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Production of competing water knowledge in the face of water crises: Revisiting the IWRM success story of the Lerma-Chapala Basin, Mexico

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ABSTRACT

Integrated Water Resources Management (IWRM) is an approach that aims to change conventional water management. International agencies and organizations have promoted IWRM across the globe. The Lerma-Chapala Basin in Mexico is an archetypal case study on basin closure, where IWRM principles were said to have been applied in the early 2000s to help solve a serious water crisis. This paper analyses the controversies around socio-hydrological uncertainties that were raised during this and an earlier crisis of Lake Chapala, whose resolution defined the water management policies of the basin. We interviewed key stakeholders, analysed different hydrological models, and reviewed the most important literature assessing the case. Then, we analysed how stakeholders understood the functioning of the socio-hydrological system, and how that determined their perception of what the root causes of the crisis were, and ways to resolve it. We found that the modelling efforts by two stakeholders to understand the root causes of the crisis could not clarify important socio-hydrological uncertainties, which limited the scope of their conclusions. From the proposed responses, only those based on the existing institutional and regulatory framework were implemented. Our results question the assertion that IWRM principles of public participation, sound knowledge, and river basin institutions, actually changed the traditional water management paradigm. We conclude that economic and political interests, more than IWRM principles, influenced the decision-making process to solve the water crisis in the Lerma-Chapala basin.

1. Introduction

Water crises are generally characterized by uncertainties, which makes it difficult to find their root causes and propose policy solutions (Srinivasan et al., 2012). Controversies abound on whether water crises are caused by mismanagement, a crisis of governance or a lack of investment in water infrastructure (UNESCO, 2006; Castro, 2007; Grey and Sadoff, 2007; Sivakumar, 2011; Muller et al., 2015). Resolving controversies plays an important part in the decision-making of water resources management, since they determine policy responses. Molle (2003) argues that the set of responses to water crises vary from increasing supply, managing demand and reallocating water. Proponents of Integrated Water Resources Management (IWRM) argue that to improve water access and solve water crises, water managers should manage water at the river basin scale, include public participation and consider water as an economic good, rather than the creation of new infrastructure (Young et al., 1994). The Global Water Partnership (2000) later included these principles in its definition of IWRM: "a process which promotes the coordinated development and management of water, land and related resources to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment." International water agencies and organizations like the Global Water Partnership and the World Bank promote IWRM principles and disseminate successful case studies of IWRM implementation (Molle, 2008a). Between the years 1989 and 2004, IWRM principles were reported to have been applied to solve the water crisis in the Lerma-Chapala basin, characterized by basin closure. This case has been portrayed as a success story, where the Mexican water authority, Conagua, solved a water crisis by building compromises and cooperation between all actors through public participation (Hidalgo and Peña, 2009).

Despite this assertion, other researchers have claimed that the resolution of the Lerma-Chapala's crisis has not addressed the root causes, and that the policies implemented were not appropriate (von Bertrab, 2003; Torres-Gonzalez and Perez-Peña, 2005; von Bertrab and Wester, 2005; Torres-Gonzalez and Perez Peña, 2009; Wester et al., 2009b). This is a controversy formed also by several uncertainties in the socio-hydrological system: volume of surface and groundwater used,

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efficiency by agriculture upstream Lake Chapala, volume of water supplied to the main urban settlements and industries within and outside the basin, growth of water demand by different uses, effects of different water allocations, water availability and average renewable water in the basin, as well as the relationship between surface and groundwater.

The Lerma-Chapala basin underwent two major water crises manifested by the dramatic decrease of the water level of Lake Chapala, the first starting in the 1950s, and the second in the 1990s. Detailed descriptions of both crises allowed us to analyse and compare the two events and the uncertainties of each crisis and the controversies on the implemented responses that followed. We describe how water authorities framed the uncertainties around water management in the Lerma-Chapala basin in narratives that transited from the ‘hydraulic mission’, inspired by the Tennessee Valley Authority (Wester et al., 2009c), to that of IWRM. That transition implied a change in perception of agriculture as a driver of economic development, poverty alleviation and food security in Mexico, to a sector viewed as inefficient.

A major change in both crises is the use of river basin modelling as the main tool by water managers and stakeholders to identify the crisis' main root cause, and hence, propose adequate responses to solve the water crisis. This article poses the question whether the use of IWRM principles in general, and public participation, transparency and sound technical knowledge in particular, changed the perception and positions of the actors to cooperate and compromise to a new allocation agreement. Conagua (2011), Hidalgo and Peña (2009) and Güitrón (2005) have suggested that the participatory modelling process shaped the decisions that resulted in the policy responses implemented to solve the water crisis. We aim to investigate whether and how this happened and whether it generated policies based on IWRM that solved the crisis.

Despite the vast literature that has studied this case (Mestre, 1997; Huerta, 2004; Pérez-Peña, 2004; DOF, 2006; Wester, 2008; Wester et al., 2008, 2009b; Hidalgo and Peña, 2009; Torres-González and Pérez-Peña, 2009; Conagua, 2011), the modelling process, central to the decision-making mechanisms of the case, has not received sufficient attention. In this paper, we aim to fill that gap, and to link uncertainty with knowledge claims, policy responses and their impact on the socio-hydrological system. We argue that water knowledge based on hydrological modelling, which helped reach conclusions and recommendations for decision-making in the basin, was influenced by politics, culture and economics.

2. Uncertainties and controversies in the hydrosocial cycle

A crucial endeavour for sociology is to study and understand historic changes in society. Latour (1986: 273) argued that uncertainties and controversies are decisive in societal changes, because they are “part and parcel of the very definition of the social bond”. In the field of water management, the scientific attempts at solving controversies redefines the relationship between society and the hydrological cycle (Bouleau, 2014). In the context of a water crisis, uncertainties and controversies become even more relevant because any stakeholder's definition of the root causes of the crisis will be linked with a specific response. These attempts at defining the appropriate responses to a water crisis are an exercise of power, understood as the “intense activity of enrolling, convincing and enlisting [other actors]” (Latour, 1986) into one's own perspective.

Political ecologists have pointed out the difficulty of presenting scientific proof for a single root cause (Brown, 2004; Budds, 2009; Porto et al., 2016; Jansen, 1998). Funtowicz and Ravetz (1990: 24) argued that this is similar to forensic science, where uncertainty is managed by skilled judgements in piecing together and sifting evidence to understand and explain the behaviour of a system, rather than mathematical techniques (Srinivasan et al. (2015) used this approach to confront the many hypothesis for the causes of a drying river in India.) However, the uncertain nature of complex environmental problems opens the possibility for actors to exploit every bit of uncertainty in water knowledge to impose their interests (Karl et al., 2007). This makes it important to be aware of the uncertainties and limitations of decision-making processes and resulting policies by assessing the mutual influence between water knowledge, politics, culture and economics (Krueger et al., 2016).

An alternative way to address these controversies is through public participation, which has been considered an important tool to improve decision-making in conflict management (Savenije and van der Zaag, 2000; Delli Priscoli, 2004). However, Cabello et al. (2018) argued that participatory processes also introduce epistemic uncertainty, which question not only policy responses to a problem, but also what the problem really is about.

Public participation in uncertain complex environmental problems can catalyse increased reflexivity and new creative policy responses, instead of perceiving uncertainties as problems to solve (Cabello et al., 2018). However, reordering social institutions may be too unstable for some actors, who seek instead “associations that last longer than the interactions that formed them […] to be able to stabilize a particular state of power relations” (Callon and Latour, 1981: 283). These associations are constituted by actors, claims of knowledge, discourses and practices. Such associations create a tension between macro-actors and micro-actors. Callon and Latour (1981) defined the first as the main actors that have aligned more actors to their own interests and values, like policy makers, think tanks and water authorities. While the second are those aiming to challenge macro-actors' influential associations by enrolling additional actors into their own particular interests and values. This tension increases with public participation in water management, because its aim is to include micro-actors, which present alternative arrangements of associations that compete with those of macro-actors.

Molle (2008a) analysed the process of association in epistemic communities, consolidated groups of actors who share “causal beliefs and cause-and-effect understandings”, and strengthen a concept or an approach in water management to a point where it can be considered a truth. These communities articulate their approach in discourses, which Allan (2003) described as water management paradigms or sanctioned discourses.

Despite the best efforts of these epistemic communities to stabilize associations in society, the interaction of the hydrological cycle and actors with diverging interests constitute powerful forces that can open the ontological question of what water is in relation to society (Bouleau, 2014). These forces can include: water crises and/or new actors challenging the sanctioned discourses. We hypothesize that these forces, especially water crises, represent opportunities for micro-actors to redefine and challenge how the hydrosocial cycle must be.

This ongoing interaction of water and society shapes and defines each other in a dialectical way (Linton and Budds, 2014). To understand the continuous change in society with the material world, such as the hydrological cycle, Callon and Latour (1981) suggested directing our attention to two kinds of processes: (1) actors creating lasting social asymmetries, like creating laws, institutions or reaching agreements based on a sanctioned discourse, and (2) actors defining methodologies to solve controversies and uncertainties, like the use of supposedly neutral science. Molle (2008b) argued that beliefs, viewpoints and ideology can influence scientific assessments. Jacobs et al. (2018) illustrate how these assessments represent different values and interests in function of the methods and tools used. Therefore, models can be used by actors as tools for enlisting, convincing and enrolling actors with diverging interests. In order to understand the outcomes of a water crisis' negotiation, the analysis might thus focus on the tools used by the actors to convince others.

3. Methodology and case study

3.1. Methodology

We performed a meta-analysis of the different perspectives on the root causes of two water crises of the Lerma-Chapala basin through an extensive literature review and in-depth interviews with two key stakeholders in the modelling process during the second crisis of Lake Chapala. We reviewed the most important articles published in the scientific literature, grey literature and governmental reports depicting the uncertainties and controversies during both crises. The meta-analysis reconstructs the way actors' narratives interpret cause-impact-response relationships through their own knowledge and economic and socio-political contexts to understand water crises. Our approach combines methods from political ecology of environmental crisis (e.g. Porto, 2012) with the sociology of science of (Callon and Latour, 1981). These methods assess how actors propose rival hypotheses to define uncertain system boundaries (contextual uncertainty) (Dunn, 2001; Walker et al., 2003), and how actors with different positions and interests tend to overlook uncertainties and influence policy-making. By mapping competing narratives, sanctioned discourses and responses, we then analyse how co-existing narratives influence the hydrosocial outcomes.

To describe the 1950s crisis of Lake Chapala, we relied on excerpts of speeches and documents by relevant stakeholders. In this way, we reconstructed the narratives that addressed uncertainties to promote or block hydraulic projects. In the 1990s crisis, we focused on eight papers and reports analysing the crisis from different viewpoints. The first five divulged at international fora the apparent success of the Mexican water authority, Conagua, in managing the Lake Chapala's crisis: Huerta (2004), Güitrón (2005), DOF (2006), Conagua (2011), Hidalgo and Peña (2009). The other three papers critically analysed the management and negotiation processes that took place during the crisis: Torres-Gonzalez and Perez-Peña (2005), Huerta et al. (2001), and Wester et al. (2009b). These sources were chosen because they analysed some of the same elements of the crisis: (1) the creation of a river basin council, (2) the negotiations that took place in the Lerma-Chapala basin council, (3) the modelling process and/or data regarding precipitation, run-off and Lake Chapala water levels, and (4) possible responses to the crisis. We analysed all these different sources to identify the spectrum of the root causes identified for the water crisis in the Lerma-Chapala basin. As different accounts elaborated different narratives on the crisis, together they demonstrate the perceived uncertainties on the dynamics of the basin's hydrosocial cycle.

The second crisis culminated in a modelling process of the Lerma-Chapala basin, led by the Mexican water authorities (Conagua & IMTA) and Guanajuato's water commission (hereafter CEA-Guanajuato), which aimed at settling the crisis' uncertainties. We analysed to what extent this was achieved. Although all authors referred to the modelling process as having been central to the decision-making for solving the Lake Chapala's crisis, only Güitrón (2005) and Huerta (2004) analysed the model in depth. However, Güitrón's analysis presents inconsistencies, as it assumes that the model gained legitimacy despite not fully convincing CEA-Guanajuato; while Huerta described how the model worked to resolve a water conflict, but did not describe the conflict within the modelling process. To fill this gap, we interviewed the main modellers that represented IMTA-Conagua and CEA-Guanajuato in the Lerma-Chapala conflict and the modelling process. Between April and August 2017, we interviewed these modellers following the semi-structured type of interviews on the technical aspects of the modelling process during the second Lerma-Chapala crisis. Thereafter, we received additional information through personal communications until May 2018.

Finally, we analysed other proposed policy responses, which were not based on hydrological models, but addressed other uncertainties left out in the modelling process.

3.2. Case study

Lake Chapala is at the receiving end of the Lerma-Chapala basin in central Mexico, and the beginning of the Santiago-Pacífico Basin that discharges in the Pacific Ocean. Covering an area of 110,000 ha and with approximately 7900 hm^3 of storage capacity, Lake Chapala is the largest and most important lake in Mexico. Due to its magnitude, the first Spanish colonizers called it the Mar Chapálico (the Chapalean Sea). Its cultural heritage is also important, because Mezcala, one of Chapala's islands, was the scenery of the last indigenous stand against the invaders; the lake is also considered a sacred place by the Wixárikas, an indigenous community.

The shallowness of the lake is its defining feature as an ecosystem, with a mean depth of only 3 m (Lind and Dávalos-Lind, 2001). The lake's inputs are the Lerma River and direct rainfall. Since the 1980s the Lake has not naturally discharged water into the Santiago River, due to a water gate at the beginning of that river that controls the level of the Lake (Lind and Dávalos-Lind, 2001; Hidalgo and Peña, 2009).

The headwaters of the Lerma-Chapala basin are located near Mexico City, which currently draws part of its water supply from the basin. The Lerma River passes through 5 States in Mexico: Mexico State, Querétaro, Michoacán, Guanajuato and Jalisco (see Fig. 1). Precipitation varies from 300 to more than 1000 mm/year, the median precipitation being 730 mm/year (Aparicio, 2001). The basin has a well-defined rainy season from June to October. Therefore, the hydrological year for water allocation starts at the beginning of the dry season on the first of November.

The Lerma-Chapala basin is second in socio-economic importance to Mexico after the Valley of Mexico basin. More than 10 million people live in the basin, roughly a tenth of Mexico's population. Although the size of the basin is 54,421 km^2, a mere 2.8% of the total Mexican territory, the basin produces 53% of the country's manufacturing exports, and its industrial output represents 11% of Mexico's GNP (Conagua, 2011). Agriculture has also played a big role in developing the basin. Irrigation area grew 500% in the last 50 years, extending the agricultural frontier to 830,000 ha, approximately 15% of all irrigation area in Mexico (DOF, 2006).

4. Meta-analysis of the two Lake Chapala crises

4.1. First crisis, 1945–1956

Immediately after the Mexican Revolution ended in 1921, the government implemented new reforms to develop the economy, end poverty and alleviate hunger. The agrarian reform changed the land ownership from *hacendados* (large landowners) to the peasants working the land. Wester (2009) described two major phases in the historical evolution of water institutions of modern Mexico. The first, from 1926 to 1946, is characterized by "the rise of the hydraulic mission", whose aim was to increase irrigation land to deliver the benefits promised by the revolution to impoverished farmers through the *Comisión Nacional de Irrigación* (CNI: National Irrigation Commission). The second, from 1946 to 1976, was "the zenith of the hydraulic mission", whose goal was to develop river basins based on the Tennessee Valley Authority model through the *Secretaría de Recursos Hidráulicos* (SRH: Ministry of Hydraulic Resources). In 1989, after the federal government adopted a neoliberal agenda (Wester, 2008), a third phase began, that of IWRM, when the *Comisión Nacional del Agua* was created (Conagua: National Water Commission). These three phases conditioned policies that would affect water management and water bodies in Mexico in different ways.

In 1950, SRH created the Lerma-Chapala basin commission consisting of only SRH engineers to discuss the basin's problems and reach agreements with the stakeholders. Hydraulic engineers argued that based on below-average rainfall between 1942 and 1955 (Fig. 2) and high evaporation rates, allocating water to lakes would be a waste. Andrés García Quintero, at the time a respected hydraulic engineer,

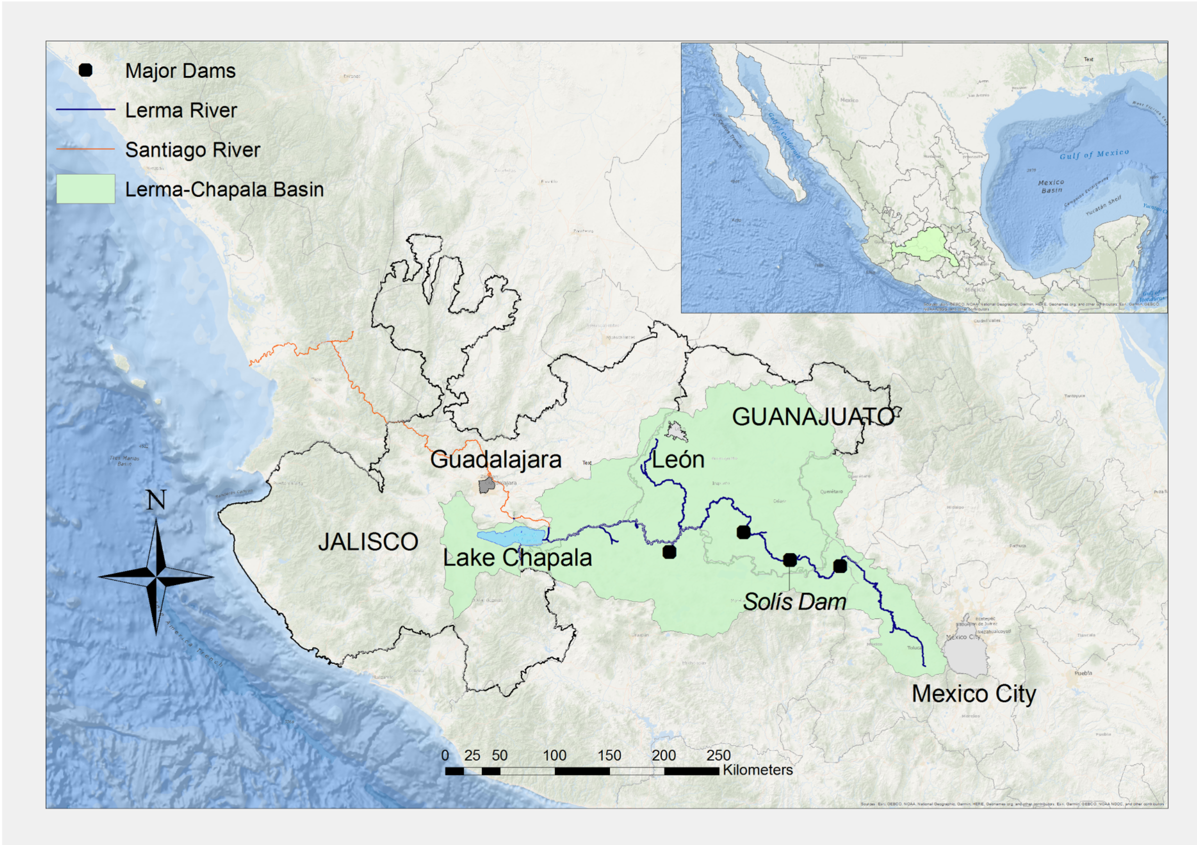

Fig. 1. Map of study area.

argued in 1947 that "[*El lago de Chapala] es un lujo dispensioso, que México no puede permitirse*" ("Lake Chapala is a lavish luxury that Mexico cannot afford") (cited in Helbig, 2003), referring to the large evaporation rate of Lake Chapala. The basin commission recommended the desiccation of Lake Cuitzeo, Lake Yuriria, and 25,000 ha of Lake Chapala, "to allocate the largest possible volume of water to irrigation" (SRH 1953, cited in Wester, 2009). Because of these recommendations, a presidential decree in 1953 allowed the reclamation of 18,000 ha of Lake Chapala.

The defence for Lake Chapala came from two groups. The first came from the economic interests of Guadalajara. A hydropower plant for the city of Guadalajara depended on 520 hm^3/year of Lake Chapala's water to operate. In 1947, when the level of the lake dropped to a point that it did not feed the Santiago River anymore, the hydropower plant could not operate at full capacity. This caused several blackouts and increased production cost for industries in the city. The second group, composed

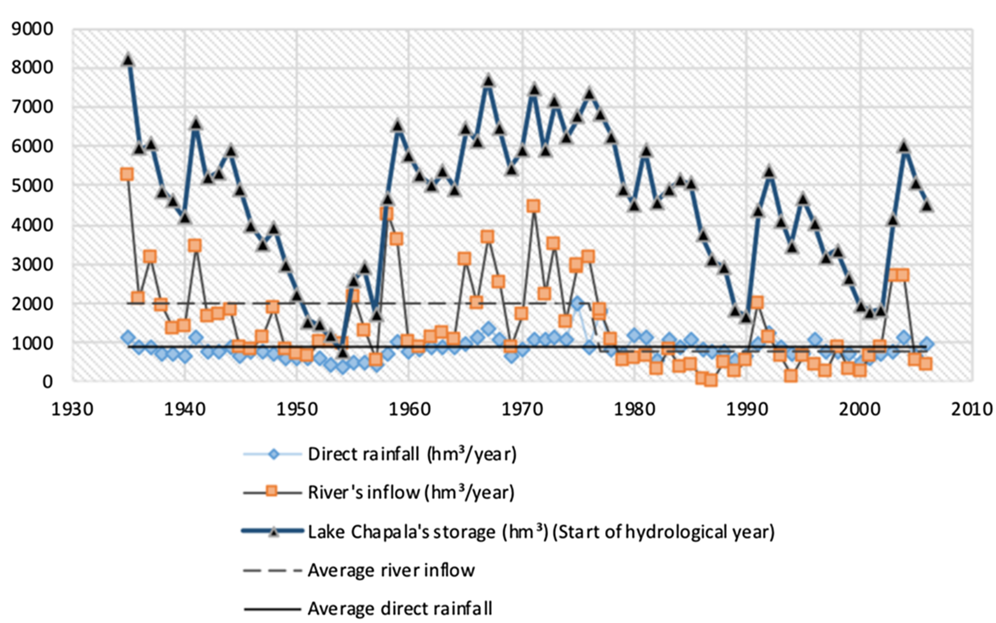

Fig. 2. Historical water dynamics of Lake Chapala (Data provided by Conagua).

Fig. 3. Reclaimed land from Lake Chapala (Burton, 2010).

of Guadalajara's intelligentsia and environmentalists, created the *Comité Pro-Defensa del Lago de Chapala* (Committee for the Defence of Lake Chapala) (Pérez-Peña, 2004). This group had two arguments: first, that evaporation was a natural process inherent to the water cycle, which was worth preserving; and second, that to reclaim 18,000 ha from the lake, additional to the 50,000 ha reclaimed in 1910 (Fig. 3), would have permanent negative effects for the lake.

By 1955, the volume of water in Lake Chapala decreased to 980 hm^3, a mere 10% of its storage capacity. This downward trend had started in 1945, when the lake still had 6354 hm^3. This generated an important controversy over the future of the lake. Proponents for the land reclamation argued that a lack of sufficient rain since 1941 contributed to the low levels of the lake (González-Chávez, 1956: 103, cited in Helbig, 2003); while environmentalists and other stakeholders from Guadalajara maintained that rain had been sufficient, if not abundant, between 1934 and 1954, and that the lake's crisis should be attributed to the basin development policies of the National Water Commission (Palencia, 1956: 41–52, cited in Helbig, 2003), who built the Tepuxtepec Dam in 1930 with a storage capacity of 370 hm^3 to irrigate 55,000 ha, and the Solís Dam in 1949 with a storage capacity of 800 hm^3 to irrigate 116,000 ha.

The environmentalist groups regarded the politicians and hydraulic engineers as "*magos de los cálculos*" (magicians of calculations) (Helbig, 2003), because of the way they juggled with numbers to justify hydraulic interventions.

Due to the avid opposition campaign from Guadalajara, the plan to desiccate 18,000 ha from Lake Chapala did not happen. Although stakeholders ardently discussed how overdevelopment upstream was causing the ecological destruction of Chapala and not the evaporation, as stated by the hydraulic engineers, the development trend continued unabated:

> "Today, the tragedy weighs in with the frigid breath of fatality over the sad fate of the once mighty Chapala […] new dams and irrigation canals being built upstream, divert and slurp more than half of its volume, to the extent of ignominiously exhausting the estuary of La Barca, where the lake used to enter. This, the scarce rainfall originated from deforestation of all the forests of the region, and the pumping stations to irrigate crops that sprouted like pockmarks in all of its shores, seemed to have combined to result in the tragic end of the consistent drama of the gentle Chapalean Sea." (Rubín, 1993, cited in Pérez-Peña and Torres-González, 2001, our translation).

At this point, a clear shift emerged from policies seeking to expand cultivable land to policies seeking to develop as much as possible the basin's water resources. Luis Ballesteros, the engineer in charge of the basin's waterworks, considered that the 1500 hm^3/year leaving Lake Chapala to flow into the Santiago River was a waste, except for the 520 hm^3/year used for hydropower. He proposed to capture the remaining 1000 hm^3 upstream before reaching the lake to develop irrigation. The government built 26 dams upstream Lake Chapala between the years 1926–1955, adding a total of 1462 hm^3. In addition, two interbasin water transfers were undertaken. In the first, 126 hm^3/year were transferred to Mexico City from the Lerma River headwaters in the early 1950s, increasing to 315 hm^3/year by the 1970s (Wester, 2009), and 788 hm^3/year in the 1990s (Escobar, 2006). The second transferred 31 hm^3/year to Guadalajara, which started building the waterworks in 1953, at the peak of the lake's crisis, and started operating in 1956. By the end of the 1950s, abundant rainfall increased the water levels of the lake, which allowed the basin commission to conclude that the basin could still be further developed and requested a loan of $150 million from the Inter-American Development Bank to build more irrigation systems (Wester et al., 2001).

4.2. Second crisis, 1989–2004

Basin development continued for agriculture and urban uses. Following the construction of 118 dams in the basin from 1960 to 1969, and 80 from 1970 to 1989 (Cotler and Gutierrez, 2005), the dam storage capacity of the basin increased 2682 hm^3 since the first crisis (Fig. 4). The Green Revolution increased groundwater development at a rate of 7% per year (Vargas-Velázquez and Mollard, 2005). In Guanajuato alone, almost 18,000 additional boreholes were constructed (Acevedo-Torres, 2004), leading to serious groundwater over-exploitation (Sandoval, 2004). Guadalajara also increased its dependency on the lake's water by building an aqueduct to deliver 283 hm^3/year in 1992.

In 1989, the central government undertook a complete overhaul of the water institutions based on neoliberal policies and IWRM principles, including 3 actions: (a) introduction of a new water bill that expanded

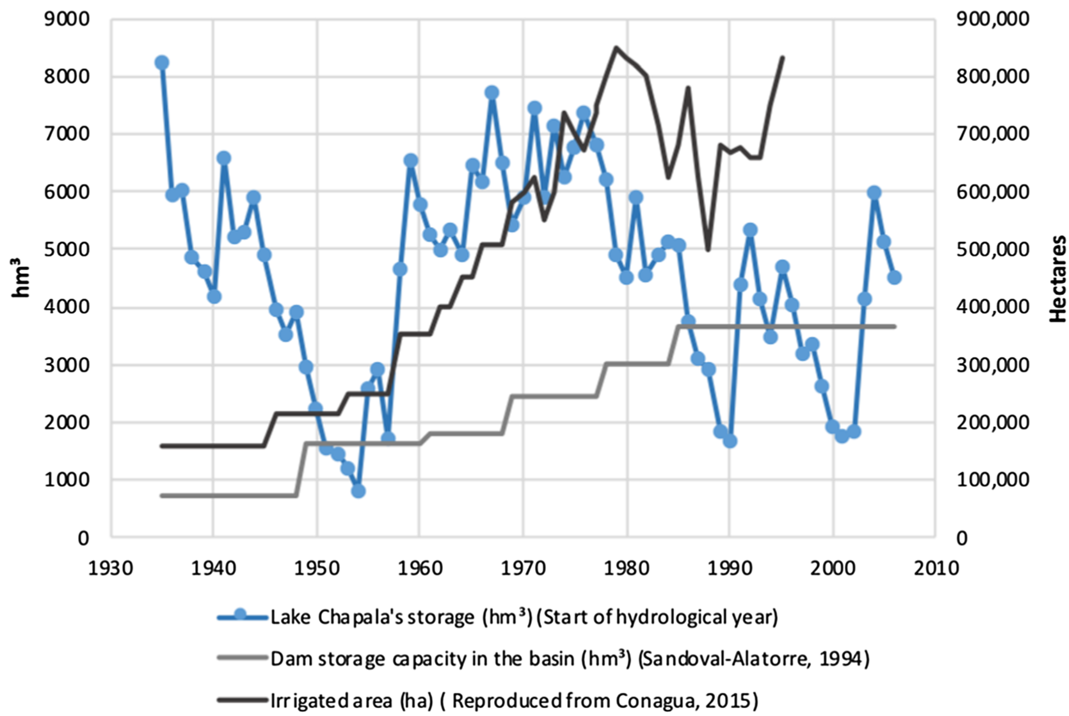

Fig. 4. Water infrastructure and irrigated land in the Lerma-Chapala basin.

the reach of the previous water rights system to tradeable water rights (Rosegrant and Schleyer, 1996), (b) implemention of the subsidiarity principle, which led to the creation of local and regional water management institutions, and transfer of irrigation districts to users (Rap and Wester, 2013), and (c) the creation of a new overarching water authority, Conagua. During the same time, Lake Chapala's levels started to drop again. Vargas-Velázquez and Mollard (2005) stated that this environmental problem was an opportunity for the State to gain legitimacy for their new set of policies. Therefore, in 1989 a new Lerma-Chapala commission, composed of the governors of all States within the basin, addressed the falling lake's levels. The commission implemented a top-down program that included a new allocation agreement to save the lake, as promised by the President of Mexico in his election campaign. The allocation agreement distributed water among users based on the level of the lake and the annual surface run-off generated in the basin every start of the hydrological year.

As part of the water reforms, a Lerma-Chapala River Basin Council (RBC) was established in 1993, the first of its kind in Mexico (Wester et al., 2001). Because the lake's levels continued to drop, the members of the RBC deemed additional actions necessary. The root causes of the lake's crisis became a topic of heated debates between stakeholders. The problem became so complex that it was difficult to identify a single culprit (Table 1).

Güitrón (2005) and Wester et al. (2009b) argued that the reasons for the failure of the water agreement were an underestimation of the lake's evaporation with at least 16% (Aparicio et al., 2006), an overestimation of runoff (based on hydrological data of the relatively wet period of 1950–1979) and irrigation efficiency, and an underestimation of the irrigated area, illegal water abstractions, over-concessions, and finally, reduced river base flow due to groundwater overexploitation. This failure led Lake Chapala to a crisis comparable to the one in the 1950s.

Despite uncertainty regarding the degree of responsibility of agriculture in Guanajuato and urban demand of Guadalajara for the crisis, Conagua (2011) stated that "In all cases, irrigation has been positioned as the main reason of all basin calamities regarding water deficiencies." Conagua commissioned a socio-economic study on inter-sectoral water productivity, and agriculture was evaluated as the most inefficient

Table 1
Dimensions of the water crisis and root causes according to several sources.[a]

Dimension	Root causes (proposed by source reference)
Water quantity	Low rainfall **(1, 2, 3, 4)**
	Expansion of irrigation infrastructure **(3, 4, 5, 6)**
	Over-concession of water rights **(1, 3, 5, 6)**
	Low water efficiency in agriculture **(1, 2, 4, 5)**
	Low water efficiency in Guadalajara and other urban centers **(1, 2, 7)**
	Groundwater overexploitation by all sectors **(1, 2)**
	Climate change **(4)**
	Illegal water abstractions **(5)**
Ecology	Forest depletion due to agriculture **(1, 2, 4, 5)**
	Economic and population growth **(1, 2, 4, 5)**
	Soil damage due to agroindustrial pollution **(1, 2, 5)**
	Biodiversity loss **(1, 2)**
	Low water quality **(2)**

[a] (1) IMTA (Güitrón, 2005), (2) Conagua (DOF, 2006), (3) Hidalgo and Peña (2009), (4) Conagua (2011), (5) Torres-Gonzalez and Perez-Peña (2005), (6) Wester et al. (2001), (7) Huerta et al. (2001).

(Goicoechea, 2005). Table 1 shows how agriculture was generally perceived as the main sector responsible of the water crisis in the basin, mainly because agriculture is the largest user. Low efficiency and the expansion of irrigation infrastructure, and over-concession of water rights were mainly considered the human-made root causes of the lake's crisis.

With this mind-set and the continued dropping of water levels, Conagua ordered in October 1999 a release of 200 hm^3 of water from irrigation dams in Guanajuato to Lake Chapala. This resulted in Alto Rio Lerma irrigation district to fallow 20,000 ha out of 77,000 ha (Wester et al., 2005). Because of the historic low rainfall in 1999, the water allocation for the year 2000 was also the lowest since the beginning of the agreement. That year, the Water User Associations of all irrigation districts in Lerma-Chapala basin decided to fallow 200,000 ha of irrigation lands (Wester et al., 2005). In 2001, Conagua enforced a new 270 hm^3 water release.

Because farmers were not compensated, they resisted the water release and threatened Conagua with civil disobedience (Wester et al., 2009b). In 2001, Guanajuato's farmers created the *Grupo de Trabajo Especializado en Planeación Agrícola Integral* (GTEPAI: Specialized Working Group on Comprehensive Agricultural Planning), which aimed at proving how the agricultural sector could be more water efficient by changing cropping patterns and be a relevant member of the RBC. This resulted in a 60 hm^3 saving (Paters, 2004, cited in Wester et al., 2009b).

CEA-Guanajuato wanted to assess the impact of water releases from dams upstream to both the lake and farmers and hired Juan Huerta[1] in 2001, a system dynamics modeller, who had previously built the ProEstado-MAUA model for Guanajuato in the mid-1990s. This was a system dynamics model that described how water resources interacted with human activity to facilitate policy decision-making for all of Guanajuato's basins. The model consisted of 2500 differential equations and 800 variables that integrated rainfall, surface and groundwater along with socio-economic variables. For the Lerma-Chapala basin, Huerta's team built a new model of the whole basin dubbed "Cuenca Lerma", which was based on the same foundations of ProEstado-MAUA. With the model, alternative scenarios were run, which made the modellers conclude that water transfers from agriculture to Lake Chapala would cause a 17% increase in agricultural unemployment, a 39% of reduction in crop value, a 19% increase in unemployment in other sectors, and a 6% overall economic loss; only to improve Lake Chapala's storage by 9% (Huerta et al., 2001). They also concluded that "a more obvious cause for the lake's drying up is the near explosive growth of Guadalajara, […] The national water authorities adamantly refuse to accept this fact as the main source of trouble for the lake."

The mounting pressure came from two sides, the social and political pressure in Jalisco because of the drying Lake Chapala, and the agricultural lobby in Guanajuato because of the economic losses caused by the water releases. Therefore, in March 2002, Jalisco's representatives proposed a new allocation agreement to be worked out in the *Grupo de Ordenamiento y Distribución* of the RBC (GOD: Planning and Distribution Group) (Güitrón, 2005).

In 2002, Conagua engaged IMTA, the technical branch of Conagua, to build a rival model of the Lerma-Chapala basin. Previously, during the early 1990s, Conagua had hired Huerta to introduce system dynamics modelling in water management to IMTA's engineers. However, most of the engineers trained by Huerta were absent during the 2000s conflict. Huerta evaluated IMTA's staff as being composed of 'managerial engineers' with little understanding of dynamic models, as opposed to 'analytical engineers' as himself, who are trained in systems thinking (Huerta, 2004). Also, CEA-Guanajuato perceived this absence of technical capabilities as a handicap for the negotiation process. Therefore, technical training was offered to Conagua's, Jalisco's and Guanajuato's representatives, but not to other civil society's stakeholders (Güitrón, 2005).

Because Lake Chapala was still in crisis while the models were being developed, by the end of 2002 Conagua was pressured to undertake a new water release of 280 hm^3 from the Solis Dam in the summer of 2003. Farmers deeply resented this action, and disbanded the GTEPAI group. By the end of 2003, Conagua again ordered to release 205 hm^3 from the Solís Dam, out of which only 173 hm^3 reached Lake Chapala because a court order signalled the illegality of this action, precluding the remaining 32 hm^3 to be released (Wester et al., 2009b).

According to Güitrón (2005), all engineers involved in the conflict criticized each other's "simple models" and pointlessly made their own model more complex. IMTA's engineers rejected the hybrid nature of the "Cuenca Lerma" model, regarding the integration of its socio-economic and hydrological variables. Still, IMTA intended to use CEA-Guanajuato's rainfall-runoff algorithms, but Huerta blocked this move based on copyright violations, compelling IMTA to develop its own. IMTA's model, referred as IMTA's Lerma model, consisted of hydrological variables to calculate run-off in all 17 sub-basins of the Lerma-Chapala: precipitation, evapotranspiration and soil humidity based on the USDA's Soil Conservation Service (López-Pérez et al., 2014); it also included the interaction with 7 main reservoirs, Lakes Yuriria and Chapala; and, the water demand of 8 irrigation districts, 7 small irrigation units, and industrial and urban uses. With 52 years of historic rainfall data as input, the model was used to test different allocation policies proposed by Jalisco and Guanajuato, such as the water requirements to have a full lake at 8000 hm^3, and the possibility to stabilize the lake with only the upstream surplus from agriculture (Güitrón, 2005).

CEA-Guanajuato's representatives suggested improvements to IMTA's rainfall-runoff model, but they were dismissed arguing that each improvement could take from 6 to 12 months to be included in the model (Güitrón, 2005), a situation that IMTA's group interpreted as an attempt to gain time for Guanajuato's farmers. This interpretation prevailed despite evidence that some results from IMTA's model were not able to replicate the behaviour of the Solís Dam (Personal communication with the modeller, May 9, 2018).

After calibrating the model, IMTA's Lerma model showed that sporadic water releases from agricultural dams to Lake Chapala were not a definitive solution to stabilize its levels (Huerta, 2004). This, and the legal instrument undertaken by farmers, proved to be a successful strategy against future discretionary water releases to Lake Chapala. However, IMTA justified past water releases, arguing that without them the levels of the lake would have dropped to 746 hm^3, lower than during the first crisis (Dau-Flores and Aparicio, 2006, cited in Wester et al., 2009b).

When IMTA decided that its model was consistent, they developed a linear optimisation model using genetic algorithms, dubbed SIMOP (Güitrón, 2005). SIMOP's objective function maximized the water volume extracted from the nine largest reservoirs in Guanajuato, while penalizing extraction deficits (Consejo de Cuenca Lerma-Chapala, 2005). IMTA's motivation for introducing a penalty function was that if there were no deficits, the stakeholders would not contest the optimisation results (Huerta, 2007).

CEA-Guanajuato criticized IMTA's model for not considering seven major inconsistencies and uncertainties: (1) the high variability of agricultural water demand; (2) monthly time-steps; (3) surface and groundwater interaction; (4) not considering Lake Chapala as a water user; (5) Conagua assumed that current water demand equalled the volume of water rights, hence disregarding illegal overdraft; (6) information on agricultural land, especially in Irrigation Units was dispersed, incomplete (Silva-Ochoa and Vargas, 2005), and contradictory (Winckell and Le Page, 2004); and finally, (7) the model was not tested with an urban water demand management policy; IMTA only tested how demand management of Irrigation Districts could stabilize Lake Chapala (Huerta, 2004).

CEA-Guanajuato considered the first uncertainty very important because water demand for irrigation cannot be calculated *a priori*. Water demand for crops is determined by soil humidity, which varies according to rainfall. With favourable rainfall, farmers could use less water than what was allocated, but Conagua would refuse to count that unused water for next year's water allocation. The farmer would then proceed to sell water or overuse it, instead of saving it or letting it flow to Lake Chapala. Despite this deficiency, IMTA's *a priori* water allocation was preserved until the end, when the agreement became federal law (DOF, 2014).

The second issue, the monthly timestep, introduced new uncertainties as the optimisation model could overlook periods of extreme rainfall and dry spells, which influence actual irrigation demands. Next, the groundwater model was never fully developed due to lack of data and knowledge (source: IMTA's interviewee). However, this third issue introduces a very important uncertainty in the model, since aquifers are

[1] Huerta studied electrical engineering in Mexico, and did his PhD on systems and control engineering in the University of Cleveland in USA, with a thesis related to the Stanford Watershed Model.

Table 2
Water use (hm^3/year), according to the literature.

Source	Agriculture	Urban	Out-of-basin transfer	Industry	Net lake evaporation	Other	Total water use
(1) Wester et al. (2001)	6584	791	560	278	2270	154	10,637
(2) Hidalgo and Peña (2009)	9859	1138	–	382	–	277	11,656
(3) Official (DOF, 2006)	7484	1598	518	295	1497	342	11,734
(4) Güitrón (2005)	7882		237	273	1700	0	10,092

known to be over-exploited in the basin, while their contribution to Lake Chapala is not precisely known.

The fourth and fifth uncertainties are related. Since Lake Chapala was never considered a user, but only the end recipient of the basin, there could not be any accountability on the water used by Guadalajara. Guzmán (2003), the director of the department of Limnology of the University of Guadalajara, claimed that Guadalajara was drawing 450 hm^3/year, instead of the 240 hm^3 for which it had a right. Durán-Juárez and Torres-Rodríguez (2001) also suggested that Guadalajara may have taken extra water from the Atequiza canal. Moreover, some farmers were also known for illegally over-extracting surface and groundwater.

The sixth uncertainty was central for agriculture and the calibration of the model. A new agreement based on reducing agricultural water use would also have different effects for the distinct economic strata of farmers (Torres-Gonzalez and Perez-Peña, 2005; Flores-Elizondo, 2013). The model had serious gaps of input information regarding small irrigation, which accounted for approximately 30% of water demand (Conagua, 2015), which were not addressed (Güitrón, 2005). Tables 2 and 3 show this disparity in the figures as well as in the water balance, which remained sparse and contradictory.

The last uncertainty is the role of urban water demand management to stabilize Lake Chapala. SIMOP used agricultural control variables from Guanajuato to stabilize the lake. But, because urban water supply is set as a priority in the Mexican water law, the model never simulated urban control variables, such as improved efficiency, reduction of water use per capita or demand management in Guadalajara.

CEA-Guanajuato proposed to redo the model with a different philosophy, based on tracking irrigation areas to control water demand, and balance demand with available water. This required a dynamic algorithm based on real-time agricultural water demand (based on the phenological water requirements of crop growth and size of irrigation areas) in daily time-steps, and to consider Lake Chapala as a user. This implied a daily water allocation to agriculture and a closer look to groundwater use. However, this was again dismissed by Conagua, arguing lack of time and resources. An expert from IMTA commented that "the goal of CEA-Guanajuato's proposal was to delay the negotiation as much as possible; without them the agreement would have been reached two years before." At this point, Conagua threatened that if no consensus was reached, they would impose new water allocation rules (Flores Elizondo, 2013).

A new allocation agreement was signed based on the Política Óptima Conjunta (POC: Optimal Allocation Policy), which reduced agricultural allocation as a function of Lake Chapala's water levels (critical, intermediate, and abundant) and the previous year's accumulated basin run-off (see Fig. 5). This would affect all major agricultural dams in the basin. CEA-Guanajuato accepted the new

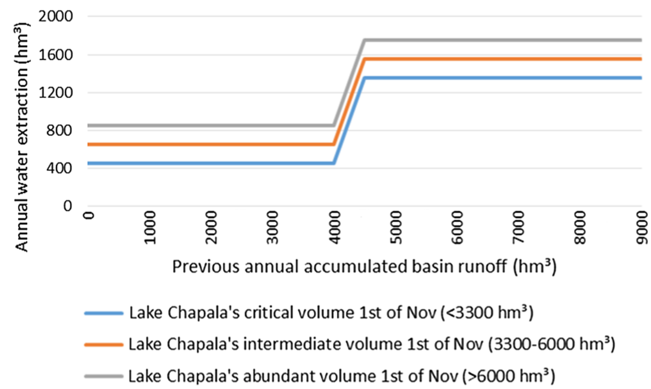

Fig. 5. The new allocation rules for agricultural dams in Guanajuato (Conagua, 2015).

allocation regime only after high level negotiations between Vicente Fox, the then President of Mexico, and the governors of Jalisco and Guanajuato. They agreed to include the building of two dams in the Verde River Basin in Jalisco for urban supply augmentation for Guadalajara, Jalisco, and León, Guanajuato (Wester et al., 2009b). This *quid pro quo* was so important that the IMTA expert concluded that "CEA-Guanajuato would have never signed the agreement without the water transfer from the Verde River."

Currently, the supply augmentation dam for Guadalajara has been put on hold indefinitely due to financial and structural constraints, while the construction of the supply-augmentation dam for León has been halted for the past 12 years, due to social and legal conflicts (Ochoa-García, 2015; Ochoa-García et al., 2015).

4.3. Alternative responses

This section analyses alternative responses that were presented by various stakeholders, but dismissed by Conagua. A first set of proposals focused on the agricultural sector, the largest consumer of water in the basin. A second set addressed urban centers.

In the first group, Scott et al. (2001) proposed compensation mechanisms for affected farmers due to water releases to Lake Chapala. This proposal was later supported by information provided by Vargas-Velázquez (2008), who surveyed urban homes in the basin, 60% of whom were willing to pay for the lake's recovery. Farmers were also surveyed, and 39.9% of farmers supported the idea of saving the Lerma River, and 26.8% to save Lake Chapala. But, in the absence of compensations, farmers considered their livelihood more important; as a farmer from Guanajuato described: "As a Mexican I care [about Lake Chapala], it is part of a landscape that affects me. International opinion

Table 3
Water balance (hm^3/year), according to the literature.

Source	Renewable water	Total water use	Water balance	Water use as % of renewable water
(1) Wester et al. (2001)	9737	10,637	−900	109%
(2) Hidalgo and Peña (2009)	9529	11,656	−2127	122%
(3) Official (DOF, 2006)	8893	11,734	−2841	132%
(4) Güitrón (2005)	8750	10,092	−1342	115%

also affects me, many will say: 'they let it desiccate!' It will affect us. But as a farmer […] my crops and family come before Jalisco's" (excerpt from an interview in Muñíz-San Martin and Torres-González, 2012). Instead, Conagua (2011) argued that the industrialization of the basin was an alternative to agriculture, because industry in the basin generates 11% of Mexico's GNP, four times the output from agriculture, while using only 3.9% of water, instead of the 82% used by agriculture.

Conagua also proposed to financially support modernization of irrigation to enhance water savings, a promise that remains to be realized (Conagua, 2015). Huerta et al. (2001) suggested that if irrigation districts improved their water use efficiency from an estimated 36% to at least 55%, then the problems of surface water deficit and the Lake Chapala's decreasing levels would be solved. However, Scott and Garces-Restrepo (2000) argued that an increment in water use efficiency could lead to lower aquifer recharge, therefore worsening the existing aquifer crisis. Besides, it is likely that a large portion of the estimated 500 hm^3 annual gains in efficiency calculated by Huerta et al. (2001), would be used by downstream users, if not by the now more efficient users themselves, as Mollard et al. (2005) argued in the case of the Lerma-Chapala basin, as well as other authors have suggested around the world (van Halsema and Vincent, 2012; Berbel et al., 2014; Grafton et al., 2018). Mollard et al. (2005) suggested that more water savings can be made by better organizing those irrigation districts where internal norms of water allocation are not abided. They argued: "the primary goal [of the water users] is to have security in their annual water supply, and for that, they are insatiable. Every water saving should serve their interests first." This means that modernizing irrigation cannot guarantee water savings without new institutional arrangements to restructure the water rights system in accordance to the necessities of the sector, as Torres-González and Pérez-Peña (2009) proposed.

The need for new institutional arrangements between users and water authorities is more evident in groundwater management. Sandoval (2004) and Wester et al. (2011) proposed that all groundwater should be managed by users' associations, with autonomy and legal and enforcement competencies to grant or withdraw water rights to balance the aquifers.

CEA-Guanajuato has been working since 1997 on a bottom-up approach to raise awareness and organize more than 100,000 groundwater users (Silva-Ochoa and Vargas, 2005; Wester et al., 2011). The institution of the *Consejo Técnico de Aguas Subterraneas* (COTAS: Technical Committee of Groundwater) was promoted by CEA-Guanajuato and consisted of a group of groundwater users, with the goal of self-regulating water use to stabilize the water table of their aquifer. This marked a paradigm shift according to Sandoval (2004: 12), the director of CEA-Guanajuato at the time: "[Conagua's is a] centralized, rational approach, according to which water problems are relatively stable, isolatable and manageable from a purely scientific and technical approach". Instead, the COTAS approach was based on "models, which work upon the basis of best science and technology available, thus making progress through achievement of social agreements by means of maintaining ongoing communication with the subjects of the initiatives." Although COTAS has organised many users in curbing groundwater over-exploitation, it has not been able to decrease groundwater over-exploitation due to lack of participation of all groundwater users and legal support from Conagua (Wester et al., 2009a).

Conagua, with a top-down approach, has also been unable to balance the aquifers through law enforcement, while economic measures like higher energy prices have been ineffective (Hoogesteger and Wester, 2017). Users' self-regulation through COTAS could be an appropriate solution since buying back water rights from farmers is financially unfeasible (Wester et al., 2011).

Market-based alternatives were proposed by Bravo-Pérez et al. (2005, 2006, 2013) and Guzmán-Soria et al. (2009), who conceived the Lake Chapala water crisis in terms of market failure. They proposed an agricultural water tax to increase the levels of Lake Chapala, and water banks to promote efficiency.[2]

Other authors have argued that a more comprehensive and coherent set of actions is needed to address the ecological dimension of the water crisis. The actions range from reforestation, to groundwater demand management, and a river basin approach, to be implemented simultaneously (SEMARNAT, 2001; Cotler and Priego, 2004; Cotler et al., 2004; Priego et al., 2004). Although water authorities have implemented some of these actions, their budgets were limited and actions were implemented in a haphazard manner.

Urban centers have also been targeted by proposals requesting demand management (von Bertrab, 2003; von Bertrab and Wester, 2005), with non-revenue water reaching 35% in Guadalajara and 49% in León (DOF, 2006). Although there could be significant gains in reducing non-revenue water and excessive water use per capita, the only response so far to urban water scarcity in Jalisco has historically been supply augmentation (Berrones, 1987). Jalisco's Water Commission defended supply augmentation solutions to avoid the social-economic costs of fixing the leaks of the city's distribution network, a process that has not been done in some cases for over 80 years (Gómez-Jauregui-Abdo, 2015). However, there seems to be a gap of perception between Jalisco's water authorities and urban water users regarding urban demand management, because 90% of surveyed households were open to decrease their consumption for the benefit of the water systems in the basin (Vargas-Velázquez, 2008).

5. Discussion

After we examined how competing actors in different contexts interpret the root causes of water crises to provide policy responses, we analyse two processes in detail: (1) the use of water crises and uncertainties to define sanctioned discourses that outline what the relationship with water and society should be; and (2) IWRM and the role of politics in science and decision-making.

5.1. Uncertainties and discourses

We have analysed that when society is confronted by a water-related crisis, micro-actors propose new values and solutions that challenge macro-actors' policies. This insight supports Bouleau (2014), who argued that challenging circumstances open the debate in water management of what the waterscape should be. Fig. 6 presents how the two Lake Chapala's water crises allowed micro-actors to challenge the policies of the water authorities.

During Lake Chapala's first recorded crisis the water authorities defined the system and the problem in hydraulic terms: moving water from one point to the users, while avoiding losses in the system. Lake Chapala's evaporation was seen as a wasteful outflow, one that the nation could not afford. The environmentalist group, however, defined the system as hydrological, claiming that evaporation was a natural physical process, and that the real culprit of the lake's crisis was the intense use of water upstream in Guanajuato. These two water knowledges collided in the public arena to support or reject a project for reclaiming part of the lake's area. The environmentalists were micro-actors who mobilized several concerned public figures from the cultural field to reject the reclamation project. The State, a macro-actor by definition, did not manage to convince Jalisco's public that this was the most appropriate decision, and the project was cancelled. The lake's crisis allowed environmentalists to contend with the 'hydraulic mission'

[2] Since 2009, water banks can reallocate water from users who are not fully using all the water entitled in their rights to users who need water. That would avoid the need to grant more water rights and still make water more productive, but Reis (2014) claimed that in practice institutional corruption has increased overall water use in the aquifer by doubling water rights.

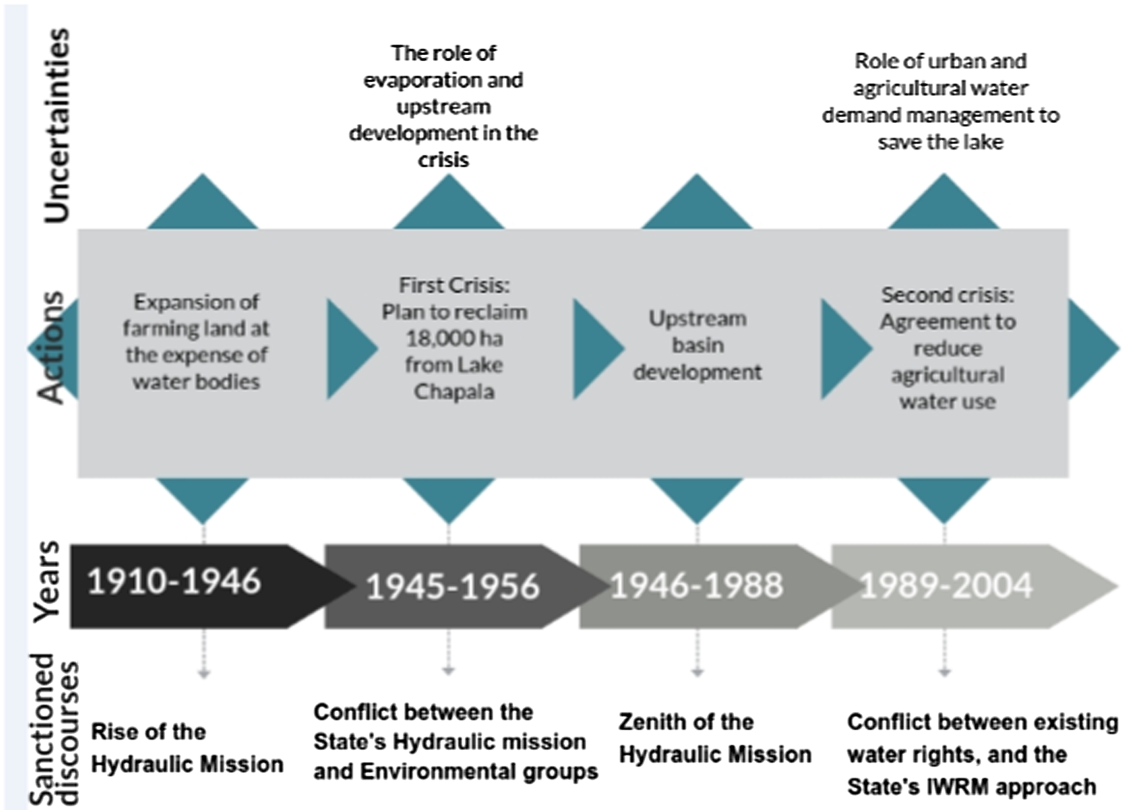

Fig. 6. Timeline of the dynamic relationship between uncertainties, events and sanctioned discourses in the Lerma-Chapala basin.

sanctioned discourse, and successfully introduced an ecosystemic interpretation of a physical process.

The second crisis of Lake Chapala would increase in complexity, as the problem transited from the dual confrontation of society-government to multiple actors (Escobar, 2006). Conagua, as the new water authority, replaced the 'hydraulic mission' discourse to IWRM. This discourse was aligned with that of the World Bank (Molle, 2008a), which perceived agriculture as inefficient and wasteful. Jalisco kept its environmental discourse, while Guanajuato was still profiting from the 'hydraulic mission' infrastructural legacy by referring to itself as 'Mexico's breadbasket'.

The two main actors in the conflict, CEA-Guanajuato and IMTA-Conagua, used different approaches of hydrological modelling to resolve contextual uncertainty, each defining system boundaries to find out what the root causes of the problem were. CEA-Guanajuato modelled the social and natural systems as a coupled system to assess the interrelationship between water and the economy. IMTA modelled the system as a surface water balance with a stock of water at the end of the basin, Lake Chapala. These two different approaches concluded with opposite root causes of the crisis and opposite solutions.

Since Conagua (2011) identified agriculture as the main culprit of the crisis, no compensation to farmers was considered in the new reallocation agreement. Molle and Berkoff (2006) argued that authorities are reluctant to discuss compensation because it would "expose the hidden consequences of reallocation", undermining their own legitimacy, and faith in their capacity to solve the problem. Such consequences would generally mean farmers: (1) going out of business, (2) using wastewater, (3) over-exploiting groundwater, and/or (4) improving irrigation efficiency (Molle and Berkoff, 2006). Some publications warned about farmers going out of business, especially poor farmers who solely relied on surface water (Torres-Gonzalez and Perez-Peña, 2005; Wester, 2008: 214; Flores-Elizondo, 2013), and for whom improving irrigation efficiency is not a feasible option (Vargas-Velázquez, 2010). Instead, wastewater use for irrigation was gradually generalized (Vargas-Velázquez, 2010). And finally, unsustainable groundwater use has proliferated and remained unabated until today in Guanajuato (Hoogesteger and Wester, 2017).

When the sanctioned discourse changed from the 'hydraulic mission' to IWRM, agriculture lost its central position in the water authorities' policies. During the first crisis, agriculture needed to be protected and even increased. This position changed during the second crisis when the sector was perceived as inefficient. Jalisco and Conagua formed a steady alliance by building a discourse with elements of IWRM and environmental protection. Such discourse was solid enough to force the water allocation agreement in the basin despite the uncertainties and hidden consequences to agriculture and groundwater.

5.2. IWRM and the role of politics in science and decision-making

Some authors have argued that normative recipes like IWRM do not work in the real world (Biswas, 2008; Ingram, 2008), because the approach can prove to be too restrictive, at least in terms of avoiding infrastructure development (Woodhouse and Muller, 2017). Therefore, the solution of the Lerma-Chapala conflict was celebrated as a non-normative approach to IWRM (Lenton and Muller, 2009).

Still, IWRM principles like public participation, management at the river basin scale and sound knowledge were said to have been exercised during the conflict (Güitrón, 2005; Hidalgo and Peña, 2009). These authors suggested that the water allocation agreement of the Lerma-Chapala basin was the result of IMTA's scientific assessment of the basin's water resources and of the stakeholder participation in the process. Güitrón (2005) argued that IMTA's model gained legitimacy and trust through the participation of the stakeholders, and because it could reproduce the lake's behaviour.

Although participation is supposed to be a central tenet to water governance in Mexico, its weaknesses are widely recognized in practice

(Mollard et al., 2010; Wilder, 2010; Herrera, 2017). These authors suggested that a combination of weak institutions, politicisation and elite capture is the largest risk of the participation process.

The Lerma-Chapala case was allegedly different, because of how the modelling process influenced the conflict. Ananda and Proctor (2013) argued that modelling can be a tool to fill information gaps for decision-making and collaborative planning, and GWP (2000) argued that modelling could help depoliticize conflicts. However, too much trust in models may not be justified, as Savenije (2009) argued that although a model can mimic reality, is not the same as reality and cannot predict the future. Sanz et al. (2018) argued that since policies informed by models generate winners and losers, they can be used to promote legitimacy to top-down decisions and acceptance among stakeholders. Since scientific assessments can have so many repercussions in reality, Molle (2008b) argued that they can be influenced by different political and economic interests.

The modelling process in the Lerma-Chapala case lacked legitimacy, since CEA-Guanajuato remained reluctant to accept what they perceived as a flawed modelling solution that would protect Guadalajara's interests and harm its own. IMTA's basin approach left out any policy alternative involving Guadalajara's water use, despite its important role as an out-of-basin user. Although Conagua commissioned a socio-economic assessment of water reallocation (Goicoechea, 2005), their results only concluded the low profitability of agriculture, which contributed to the policy of reducing agricultural water use. This study did not evaluate any socio-economic consequences for agriculture, institutionalizing asymmetrical consequences to farmers.

The water allocation agreement that followed was a solution to solve Lake Chapala's crisis, but only a partial solution to the overall socio-hydrological problem. IMTA's model did not address groundwater overexploitation and negative socio-economic consequences to farmers. This is because a purely physical model of the system would necessarily omit socio-political and economic considerations, as Budds (2009) concluded in the case of Chile. Conagua did not consider alternatives like compensating farmers nor supporting bottom-up institutions like groundwater users' association (COTAS) to regulate groundwater overexploitation.

This apparent IWRM success story seemed to have become an instrument to mask a business-as-usual political agenda based on infrastructure development, like Giordano and Shah (2014) suggested for other cases around the world. The water allocation agreement was achieved by the pressure exerted by the Governor of Guanajuato's political party (Flores-Elizondo, 2013), and the promise of an inter-basin water transfer. This infrastructural scheme would only transfer the conflict to the new donor basin (Ochoa-García, 2015). This was an exercise of power framed as IWRM, and modelling was just the continuation of politics by other means.

6. Conclusion

This research analysed whether and how implementation of IWRM principles solved a multi-dimensional water crisis in the Lerma-Chapala basin in Mexico. Although some scholars and policy makers have argued that indeed Conagua successfully implemented IWRM to reach a water allocation agreement that solved the social conflict and saved Lake Chapala, we claim that the agreement merely postponed a real and sustainable solution to the water scarcity problem and conflict in the basin. We have come to this conclusion by analysing the decision-making and modelling process in the conflict with the lens of political ecology and sociology of science.

Actors with decision-making capacity conditioned the agreement through the promise of two supply augmentation schemes: the Zapotillo Dam and inter-basin water transfers to Guadalajara and León. Furthermore, the agreement addressed only surface water for agriculture, and did not seriously consider other alternatives, such as urban demand management. Local IWRM institutions, like COTAS, were also not supported by Conagua as a plausible response to groundwater overexploitation. This means that although Conagua's discourse encouraged public participation and used technical knowledge to find responses to the crisis, the alternatives were already restricted by politics and deals behind closed doors. This goes against principles of transparency and real public participation lying at the core of IWRM (van der Zaag, 2005).

We also researched how actors' perceptions had direct consequences for the hydrological models and the agreements based on them. We analysed this through the modelling artifacts that actors produced. We found that participatory processes can improve the quality of water distribution models, but due to large uncertainties some modelling decisions cannot be resolved through scientific debate only. This can result in an impasse, which can be exploited by political actors to impose top-down solutions. This negatively influences creative solutions by limiting policy responses to pre-defined alternatives.

Our findings call for improved scientific transparency, and social scrutiny and evaluation of the water knowledge generated to avoid an inequitable distribution of impacts on certain actors. Further research is needed to find mechanisms to meaningfully involve and inform actors in the design, understanding, implementation and assessment of hydrological and optimisation models for decision-making.

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Declarations of interest

None.

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