detail the variables and development of the model, which we dubbed
SimVerde (Craven, 2018; Godinez Madrigal et al., 2018b).

 4 Results

4.1 The co-evolution of the urban water systems of León and Guadalajara

With a population of approximately 1.5 million in the city of León and 4.5 million in Guadalajara, these are the two most important cities of Western Mexico (Fig. 1). Due to the water shortages and groundwater overexploitation experienced in both cities, Conagua developed the intra-basin water transfer Zapotillo project, a large-supply augmentation infrastructure to
 increase urban water supply. The sub-sections below describe the urban water system development pathways of León and Guadalajara to understand how certain hydrological, technical, socio-economic and political factors explain the development of this infrastructural solution.

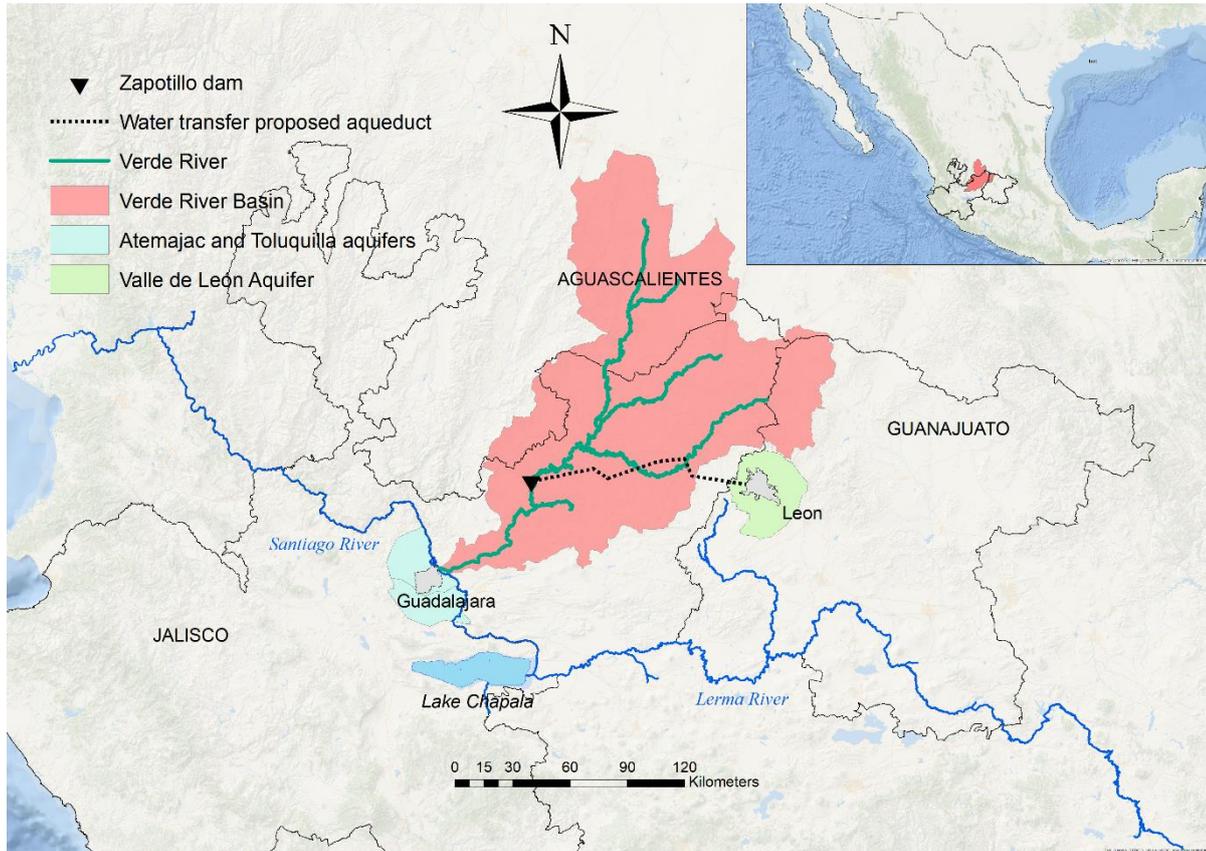
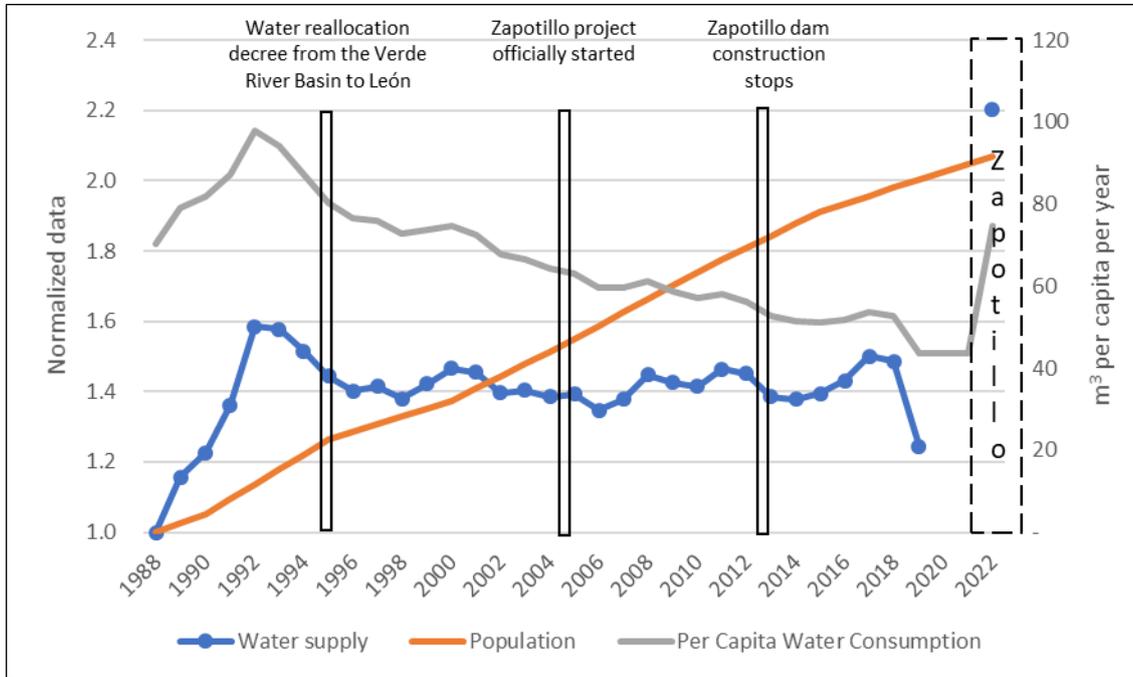



Figure 1: Map of the Verde River Basin and main cities (Source of GIS layers: © 2018 Conagua, and © 2019 Esri, Garmin,
 GEBCO, NOAA NGDC, and other contributors).

4.1.1 León

Currently, León's water system appears to be in a dire situation. Local and national authorities recognize a severe over-exploitation of groundwater averaging a decline rate of 1.5 m/year (SAPAL, 2015). This level of overexploitation has had

increasing negative consequences for the water quality of its aquifer (Villalobos-Aragón et al., 2012; Cortés et al., 2015).

175 Despite this, León is the most economically vibrant city of Guanajuato producing 25 % of its GDP, partly due to its vibrant leather industry (Herrera, 2017: 86), and with the largest population, which grows at a rate of 2 % per year (Fig. 2). This constitutes a water challenge (or a dilemma) since this level of growth and groundwater over-exploitation seems untenable in the long term.

180 **Figure 2: The reservoir effect in León (the dashed rectangle denotes the projected new water demand of a large new supply-augmentation scheme).** Sources of data: INEGI, 1990, 1995, 2000, 2005, 2010; 2015; CONAPO, 2015; CEA-Guanajuato & Conagua 2018; SAPAL, 2020.

The history of León's water utility can be divided in two periods. One, where the local government ran the water utility until 1988, and a second one where the water utility became autonomous under the rule of an administration committee formed by

185 representatives of various sectors of society, especially businesspeople. In the first period, pork-barrel politics characterized the water utility's administration, a common practice during the authoritative regime of PRI (Partido Revolucionario Institucional) (Costa-i-Font et al., 2003). Keeping a low-cost, albeit crumbling, water service was important for the political aspirations for the city mayors. Non-revenue water reached 60%, and neglected infrastructure caused high levels of physical losses and poor bookkeeping and corruption led to high commercial losses (Herrera, 2017). As a result, only 37% of users

190 enjoyed daily water service while poor neighbourhoods would suffer no water service for days (Herrera, 2017).

The second period started during the late 1980s, when, under the influence of international organizations like the World Bank and the IMF, Mexico began adopting neoliberal privatization policies as a remedy to the overall perception of the state inefficiency. In 1988, under the notion that water shortages were limiting their growth, several business organizations in León

coalesced under the banner of democratizing the municipality of León and improving its water service by giving autonomy to the water utility. During the 1988 local elections, this coalition ran under PAN (Partido Acción Nacional) a pro-business political party and won the election.

In the 1990s, the city sought to invigorate its vibrant leather industry and, with the new free trade agreement with the United States and Canada, to attract foreign investment. This also marked a political transition to favour industrialization and export agro-export businesses as a vehicle to development, leaving traditional farming as a thing of the past (Godinez Madrigal et al., 2019). However, politicians and business organizations recognized that limited water availability in the region and severe groundwater overexploitation represented a limiting factor for a sustained economic development of León and Guanajuato (Rodriguez, 2004; 2008; Herrera, 2017; Pastrana et al., 2017).

To solve this problem, the business-led water utility aimed at running the water utility as a business and relied on two strategies to improve the water service of León. One, depoliticizing the prices of the water service to increase physical and commercial efficiency beyond cost recovery (Tagle-Zamora & Caldera-Ortega, 2021). Two, since the 1990s, lobbying for a large water transfer (Godinez Madrigal et al., 2020). These two strategies were interlinked, since with the financial surplus of the utility's efficiency the water utility could partially afford the high costs of the water transfer.

The first strategy made León´s water tariffs the highest in the country and, consequently, per capita water use became one of the lowest in the country (Consejo Consultivo del Agua, 2011). This strategy was so effective in improving the utility's efficiency (reducing non-revenue water from more than 60% to less than 35% and water coverage improved to almost 95%), that Conagua awarded them with the prize of the best managed utility in the country in 2012. However, the public perception of the utility´s price hikes was that the utility operated as a business instead of a steward of the human right to water (Caldera-Ortega, 2009; 2014; Lozano, 2014). Domestic water users experienced a sudden hike in their costs, with the poorest users struggling to pay the water bills, while large automotive industries were attracted with water access subsidies (García Garnica & Martínez-Martínez, 2017; García Garnica 2018). This strategy has also brought about unintentional consequences, since it led many industries, especially the small units of the leather industry, to resort to the black market, where they would buy water tankers from farmers engulfed by the city sprawl (Caldera Ortega & Tagle Zamora, 2017; Hernández-González, 2020). This also indicates that SAPAL´s (León'swater utility) official water demand might be underestimated. Despite this, the policies of the city and the state have incentivized the formation of long-term large industrial clusters in the region by promising secured water supply (García-Garnica, 2017).

With the second strategy (the Zapotillo project), León and Guanajuato's authorities sought a water reallocation from the nearest sub-basin, the Verde River Basin, which Conagua awarded in 1995. However, the materialization of an infrastructure project was delayed until 2005, when the then Mexican president (Vicente Fox, a former governor of Guanajuato) and the governors of Jalisco and Guanajuato belonged to the same political party of PAN. The importance conferred to this project was such that SAPAL´s director mentioned that "[I]f we do not undertake a [supply augmentation] project in the coming five years […], we will not be able to have the same growth in León as we have today. We need to bring water, because we can still grow for five more years; afterwards, although we can sustain the supply to the city, we would need to halt its growth." (Rodríguez, 2004).

However, since 2013 the project and dam construction have been stopped because of a social conflict of the dam-affected communities (Godinez-Madrigal et al., 2020). In response to the growing water demand of the rapidly growing city, SAPAL expanded its groundwater supply network to the aquifer of León as well as in the neighbouring aquifers of Silao-Romita, Turbio River and La Muralla. The number of deep tube wells of SAPAL grew from 124 in 2008 to 196 in 2019 and is pumping at ever increasing depths in all aquifers (Konijnenberg, 2019), in a context in which groundwater use for agriculture (accounting for up to 80% of all extracted groundwater, from more than 18,000 wells) has gone by-and-large unchecked because of toothless demand management institutions and weak and incomplete administration and regulatory systems (Hoogesteger and Wester, 2017).

Although it is still unclear whether the project can be finalized, SAPAL and Guanajuato's government consider the Zapotillo project not only the preferred but the only solution to bring water security to León (SAPAL 2009, 2012, 2016, CEA-Guanajuato & Conagua 2018). However, it is still uncertain if the objective of the Zapotillo project is to contribute to the sustainability of the water system or to a sustained capitalist expansion since Guanajuato's water authority expects water demand to almost double when the Zapotillo project is implemented (see Fig. 2's dashed rectangle). Thus, even with the new water transfer the authorities do not expect a reduction of the groundwater overexploitation, since the 3.8 m^3/s water transfer will not completely satisfy the new expected water demand of around 5 m^3/s (CEA Guanajuato & Conagua 2018). This provides evidence of a future supply-demand cycle triggered by the Zapotillo project that will not reduce groundwater overexploitation because of an increased water demand.

In conclusion, although León has implemented promising strategies regarding cost-recovery and reclaimed wastewater, they have been limited in scale, partly due to the high expectations of the Zapotillo project to provide water security once and for all (Caldera-Ortega et al., 2020), which is a problematic expectation in light of the demand-supply cycle. Furthermore, León's and Guanajuato's authorities have passively accepted groundwater overexploitation by focusing on the Zapotillo project and overlooked an increased accumulation of groundwater rights in the hands of few powerful farmers, agro-export businesses, and industries that perpetuates a severely unsustainable groundwater dynamic (Hoogesteger & Wester, 2015; Hoogesteger, 2018).

4.1.2 Guadalajara

At the moment of writing this paper (2021), Guadalajara is suffering from a water shortage. The Calderón dam, a key water source contributing 14% of total water demand, is running dry and Jalisco´s politicians demand for the continuation of the Zapotillo project as the only solution (Del Castillo, 2021). This is the latest event of a controversial issue that has characterized Guadalajara for the past decades: expanding its water sources to further regions to keep up with the apparent ever-increasing water demand (López-Ramírez & Ochoa-García, 2012). The urban dynamics of Guadalajara have been characterized by a relentless urban growth that outpaces the capacity of the local governments to regulate it, and the water utility to incorporate new urban stretches into the networked system (Castillo-Girón et al., 1994; Del Castillo, 2018; Gleason & Casiano, 2021). Consequently, the urban water system of Guadalajara resembles an infrastructure archipelago (Baker, 2003; Allen et al., 2017),

with approximately a hundred of non-networked neighbourhoods with scarce water access (Greene, 2021), hundreds of networked but intermittent neighbourhoods with low water quality (Pérez-Peña et al., 2009; Rubino et al., 2019) and high-income neighbourhoods and large industries with an independent and secure groundwater source (González-Valencia, 2020). As a result, the city faces a precarious and low-quality water access for hundreds of thousands of people, and over-exploited aquifers (Pérez-Peña et al., 2009; Rubino et al., 2019; Greene, 2021).

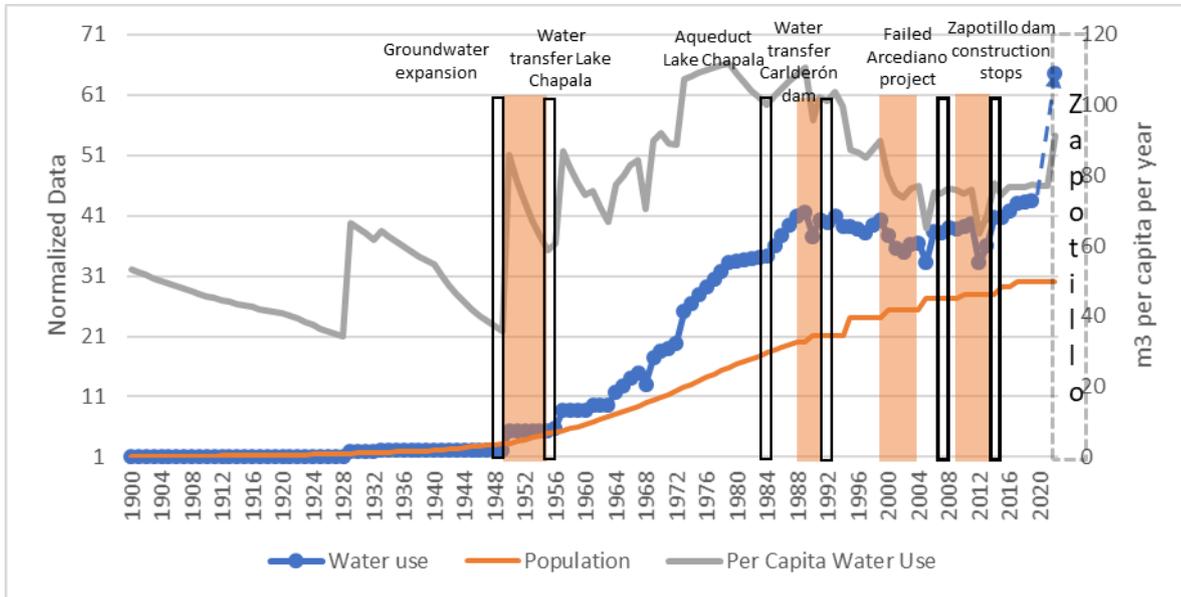



Figure 3. The reservoir effect in Guadalajara (the blue bars denote the implementation of a large supply augmentation schemes in 1947, 1956, and 1991; red bars the presence of droughts; and the dashed rectangle the official projected new water demand for the proposed large supply-augmentation scheme). Sources of data: INEGI 1900, 1910, 1921, 1930, 1940, 1950, 1960, 1970, 1980, 1990, 1995, 2000, 2005, 2010; 2015; Duran Juárez & Torres Rodríguez, 2001; Jalomo Aguirre, 2011; Torres Rodríguez, 2013; Conagua 2015; SIAPA, 2014b; Gómez-Jauregui-Abdo 2015; CEA-Jalisco & Gobierno del Estado de Jalisco, 2018; SIAPA 2020.

Historically, Guadalajara has benefited from three large supply augmentation projects in the past (Fig. 3). The first was based on groundwater supply augmentation in the late 1940s that has continuously expanded until today. However, the accelerated population growth (higher than 6 % per year) typical of Latin-American cities of the time (Camisa, 1972), and a severe drought created an image of acute water scarcity. This generated a pressure to increase water supply sources. Therefore, in 1956 when the drought ended, Guadalajara's government decided to build the Atequiza sluice to make use of the largest natural lake in Mexico, Lake Chapala. The city also built a large drinking-water plant with an installed capacity of 9 m3/s (more than twofold of what was needed) to increase water supply from the lake on demand. The governor of Jalisco considered this project "monumental" and a permanent solution to water scarcity for Guadalajara (Pérez-Peña & Torres-González, 2001). Moreover, the project was embedded in a larger policy of the hydraulic mission to make water available as much as possible for economic

and urban uses (Boehm-Schoendube, 2005), a tendency that later led to basin closure and water conflicts between Jalisco and Guanajuato (Wester et al., 2005; Godinez-Madrigal et al., 2019).

However, the "permanent" Lake Chapala solution lasted only a couple of decades, because during the 1970s and 1980s Guadalajara's increased water demand did overshoot water availability again. Therefore, the local authorities created SIAPA (Sistema Intermunicipal de Agua Potable y Alcantarillado) in 1978, an intermunicipal water utility to increase the water management capacity of the growing city. However, expert engineering and management knowledge have always been secondary to varied vested interests of Jalisco´s government (Del Castillo, 2018). Therefore, the water managers and engineers needed to solve water problems without affecting the status quo of a continuous expanding city and a large per capita water consumption ($\approx$ 300 l/cap/day). Next, water engineers of Jalisco and Conagua developed a basin development plan of the Verde River Basin, known as Zurda-Calderón, to build more than 15 dams to expand Guadalajara´s water supply to meet an estimated future water demand of Guadalajara of 24 m^3/s by the year 2000, more than double the city's actual water use in 2021's (Flores-Berrones, 1988; Cabrales-Barajas et al., 1993; Ochoa-García et al., 2014). To date, only Calderón dam (1.5 m^3/s) has been implemented.

Although integrating urban planning with water management would have contributed to alleviate the increasing pressure over Guadalajara´s water supply sources, the city´s dynamics (as in many other cities in Mexico) has been characterized by a deregulated urban planning and an unrestrained urban speculation fostered by national neoliberal policies (Pérez-Peña et al., 2009; Pfannenstein et al., 2017, Reis 2017; Greene 2021). "Guadalajara´s business model is to expand horizontally and vertically" (Del Castillo, 2018). As a result, SIAPA was perceived as a water utility mainly managed to generate political and economic gains rather than a good service based on technical and administrative sound decisions (Del Castillo, 2011).

In the last 30 years, the network system deteriorated to a point where water service became intermittent and poor water quality led to the bottled water industry completely replacing tap water for human consumption (UASLP & CEA Jalisco, 2010; Greene, 2018; 2021; McCulligh et al., 2020). Under the neoliberal sanctioned discourse, this does not represent a problem since the market provided a solution to an inefficient public water utility. With this perspective, affluent neighbourhoods and large industries were also allowed to develop in protected natural areas and managed their own (secure) groundwater supply systems (Pérez-Peña et al., 2009; González-Valencia, 2020). Despite this, the focus has always been on the gap between demand and supply with the recurring threat of water scarcity. This threat was especially tangible when in 2004 Lake Chapala suffered again a water crisis that threatened 70% of Guadalajara's water supply that depended on it (6 out of 9 m^3/s of Guadalajara´s water demand). SIAPA suspended water service in several parts of the city (Flores-Elizondo, 2016). Continuing with a techno-managerial solution approach to solve the crisis, in 2004 Jalisco spent millions of dollars in prospective studies for an intra-basin water transfer project from the Santiago River called Arcediano, which would supply as much as 10 m^3/s to Guadalajara. The government had such high hopes that this project would solve the increasing water demand of Guadalajara in years to come that Jalisco´s government ordered SIAPA to grant any new domestic water request: "We can´t stop the city from growing" mentioned a high-ranking civil servant (Del Castillo 2018). Whereas the water transfer was not yet concretized, it had already increased water demand. Ultimately, the Arcediano project fell apart due to geological complications (López-

Ramírez, 2012), prompting the search for a new supply augmentation project. In the meantime, the distribution network continued to deteriorate and water losses persisted, despite having the technology to swiftly repair leaks (Delgado-Aguiñaga et al., 2017).

Currently, the entrenched faith on large supply augmentation infrastructure continues while pressing issues of highly unequal access to water of poor quality, over-exploited groundwater and unabated urban growth are neglected, as are the high levels of unaccounted-for-water of the water utility. This omission could rapidly offset the benefits of a large supply augmentation project, because should the Zapotillo project be implemented, the state water authority expects water demand to grow to a level that would equalise the new water supply (represented by the dashed rectangle in Fig. 3; CEA-Jalisco & Gobierno del Estado de Jalisco, 2018).

4.2 Opening up the decision space

The previous subsection shows that the growth of both cities´ have increased water demand beyond current water supply and for both cities the Zapotillo project is perceived not as the main but the only viable strategy to bridge that gap. However, both cities experience water problems beyond a gap between supply and demand that a large supply augmentation will not fix. On the contrary, there are indications in both cases that it could further foster a supply-demand cycle (Kallis, 2010), and possibly the reservoir effect by increasing their dependence on the Zapotillo reservoir (Di Baldassarre et al., 2018). Therefore, considering the conflict that has put the Zapotillo project indefinitely on hold, the urban water systems of Guadalajara and León are facing a crossroads that warrants the question of what alternatives solutions can address León's and Guadalajara's water problems, and what are their challenges, obstacles, and potential.

The grassroots movement consisting of the dam-affected communities along with an international network of academics, practitioners and experts have been developing and proposing a portfolio of alternative strategies with fewer socio-environmental externalities than the Zapotillo project (Godinez Madrigal et al., 2020). The main alternatives that have been debated in the media and the public agenda are rainwater harvesting, limiting urban growth, reclaimed wastewater reuse for industrial water demand, implementation of water-saving devices, reallocating water from agro-export businesses to domestic uses and reduction of physical losses in the distribution system. However, local and state governments and water engineers conceived these alternatives as distractions to the only feasible solution, the Zapotillo project (anonymous interview with a retired water engineer of the state of Jalisco, 25 May 2018). "Many organizations say they have been fighting for 10, 15 years for a position related to different alternative solutions for water [supply]. I think that if we continue like this for another 10, 15 years, then that method [sic] cannot deliver. It is just not possible to continue in the same situation for another 10 or 15 years." (transcript of a public talk of the Head of the civil engineer college of Jalisco, 22 Nov 2018). Even when the alternatives´ potential is acknowledged, they are dismissed as unfeasible because "If we would consider implementing these projects [i.e., reducing physical losses and rainwater harvesting], it would take years and be very costly" (interview with the head of the Water Council of Jalisco, 22 December 2020). Nevertheless, these negative assessments of alternatives are not backed up by

thorough studies, but based on a priori judgements on water knowledge and dubious expert opinions (interview with local academic, 8 December 2018).

350   However, these negative assessments have become a talking point for actors supporting the Zapotillo project. Water engineers have depicted the actors against the Zapotillo project as bad faith opposers without a constructive criticism. In engineering circles, they are known as 'oposi-todos´ (anti-everything people). (Anonymous interview with a retired water engineer of the state of Jalisco, 25 May 2018).

Conscious of how the governments and experts portrayed the grassroots movement, members of the movement introduced to

355   the public discussion the need to look for alternatives to large-scale supply augmentation infrastructure besides their main argument that the Zapotillo project was a mistake. However, with limited expertise and scarce resources, the grassroots movement faced limitations to clearly argue which alternatives would be more suitable to Guadalajara and León, and to what extent would they provide a reliable solution to the different needs of each city. Given this void, the authors of this paper collected the dispersed alternative solutions into an integrated water resources model. (see Supplementary material).

360   These two contrasting narratives collided during our participatory modelling workshop to compare alternative water supply solutions and the Zapotillo project for Guadalajara and León. The workshop was powered by a water resources model originally used to assess the Zapotillo project using reliability, resilience, and vulnerability (Godinez Madrigal et al., 2020). We compiled the most important alternative solutions and built them into the model to assess and compare all alternatives. Through a user-friendly interface, participants could choose their preferred strategies and analyse their performance. However, this time the

365   indicators were based on both perspectives against and in favour of the Zapotillo project: water supply reliability for León, Guadalajara and water users in the donor basin, groundwater dynamics, and environmental flows.

During the workshop, engineering participants of IMTA, opted to test the communities' position and the alternative solutions they proposed. Their overall criticism of the participatory model was the underlying assumptions of the alternatives and that models are much more complex than what lay people can understand. "To lay people it is very obscure what a model entails;

370   it is not as easy as giving them a computer and off they go […] [Regarding alternatives] you are trying to limit urban growth. I don´t think that is viable, I didn't understand that [measure] of limiting urban growth […] So, how are you going to make it happen [limit urban growth to 1 %/year?] It is unrealistic. If we are growing 2 %/year, how am I going to decrease it to only 1 [%/year], sure not magically."

Social actors comprised of NGOs and dam-affected communities preferred to test the performance of the Zapotillo project and

375   realized that it would also take years before the dam could be filled and be ready to use for León and Guadalajara, and that it would not be a solution for the groundwater over-exploitation. As a response to the engineering group, they acknowledged that the data in the participatory model may not be optimal and found the need to democratically curate input data, which led them to critically assess how data and expert opinions of water managers and engineers could also easily be manipulated: "The model is not perfect, because there is incomplete information, and needs to have more adjustments to become more useful.

380   But we agree that previous governmental models [that warranted the Zapotillo project] were also running with incomplete information and were biased by their own interests. […] This tool can be useful for communities to criticize technical and

political arguments and support alternatives, because the situation can be analysed in a more integrated way, with more social criteria, not like the government´s previous models." (representative of IMDEC).

Although all actors agreed that the model itself was incapable of finding an optimal solution to the conflict because of its inherent uncertainties and numerous configurations, most actors stated that participatory modelling could become a powerful process to engage actors to find negotiated solutions in the long run. They reflected on how essential it is to improve our governance processes to better deal with complex issues and uncertainties, since they cannot be reduced by technical studies nor expert engineers: "The more connections we make [in the model], the less certainty we have, therefore, it is an issue of governance, where all actors must be present to discuss and build agreements, because there will never be a 100% satisfactory technical solution." (representative of Tómala). Other civil society participants acknowledged the uncertainties of the model as well and considered that citizens should also be part of choosing which data to feed the model to increase trust. Especially for communities affected by socio-environmental problems, the modelling tool seemed to also have an additional potential: "I sincerely see this tool´s potential not so much for helping make decisions, but for understanding what the problem is. I was envisioning... and felt emotional, that in my community we could have the chance to work the model with a lot of people. Because just imagine that the community could make a leap in understanding in a brief period of time a whole problem." (Member of an affected community, 6 Dec 2018).

After the workshop, the head of Conagua and the engineers who participated in the workshop stated their commitment to continue developing alternatives to solve the conflict. This participatory modelling workshop led to follow-up activities. A year later some of the social actors who participated further explored alternative technical solutions by organizing a series of workshops in coordination with the newly elected leftist federal government of Mexico, in which three alternatives were further explored with the assistance of a dozen of international and national experts in different fields: improving groundwater management, including rainwater harvesting and reducing physical losses. However, the state governments of Jalisco and Guanajuato criticised and disapproved the participation and support of the federal government in these workshops on alternative solutions. The president of the business association of León mentioned that "We do not know the intention of these workshops, but we are against exploring new alternatives, especially if they are serious […] All this affects our competitiveness." (Aristegui, 2019).

In this context, the public attention and federal public policies have shifted from the Zapotillo project as the only option, to the potential of alternative water solutions for Guadalajara and León. Currently (November 2021), the federal government has agreed to decrease the operation scale of the Zapotillo dam from 105 m to a maximum dam height of 50 m (which implies that the water supply from the dam to Guadalajara will reduce to 3 m^3/s, and that the water transfer to León is cancelled)" (Conagua, 2021) in order to spare the dam-affected communities. Guadalajara and León will either search for new, further and more costly large-scale supply augmentation projects with the risk of triggering more conflicts or be forced to start experimenting and adopting some of the alternative solutions described in this paper.

5 Discussion

415 To fully understand the pathways of León and Guadalajara, they need to be framed under larger social, economic, and political dynamics and the Zapotillo supply augmentation project. With a sociohydrological perspective, we analysed the interplay of social, and hydrological processes that resulted in the current predicament of León and Guadalajara. Moreover, our political ecology analysis of the co-evolution of Guadalajara´s and León´s human-water systems shows that although water managers have warranted the quest for new water supply sources based on the "inevitability" of socio-economic growth, we found that

420 more than inevitable, socio-economic growth has been actively promoted as a development pathway.

Our results show that the Zapotillo project is conceived by the authorities´ own accounts as a provisional strategy (CEA-Guanajuato & Conagua, 2018; CEA-Jalisco & Gobierno del Estado de Jalisco, 2018), since they would require additional future large supply augmentation infrastructure once water demand outstrips water supply again in the coming decades. This is so, because there are socio-economic dynamics that are currently bounded by limited water availability, which would then

425 be unleashed and be supported by an increased water supply. This behavioural pattern of cities and water managers is understood as a driver of the supply-demand cycle found in other cases around the world (Kallis 2010, Di Baldassarre et al., 2018).

Analysing the case of Guadalajara through the lens of socio-hydrology we found that the city´s current water shortage and its concomitant socio-economic damage (as of June 2021) is the result of the increased water demand fostered by its intra-basin

430 water transfers (Calderón dam and Lake Chapala), and its increased dependency on these reservoirs. Moreover, a critical perspective on this urban water system shows that the emphasis given to the large supply-augmentation Zapotillo project will not fix the current situation of non-networked residents and the multiple network deficiencies (high physical losses and aging infrastructure). These deficiencies are partly responsible for the water shortages and an intermittent water supply experienced by mostly poor neighbourhoods. This shows a policy gap between non-networked and intermittent water systems and large

435 infrastructure, as shown in other cases (Allen et al., 2017). Despite this policy gap, politicians peddled the Zapotillo project as the only solution to bring about water security for Guadalajara, despite that the supply augmentation will most likely attend new water demand. Thus, this project would further continue the supply-demand cycle and thus increase the vulnerability of Guadalajara in the future.

In the case of León, although its urban water system characteristics are different than Guadalajara´s, the effect of the supply

440 augmentation Zapotillo project is similar. Our analysis shows that, due to its almost total water supply dependency on groundwater, León´s water utility has improved its efficiency indicators better than Guadalajara´s in terms of lower non-revenue water, higher percentage of networked households and reclaimed water for agricultural purposes. However, its alarming groundwater situation, also affected by large-scale agricultural dynamics, is not likely going to change with a water transfer. To the problem of groundwater over-exploitation in the region, water managers need to consider radically different

445 and equitable institutional arrangements between rural and urban users to curb its unsustainable water use, as suggested by Hoogesteger & Wester (2015) and Molle & Closas (2019) (see also Hoogendam, 2019, for a similar case in Cochabamba).

Therefore, the similarity between the two cases lies in the way politicians overestimate the capacity of the large supply augmentation Zapotillo project to solve the current water problems and future challenges of these urban water systems. Moreover, these politicians also underestimate the potential of alternative solutions as well as the likely unintended negative

450 consequences of such an infrastructure project, such as like the supply-demand cycle (Kallis, 2010; Gohari et al., 2013) or the reservoir effect (Di Baldassarre et al., 2018).

Leach et al. (2010) work on development pathway argues for the need to unearth alternative, often marginalized pathways by using different assessment tools and methods. Therefore, with a transdisciplinary approach, we analysed the emergence and dynamics of the competing alternative development pathway of the conflict. Our analysis on the decision space shows that the

455 engineering mentality prevalent among water managers tended to dismiss any alternative pathway based on the perceived incapacity of the grassroots movement to show results or empirical evidence of the alternatives. Water managers also dismissed alternative solutions based on the lack of time and resources to investigate their merits, since the groundwater overexploitation and water shortages facing Guadalajara and León are so urgent that only the tried-and-tested, ready-made solution of the Zapotillo project is framed as feasible.

460 Transitioning to an alternative development pathway is usually faced with fierce opposition, since "[t]here is often assumed to be a singular path to progress, any questioning of which is taken to indicate an 'anti-innovation', 'anti-technology' or 'antidevelopment' stance" (Leach et al., 2010), and in the Zapotillo case personified by the "*oposi-todos*". Critics often pitch a simplistic narrative of pitting the rights of the majority against the rights of the minority and ask the latter to sacrifice for the "common good" (Roy, 1999; Leach et al., 2010). This narrative frames the minority as the culprit for not accepting the project,

465 which is left unquestioned. In fact, Scott (1998) and Agrawal (2005) explain that 'high modernist' planning actively excludes political processes such as deliberation and negotiation precisely to avoid further questioning and preclude the emergence of alternatives.

Regarding the dynamics that determine the decision space of urban water systems, our experience from the participatory modelling process showed the importance of open science not only to replicate results (Godinez Madrigal et al., 2020), but

470 also to repurpose the design of a water resources model that was initially used to justify the Zapotillo project by expanding its system boundaries. By adding the Guadalajara and León water systems in the model, alternative water supply strategies could be tested, allowing participants to explore different strategies based on contrasting narratives.

The results of the participatory modelling workshop show that stakeholders critically reflect on the role of data, information and scenarios that are often used to justify policies, decisions and infrastructures ("because the situation can be analysed in a

475 more integrated way, with more social criteria, not like the government's previous models" as said by the representative of Tómala). This critical perspective also allowed for a reflection on the purpose of water resources models as decision support systems. When an IMTA participant warned on the risk of giving a complex modelling tool to lay people, a representative of the grassroots movement acknowledged the assumptions and uncertainties of the model and foregrounded the key role of governance processes in relation to these unavoidable technical shortfalls of models. Participants of the grassroots movement

480 were eager to participate in designing the model and deciding on the input information. This interest further contributed later to technical workshops with the federal government to develop alternatives to the Zapotillo project.

Therefore, we argue that in the socio-hydrological conceptualization of the supply-demand cycle and the reservoir effect, scientists need to pay special focus to the almost inevitable water conflicts inherent to endless supply augmentation projects, and to the emergence of grassroots movements presenting alternative narratives. This can evolve into a development pathway

485 crossroads that opens up the decision space as presented in Figure 4. Based on our analysis of the cases of León and Guadalajara in relation to the Zapotillo project, water conflicts driven by grassroots movements have a role in disrupting the supply-demand cycle. First, by blocking and delaying the implementation of the large supply augmentation project, and second, by fostering a more conscientious public debate about the decision space of the urban water systems. The main narrative that framed the Zapotillo dam as a necessity and the only solution and ignored alternative solutions has changed. Water managers no longer

490 ignore alternative solutions, at first, they criticized them, and now they take them seriously. Further research is needed to see if they will be implemented, but judging from the recent downscaling of the Zapotillo project, they may be forced to at least consider them. Without a large supply augmentation project, the cities will need to implement demand management (negative feedback for water demand in Fig.4) and/or decentralized small-scale supply augmentation strategies (positive feedback for water supply in Fig. 4) that could thwart the supply-demand cycle.

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Figure 4: The water conflict disruption in the reservoir effect (the dashed lines indicate their hypothetical status, while the pink lines indicate new variables not yet considered by the original conceptualization by Di Baldassarre et al. (2018).

 6 Conclusion

This paper conceptualized and investigated the current development pathway crossroads of the cities of León and Guadalajara to understand the role of water conflicts and grassroots movements in interfering with the supply-demand cycle. It did so by analyzing the urban water system trajectories that configured the present water scarcity and over-exploitation problems in León and Guadalajara, and exploring the socio-political dynamics of alternative future pathways proposed by actors in conflict.

505 The dominant development pathway in León and Guadalajara has been characterized by a techno-managerial approach that went unchallenged for almost a century, what Leach et al. (2010) describe not as a pathway, but a 'motorway'. However, in the last three decades this pathway has been heavily scrutinized and thoroughly criticized by a grassroots movement opposing this development pathway. This social opposition disrupted and caused large infrastructural projects to fail and put the Zapotillo project in an indefinite hiatus. This hiatus has lasted 15 years, and to date it remains unclear which development

510 pathway León and Guadalajara will embark on.

With a transformative spirit infused by the work of Leach et al. (2010) Di Baldassarre et al. (2019), Zeitoun et al. (2019), and Rusca & Di Baldassarre (2019) we aimed at analysing the development pathways of urban water systems with a transdisciplinary political ecology and socio-hydrology approach and explore the role of conflicts and grassroots movements in forcibly creating a development pathway crossroads. Our research showed that the methodological framework of socio-

515 hydrology related to the 'reservoir effect' (Di Baldassarre et al., 2018), combined with the critical political ecology approach of hydrosocial studies (Kallis, 2008; Molle & Wester, 2009, Savelli et al., 2021), can be used to problematize the still dominant sanctioned discourse of large supply augmentation infrastructure in other contexts. This exercise in conjunction with a participatory modelling workshop with key actors based on an empowering design (Stirling et al., 2007; Leach et al., 2010) can broaden what are the issues at stake in the urban water systems and open up the decision space beyond large supply

520 augmentation infrastructure.

We broadened the issues by identifying that the main urban water problems are not only related to a gap of water supply and water demand over time, but also to an unchecked and even sponsored economic and population growth, uneven water access, aging distribution infrastructure and neglected rural-urban dynamics related to groundwater overexploitation. This is relevant because a large water supply augmentation project will not solve these issues. With our participatory modelling workshop, we

525 contributed to opening up the decision space by modelling most of the alternative solutions brought up by the grassroots movement.

We arrived at three main conclusions. One, that the supply-demand cycle is fuelled by the perceived inevitability of urban and economic growth, and an unwarranted faith that large-scale augmentation projects will solve complex current and future water problems like water shortages and groundwater overexploitation. Two, that water conflicts driven by grassroots movements

530 have an important role in interfering with the supply-demand cycle by stalling the implementation of large infrastructure projects, creating a development pathway crossroads and fostering public discussion on alternative pathways. And three, that participatory modelling is a promising tool to open the decision space by co-developing alternatives proposed by actors representing a competing pathway to have a more balanced deliberation and negotiation process even in contexts of power asymmetry.

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Code Availability

The reader can access the SimVerde software at: https://github.com/jongmadrigal/SimVerde.

Data Availability

The reader can access the data produced in the analysis of the different infrastructure configurations of the SimVerde at:
540 https://github.com/jongmadrigal/SimVerde

Author Contribution: Conceptualization, JGM, NVC and PvdZ; Data curation, JGM and PCG; Formal analysis, JGM; Investigation, JGM, JH, PCG and NVC; Methodology, JGM, NVC and PvdZ; Software, JGM and PCG; Supervision, NVC and PvdZ; Writing—original draft, JGM; Writing—review & editing, NVC, JH and PvdZ

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