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Unravelling intractable water conflicts: the entanglement of science and politics in decision-making on a large hydraulic infrastructure project

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Abstract. Global trends suggest that cities around the world are increasingly depleting available water resources. A common strategy is to opt for supply augmentation infrastructure. However, this response can be a financial and social burden for many cities, because they entail developing expensive infrastructure and can trigger social conflicts. Science is often expected to play a key role in informing policymakers and social actors to clarify controversies surrounding policy responses to water scarcity. However, managing conflicts is a socio-political process, and the use of models may have the effect of de-politicizing such processes; conveying the idea that optimal solutions can be objectively identified despite the many perspectives and interests at play. This raises the question whether science can depoliticize water conflicts, or whether instead conflicts politicize science-policy processes? We use the Zapotillo dam and water transfer project in Mexico to analyze the roles of science-policy processes in water conflicts. The Zapotillo project aims at augmenting urban water supply to Guadalajara and León, two large cities in Western Mexico, but a social and legal conflict has stalled the project until today. To analyze the conflict and how stakeholders make sense of it, we interviewed the most relevant actors and studied negotiations between different interest groups through participant observation. To examine the role of science-policy processes in the conflict, we mobilized concepts of epistemic uncertainty and ambiguity and analyzed the design and use of water resources models produced by key actors aiming to resolve the conflict. While the use of models is a proven method to construct future scenarios and test different strategies, the parameterization of scenarios and their results depend on the knowledge and/or interests of actors who own the model. We found that in the Zapotillo case, scenarios reflected the interests and strategies of actors on one side of the conflict, resulting in increased distrust by the opposing actors. We conclude that the dilemma of achieving urban water security through investing in either large infrastructure (supply augmentation) or alternative strategies (demand-side management), cannot be resolved if some key interested parties have not been involved in the scientific processes framing the problem and solution space.

1 Introduction

Urban water systems around the world are experiencing many urgent challenges related to secure themselves from water scarcity, flooding and bad water quality (Zevenbergen et al., 2008; McDonald et al., 2014). The scope of these challenges is

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such that individual scientific disciplines and traditional approaches fall short of addressing them in a thorough manner to unequivocally inform policy (Funtowicz & Ravetz, 1994; Larsen et al., 2016; Hoekstra et al., 2018). Any solution to the challenges facing urban water systems will have manifold uncertainties in projected costs, benefits and risks, and this is especially true when large infrastructures are considered (e.g., see Flyvbjerg, 2009 and Crow-Miller et al., 2017, for a general description of the contentious process of cost-benefits assessments of large infrastructures, and for specific cases, see Berkoff, 2003, for China, Hommes et al., 2016, for Turkey; Hommes & Boelens, 2017, for Peru, and Molle & Floch, 2008, for Thailand). How the perceived costs, benefits and risks are shared among the stakeholders is one of the causes of water conflicts (Delli Priscoli & Wolf, 2009).

Since these conflicts are politically perilous situations, many policymakers seek the need of specialized scientific knowledge that is perceived as neutral and unbiased to serve as the basis of making difficult decisions over controversial issues (Schneider & Ingram, 1997). In recent years, political ecology literature has acknowledged that this specialized scientific knowledge can act as a form of covert advocacy in politically charged socio-environmental problems (e.g. Budds, 2009, and Sanz et al., 2019, for groundwater over-exploitation and allocation; Godinez-Madrigal et al., 2019, for water scarcity and surface water allocation). This paper has two objectives, 1) to contribute to identifying the causes of failure in science-policy processes to solve intractable conflicts and promote well-informed water management solutions; and 2) to explore the multiple influences in the production of water knowledge in a context of conflict, and its political use by actors. We contribute to the literature on science-policy process by analyzing the conflict over the Zapotillo dam and water transfer project, perhaps the most politically charged water conflict in Mexico in recent years. This case is of special relevance due to what is at stake: the water supply for the two most important cities in Western Mexico, the economic importance of its semi-arid donor basin, and the possible displacement of three communities lying in the reservoir's area. Furthermore, the conflict can be considered intractable, given its length (started more than 15 years ago) and that is still largely unresolved due to the immobile positions of the stakeholders (Putnam & Wondolleck, 2003). The focus of this paper is the scientific knowledge produced through a water resources model as a means to clarify controversies, fill gaps in knowledge and depoliticize the conflict; while emphasizing how the process of scientific production favored the Zapotillo project, ignored alternatives based on demand management strategies in the recipient cities, proposed by the dam-affected stakeholders, and improperly managed core uncertainties related to climate change and future water demand.

The paper is structured as follows. The paper starts with an analysis of science-policy processes literature in relation to epistemic uncertainties and controversies in water conflicts. We then describe the case of the Zapotillo project, and the methods used to analyze it. Subsequently, we describe the main scientific controversies of the conflict, and analyze the water resources models that were developed to help resolve the conflict, albeit unsuccessfully. Finally, we discuss the theoretical contributions of the case to the literature of the role of science-policy processes in water conflicts.

2 Science-policy processes and water conflicts

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2.1 Uncertainties and ambiguity in science-policy processes

Effective science-policy processes in water management are those where water knowledge informs decision-makers as to what are the most appropriate solutions to water challenges, and what is likely to happen if nothing is done (Karl et al., 2007). However, Funtowicz & Ravetz (1994) have argued that complex socio-environmental issues like climate change are confronted by uncertainties, ethical complexities and policy riddles regarding societal values, from which no clear-cut policies can be concluded.

Uncertainties consist not only of matters of lack of precision and accuracy in the data being analyzed, but also of epistemic uncertainties, understood as the ignorance of the functioning of a given system (Funtowicz & Ravetz, 1990; Di Baldassarre et al., 2016; Cabello et al., 2018) and of ambiguity, understood as multiple knowledge frames (Brugnach et al., 2011). Scientists cannot address these levels of uncertainty by simply improving their techniques or computational prowess, which can only reduce aleatory uncertainty of data (Di Baldassarre et al., 2016). However, epistemic uncertainties and ambiguity stem from controversies of what the real problem is and how to frame the solutions in the political arena between actors with different interests (Gray, 2003; Cabello et al., 2018).

When facing epistemic uncertainties in a complex socio-environmental problem, stakeholders stand on unexplored territory; even scientists face an ambiguous path in deciding which methodologies to use and how to interpret the phenomena (i.e. Melsen et al., 2018, and Srinivasan et al., 2018; see also Brugnach & Pahl-Wostl, 2008). Boelens et al. (2019) noted the relation of knowledge and power asymmetry between stakeholders in the context of large infrastructural schemes. Such asymmetry is characterized by hegemonic discourses and does not allow for a fair assessment of different kinds of knowledges to understand a socio-environmental problem (Schneider & Ingram, 1997; Wesselink et al., 2013). This may result in what Boelens et al. (2019) denominate 'the manufacture of ignorance', understood as the process of cherry-picking facts and knowledge to further one´s position, while discrediting ex-ante competing knowledge without a thorough debate (see also Flyvbjerg, 2009, Moore et al., 2018). In case of large infrastructures, this process is often undertaken by invoking scientific evidence (Brugnach et al., 2011), which is as the only valid frame to understand the socio-environmental problem.

When science-policy debates ignore intrinsic epistemic uncertainties and ambiguity, it is expected that irreducible uncertainty be present in their scientific recommendations to policy (Funtowicz & Ravetz, 1994), which makes such recommendations dubious, or at least contestable. Instead, epistemic uncertainties and ambiguity can be made manageable through bottom-up approaches[1] consisting of the inclusion of local stakeholders, their knowledge, problem-framing and alternative solutions in the policy debates (for a general description see Brugnach et al., 2011, and for hydrological risk management see Lane et al., 2011, and Blöschl et al., 2013). But this kind of public participation in socio-environmental decisions is a political decision often aimed at improving the acceptability and legitimization of policies (Newig, 2007), rather than reducing epistemic

[1] The difference between a top-down and a bottom-up approach is that the first focuses on highly technical assessments, while the second on the communities' vulnerabilities, making the latter more robust to a changing and unpredictable climate, no matter how low the probabilities of the occurrence of any event (Blöschl et al., 2013).

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uncertainty and handling ambiguity (Bloomquist & Schlager, 2005; Brugnach & Ingram, 2012). In a context of conflict, however, the possibility of acceptability and legitimization of policies is already severely constrained, which changes the dynamics of science-policy processes. The next section analyses the literature regarding water conflicts and science-policy processes.

2.2 Water conflicts and co-production of knowledge

Water conflicts emerge for many reasons, but we will explore those that emerge from the imposition of large infrastructural projects. These projects may produce many benefits, but also socio-environmental costs and risks that are unevenly distributed between stakeholders. An example is the apparent urgency to implement supply augmentation and reallocation solutions to guarantee water supply to large cities. These solutions may hamper due processes of transparency, public participation and the rights of other water users and stakeholders. The absence of these processes may create social conflicts (Barraqué & Zandaryaa, 2011; Roa-García, 2014), which are defined as "two or more entities, one or more of which perceives a goal as being blocked by another entity, and power being exerted to overcome the perceived blockage" (Frey, 1993, cited in Delli Priscoli & Wolf, 2009). Thus, water conflicts may block such supply augmentation projects to alleviate water scarcity, while no alternative solutions are implemented. In doing so, actors in conflict may worsen the system as a whole (Madani, 2010), aggravating the social conditions by rationing water, and deteriorating hydrological conditions by further depleting available water reserves like aquifers or dams.

When these conflicts are prolonged in time, the positions of the actors in conflict tend to harden and the conflict may become intractable with small chances for a negotiated solution (Putnam & Wondolleck, 2003). Intractable conflicts are often characterized also by ambiguity, in which actors with different systems of knowledge (engineers, communities, policymakers, etc.) perceive the problem with different frames, as well as its possible solutions (Brugnach & Ingram, 2012). Even within stakeholder groups, stakeholders can make sense of the conflict in different frames (Brummans et al. 2008). The water problems are often unstructured and riddled by uncertainties in information and cause-effect relationships (Islam & Susskind, 2018). Due to the high public regard of science, it is expected for scientists to contribute to unravelling what the problem is, and to offer solutions supported by all actors (Schneider & Ingram, 1997). However, many studies have identified biases in allegedly neutral scientific studies (Budds, 2009; Sanz et al., 2018; Godinez-Madrigal et al., 2019), which has lately discredited the public perception of science as a fair knowledge creator in some controversial large infrastructural water projects around the world (Boelens et al., 2019). Due to this situation among others, more attention has been given to non-expert knowledges in research and decision making (Armitage et al., 2015; Krueger et al., 2016).

The literature has some consistent recommendations regarding knowledge in contexts of conflict and a diversity of values in socio-environmental problems. Van der Zaag & Gupta (2008) recommend five principles based on feasibility, sustainability, looking for alternatives, good governance and respecting rights and needs before undertaking large infrastructural schemes; Funtowicz & Ravetz (1994), Islam & Susskind (2015), Armitage et al. (2015) Dunn et al. (2017) and Norström et al. (2020)

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argue that since no expertise or discipline can claim to have the monopoly of wisdom in complex socio-environmental issues, then the problem definition and possible solutions need to include local and non-technical knowledges, therefore engaging in co-production of knowledge. This approach even provides the advantage of designing more robust and resilient solutions (Blöschl et al., 2013). This does not belittle scientific studies, but changes their role to become boundary objects, which cannot illuminate stakeholders´ decision-making, but rather elicit new relationships and innovative solutions among the different systems of knowledge and frames present in all stakeholders (Lejano and Ingram, 2009). True knowledge controversies have the potential to be generative events in the sense that they open the ontological question of what is reality and how it is framed, and redefine it in, hopefully, better terms (Callon, 1998; Latour, 2004; Whatmore, 2009).

However, little attention has been paid to science-policy processes in cases of intractable water conflicts based on the development of large infrastructures to solve urgent water problems. The next sections will present the historical context of the conflict over the Zapotillo water transfer project in Mexico, analyze the knowledge controversies around the conflict and the scientific products that were developed with a view to solve the conflict and generate acceptance and legitimacy for the project.

3 Case study and Methods

3.1 Case study: a tale of two cities

Guadalajara and León are the most important cities of their respective States, Jalisco and Guanajuato, in terms of population and economic size. Currently, Guadalajara has more than five million people, and León almost two million. Since the 1950s, Guadalajara's local water resources availability was overrun by the increasing water demand and water managers sought to increase its water supply from Lake Chapala, the largest lake in the country (see Table S1 in the supplementary material). Guadalajara's aquifers are considered as over-exploited and with presence of heavy metals (Hernandez-Antonio et al., 2015; Mahlknecht et al., 2017; Moran-Ramirez., 2016). León, on the other hand, does not have large bodies of water in close vicinity and therefore it has historically relied solely on groundwater, which now is considered as heavily exploited with a drawdown of 1.5 m/year and with presence of metals due to the over-exploitation (Villalobos-Aragon et al., 2012; Cortes et al,. 2015; SAPAL, 2020).

During the 1980s, water managers in Jalisco were aware of the relentless growth of Guadalajara and sought to develop new sources of water besides groundwater and Lake Chapala (Flores Berrones, 1987). They analyzed that the only nearby region with enough water to supply Guadalajara was the Verde River basin, located in the north of Jalisco (Figure 1). They calculated a potential of more than 20 m^3/s, enough to supply water for Guadalajara for the coming decades with its expected urban growth and future water demand. However, it was technically complicated to develop the Verde River basin and transfer its water to Guadalajara. The Verde River discharges into the Santiago River at more than 500 meters below the altitude of Guadalajara, which skyrockets energy costs. Also choosing a good site for the dams was difficult, because some dam sites were situated on tectonic faults (López-Ramírez & Ochoa-García, 2012). During the slow process of concretizing realizable

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projects, Guanajuato requested to Conagua (Federal water authority) legal rights over a portion of the Verde River's water for the city of León. In 1995, Conagua accepted this request and added Guanajuato as a potential user of the river's water.

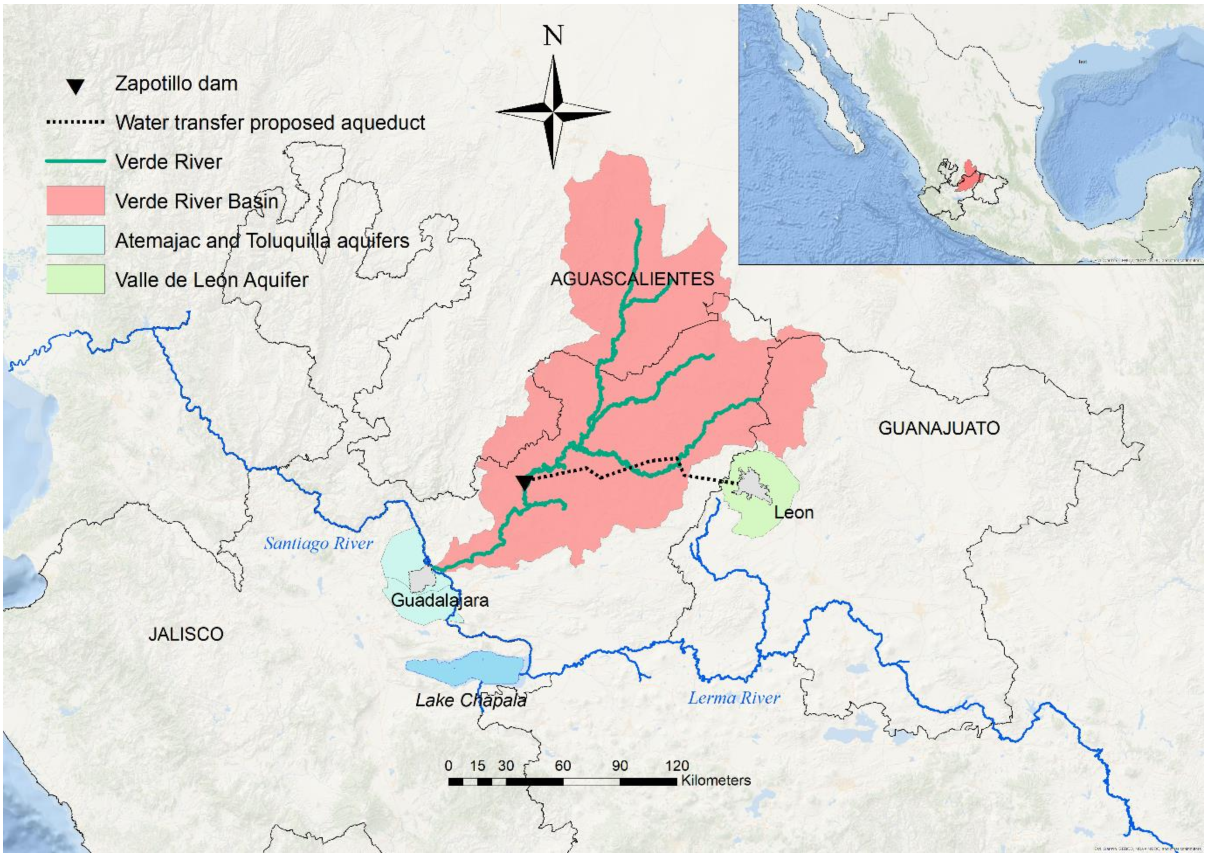

Figure 1: Map of the Verde River Basin and main cities (Source of GIS layers: © 2018 Conagua, and © 2019 Esri, Garmin, GEBCO, NOAA NGDC, and other contributors).

During the year 2000, a drought started in the Lerma-Chapala basin that caused a water crisis for Lake Chapala, which decreased its volume to less than 10% of its capacity. Since Guadalajara heavily relied on the lake for its water supply and upstream farmers in Guanajuato used most of the surface water that fed the lake, the situation triggered a surface water allocation conflict between Jalisco and Guanajuato (Godinez-Madrigal et al., 2019). The conflict was resolved by reducing the water rights of upstream farmers to increase the volume of water reaching the lake. But, in exchange, Conagua promised to build a dam in the Verde River basin to transfer water to León (Godinez-Madrigal et al., 2019). In 2005, the Zapotillo project was concretized with an agreement where León was the only beneficiary. The dam's height was supposed to be 80 m and provide 3.8 m^3/s to León. Nevertheless, because Jalisco failed to concretize a project of its own to increase water supply for

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Guadalajara, Jalisco's government advocated in 2007 to change the design of the Zapotillo project to include Guadalajara as a user and receive 3.0 m^3/s by increasing the dam's height to 105 m to increase its storage capacity.[2]

By this time, the dam-affected communities, Temacapulín, Acasico and Palmarejo, started a fierce opposition against the project with the objective to avoid the flooding and relocation of their communities. Their representatives followed a social and legal strategy, which consisted of claiming that the 2007 agreement was unconstitutional because Jalisco's governor did not consult the State congress. In 2012, the Mexican Supreme Court ruled in favor of the communities and ordered Conagua to stop the construction of the dam, which by then already had a 80 m height (DOF, 2012).

The Zapotillo project has remained paralyzed since then. Although the dam wall has already been built, the reservoir has not been filled, because of the uncertainty of the dam's final height. Given the politicization of the conflict and the urgency of meeting the water deficits of Guadalajara and León without implementing any additional or alternative strategy, new actors entered the arena (Figure 2). Some farmers' associations in the Verde River basin coalesced and lobbied against the Zapotillo project on the basis that the region is semi-arid, already has water over-exploitation, that climate change will worsen the condition of the regional water resources, and that the region is one of the most agricultural productive regions in the country (Ochoa-Garcia et al., 2014). In 2014, Jalisco's government supported the creation of a Citizen's Water Observatory that could theoretically have the mandate to formulate binding recommendations to local and state governments within Jalisco. The Observatory, NGOs and local universities proposed that demand management strategies in Guadalajara and León could be more sustainable and socially just than the Zapotillo project. In contrast, IMTA (the engineering body of Conagua) released a technical study concluding that the Zapotillo project was feasible even in the context of climate change.

[2] Several urban locations in the Los Altos region were included as well in the water allocation agreement of the project, which would receive 1.8 m^3/s.

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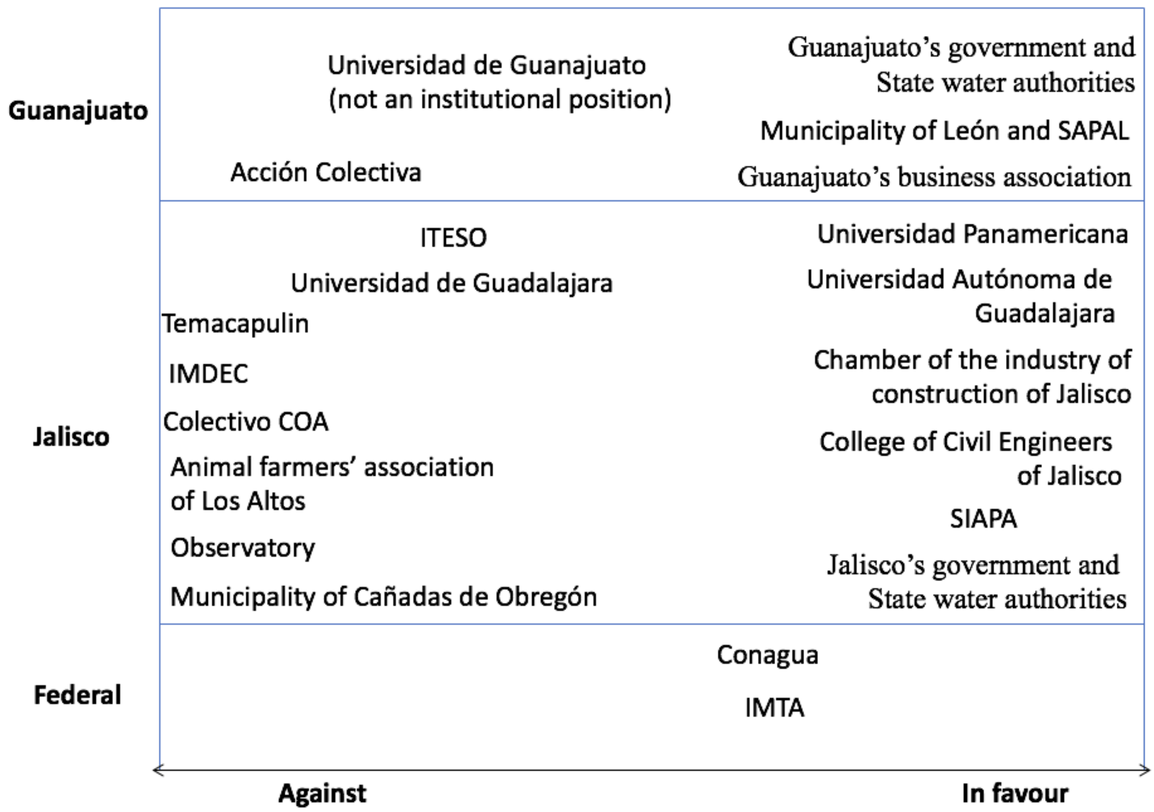

[1]Universidad de Guanajuato has not released any official position on the project, however many of its academics have publicly support its cancelation.

Figure 2. Position of key actors in favor and against the Zapotillo dam project (for more details on the actors see Table 2 in the supplementary material).

In 2015 Jalisco's government hired the United Nations Office for Project Services (UNOPS) to develop a water resources model of the Verde River basin and formulate an informed recommendation to address, once and for all, the controversies regarding the possible negative effects in the Verde River basin and analyze the optimal configuration of the Zapotillo project. The study took two years and the process followed and methods adopted were largely unknown by most actors. Finally, UNOPS recommended that the Zapotillo dam should have a height of 105 m and that the original water allocation should decrease by 13%, since Conagua over-estimated the available water in the Verde River basin (UNOPS, 2017b). This recommendation was based on the assessment of three indicators: reliability, vulnerability and resilience (these are explained in the following section). The results of the study were discredited and discarded by some of the main stakeholders in the conflict. Currently, at the publication of this paper, the conflict continues.

3.2 Methods

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To understand the science-policy processes in a context of an intractable conflict we adopted an interdisciplinary method to assess the scientific products that were developed with the intention to have a decisive role in de-politicizing the conflict, and their effect on the perceptions of actors. We spent five months previous and one month after to the public release of the UNOPS' report in Guadalajara in 2017. We conducted 22 in-depth, semi-structured interviews to most of the key actors of the conflict (Figure 2): members of Jalisco's government, national and state water authorities, NGOs, scholars, the Citizen Water Observatory (hereafter referred to as the Observatory) and representatives of the communities affected by the dam. The semi-structured interviews consisted of asking three main themes: the root causes of the problem and the conflict, what were the sources of controversy in the conflict, and what would be the ideal solutions to the conflict and the water scarcity problem. We then conducted participant observation during five key meetings of the Observatory and Jalisco's government to analyze the discourses, knowledge claims, and main controversies on the coupled human-water system of the region. This allowed us to identify controversies and link the position of actors in the conflict to knowledge frames. Immediately after the presentation of UNOPS' results, we conducted informal interviews with most of the key actors that were present, to record their reactions and opinions of the outcome of UNOPS' study.

Afterwards, we requested from Jalisco government the full water resources model that UNOPS developed; we received it by the end of 2017. The model was developed on the Water Evaluation and Planning System (WEAP21) software and contained the five scenarios that UNOPS used to test the viability of the Zapotillo dam project to reliably allocate water until the year 2069 (Figure 3). The five scenarios switched parameters under different reservoir storage volumes (at dam heights 80 m and 105 m), different water allocation volumes to Guadalajara, León, and the urban localities within the Verde River basin (8.6 m^3/s, 4.8 m^3/s and 7.5 m^3/s), and changes in water availability related to climate change (RPC 8.5 or no climate change) and changes in agricultural water demand in the donor basin (static water demand since year 2018 or expected water demand in year 2030).

UNOPS recommended to the decision makers that the best possible configuration of the Zapotillo project was that of scenario 5: to build a dam at 105 m, with the only caveat of reducing the water allocation by 13%. However, many actors were negatively surprised that although UNOPS developed a scenario with climate change and future water demand (scenario 4, see Figure 3), these changing future conditions were not included in their scenario 5, which only considers current water demand and ignores reduced water availability due to climate change. Therefore, we considered it important to replicate the results developed by UNOPS, and to test and analyze UNOPS' choice of scenarios and its recommendation by developing an additional scenario (our) that included the variables climate change and future water demand as developed by UNOPS in scenario 4 to their scenario 5 (Figure 3). We then compared the results of our scenario with the original scenario 5 using the same indicators UNOPS used to assess their own scenarios. These indicators were based on the methodology of Loucks and Gladwell (1999). Reliability assessed the percentage of months the dam was able to supply its intended volume. The ideal score would be 100%. Vulnerability assessed the percentage of water supplied vis-à-vis water demand for all months. The ideal score would also be 100%. And resilience assessed the speed of recovery of the dam after a period of being empty by calculating the number of

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times a satisfactory value follows an unsatisfactory value divided by the number of unsatisfactory values. The scores range from 1 to 0, being close to 1 represents a highly resilient system, and 0 a poorly resilient system.[3]

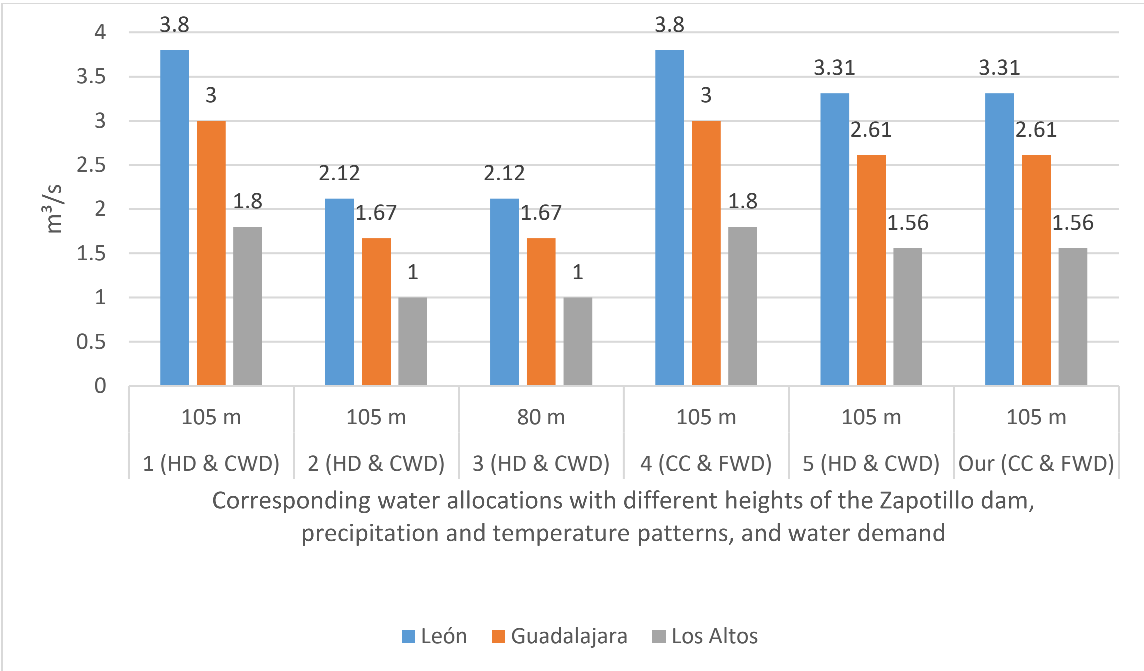

Figure 3: Comparison of the five water allocation scenarios (in m³/s for León, Guadalajara and Los Altos) developed by UNOPS (2017a) and ours ("HD & CWD" = historical run-off data and current water demand; "CC & FWD" run-off under climate change and future water demand).

4. Results

4.1 Controversies

Table 1 summarizes the main controversies and frames raised by the actors interviewed in the conflict. They can be divided into two: 1) what are the appropriate policies to solve the water scarcity problems in Guadalajara and León; 2) what are the risks, uncertainties and negative effects of a dam and a water transfer in the Verde River Basin.

Table 1. Main controversies and frames on the coupled human-water system of the regions.

General controversies	Specific controversies	Frames

[3] The resilience indicator is only useful when the system presents unsatisfactory values, therefore If the system does not present any unsatisfactory values, the indicator is non-existent, as seen in Figure 5.

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Recipient basins: policies for urban water security	– The urgency to apply supply augmentation policies – Demand management policies as an alternative to supply-side policies: reducing physical losses and rainwater harvesting – Increasing costs of large infrastructure – Alternative, in-basin water sources for León and Guadalajara – Sectoral water transfers	– Actors in favor of the Zapotillo project: alternatives are unrealistic. The Zapotillo project is the only feasible solution. – Actors against the Zapotillo project: Alternatives exists and can be cheaper, more sustainable and socially just than the Zapotillo project.
Negative consequences for the donor basin	– Dam's height in relation to the resettlement of the three communities – Overestimation of surface run-off – Droughts and climate change – Underestimated official water abstractions – Regional socio-economic dynamic is growing, as well as water demand – Groundwater overexploitation	– Actors in favor of the Zapotillo project: There is enough water in the donor basin for all existing and future users. – Actors against the Zapotillo project: There is currently not enough water in the donor basin, and a water transfer will have enduring negative effects.

4.1.1 Recipient basins: policies for urban water security

Since the 1980s, Guadalajara's per capita water use has remained above 200 l/cap/day (Flores-Berrones, 1987; Consejo Consultivo del Agua, 2010). Ever since, water authorities have strived to keep pace with the fast-growing city population, because they consider a relatively large per capita water use as an important indicator for water security. The actors in favor of the Zapotillo dam project have emphasized of the urgent necessity of supply augmentation for the cities of León and Guadalajara. Representatives from CEA-Jalisco (Jalisco's water authorities) and Sapal (León's water utility) argued that without supply augmentation, both cities might suffer a water crisis due to the over-exploitation of its aquifers. Water authorities from Jalisco and Guanajuato concluded that pressure on aquifers in both cities and Lake Chapala need to be decreased, as aquifers represent a safe backup in times of drought. An additional risk for Guadalajara is the aging Lake Chapala aqueduct, whose life expectancy has already been exceeded. Repairing the aqueduct may affect the water supply for the city for weeks or even months.

Against this argument, representatives of Temacapulín, the Observatory, NGOs and universities have argued that supply augmentation will always lag water demand. Del Castillo (2018a) described how a high-ranking public servant of Jalisco ordered Siapa's (Guadalajara's water utility) director to grant any water request to promote the city's growth in 2004 when the

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construction of the Arcediano dam was announced[4]. This group of opposing actors argues that there is an urgent need to curb the per capita water use, and to limit the cities' physical expansion and demographic growth, supported by a transition to a demand management paradigm that considers a reduction of physical losses, development of alternative water sources like rainwater harvesting, sectoral water transfers and full cost recovery.

Representatives of CEA-Jalisco considered all these alternative solutions as too expensive and cumbersome. For example, rainwater harvesting would require the installation of hundreds of thousands individual systems. However, in 2006, the Zapotillo dam's original budget was USD 750 million (USD 1,250 million in today's value). Currently, the project's total costs are officially estimated at USD 1,800 million (IMDEC, 2019). Considering these escalating costs, NGOs argue that demand management solutions can be more economical and without the social costs of the Zapotillo project.

When looking at a reduction of physical losses, Fitch Ratings (2015) stated that the current losses of Guadalajara's distribution system account for more than 3 m³/s (around 32% of distributed flow). Gómez-Jauregui-Abdo (2015) warned that this situation may worsen, because of the network's obsolescence rate, which is higher than the replacement rate. CEA-Jalisco has argued that Siapa's budget is not sufficient to replace the entire distribution system and that even if sufficient financial resources were available it would imply a huge social cost by opening the streets of the whole city. This would also imply a political cost that no local politician is willing to assume. In León, Sapal's physical losses amount to around 32%. Although the replacement rate of their distribution system is higher than Guadalajara's, their distribution system's deterioration rate is not precisely known.

As an alternative to fixing the distribution system, a group within the Universidad de Guadalajara has suggested to develop an urban rainwater harvesting system (Gleason-Espíndola et al., 2018). They claim that the system could harvest approximately 21 hm³/year, which could account for about 7% of the total water use of 313 hm³/year (SIAPA, 2017). Similarly, researchers at the University of Guanajuato calculated an approximate annual harvest of 27.3 hm³/year for the city of León, amounting to 33% of the total water use of 81 hm³/year (Tagle-Zamora et al., 2018).

The Observatory argued that the municipality of León and the government of Guanajuato should integrate their water resources at the basin scale to save water and reallocate it to where it is most needed. For this, Jalisco´s Observatory proposed a two-way strategy for León: to abstract water from Sierra de Lobos, a mountain range located close to León, and to implement an agricultural water modernization program and to reallocate its savings to León. The Observatory claims such a strategy would increase available water for León with 360 hm³/year, which is four times León's current water use (Del Castillo, 2018b). However, the technical details of this alternative have not been shared nor made public.

4.1.2 Negative consequences for the donor basin

[4] In 2001, Jalisco's water authorities announced the Arcediano dam in the Santiago river to increase water supply for Guadalajara. In 2009, due to technical infeasibilities, the project was indefinitely postponed (López-Ramírez & Ochoa-García, 2012).

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In the past decades Los Altos has experienced two major socio-economic changes. First, a decreasing rural population due to migration to the United States (Durand and Arias, 2014) and to nearby cities in Jalisco. Second, the industrialization of the regional economy. In the 1990s, Mexico liberalized its markets and supported agriculture for export. This industrialized the agricultural sector of Los Altos (Cervantes-Escoto et al., 2001). Currently, the region is the second largest producer of animal protein in the country (Ochoa-García et al., 2014), and hosts one of the largest egg producers in the world (WATTAgNet, 2015). This economic development has increased competition for water, especially groundwater, due to the government´s restrictions on surface water use (DOF, 2018). Several water users confirmed the existence of a black groundwater market, and groundwater rights hoarding in hands of industrial farmers. Consequently, most aquifers present serious water balance deficits, which jointly amount to more than 150 hm^3/year in Los Altos' aquifers (CEA Jalisco, 2018); and many have presence of fluoride and arsenic (Hurtado-Jimenez & Gardea-Torresdey, 2005, 2006).As agricultural outputs keep increasing around 9%/year (Ochoa-García et al., 2014), groundwater overexploitation may exacerbate the future water demand. Although there are no clear numbers on the water balance for surface and groundwater separately, water authorities calculated a combined renewable water availability in the Verde River basin, which also includes groundwater in Aguascalientes (Figure 1), of 1,624 hm^3/year, while water demand was 1,804 hm^3/year (Conagua-Semarnat, 2012).

Due to the water deficit in the basin, the technical chair of the Observatory has argued that there is insufficient water in the basin to fill the dam at the planned 105 m height, and that, based on the precautionary principle, the donor basin should not be burdened with additional commitments due to a water transfer. Additionally, he has stated that water information provided by gauging stations in the Verde River Basin cannot be trusted, as the network of hydrological stations is defective and unattended. CEA-Jalisco claimed that even if it is true that run-off is overestimated in the basin, it is confident that the gauging station at the entry point of the dam is reliable. This station has measured an average flow of 599 hm^3/year (IMTA, 2015), which is enough to fill the Zapotillo dam in one year at a height of 80 m, or two years at a height of 105 m. Currently that water flows directly to the Santiago River (see Figure 1). Farmer representatives in Los Altos have stated that, if indeed these claimed surface water resources of the Verde River exist, they should be used to contribute to the potential growth of Los Altos.

Regarding the three communities under threat of displacement, Temacapulín's representatives proposed a dam with a height of 60 m, whereby the towns would be safe from floods. However, a smaller dam would not be able to transfer the agreed volume of water to Guadalajara and León, since the dam's capacity would then be 145 hm^3. At a height of 80 m, Temacapulín would be flooded. CEA-Jalisco's representatives claimed that the construction of dikes could prevent this. Temacapulín and IMDEC are against this solution as it would create a huge unnecessary risk for the inhabitants in case of the dikes would fail. Also, a 80 m dam with a capacity of 411 hm^3 would not be able to allocate sufficient water for both León and Guadalajara. With a height of 105 m and a storage capacity of 910 hm^3, the dam could be potentially supply sufficient water for both Guadalajara, León and Los Altos.

4.2 Analysis of scientific products

The history of the conflict over the Zapotillo project has created several scientific products that have attempted to address the many uncertainties and risks of a project of this magnitude. But most of them have not analyzed the system in an integrated way. The first one (IMTA, 2005), based on the Mexican norm of NOM-011-CAN-2000, estimated not the feasibility of the dam, but the relationship between its height and its maximum water extraction. Although this study explored scenarios of future water demand in the donor basin, it did not explore scenarios of the effect of climate change on precipitation patterns. Moreover, the study did not consider the role of increasing groundwater over-exploitation in the basin on the base flow of the river. The study recommended the most optimistic scenario where surface water use in the donor basin would not increase in the future.

Conagua (2006, 2008) released the Environmental Impact Assessment of the project, which dismissed any potential negative impact on the donor basin, based on the argument that local farmers have caused already most of the environmental degradation. However, the studies analyzed the impact of the dam only at the dam site, not the overall regional impact (CACEGIAEJ, 2018). Later, when the dam design was redesigned to 105 m in 2007, IMTA did not release any complementary study to assess the implications of a larger inundated area, of including a second water user (Guadalajara) nor of an increased water allocation.

In 2014, the Los Altos' Animal Farmers Association commissioned ITESO (the Jesuit University in Guadalajara) to study the possible social effects of the water transfer. The study (Ochoa-García et al., 2014) concluded that according to official data the Los Altos region already had a groundwater deficit of more than 100 hm^3/year and growing, due to the continuing growth of the agricultural output of the region. It also concluded that, since the region's climate is semi-arid, the region was especially vulnerable to droughts, hence the water transfer project would have serious negative socio-economic and environmental effects. However, the study could not make a surface water assessment nor a climate change analysis due to lack of information. Recently, the Observatory released a haphazard hydrological footprint analysis to assess the water needed for supporting the agricultural activity in the region (Ágora, 2018). It concluded that the water footprint of Los Altos agricultural output was 14,081 hm^3/year, therefore the 12 hm^3/year allocated to animal farming in the allocation agreement of the Verde River of 1997was insufficient. However, this argumentation is flawed, since they did not consider that the water footprint of a given agricultural product includes the virtual water imported from other regions in the form of fodder. So, the actual water needed is much less than 14,081 hm^3/year.

To counter the study of Ochoa-García et al. (2014), CEA-Jalisco released a water availability study based on the updated Mexican norm NOM-011-CAN-2015 (IMTA, 2015). Although the study included climate change as a variable in the water resources by using IPCC's regional models based on RCP-4.5 and RCP-8.5 climate scenarios, the same study discarded its negative effects to the surface water balance due to its high uncertainty: "Climate change results should not be analyzed deterministically, but probabilistically… [we should not lose] perspective that climate change studies are still in an early stage, thus, their results cannot be taken as absolute truths, due to their low probability of occurrence… There is no certainty that projected rainfall and temperatures in climate change models will occur." (Our translation from IMTA, 2015: 212). The study did not consider possible future increases in water demand nor evaluated the dam´s behavior according to input variables (river run-off) and output variables (water allocation and other losses). As a result, the study could conclude that sufficient water was available in the Verde River Basin to comply with the water allocation agreement and environmental flows for the coming decades.

What can be concluded from the previous studies is that there were at least four important uncertainties that were still ignored: (1) groundwater and its interaction with surface water in the Verde River basin, (2) the effect of future water demand in Los Altos' water resources, (3) the effect of climate change, and (4) potential impact on water quality and ecosystem services downstream in the Santiago River.

In late 2015, Jalisco's government hired UNOPS to develop a comprehensive water resources model of the Verde River Basin. For Jalisco's government, UNOPS scientific role would represent a milestone in the history of science-policy processes in Mexico, because of its alleged impartiality and technical capacity to analyze these uncertainties and make a depoliticized evidence-based decision. UNOPS' multidisciplinary team of international experts addressed the four uncertainties in the following way. 1) They analyzed groundwater dynamics by using information from NASA's GRACE earth observation project. 2) For two years, the team collected social and hydrological information in situ from the Verde River Basin to calculate current water demand and project future water demand. 3) They used IPCC's RCP-8.5 regional model of climate change for Los Altos; i.e. the worst-case scenario. And 4), they calculated environmental flows downstream of the Zapotillo dam. These analyses were used as input variables for the water resources model of the Verde River basin using WEAP software, which allowed to simulate future scenarios.

After months of speculation over UNOPS' results, the team released a preliminary study where they found a 50% increased water demand compared to current official data (UNOPS, 2017b). A year later, they presented the final results in a public meeting (29 June 2017). UNOPS developed five main scenarios which alternated different variables (see Figure 3). They assessed the performance of each scenario based on reliability (to supply urban water), vulnerability (volume of unmet water demand) and resilience (of the dam to recover its water levels after an empty period) indicators. UNOPS' team concluded that only scenario five satisfied all these three indicators. However, the good performance of scenario five (Figure 3) depended on reducing by 13% the volume of water to be transferred to León, Guadalajara and Los Altos in the 2007 agreement. UNOPS' team recommended Jalisco's government to proceed with the project with such settings and a dam height of 105 m. Jalisco's governor immediately confirmed this decision during the public meeting.

The results were controversial because under this scenario Temacapulín would be flooded. Despite this, the consultants immediately left the venue after the presentation, leaving no time to discuss the key assumptions of the model, nor the justification and relevance of the five scenarios. Temacapulín's representatives responded negatively and took over the podium to declare their distrust in UNOPS and its results.

The local academics criticized UNOPS' study for not considering climate change nor future water demand in scenario five, the limitations of the chosen indicators, and the still incomplete assessment of groundwater given the low reliability of GRACE's coarse spatial resolution data. Members of the Observatory interpreted these omissions in the study as deliberate,

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alleging that the UNOPS experts, who were financed by Jalisco's government, would have never recommended a solution against the Zapotillo project.

To explore the possibility of a deliberate omission, Figure 4 shows a comparison between scenario 5 and our own scenario, which configures a scenario with the allocation variables of scenario 5 and the climate change and future water demand variables of scenario 4, as described in section 3 and illustrated in Figure 3. The results show a poor performance of the Zapotillo dam's projected storage and the three indicators chosen by UNOPS (Figure 5); whereas scenario 5 shows all three indicators (reliability, vulnerability, and resilience) on target, our scenario results into substantially lower performance, notably on vulnerability and resilience.

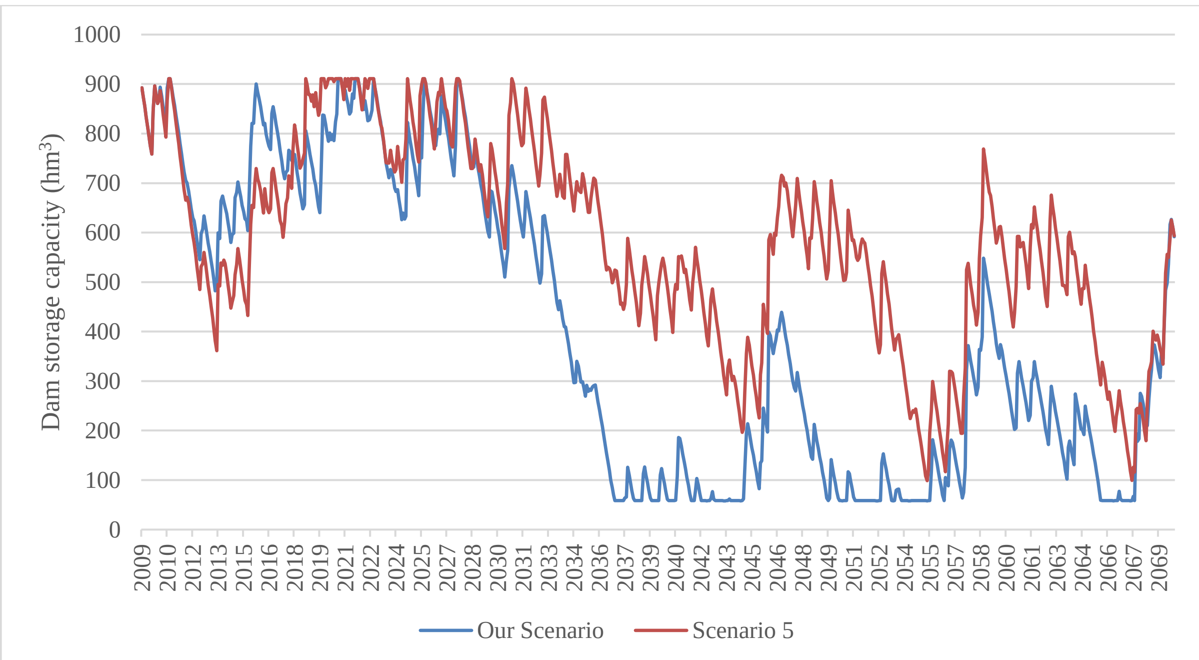

Figure 4: Comparison of Zapotillo Dam's behavior in scenario 5 (UNOPS, 2017a) and our scenario, which includes climate change and future water demand.

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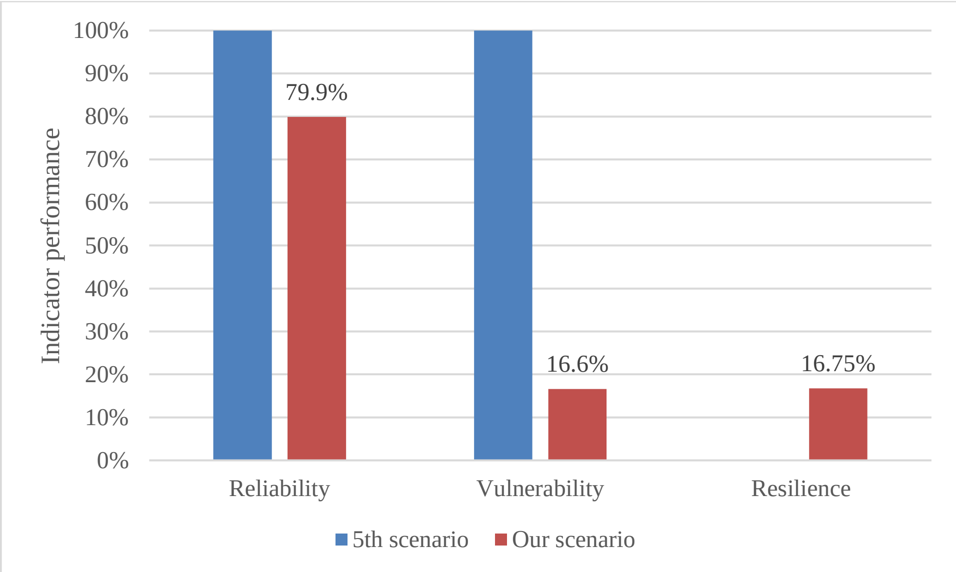

Figure 5. Performance of the indicators for the two scenarios.

5 Discussion

Since large infrastructural projects are still depicted as the main solution to current water problems (Muller et al., 2015; Boelens et al., 2019), it is important to critically assess the uncertainties embedded in the scientific products that support such projects in the face of the social and environmental costs they can cause. In the case of the Zapotillo project, we found that although a lot of efforts were made to reduce uncertainties, the efforts were directed towards reducing uncertainties of accuracy and precision, not epistemic uncertainties nor the ambiguity of multiple frames. UNOPS improved the assessment of groundwater dynamics, future water demand, climate change and environmental flows in the Verde River basin, but did not improve the understanding if the Zapotillo project was adequate to improve the urban water problems of Guadalajara and León, nor how the Zapotillo project would negatively affect stakeholders in the donor region.

Regarding the efforts to reduce the four uncertainties of accuracy and precision, the UNOPS study improved the knowledge of the system, but not without caveats. Since the effects of climate change depend on the severity (moderate or extreme) of the chosen IPCC climate scenarios, water authorities seemed doubtful to accept that uncertainty in their decision-making. The water balance assessment by UNOPS (2017b) found that Conagua was underestimating water demand and revealed a serious over-exploitation of surface and groundwater in the Verde River basin. Hence, future water demand becomes a large uncertainty since Conagua cannot properly estimate current water demand. The third uncertainty is still largely unresolved: the groundwater situation in the Verde River basin. Conagua lacks sufficient measuring infrastructure to gauge the state of the aquifers, and there are no long-term series of groundwater levels available. Also, UNOPS's use of earth observation (GRACE) to estimate groundwater added little new information. It may even have been inappropriate, given the very coarse spatial resolution of GRACE, rendering it only suitable for very large aquifers, much larger than the Verde River basin aquifers.

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Finally, as all previous studies, this study also ignored possible downstream effects of the dam beyond the city of Guadalajara and until the natural outlet of the receiving Santiago basin in the Pacific.

Regarding the epistemic uncertainties, since UNOPS did not address the epistemic controversies and ambiguity related to the (un)feasibility of the project, the possible alternatives for water supply in the recipient regions, the possible negative effects in the donor basin, and the injustice and unfair treatment of communities in the vicinity of the dam, the results of UNOPS' study remained contentious and mistrusted. UNOPS´ model seemed to answer the wrong question: how to optimize the management and operation of the Zapotillo project. Deciding this question is a political choice, since it implies that the decision to proceed with the infrastructure is already taken, and that the only valuable decision criteria are those related to optimizing the water supply to Guadalajara and León, leaving other controversies described in this paper unaddressed. DFID (2013) and Feldman and Ingram (2009) argued that research that lacks a deliberative process with stakeholders, including in the definition of what the questions are, may decrease its impact. We argue that this applies to development projects as well. Since the 1990s, research have been consistent in promoting knowledge co-production to solve pressing and disputed environmental problems (i.e. Funtowicz & Ravetz 1994; Brugnach et al., 2011; Islam & Susskind, 2015; Armitage et al. 2015; Norström et al. 2020). UNOPS missed the opportunity for answering a much more relevant question for all actors in the conflict: based on indicators agreed by all stakeholders, how does the Zapotillo project compare to alternative solutions for creating a sustainable and socially just urban water system?

The knowledge generated by UNOPS effectively filtered other feasible solutions to the water problems of the three regions in conflict and did not take into consideration downstream users nor environmental flows for the Santiago River. If the goal is to achieve water security, then it was not justified to restrict the research and modelling to supply augmentation by the Zapotillo project. According to the best social and hydrological knowledge available, it can be inferred that there are insufficient surface water resources to satisfy the demand of the three regions' explosive demographic and agricultural growth, which means that at least one region will continue to unsustainably deplete its groundwater resources. In fact, UNOPS fifth scenario generated positive results only because it considered null demographic and economic growth for the future and did not consider climate change.

The case shows that water authorities have lost their power to impose their decisions and need the support and legitimacy of the incumbent social actors in the donor region. Given the absence of a legitimate authority to enforce decisions, actors from the three regions have entered the knowledge arena to build their cases that support their interests. Norström et al. (2020) proposed that pluralistic, goal-oriented, interactive and context-based knowledge co-production can improve system understanding and reduce conflicts. The opposite also seems to be true - when actors in conflict produce knowledge only in relation to their interests and in isolation, they reinforce their frame and lose the overall perspective of emerging problems in the coupled water-human system at hand.

Although the conflict is related to the control of surface water resources, groundwater seems to be a defining issue and emerging problem in the conflict. The three regions are competing for limited surface water resources aimed at protecting their available groundwater resources and their current and future demographic and economic growth. However, given the heavy

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reliance on groundwater for water supply, other threats seem to have been overlooked. Water quality and land subsidence has been almost absent in the debate, even though there is increasing evidence that groundwater quality is rapidly declining and land subsidence is increasing as over-exploitation intensifies (for Guadalajara see Hernández-Antonio et al., 2015; Morán-Ramírez et al., 2016; Mahlknecht et al., 2017; for León see Villalobos-Aragón et al., 2012; Cortés et al., 2015; Hoogesteger & Wester, 2017; and for Los Altos see Hurtado-Jiménez & Gardea-Torresdey, 2005, 2006, 2007).

This case study serves as a cautionary tale for actors in a water conflict, who are embroiled not in solving the problem, but in implementing their own preferred solution. Madani (2010) warned that the behavior of non-cooperative actors might result in a worse condition for all. Although science has the potential to bridge the positions of actors, it can also be misused by hegemonic actors to support their own solutions. However, as this case exemplifies, that can be counter-productive and backfire instead.

6 Conclusions

This paper sought to scrutinize and unravel the entanglement of politics and science in the production of water knowledge for intractable conflicts, by analyzing the case of the Zapotillo conflict in Mexico. The conflict is defined by several knowledge controversies regarding water availability and the negative effects of the water transfer and dam construction in the donor basin, and the possible alternatives to supply augmentation strategies in the recipient basins.

This study has two main findings. 1) Intractable water conflicts tend to isolate the process of knowledge production, which then creates knowledge controversies. And, 2) isolated knowledge have less potential for transforming the conflict by missing core epistemic uncertainties. After analyzing the model of UNOPS, we found that its research team made a significant contribution to knowledge by reducing uncertainties related to precision and accuracy of future water demand, climate change, groundwater dynamics and ecological flow. But the team failed to address epistemic uncertainty around emerging problems induced by groundwater over-exploitation as well as ambiguity related to the negative effects in the donor basin and more sustainable and socially just alternatives to the Zapotillo project. We found some indications that UNOPS indulged into what Boelens et al. (2019) call the manufacture of ignorance, by recommending Jalisco's government to build a 105 m dam without taking into account climate change, future water demand, nor alternative water supply options. But this result may also be explained by the absence of efforts by UNOPS to facilitate the co-production of knowledge. As the UNOPS team never organized workshops with the stakeholders to design the research, except for Jalisco's government, the research results did not contribute to reduce epistemic uncertainties nor to handling the ambiguity of different frames. So, even if UNOPS did not deliberately indulge in the manufacture of ignorance, their research suffered from tunnel vision. Nevertheless, the mere suspicion of deliberate manufacture of ignorance was enough to discredit UNOPS results by most stakeholders.

However, contrary to the conclusion of Boelens et al. (2019), production of knowledge with epistemic uncertainties is not exclusive to powerful actors. Instead, this kind of knowledge was produced by most of the actors in the conflict. There was a lack of systematic analysis, methodological transparency and open discussion from which firm conclusions could be drawn

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from the side of both the water authorities and opposing actors like the Observatory, communities and the NGOs. Especially the Observatory produced unverifiable but allegedly scientific knowledge that hardened the multiple frames at play and contributed to increased ambiguity.

We conclude that science has the potential to reduce the intractability of a water conflict, and contribute to its transformation, but only if science is carried out in an open and participatory manner (Voinov & Gaddis, 2008; Armitage et al., 2015; Basco-Carrera et al., 2017; Norström et al., 2020), and by collaboratively bringing about research questions that address the interests of all relevant actors. There is an urgent need to design water resources models in a more open way to allow the participation of stakeholders and legitimize the data used in them (Islam & Susskind, 2018). This can allow the revision of alternatives to large infrastructures (Van der Zaag & Gupta, 2008), such as demand-oriented alternatives in the domestic, industrial and agricultural sectors, link them within an integrated basin management framework, and systematically compare them with the proposed centralized supply-side infrastructure options. This might not be a panacea against vested interests (Molle, 2008), but can be an improvement to identify arbitrary decisions in public policies by hegemonic actors.

Nonetheless, social movements, often regarded as weak actors, already represent a force to be reckoned with in the water sector, yet many still lack technical knowledge to propose feasible alternatives. Building technical capacities of stakeholders and the general public through reiterated and interactive stakeholder workshops can allow for in-depth discussions on the nature of the problem, alternative solutions, risks, and epistemic uncertainties, as discussed by Lejano & Ingram (2009), Di Baldassarre et al. (2016), Van Cauwenbergh et al. (2018), van der Molen (2018) and Norström et al., (2020). Therefore, knowledge by itself cannot solve conflicts, since it needs to be trusted. And a process of knowledge co-production can offer that; one that engages not only technical issues, but also social ones: recognizing interdependencies, fostering good relationships and working together through boundary objects (Brugnach & Ingram, 2012). This effort is not only recommended to water authorities, but also boundary organizations such as the Observatory, who all lack transparency in their practices and willingness to work together. Without bridging open science through co-production of knowledge and capacity building of non-technical actors in a water conflict, partisan science and epistemic controversies will remain a recurring issue in intractable water conflicts against the urgency of providing reliable and sustainable water to all.

Data availability

The reader can access the Verde River basin model developed by UNOPS and modified by the authors at: https://github.com/jongmadrigal/Verde-River-Basin. Although the model is only accessible through the software WEAP (www.weap21.org), it is possible to download the software for free and run its test version to replicate this article´s findings.

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