Mental Models, Meta-Narratives, and Solution Pathways Associated With Socio-Hydrological Risk and Response in Mexico City

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Cities are far more than the people who reside within them, the activities that drive urban dynamism, and hard and soft infrastructure that create urban structure and form. Cities are also composed of stories–narratives–that emerge from the experiences, ideas, knowledge and agendas of urban residents, administrators, and individuals with stakes in the city's future. These narratives collectively not only reflect how the material landscape is perceived and socially and culturally appropriated, but also, by motivating and rationalizing human actions, contribute to shaping that material world, including the behavior and attitudes of humans within it. Here, we explore the narratives and associated solution pathways that have emerged and consolidated around the issue of water scarcity and flooding in the megalopolis of Mexico City. Effective and sustainable management of water resources has long been considered essential to the city's future, yet many scholars consider the city "stuck" in path-dependent development trajectories that seems unable to address pervasive social inequity, infrastructure fragility, and the city's precarious supplies. Through mental model data elicited from qualitative interviews and workshops with a cross section of urban stakeholders, we identify dominant narratives that articulate distinct causal premises and consequences associated with water related risk in the city. We juxtapose these narratives with the current and proposed solution pathways proposed by the interviewees. Our analysis demonstrates how, on the one hand, dominant narratives may quell innovation, and on the other, narratives collectively can foster the seeds of urban sustainability transformation.

Keywords: mental models, cognitive mapping, flood risk, water scarcity, urban resilience, governance

INTRODUCTION

Cities can be thought of as systems. They incorporate the soft and hard infrastructure that creates urban form. They contain a diversity of actors, and enable activities that take place in and around urban boundaries. Cities also consist of the immaterial and material flows of ideas, capital, and information that bind people to place; together these flows contribute to the dynamic identities that cities claim as their own (Pickett et al., 2003; Boone et al., 2014; Childers et al., 2015). Like

other places of significance for human activity and well-being, cities are also places in which, and about which, people create narratives. Narratives are socially and ecologically situated stories or explanations about one's lived experience. Narratives refer to a sequential ordering of events that serve to communicate and share experience as well as to confirm identities–e.g., stories of cause and effect, and significance, stories about ourselves in a certain situation and about others (Elliot, 2005; Moezzi et al., 2017). Collectively, these narratives not only reflect how the material landscape is perceived and appropriated but also, by motivating and rationalizing human actions, contribute to shaping that material world, including humans in it (Manuel-Navarrete, 2015).

Sustainability scholars have argued such dominant narratives correspond to specific management strategies that can close off potential innovations and alternative solutions, potentially leading to unsustainable trajectories (Smith et al., 2005; Leach et al., 2010; O'Brien and Sygna, 2013; Fünfschilling and Truffer, 2014). The diversity of narratives that exist about any particular urban issue reveal "how geography, history, and politics have shaped the built environment, patterns of supply and demand, and the impacts of change on relatively vulnerable citizens…" (Darby, 2017, p. 120). However, the dynamics of power and influence among actors and institutional processes in cities can result in one or two narratives dominating the political discourse in a particular problem domain. These dominant narratives then become embedded as an institutional paradigm or "collective idea" regarding "the problem." Thus, the dominant narratives define what actions are considered legitimate for addressing that problem (Hall, 1993; Legro, 2000; Schmidt, 2010; Shanahan et al., 2017). While individuals, businesses, and political leadership come and go, many of the narratives and the ideas that they represent persist in the population (Legro, 2000). Individuals act in relation to their investment in specific narratives: they vote for representatives who resonate with or champion the narratives to which they relate. Individuals act to preserve their interests in relation to threats and opportunities embedded in such narratives, and in this way reinforce them (Ostrom and Janssen, 2002).

In this paper, we begin with the premise that understanding the dominant narratives about particular urban processes and outcomes should precede and accompany any effort to address persistent urban challenges. We argue that any effort to mobilize more sustainable trajectories of development should first account for the diversity of narratives within the city, which narratives are dominant and how they are shaping or blocking potential solutions to specific urban challenges, and how these narratives relate to subordinate narratives articulating different problem definitions and solution options.

In our case, we focus on the problem of water-related risk in Mexico City: flooding and water scarcity. These problems have existed since the city was founded in the fourteenth century (Tellman et al., 2018). Through the aggregation of individual and group narratives concerning the problem of water in the city, elicited through mental-model interviews and participatory workshops, we define a suite of "meta-narratives": collective associations of terms, represented as cognitive maps,

that together create distinct stories about water with specific meanings concerning causal factors, associated problems, actors, and outcomes. We evaluate how urban actors residing in, or responsible for, specific areas of the city are differently associated with these meta-narratives, and explore how these differences may be contributing to unsustainable trajectories of water resource management in the city.

CONCEPTUAL FRAMING AND CASE STUDY

Narratives are hypothesized to be essential properties of what it means to be human (Elliot, 2005). Individuals and groups construct narratives to assimilate phenomena in their surroundings and their lived experience into mental schema and existing cognitive structures (Pokinghorne, 2013; Brown, 2017). Narratives correlate with mental models. Mental models are the cognitive structures that reflect how an individual perceives the environment. For example, an individual may have a mental model that associates forested area with greater rainfall; such a model supports a narrative that planting trees will bring rain, ultimately alleviating drought. The narrative may also incorporate the corollary that drought has been caused by deforestation. Such narratives are not only informed by one's individual, direct experience, but also by the experiences of neighbors, family and friends, social and cultural networks and belief systems, information read and heard, the particular history of the interaction between the group to which a person belongs and the environment, as well as a diversity of other influences (Jones et al., 2014; Shanahan et al., 2017).

Sustainability research has recently turned to knowledge on mental models to help evaluate why and how social and behavioral change does or does not occur, and thus how decision-making and management can be improved to address sustainability concerns (Biggs et al., 2011; Gray et al., 2014; Jones et al., 2014; Levy et al., 2018). Cognitive mapping analysis can help reveal, for example, the degree to which an individual's cognitive understanding (e.g., the content of their internal mental models) of social-environmental system interactions differs from an objective reality of such dynamics (Gray et al., 2018). Differences between "lay" mental models of a particular risk and "expert" mental models, as expressed in cognitive mapping exercises, can illustrate deficiencies in risk communication, and points for intervention (Morgan et al., 2002). Cognitive mapping is also being used in participatory natural resource management, as a means of understanding the baseline perspectives of individuals and groups entering into management negotiations, and to identify existing or potential sources of conflict (Biggs et al., 2011; Gray et al., 2014; Voinov et al., 2018).

In the case of water management and Mexico City, we argue that mental model analysis is critical for another reason. Mental models of individuals inform, and are informed by, the narratives of social groups as they act in a particular environment (Legro, 2000). Individuals draw on these narratives to understand and explain what happens in the world and their interactions with it and with others. The dynamic relationship

of mental models and emergent, shared narratives, which we will refer to as "meta-narratives," about a problem domain legitimize and justify particular individual and collective action, and, when informing processes of governance, can be codified in institutions (Spoor et al., 2004; Pahl-Wostl et al., 2010). It is through the translation of cognitive models to meta-narratives and then into to action and policy, that meta-narratives, as intangible constructs, become materialized as part of the physical world (Eakin et al., 2017). In the context of urban areas, meta-narratives thus become embedded in urban infrastructure: they inform what decisions are made, when and where, and thus how the city expands, what is built, for whom and why (Eakin et al., 2017; Tellman et al., 2018).

Mental models are difficult to ascertain. Verbal narratives about specific real-world phenomena can be elicited in open-ended cognitive-model interviews (Carley and Palmquist, 1992; Cone and Winters, 2011) and this qualitative data can then be coded for more quantitative and comparative analysis (Jones et al., 2014). Alternatively, given that mental models are essentially *relational* (composed of related concepts and ideas), individuals and even social groups can directly create cognitive maps of constructs and their relationships (Carley and Palmquist, 1992; Kearney and Kaplan, 1997; Gray et al., 2014). These cognitive maps are then analyzed through methods such as network analysis and graph theory applications (Gray et al., 2012; Septer et al., 2012; Levy et al., 2018). The validity and reliability of these methods for capturing mental models is a point of discussion: we know, for example, that the location of any elicitation activity, the method of elicitation and the immediate social context and motivation of actors will likely influence the content and structure of elicited cognitive models (Jones et al., 2011, 2014; Lynam et al., 2012). Nevertheless, as the use of mental model methodology has increased in natural resource management research and sustainability science, there is growing confidence that the elicitation and visual and verbal depiction of cognitive models and their associated narratives can provide material for social learning, collaborative planning and conflict resolution (Biggs et al., 2011).

While water challenges are notorious in Mexico City, only a fraction of the city experiences acute exposure to water related risk on a regular basis. The focus of the case we present here is on the problem framing and meta-narratives associated with the experience of those most closely related with the problem. The sources of our data thus includes those in position of authority over water management and civil protection at the city level, and residents of neighborhoods most directly exposed to risk in three boroughs known for water challenges. Accordingly, we elicited the mental models of individuals and groups (technical experts, public officials, and residents from three city boroughs who frequently experience flooding and water scarcity) from qualitative interviews and participatory workshops to then construct meta-narratives associated with water challenges.

Mexico City has struggled with the twin problems of episodic flooding and chronic water scarcity since the city was founded in the fourteenth century (Tellman et al., 2018). The megacity of over 23 million people has expanded over a watershed, desiccating the natural springs, rivers and lakes. Today, ∼60%

of the city's water comes from an over-exploited aquifer; the remainder of the city's supply is piped in from neighboring watersheds at increasingly high social, economic and political costs (Tortajada and Castelán, 2003; Delgado-Ramos, 2015). The location of the city in what was originally an endoreic (closed) basin supporting 5 shallow lakes has exposed it to flooding. The city has responded over time with the construction of elaborate drainage infrastructure. Yet, the challenges of constant and dramatic subsidence, population growth, land cover change, and infrastructure capacity have ensured that rainy season flooding of combined sewage and storm water has remained a significant threat to the population (Romero Lankao, 2010). Today, the city's water authority, SACMEX (Mexico City Water System), reports that 12% of the city's water supply is of a deficient quality, 26% of the city's inhabitants do not receive sufficient water and 15% lack daily water delivery [SACMEX (Sistemas de Agua de la Ciudad de México), 2018, p. 65].

There has been a wealth of research on Mexico City's water challenges over the city's history; most recently, scholars have highlighted how the water issues of the city are as much social and cultural challenges as they are technical and hydrological (Cohen and González Reynoso, 2005; Romero Lankao, 2010; Jiménez Cisneros et al., 2011). The city has tended to foster hard-infrastructure solutions, and relied on engineering expertise to address flooding and water supply concerns, yet increasingly these approaches are seen as unsustainable (Delgado-Ramos, 2015). More sustainable pathways for management will need to address the prevalent inequities in water access and distribution (Jiménez Cisneros et al., 2011), a culture in which water is used as political capital (De Alba and Hernández Gamboa, 2014), distrust of public officials (Castro, 2004) and public perceptions and misperceptions of water quality (Delgado-Ramos, 2015). As yet, however, alternatives to "big infrastructure" solutions for water resource management have not gained much traction in the decisions of city authorities.

METHODS AND ANALYTICAL APPROACH

We elicited 48 mental models of water related risk from individuals and groups at three organizational levels in the city: federal officials in agencies who are responsible explicitly for water related concerns pertaining to Mexico City, public officials at the whole-city level responsible for water and land (watershed) related concerns, and some residents and local-level political representatives and community activists and leaders of civil society groups from three urban boroughs that are frequently subjected to water scarcity and flooding (**Table 1**). We identified participants using a simple stakeholder analysis framework, listing all well-known organizations and prominent individuals with either a strong interest or influence on water and/or land use (in relation to the watershed) decision-making in the city. For local-level participants, we focused on the urban boroughs of Iztapalapa, Magdalena Contreras, Xochimilco.

All three boroughs are located in the southern half of the city, where the city's conservation zone—an area designated for watershed protection that is technically off limits for

TABLE 1 | Number of individual or group (in the case of residents) mental models elicited, by sector and organizational level.

Organizational level	Public sector	Individual civil society leaders and activists	Groups of residents*	Total mental models
Iztapalapa Borough	2	6	1	9
Xochilmilco Borough	9	1	3	13
Magdalena Contreras Borough	6	3	3	12
Mexico City Government	14	N/A	N/A	14

*The number in this column represents the number of workshops in each borough. Each workshop enabled the participation of three to twelve participants from vulnerable neighborhoods in each of the three boroughs, resulting in one aggregated mental model per workshop conducted.

new settlement—meets the consolidated urban area (**Figure 1**). Iztapalapa is densely populated and economically marginal borough, housing over 1 million residents in one of the lowest part of the city, and has consistently been identified as one of the city's boroughs most exposed to flooding, subsidence and inadequate water delivery (Jiménez Cisneros et al., 2011). Xochimilco lies at the foot of the southern conservation area, where hillside communities have expanded and continue to practice agriculture. In its urban area, Xochimilco suffers from both flooding and water scarcity. The borough contains the last remnants of the wetland ecosystem that once characterized the basin, now maintained with treated waste water. Magdalena Contreras spans a steep slope from the heavily forested highlands above the city to the city's urban core; water scarcity is common in the highland areas, although the borough also contains the last free flowing river—the Magdalena River—in Mexico City.

We recruited participants in the three boroughs from specific neighborhoods that were known, either by public officials we consulted or from available statistical data, to suffer from inadequate water availability and/or where flooding during the rainy season (e.g., Jiménez Cisneros et al., 2011). Neighborhoods exposed to water scarcity typically lacked either a connection to potable water pipe infrastructure (and thus were dependent on water tankers for delivery) or were on the "*tandeo*" system: a system in which water is delivered only for set hours during a week. Such neighborhoods were more often than not characterized by low-income populations, often, but not always, living in settlements lacking formal urban zoning ("informal settlements"), most commonly located in the southern part of the city in the higher elevations (Jiménez Cisneros et al., 2011). In contrast to areas suffering water scarcity, flood-exposed areas were typically located in the lower elevations in some of the more densely populated areas, and thus were also more likely to be part of formal urban settlements.
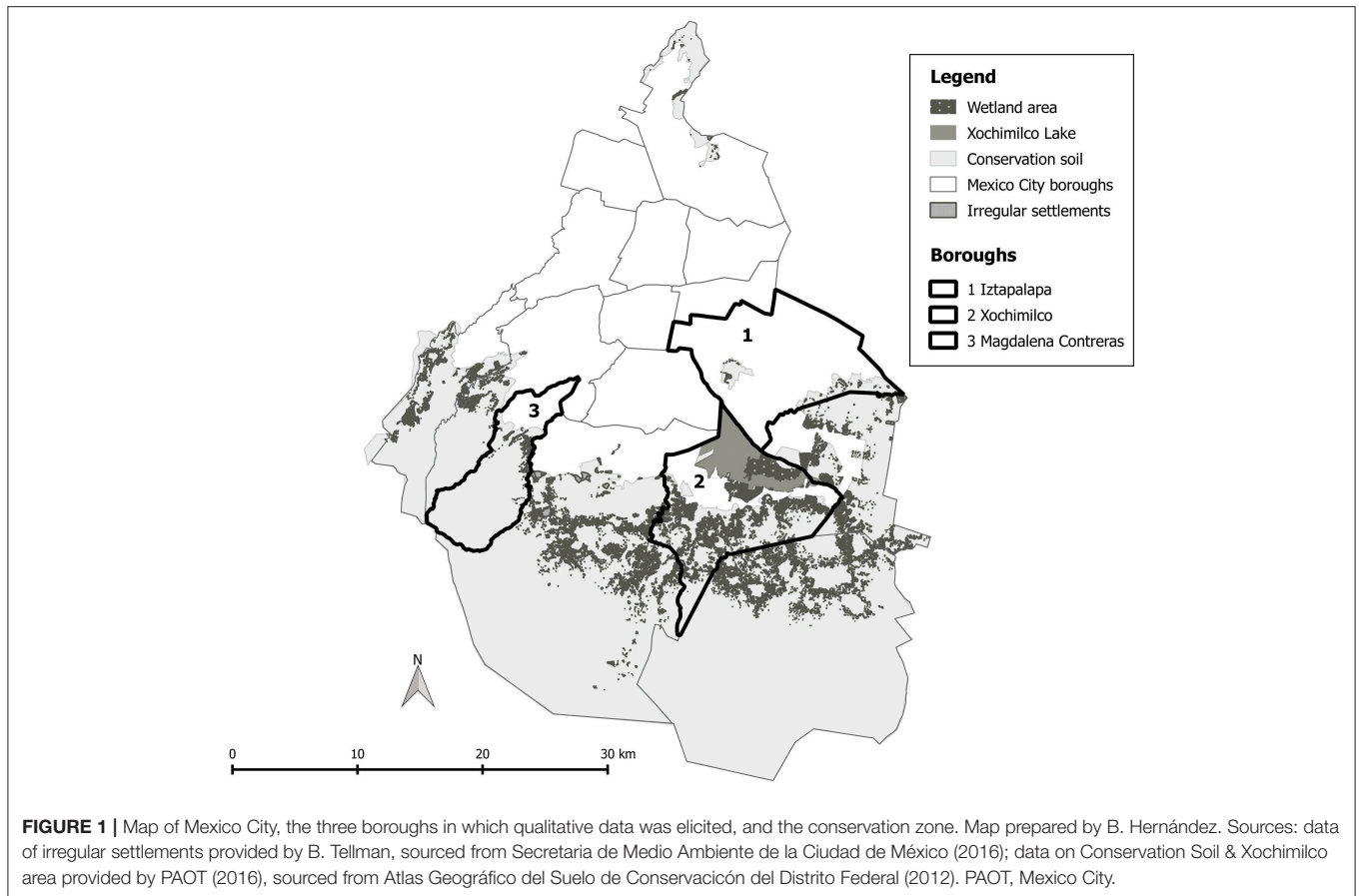
We employed one of two distinct mental model elicitation strategies. For public officials and leaders of civil society organizations, we followed a mental model interview protocol (Cone and Winters, 2011). This entailed a two-stage interview in which in the first stage the interviewee describes the water situation with minimal prompting and intervention from the interviewer. The second stage of the interview entails probing for more specific perspectives on the two issues of interest to the project (flooding and scarcity). These interviews were then transcribed and coded for key terms. The relationships among the key terms elicited were then visually represented (by the research

team) as a concept map depicting the causal linkages mentioned by the interviewee. This process also resulted in an associated relational matrix of terms for each interviewee.

A second approach was employed to elicit collective models, representing the ideas about a problem held by the groups of residents we consulted. In this approach, we contacted neighborhood leaders to recruit residents to participate in a workshop; the neighborhoods were identified *a priori* as being exposed to either water scarcity, flooding or both, according to official data from the city's water authority provided to the research team. Seven workshops were held: 3 in Magdalena Contreras, 1 in Iztapalapa, and 3 in Xochimilco. Each involving the participation of 3–12 participants resulting in a total of 22 participants in the 3 workshops in Magdalena Contreras, 12 in the workshop in Iztapalapa, and 16 in the 3 workshops in Xochimilco. Participants were typically a rough balance of men and women all over the age of 18. The workshop entailed a series of participatory mapping activities designed to help these vulnerable residents articulate, as a group, their understanding of water related issues in their neighborhood and borough. Residents participated in drawing "rich pictures" (Checkland and Poulter, 2006) of the water issues they confronted, prepared problem trees linking causal elements to outcomes, and ultimately participated in the creation of more abstract maps that depicted the terms and concepts they identified as associated with the problem, to the problems in their neighborhood and the actions they took in response to these problems. We expected each group to depict conceptualizations about water related risk that would be idiosyncratic to their particular geography and local circumstances; commonalities in the conceptualizations across the groups of vulnerable residents would thus be indicative of shared meta-narratives of water-related risk exposure among the participants.

The final result of both the individual and group approaches was the same: a relational matrix of terms, created by the research team, consisting of the terms that participants associated with water-related challenges in the city or in their own borough (depending on the system boundaries of the interviewee–e.g., city officials talked about water "in the city" while local level officials and residents discuss the issues largely within their own borough). These unweighted, and undirected matrices were then standardized through the creation of a "dictionary of terms"[1]. In

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[1]The specific computational steps entailed in the analysis of the mental model is described in a related publication: Siqueiros-García et al. (2019).
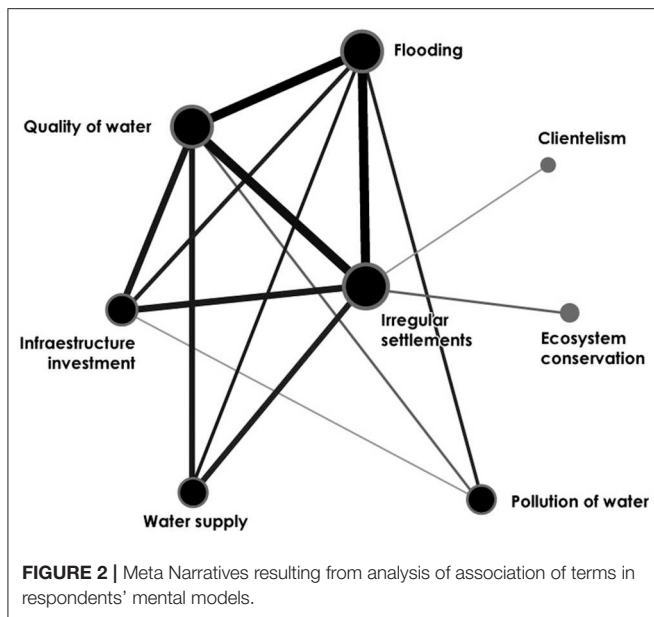
FIGURE 1 | Map of Mexico City, the three boroughs in which qualitative data was elicited, and the conservation zone. Map prepared by B. Hernández. Sources: data of irregular settlements provided by B. Tellman, sourced from Secretaria de Medio Ambiente de la Ciudad de México (2016); data on Conservation Soil & Xochimilco area provided by PAOT (2016), sourced from Atlas Geográfico del Suelo de Conservacicón del Distrito Federal (2012). PAOT, Mexico City.

this dictionary, one commonly used, generic term—for example, "water supply"—was defined by a series of terms with equivalent meaning—for example, "water supply from well water" or "water supply in the city's network"—that also were mentioned in interviews. While some nuances in meaning were likely lost in this process, we were careful to take the text of the interview into account when determining the appropriateness of using the standard term, or whether we needed to include an additional term in the dictionary to capture the specificity in the respondent's meaning.

We developed a computer program to automatically convert individual mental model inputs into the standardized language of the dictionary of terms, which then allowed us to create a global unweighted and undirected connectivity map of related terms for analysis—in other words, a "meta-model" (Siqueiros-García et al., 2019). This meta-model then served as the basis for identifying, through a process of community analysis using the algorithm and software Map Equation (Rosvall et al., 2009; Bohlin et al., 2014), the clusters of terms that were frequently associated in the aggregated data. These clusters or communities of terms were then interpreted as the prevalent, associated ideas about water-related risk, its causes, consequences and the actions taken in the city to address these issues. The most dominant clusters were identified as such by the number of terms that emerged as members of the cluster. In aggregate,

the mental models of the individuals interviewed within each borough or across the city government, as predefined groups, would have an affiliation with these clusters of terms. We analyzed this affiliation using the Jaccard Index. The Jaccard Index is a measure of similarity/diversity between groups of observations or sets, identifying the proportion of elements that are shared. The higher the percentage, the more similar are two populations (communities or sets) (Jaccard, 1901; Niwattanakul et al., 2013). In our case, we expressed this similarity as a coefficient. For example, as described below, the mental models of the respondents at the level of city government shared 21% of the terms that appear in the cluster "Irregular housing," while none of the terms in the cluster "conservation of the *chinampa* ecosystem." Thus, we can conclude the governmental actors had more affiliation with the former narrative than the latter.

In order to associate narratives with discourse on actual and proposed solutions to the water situation in Mexico City, we drew from the same database of interview data used in the narrative analysis, coded using Dedoose Software (Sociocultural Research Consultants, LLC, 2018). Separate codes were created for water scarcity as a quantity issue, water scarcity as a quality issue, and flooding. Interviews were also coded for "proposed" or "actual" solutions. The solutions presented here are those from interview excerpts that co-occurred with water scarcity or flooding codes.

FIGURE 2 | Meta Narratives resulting from analysis of association of terms in respondents' mental models.

RESULTS

Meta-Narratives

The analysis of terms of the entire set of interviews produced 8 clusters of terms, supported by the qualitative data in the interviews, and gave rise to "meta-narratives" (**Figure 2**). Of these, three were clearly dominant, as signified by the node size in **Figure 2**. The linkages between the clusters are signals of their "proximity" in the universe of mental models that served as inputs in the analysis; the three most dominant clusters also exhibit such proximity. The first of these clusters, "Irregular Settlements," focused on irregular housing and the relationship of urbanization to the challenge of water scarcity in the city. This meta-narrative was strongly associated with the mental models of the respondents at the level of the city's administration (21%), as well as with the mental models of the government respondents in the borough of Xochimilco (19%), but also prominent in the discourse of interviewees (government & residents) in Magdalena Contreras (13%) and less with residents of Iztapalapa (10%) (**Figure 3**). Of the three case study boroughs, Xochimilco is still experiencing significant urban growth and contains a large segment of the conservation zone.

The concepts that were most frequently connected in this meta-narrative were urban growth, loss of agricultural areas, new infrastructure construction, urbanization of the conservation zone (watershed), and construction of housing in high risk areas. Other concepts included in this cluster of terms were land use change, land sales, deforestation and lack of urban planning. The narrative implication of this cluster is that the water challenges of the city are intimately linked to the expansion of the city's population, the physical urban footprint and land use change in high-risk, ecologically valuable areas.
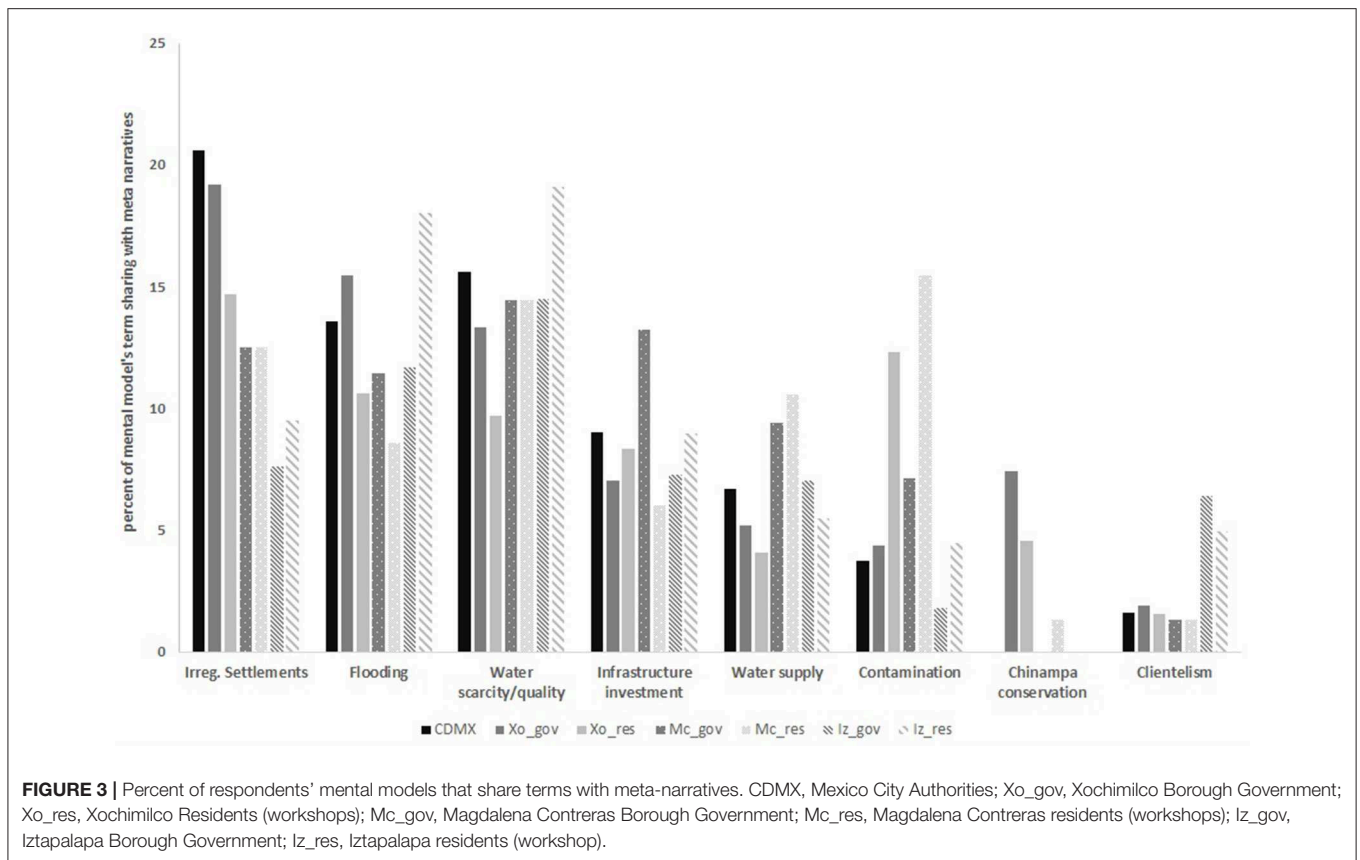
The qualitative data illustrates that the prominence of irregular settlements in this cluster is largely associated with

"blame": an expansion of housing in the city that is perceived to be unsanctioned, unregulated and out of formal control and management. As an example of such a narrative, one official of the city government explained that "*it hasn't been possible to contain or control the doubling of population in some areas, because there isn't any effective mechanisms to physically inhibit growth in relation to irregular settlements, particularly in Xochimilco.*" The meta-narrative depicts a process by which land in agriculture and forest (largely in the southern part of the city's watershed) is converted illicitly to housing, impeding hydrological processes (groundwater recharge), drying up springs, and creating undue pressure on the city's over-taxed infrastructure. As one interviewee commented "…I have irregular settlements [in my mandate], they don't ask permission from anyone…what happens? The *ejidatario* [peasant farmer] says "I'm going to give to my children" and begins to divide the land… and soon we have irregular settlements." Another commented "…they [land owners] continue to divide, sell and build, to the point which they are taking over ecological areas or areas of high risk…".

The populations who settle in these areas lack sufficient infrastructure, and are presumed to engage in illegal activities such as depositing sewage in waterways and gullies, or trying to connect themselves (illegally) to the formal drainage network, and thus causing sanitation and water supply problems for themselves and those downstream in the more consolidated urban areas. Interviewees described sewage accumulating in the unpaved streets of peri-urban settlements, as well as affecting public infrastructure in more consolidated areas. A public official in Xochimilco, for example, described the cross-contamination of groundwater wells for the city with unregulated sewage from the "hill settlements," forcing the city to perforate additional wells.

This meta-narrative has deep roots, into the early part of the twentieth century when water supply concerns began to become more acute, and scientists and urban planners called for conserving the watershed that fed the city's rivers and springs (Tellman et al., 2018). The southern part of the city is the geographic target of this meta-narrative; over 50% of the city's protected watershed (the conservation zone) is in the southern boroughs, and urbanization of this zone thus often receives disproportionate policy attention. There have been a variety of policy initiatives to control growth and discourage settlement; nevertheless, analyses of land change in the city demonstrate that these areas continue to show urban expansion within the protected areas at rates that typically exceed growth of formal consolidated areas (Aguilar, 1999; Gilbert and De Jong, 2015; Connolly and Wigle, 2017).

The second dominant cluster focused on the problem of flooding in the city, and was characterized by a focus on the inadequacy of urban infrastructure, technological and financial limitations in management. This meta-narrative was most associated with respondents from the borough of Iztapalapa and Xochimilco (affiliated with 18% of Iztapalapa residents and 15% of Xochimilco government of the mental models of the respondents, **Figure 3**), both areas that frequently flood and are subject to significant subsidence. The most central terms in this cluster referred to insufficient infrastructure, subsidence,

FIGURE 3 | Percent of respondents' mental models that share terms with meta-narratives. CDMX, Mexico City Authorities; Xo_gov, Xochimilco Borough Government; Xo_res, Xochimilco Residents (workshops); Mc_gov, Magdalena Contreras Borough Government; Mc_res, Magdalena Contreras residents (workshops); Iz_gov, Iztapalapa Borough Government; Iz_res, Iztapalapa residents (workshop).

sewage discharge, and lack of sewage connections, rainfall and water retention and pumping capacities. Problems in drainage maintenance—dredging, garbage in the drains, sedimentation—are also prominent elements in this cluster.

As a meta-narrative, these terms illustrate that flooding is a result of technological and infrastructure failures. As a city official commented "… flooding is about infrastructure; our infrastructure isn't sufficiently apt to channel and release the water we accumulate in the rainy season." The meta-narrative associated with this cluster is one in which the infrastructure system is depicted as underfunded, aged, inadequately maintained, and subject to leaks, blockages, and in constant need of repair. In the words of one respondent, "… the problem gets worse when the drainage system is obsolete or in bad condition, if we add to that the topic of culture and garbage management, then we have a situation that complicates infrastructure management and generates flooding where it really shouldn't flood."

A third dominant meta-narrative centered around water quality and scarcity, depicting a somber story of water being lost in leaks, overexploited aquifers, rising water demand and ill health effects. This cluster also relates to infrastructure failures: aging pipes and the inadequacy of the stop-gap measures to meet needs, such as water delivery through "*pipas*" (water tankers) and the necessity of residents' having to purchase water from private potable water suppliers. Here there is also an implicit and

explicit critique of water management: water being "diverted" to more wealthy consumers, a lack of adequate infrastructure, anxiety about the privatization of water, and the lack of local water sources and storage capacity.

This meta-narrative is most associated with the mental models of interviewees from Iztapalapa (affiliated with 19% of resident interviewees) where water quality is often a source of deep health concerns: "Sometimes one isn't paying attention and the kids drink from the tap, and then the harm falls on them, they begin with nausea, then that their throat burns, that their stomach hurts… this is the danger we face as a family: our health." Water quality is also the dominant concern in Magdalena Contreras (affiliated with 14% of the mental models of the government & residents interviewees, **Figure 3**), but for different reasons: here the concern is related to the contamination of the last free-flowing river in Mexico City, the Magdalena River, with solid waste and sewage, which, in turn, affects flooding downstream and ecosystem services in the riparian areas.

Interestingly enough, given that water quality has essentially been "outsourced" to private potable water suppliers in Mexico City identification with this meta-narrative was associated with ∼16% of respondents from the City Government (**Figure 3**). The interviews with city officials present a defensive tone regarding water quality, suggesting that if quality problems are perceived by the public it is either a result of within-household contamination (e.g., "…the water can arrive clean to the house, but if the

cistern is dirty or the water tanks aren't clean, well, you've gone and spoiled everything"), or poor public understanding. For example, one official described a period of "smelly water" that came through the taps, but that apparently was not harmful to consumers. The official declared that the water was safe, but the public pushed back strongly, and forced the city to take palliative measures.

At a second tier of prominence, we identified three meta-narratives that reflected less widespread affiliation and a smaller overall associated number of terms, but still accounted for the perspectives of significant proportion of interviewees. While these meta-narratives were more associated with local level experience and phenomenon, they also shared many common terms with the more dominant narratives. These focused on, in order of prominence, infrastructure investment, water supply concerns, and water body contamination.

The meta-narrative of infrastructure investment reflected the politics of what parts of the city and who benefits from infrastructure improvements, as well as distrust over the city's intentions with infrastructure investments. The dominant terms of this meta-narrative were "institutional resources invested," "preventative measures," "pressure and claims on the borough government," "social mobilizations," and "efficiency in project execution." One borough official commented that when residents see infrastructure repairs taking place they can physically halt the works through protest. "They say, 'it's that they are going to take our water, they are going to steal our water!' although many times it isn't true, well, *always* it isn't true, because it is more expensive to move water to another borough than do the necessary public works within the same borough perimeter." But the residents have other perspectives, arguing that the city uses the excuse of lack of funding to justify lack of action to meet local water needs, and acts discretionally to allocate water and diverts water to meet the needs of more wealthy neighborhoods. And, under circumstances of significant "social pressure," public officials express that their hands are often forced. This meta-narrative relays the idea that there are underlying injustices in infrastructure decisions about flood risk and water supply, and that to get their voices heard and to claim rights, citizens may need to resort to more vocal and public protest.

The water supply meta-narrative was also shared across groups and levels of governance, and the terms reflected the specific challenges of managing the watershed that is perceived to be a source of Mexico City's future water sustainability. Here terms such as "water infiltration," "rainwater capture," "drying up of springs" and "check dams" are featured. In the words of one interviewee, "…at the rate that [vegetation] disappears, urbanization advances, there isn't anything that detains the water, and the water runs down… it's another element that is feeding the flooding and material impacts…". The meta-narrative reflects over a century of effort in Mexico City to control land use on the city's watershed, and the prominent place that watershed management has taken in public policy (although, given the continued urbanization of the watershed, with mixed success, see Tellman et al., 2018). This meta-narrative was given somewhat more prominence

by the interviewees in Magdalena Contreras, where the Magdalena watershed is part of the identity of the borough, and by city officials, who have struggled over time to control settlement.

Finally, in relation to this tier of meta-narratives, was the concern for contamination of water bodies. This narrative was strongly influenced by the perspective of residents in Magdalena Contreras, who have been given some authority to monitor contamination of the Magdalena River from its source in the mountains above the urban seat of the borough. Lack of control over individual behavior—be it that of tourists to the protected area above the city, or households illegally evacuating sewage or solid waste into the river—features strongly in this narrative, where the problem of contamination is blamed on a lack of "culture," problems in garbage collection, and lack of regulation of human activities.

The last two clusters were far less connected to the other meta-narratives in terms of shared terms, and did not reflect a wide affiliation across the respondents in all three boroughs and at the city level. The meta-narrative of "*chinampa* conservation" unsurprisingly was almost exclusively affiliated with the borough of Xochimilco, where the Xochimilco wetland—a world heritage site, major attraction for urban tourism, and where the last remnants of the traditional agricultural system of *chinampa* farming still is practiced—is central to the borough's identity. Here the concerns are very specific to the social-ecological dynamics of the wetland: the problem of the canals that separate agricultural beds (*chinampas*) being filled in, the problem of invasive species such as water hyacinth and tilapia, problems of contamination from agricultural activities and the need for community planning.

The concern over "clientelism" and corruption defined the last meta-narrative, with only six associated terms relating to how water is distributed, how complaints from citizens are received, the use of construction material in exchange for votes and conflicts over water. This meta-narrative was most associated with the densely populated and highly politically mobilized participants from Iztapalapa.

Solutions

Embedded within each of the meta-narratives described above are terms suggestive of solution pathways. In the interviews with actors in the city, we asked both about what *is* being currently done to address the problems that they identified, as well as what they thought *should* be done. An individual's mental model of a problem domain often contains ideas about solutions that go beyond his or her formal responsibilities, official mandate for action, scope of experience or scope of agency. In this section, we describe the scope and nature of currently implemented solutions described by three different groups—public actors at the city level, public actors at the local level, and residents—and relate these to the identification of these groups of actors to particular problem narratives. We then describe the *proposed* solutions by these groups—which tend to address a much broader range of concerns and causal factors—and evaluate how these proposals

may indicate novel points of intervention should alternative problem narratives become more prominent in urban discourse.

Current Solutions: Water Scarcity, Flooding, and Water Quality

Water authorities at the city level and borough level are obligated to provide a minimal allocation of water to every urban resident, regardless of legal status. Sending out water tankers to satisfy unmet demand is, as the meta-narratives above reflect, a political and contentious issue. Nevertheless, it is the primary "solution" to the immediate problem of water demand and scarcity at the disposal of water authorities. In some cases, also used to disincentivize growth. Xochimilco officials described limiting access to water in tankers to only those households on a registry; this policy was intended to make water access more difficult for newcomers to irregular settlements. Residents, unsurprisingly, focus on those solutions to scarcity they have at their disposal: construction of cisterns for storing water, purchasing water, and rainwater capture when they have the financial resources to do so, as well as water recycling and reuse, organizing their schedules to be available at home when water might be delivered, sharing water with neighbors and mobilizing with petitions, street protests and other actions to alert the city when they feel their needs are not being met.

Infrastructure investment dominates the solution discourse for flooding. In response to disastrous flooding over the last decade, the city and federal government has constructed huge drainage canals for the city (called "TEO II"), increased the number of pumping stations, and created new water retention lagoons. This infrastructure focus is also reflected at the borough level, where dredging, solid waste collection, construction of retention lagoons and infrastructure maintenance dominates the interviewee's commentary. Residents' solutions are also infrastructure-based, involving adding an additional story to their homes, constructing permanent or sand barricades at their thresholds, and manipulating the drainage in the street to divert sewage flooding. They also manage floods through collective action, such as turning on neighborhood pumps provided by the borough government, and clearing trash from streets and out of the drains. Proposed solutions for flooding, across all groups, emphasize further investment in and repair/maintenance of drainage, water capture, and pumping infrastructure and programs to educate citizens about or enable proper waste disposal.

Infrastructure was also a dominant theme in government interventions to address quality concerns, including fixing leaks in the distribution infrastructure to prevent cross-contamination from sewage, encouraging septic systems for the hillside populations, and in some cases, investing in local treatment plants for locally controlled wells. Many of the "solutions" to quality concerns, however, are undertaken by residents, who resort to purchasing water that they hope has been purified for drinking, boiling water, and installing filters to remove physical and other contaminants. Wealthy residents in the city typically can afford better filters, and are more likely to be able to get the delegation to respond if water is not of the quality they expect from the public service.

Proposed Solutions

What is perhaps more revealing are the solutions that are proposed by the interviewees, but are currently not being implemented. Here we see evidence that interviewees are connecting their meta-narratives to a solution space, and seeking to address the underlying conditions they believe are giving rise to the problems they experience. At the level of public administrators, for example, respondents suggested decentralized and smaller scale solutions such as green roofs to slow runoff and inhibit flooding, and local-level rainwater harvesting to address scarcity. They brought up the need for more small dams and ponds to collect rainfall and enhance infiltration on the watershed. And, in relation to the dominant meta-narrative that links informal settlements to water risk, they discussed the need to change real estate practices to encourage housing where infrastructure networks already exist, and the promotion of more ecologically-oriented construction practices in fragile areas. In general, they recognized that the current policy of prohibiting settlement on the watershed was largely unsuccessful and that novel solutions would be required.

In terms of proposed solutions to water quality issues, many city officials believed there needed to be an increased culture of care among citizens, and that citizens required education about the quality of their water. Gray water reuse also emerged as a possible solution, requiring investment in waste water treatment. Many respondents discussed a need for collaborative governance across sector agencies and with residents to find viable alternatives to current land management and water use behavior.

The residents also expressed considerable interest in demand-side conservation measures, ideally with support from public programs. These measures would include household water conservation, leak repairs, and household-level rainwater capture and cistern construction—particularly to improve water access in informal settlements. They expressed interest in containing runoff and enhancing infiltration through public works. And they concurred with public officials that better public housing was needed to alleviate irregular housing construction in the conservation areas of the city. But most starkly, they expressed a need for a different and more responsive water management system. Residents wanted to see more investment by the public sector in water quality in the public water storage tanks and distribution system, in addition to better information and an improved "culture of water" among citizens. They want financial support for water filters and decentralized, ecological solutions for waste such as bio-digestors. But more than anything, they wanted new political leadership, more transparent investment decision-making and efforts to address the injustices they perceive in water distribution and access.

DISCUSSION

The analysis of mental models and meta-narratives is not common as a means of informing urban planning and governance. Nevertheless, the persistence of sustainability challenges in urban contexts can be attributed at least in

part to path dependencies that result from dominant meta-narratives about a specific problem domain. Ideas about the city and its problems become embodied in habits, policy, planning instruments and decisions in ways that create and sustain path dependencies (Eakin et al., 2017). For example, Bausch et al. (2015) demonstrated how in the peri-urban context of Phoenix, Arizona, the meta-narrative of the inevitable decline of agriculture—and the water and land policies and development priorities built on this meta-narrative–marginalized alternative ideas depicting a more synergistic future of agricultural and urban sustainability. Similarly, Borie et al. (2019) revealed the existence of a diversity of narratives on urban resilience in Manila, Cape Town and Nairobi, which together suggested alternative ways of realizing urban policy objectives. Narratives shape what knowledge in the city is put forward and what is silenced (Muñoz-Erickson, 2014). For this reason, some sustainability scholars argue that in new policy directions must be founded in a shift in the narratives about a problem, in order to "open up" alternative solutions that would otherwise be discarded (Leach et al., 2010; Pelling, 2011; Wise et al., 2014).

Our analysis of water meta-narratives in Mexico City identifies not only a confluence of perspectives on what the problems are, but also on the determinants of these problems. The interviewees in Mexico City highlighted endogenous processes as the primary drivers of risk, rather than exogenous natural phenomena or broader national economic conditions. Interestingly, given the dominance of climate change in global discourse, and the increasing attention to "urban resilience" in the face of environmental extremes (Romero Lankao, 2010; Lankao and Qin, 2011; Childers et al., 2015; Béné et al., 2017; Eakin et al., 2017), the concepts of rainfall, climate change and other exogenous environmental stressors are not part the water meta-narratives. Instead, the interviewees describe how the city itself generates the challenges it faces through its patterns of urbanization, the relationship of citizens to the city administration, and the ability of the city to respond appropriately to the burgeoning demand for housing, for sewage infrastructure and potable water. While the popular media—particularly the international media (e.g., Watts, 2015; Kimmelman and Haner, 2017)—have highlighted Mexico City's challenges in light of changing global climate conditions, the residents and officials managing the city offer a distinct view. They are well aware that their challenges have been a long time in the making (see Tellman et al., 2018) and view the megacity's water issues as a product of individual and collective actions—albeit the actions of *others* in the city, rather than themselves.

Embedded within the meta-narratives are also stories of differential responsibilities, and differential perspectives among local residents and public officials. Flooding, for example, is described by the residents consulted as a result of the city's lack the capacity to maintain infrastructure and inadequate management plans for extreme events. Public officials deflect this responsibility by blaming informal settlers and residents for dumping garbage in drains, nevertheless, all agree about

the need for better infrastructure management. In the case of the water scarcity meta-narrative, "blame" is more implicit. The city is blamed for inefficacies in water distribution and injustices in water distribution, while the population at large in "blamed" for increased demand (see also Eakin et al., 2016). Residents perceive the city as responsible for poor water quality, while the city attributes the problem to mismanagement and lack of education among households, while acknowledging the infrastructural challenges they have in managing water contamination. In relation to the meta-narrative of irregular urban growth, illegal and irregular settlements are blamed for the water crisis. This meta-narrative thus blames the "other"—those that, by definition (being irregular), are beyond the control or influence of any "legal" resident or public official (see also Lerner et al., 2018).

The analysis of meta-narratives also help identify where there are incongruencies in how issues are perceived and understood, and what the available empirical evidence suggests in terms of causality, problem explanations and solutions (Morgan et al., 2002). For example, the rapid expansion of settlements onto the southern watershed and conservation zone is often attributed to a neoliberal shift in Mexico City's public housing policies (Guillermo Aguilar and López, 2009; Wigle, 2010; Guillermo Aguilar and López Guerrero, 2013), a shift that increased the scarcity of affordable housing in the city and left economically marginal populations with no alternatives. Land use in the urban periphery is also suspected to be manipulated by vote-buying behavior (Connolly and Wigle, 2017). Others have criticized the incentives that the city has provided to private sector housing developers at the expense of investment in public housing (de Mattos, 2007; Delgadillo Polanco, 2012). This literature thus would suggest that far from being the responsibility of irregular settlers and settlements ungoverned by the city, the water supply concerns and associated watershed development is in fact, at its roots, a result of central government policy concerning accessible and affordable housing for the urban poor (Lerner et al., 2018). The recognition that the solution to the city's water issues may well reside more in public housing development than in water infrastructure *per se* is evident in the respondents' proposed solutions, and represents a challenge to the dominant meta-narrative of irregular settlements.

Collectively, the meta-narratives of water related risk articulate a shared frustration: a perception that managers may be facing human and institutional limits, and that the capacity of infrastructural system itself has long been surpassed, and that management decisions themselves are politically motivated and often contested. Water management is seen as much an issue of governance and social relations as it is of failed infrastructure, and, conversely, the infrastructure of the city is also embedded in social and political relations (see also Eakin et al., 2017). Here again the respondents had some ideas of solutions that would go beyond the traditional efforts in "hard" infrastructure improvements. In addition to more on decentralized and "greener" options such as rainwater capture and runoff management, the interviewees revealed

nascent ideas of increased public participation, transparency and collaboration at different levels and across levels of governance as a way forward in improving water outcomes in the city.

CONCLUSION

Our analysis demonstrates how, on the one hand, dominant meta-narratives may quell innovation, and on the other, meta-narratives collectively can foster the seeds of urban sustainability transformation. While the physical infrastructure of cities and its management is a strong focus for intervention in the face of emerging and chronic threats, less attention has been paid to the meta-narratives that are constructed over time, shape public and private discourse, and ultimately influence how solutions are conceived of and implemented. In this analysis, we provide insight into the spectrum of meta-narratives on issues of water and flooding in Mexico City. The dominance of some meta-narratives over others—and particularly those that are held more closely by actors with significant influence, such as those in the public sector—provides some insight not only into how problems are social constructed but also how the lines of action implied by these meta-narratives can lead to either "dead ends" or unsustainable path dependencies. We see this in the externalization of blame on irregular and "ungoverned" settlements, and the focus of the city's managers on hard infrastructure investment, regardless of unease in the adequacy of such measures to address evolving urban water challenges.

On the other hand, residents, public officials and others interviewed in the city all appear to have a strong sense of the endogenous and social nature of water-related risk: the threats posed to the city's water system and residents are part and parcel of citizen's relationships with the government and each other, as well as decisions made about water infrastructure, land use, garbage and housing. Thus collectively these narratives point to clear opportunities for intervention: public housing, citizen participation in water conservation and ecological restoration, decentralized water storage and management, and the need to divorce water supply interventions and flood risk management from the party politics. Meta-narratives matter; collectively they form a persistent form of "ghost" infrastructure, shaping urban form, social relations and solution pathways. By making these transparent and visible, and mobilizing the solutions they imply, we expect new opportunities for urban sustainability may emerge.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author, conditional on maintaining the confidentiality of interviewees.

ETHICS STATEMENT

This study was carried out in accordance with the policies and approval of the Internal Review Board (IRB) of Arizona State University. The study was determined exempt: The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) addressing tests, surveys, interviews, or observation, on 10/28/2014.

AUTHOR CONTRIBUTIONS

HE and LB-T conceptualized the study. JS-G and LB-T organized the design of the mental model analysis. JS-G, BH-A, and RS organized the database. JS-G and BH-A performed the mental model analysis. RS and HE performed the qualitative analysis. HE wrote the draft manuscript with the support of RS and JS-G. All authors contributed to manuscript revision, read, and approved the submitted version.

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