Building urban resilience and knowledge co-production in the face of weather hazards: flash floods in the Monterrey Metropolitan Area (Mexico)

Ismael Aguilar-Barajas\textsuperscript{a,⁎}, Nicholas P. Sisto\textsuperscript{b}, Aldo I. Ramírez\textsuperscript{c}, Víctor Magaña-Rueda\textsuperscript{d}

\textsuperscript{a} Departamento de Economía and Centro del Agua para América Latina y el Caribe, Tecnológico de Monterrey, Monterrey, Nuevo León, Mexico
\textsuperscript{b} CISE (Centro de Investigaciones Socioeconómicas), Universidad Autónoma de Coahuila, Saltillo, Coahuila, Mexico
\textsuperscript{c} Departamento de Tecnologías Sostenibles y Civil and Centro del Agua para América Latina y el Caribe, Tecnológico de Monterrey, Monterrey, Nuevo León, Mexico
\textsuperscript{d} Instituto de Geografía, Universidad Nacional Autónoma de Mexico, Mexico City, Mexico

**ARTICLE INFO**

**Keywords:**
- urban resilience
- knowledge co-production
- floods
- Monterrey
- Mexico

**ABSTRACT**

In 2010, flash floods triggered by Hurricane Alex caused fifteen fatalities in the Monterrey Metropolitan Area (MMA). In contrast, an estimated 225 people died in the 1988 Hurricane Gilbert disaster and reputedly, over 5,000 in the historical flood of 1909. The magnitude of hurricane-related impacts thus appears to be decreasing, indicating higher resilience to this hazard. This paper analyses the process of building resilience to flash floods in the MMA over the last several decades. Knowledge co-production plays a significant role in this process, particularly through the Nuevo León State Reconstruction Council, the multi-institutional, public-private-civil group of stakeholders established to guide and coordinate reconstruction efforts following the Hurricane Alex disaster. Findings reveal a complex, protracted and incremental resilience building process, conditioned by the nature of the hazard (infrequent but liable to cause significant damages) and contingent upon the city’s socioeconomic and institutional local context. This local context is embedded in a highly fragmented national water governance architecture that lacks inter-institutional co-ordination and has limited the city’s adaptive responses. Despite definite gains in building resilience, the city faces challenges notably in terms of the conservation and continuing development of knowledge co-produced in the aftermath of disasters.

1. Introduction

Urban population growth - 6.5 billion people will live in urban areas by 2050 (UN, 2014) - and concomitant social, economic, environmental and political pressures, pose major challenges for the management of increasingly larger and more complex urban systems (Editorial note, *Environ. Sci. Policy*, 2016). A key challenge is to foster resilience, defined (at a minimum) as the ability of an urban system to maintain or rapidly return to desired functions in the face of a disturbance. Cities face a variety of hazards of consequence within and beyond their own boundaries, for example floods that damage their infrastructure but also affect the wider economy (Pant et al., 2013). This is in part why building urban resilience is arguably of vital necessity (Sharifi and Yamagata, 2014).

Urban resilience as a concept is amenable to different disciplinary perspectives and may be applied to a variety of distinct hazards or groups of hazards (Meerow et al., 2016). Building resilience, however, ultimately requires designing and implementing solutions on the basis of available knowledge. This introduces a close connection between urban resilience and knowledge co-production (in brief, the process by which multifaceted knowledge for tackling complex problems is collaboratively constructed by stakeholders). Knowledge co-production likewise is not a simple concept and is open to different interpretations and normative prescriptions (Muñoz-Erickson et al. 2017).

The link between knowledge co-production and urban resilience has not been fully appreciated in the resilience literature, or the actual practice of building resilience. This paper proposes to shed some light on the varied ways this link is key to building urban resilience. To this end, the paper offers an in-depth analysis of an actual case of building urban resilience and knowledge co-production in the face of hurricane induced flooding, a hazard that triggers a specific type of disaster: infrequent (once in a generation), rapid onset, impossible to forecast at more than a few days’ notice, and liable to cause significant damage to life, property and infrastructure. Specifically, the paper analyzes how the Monterrey Metropolitan Area (MMA) - Mexico’s third most populous urban area - has built up resilience to flash floods over time, through a thick and detailed description of the different historical, political and economic dimensions of resilience building and
knowledge co-production in that city over the past several decades. The evidence reveals a complex resilience building process: protracted, incremental, contingent on the city’s internal context as well the external context in which the city is embedded, and conditioned by the nature of the hazard and stakeholder’s perception of the risk it poses. Moreover, knowledge co-production shows its own complexities. In particular, there is no guarantee that knowledge co-produced can be sustained, as it depends crucially on local social capital as well as the wider national governance architecture.

From this case study, three key messages emerge. First, for metropolises like Monterrey that contribute significantly to their national economy, increasing their urban resilience to floods clearly is a matter of national interest. Second, the case of the MMA illustrates that increasing urban resilience is an achievable goal; moreover, the process is comprehensible although its complex nature precludes simple explanations (and hence, easy replication elsewhere). Third, beyond the five basic questions of resilience for whom, what, when, where and why (Meerow et al., 2016) lie three major ones, which are often not dealt with in the literature or in practice: how, at what cost and who finances. How is resilience achieved? For example, what is the appropriate combination of hard infrastructure (e.g. flood control dams) and soft infrastructure (e.g. land use regulations)? How do we make sure knowledge co-produced in a resilience building process is sustained over time? How do we equip stakeholders with a proper understanding of risk, so that they come to perceive both the costs (flood damages) and benefits (water supply) of hurricanes? Finally, how much should be spent on resilience and who pays? Answers to the last question must involve all levels of government and society, including the private sector.

The rest of the paper is organized as follows. Section 2 describes the study area and the flood hazard it faces. Section 3 presents the conceptual framework and the methodologies employed. Section 4 and Section 5 respectively address urban resilience up to and following the most recent 2010 flash flood disaster. Section 6 contains conclusions, with the major lessons learned and the way forward.

2. The city, the region and the hazard

2.1. The city and the San Juan River Basin

The Monterrey Metropolitan Area (MMA) congregates 12 municipalities including Monterrey, the capital of the state of Nuevo León. Located in the San Juan River basin (a sub-basin of the Rio Bravo/Río Grande which straddles the border with the United States), the MMA draws half of its water supply from three downstream reservoirs: El Cuchillo, Cerro Prieto and La Boca (Fig. 1). Mexico has exclusive rights over the San Juan River Basin waters according to the 1944 International Water Treaty with its northern neighbor. The metropolis of 4.5 million people is a major national economic hub and the birthplace of several of Mexico’s largest industrial and financial companies. The MMA’s water services authority, Servicios de Agua y Drenaje de Monterrey (SADM) is a pioneering organization: it is one of the few in the developing world that provides drinking-quality tap water twenty-four hours a day, seven days a week, and treats 100% of its wastewater (Aguilar-Barajas et al. 2015). Water governance in Mexico, however, is fragmented and limited by significant inter-institutional coordination problems (Aguilar-Barajas et al., 2016; Torregrosa et al., 2015; OECD, 2013c).

2.2. The hazard: moderate recurrent flooding, disastrous but infrequent flash floods

The MMA receives only 600 mm of rain per year on average and local creeks and rivers usually run dry or carry only minimal flows. Nonetheless, every 3 or 4 years intense rain showers of 100 mm or more within a 24-h period (sometimes associated with named tropical storms, e.g. Ingrid in 2013) do occur (Fig. 2). These downpours invariably overwhelm the city’s storm drainage system and cause localized, short duration problems particularly to transit.

The MMA’s distance from the nearest coast (about 200 km) protects it from the direct onslaught of hurricanes, but its location at the foot of the Sierra Madre Oriental range exposes it to a significant flash flood hazard. Powerful hurricane remnants from the Gulf of Mexico occasionally reach the region and discharge large amounts of precipitation within a short period of time over critical catchment areas in the mountains high above the city. Three to four times per century, these events result in sudden and profuse surface flows notably in the Santa Catarina River (Fig. 2), the MMA’s principal watercourse which crosses the whole urban area west to east.

2.3. Major flooding events: a brief historical summary

Monterrey has a long history of flood-related disasters since its foundation over 400 years ago. The great flood of 1909 remains the worst catastrophe in the city’s history: the Santa Catarina River burst its banks and an estimated 5,000 people lost their lives (Graham, 1911). In 1938, floods curtailed transit across large swaths of the city (El Porvenir, 29 August 1938). Hurricane Beulah in 1967 caused flooding but relatively minor damages. With Hurricane Gilbert in 1988, the Santa Catarina River again broke its banks and attained its highest-ever recorded flow (CONAGUA, 2018). An estimated 225 lives were lost and the flood caused severe damages to bridges, roads and other infrastructure, disrupting transit not just locally but regionally (Bitrán, 2001; OECD, 2013b, Benavides and Lozano, 2013). Structures built on the river’s margins (mostly private homes) and on the river bed itself (recreational and commercial outfits) were swept away, revealing loose land use regulations and enforcement (Chávez Gutiérrez, 1995; Salazar, 2008; de León Gómez, 2009).

Hurricane Alex in 2010, one of the strongest storms to ever impact Nuevo León and the MMA, generated torrential rains in the city. The river reached its second highest recorded flow (CONAGUA, 2018) - Fig. 3 provides a view of the Santa Catarina River on the day of the event. Damages - although not as severe as the previous Gilbert disaster - significantly affected the MMA (Sisto and Ramírez-Orozco, 2015) and resonated widely in Mexico given the city’s weight in the national economy (OECD, 2013b). 15 people lost their lives, more than 12 thousand were rescued or evacuated and over 68 thousand households required emergency help (food, water, cleaning supplies and materials). Around 148 thousand homes were left without power and close to 400 thousand homes (about 1.7 million residents, i.e. 37% of total MMA population) lost access to water services (SADM, 2010a; SADM, 2010b).

The event caused extensive and severe damages to public infrastructure: 7.8 million square meters of pavement washed away, 154 culverts obliterated, 100 bridges damaged or ruined, 54 km of piped water lines and 45 km of sewerage lines wiped out, 1,502 schools and 211 health clinics affected at various levels (CERNL, 2013). Of enormous relevance for large sectors of the population were the transit restrictions, traffic congestion and extended daily commutes that persisted for several months; reduced mobility impacted more than 3,700 firms (OECD, 2013b). No consensus on the monetary value of damages has been reached: estimates vary between 1.35 and slightly over 2 billion dollars (OECD, 2013b). A significant portion of damages to private property occurred on land officially classified as unfit for urban development, notably on the margins of rivers and creeks (Leal Díaz, 2012; CERNL, 2013; Barragan, 2013). In the sparsely populated upper reaches of the Santa Catarina river basin, significant erosion and some landslides (in part due to deforestation) resulted in a great accumulation of sediments downstream in the city and beyond.

3. Conceptual framework

Building urban resilience to a hazard implies a complex process,
conditioned by stakeholders’ perception of the risk involved and crucially dependent on their capacity to co-produce and sustain the knowledge required for the design and implementation of solutions.

3.1. Urban resilience

Urban resilience as a concept is amenable to different disciplinary perspectives to address a diversity of distinct hazards affecting complex urban systems (Meerow et al., 2016). In its simplest form, urban resilience refers to the ability of an urban system to maintain or rapidly return to desired functions in the face of a disturbance. This involves short-term coping as well as long-term adaptation (Sharifi and Yamagata, 2014).

Urban resilience encompasses numerous and interrelated social, economic, institutional and political dimensions: “...enacting urban resilience is inevitably a contested process in which diverse stakeholders are involved and their motivation, power-dynamics, and trade-offs play out across spatial and temporal scales” (Meerow et al., 2016). From that standpoint, “soft” socio-political infrastructure may be as relevant as “hard” physical infrastructure (Eakin et al. 2017).
Urban resilience viewed as a dynamic, socio-ecological process, does not necessarily require a system to return to its initial equilibrium state following a disturbance (Frommer, 2013; Barata-Salgueiro and Erkip, 2014). The ability to bounce back to a desirable state requires the timely recovery of basic structures and crucial functions (Meerow et al., 2016). This depends on communities’ access to resources and their organizational capacities prior to and during the occurrence of a disturbance (UNISDR, 2015; UNISDR, 2017; Hallegatte et al., 2018). The emergence of innovative measures also plays a role (Miller et al., 2018). The dynamic nature of urban resilience implies that policy responses often derive from an interrelated set of decisions, in a decision cycle where factors that shape initial decisions affect further decisions (Wise et al., 2014).

Urban resilience analysis and policy design require a comprehensive understanding of cities as complex adaptive spatial systems (Bourne and Simmons, 1978; Friedman, 2002; Ernstson et al., 2010). Depending on their configuration, urban systems will show distinct capacities for coping in the short term and adapting and improving in the long term. For instance, integrated flood management must link water and land use planning (WMO, 2009). Addressing the two as separate or rival issues will lead to inappropriate urban development (infrastructure and human settlements on land at risk of flooding) and thus increase exposure to risk. This issue is of particular significance in metropolitan areas where multiple jurisdictions often overlap.

### 3.2. Adaptive risk management

Urban resilience is directly related to stakeholders’ perception of risk and their behavior in the face of risk. There is a growing recognition that adaptive management must address risk explicitly and appropriately (WMO, 2009; UNESCO, 2012; UN, 2013; OECD, 2013a) to inform decision-making based on an understanding of the environment in which risks and opportunities emerge (World Bank, 2013). The World Economic Forum places extreme weather events, natural disasters and failure of climate change mitigation and adaptation in the top 5 of the Global Risks Landscape (WEF, 2019). The Forum also highlights the interconnectedness between these risks and their impacts, for example the risk of a water crisis and consequent disruptions to critical infrastructure and basic services.

Land reserved for flood risk management is an emerging topic for urban resilience. In 2018, the Journal of Flood Risk Management (Vol. 11) published a special issue on this (https://doi.org/10.1111/jfr3.12344) and the first issue of the International Water Resources Association’s Policy Brief series focusses on this theme (Hartman and Stavikova, 2018). This Brief proposes that a comprehensive basin-wide approach is necessary in order to integrate three scales of flood storage strategies: in the catchment; upstream of cities; and, in the cities themselves. Since in all three cases affected land is often privately owned, flood risk management should be closely linked to land management, paying special attention to the issue of jurisdiction.

Adaptive risk management requires inclusive consultation and communication with stakeholders. The public needs to be better informed but also more educated about the implications of risk-based policy scenarios (Aguilar-Barajas et al., 2015). It is not uncommon for people to ignore or be unaware of the risks they face; the combination of inadequate knowledge and unfortunate choices leads to the occurrence of disasters (Miller et al., 2018). From a psychological perspective, the likelihood of future hurricanes tends to be underestimated, the experience of past ones may be forgotten, but the impacts of an imminent hurricane tend to be overestimated (Shaw, 2005). People need to become “…more aware, less comfortable, and hence more reflective about how we intervene, in word or deed, in the changing order of things” (Jasanoff, 2010). There is thus a direct connection between urban resilience, risk and knowledge.

### 3.3. Knowledge co-production

The design of effective resilience policies that take risk into account require multifaceted knowledge collaboratively constructed by stakeholders (Hallegatte et al., 2018). This refers to as knowledge co-production and is essentially the result of a social process: “…knowledge-making and decision making are social activities that take place within social contexts, institutions, communities…” (Miller et al. 2010). Consequently, knowledge co-production for urban resilience is open to different interpretations and normative prescriptions (Muñoz-Erickson et al. 2017).

In principle, there is a beneficial role for collaboration between the scientific community, government and civil society in the co-identification of problems, the production of knowledge and its application (Sarewitz and Pielke, 2007; Muñoz-Erickson et al. 2017). Co-production of knowledge however is a costly activity and does not occur spontaneously (Jasanoff, 2010). There are several competing models of knowledge-making and governance but trusting relationships need to
be constructed and fostered (Frantzeskaki and Kabisch, 2016). The interrelated issues of legitimacy-credibility are also linked to both science and policy making (Miller et al. 2010).

In the wake of a disaster, reconstruction offers multiple and rich opportunities to deploy more resilient alternatives and new models of institutional design (Miller et al. 2018). Reconstruction should focus on future resilience and be inclusive, but it cannot substitute for sound prevention and preparedness measures - institutional, technical and financial capacities are crucial in this regard (Hallegatte et al., 2018). Knowledge for prevention is key for urban resilience policy.


Building resilience to floods has taken place in Monterrey since its beginnings, including the wholesale relocation of the original settlement hundreds of years ago. For reasons of space and availability of evidence, our analysis focuses on the post-Gilbert period. In the aftermath of that disaster, a notable process of resilience building began at both the local and national levels. State and local authorities undertook the construction of major preventive engineering works: a regulating dam upstream from the city (the Rompe Picos Dam) to dampen peak flows in the Santa Catarina River and within the city, an improved network of storm drains. At the national level and in the countrywide context of extreme weather hazards (in particular, tropical storms), federal authorities developed an early-warning system.


The Rompe Picos Dam, located 22 kilometers upstream of the MMA in the Sierra Madre Oriental mountain range (Fig. 4) was built to regulate flows in the Santa Catarina River. The dam (which presents a number of advanced technical features) was designed for a return period of 10,000 years (i.e. the probability of an event surpassing the dam’s capacity is only 0.01% per year); it controls about two-thirds of overall flows in the river’s upper catchment area (Ramírez, 2011).

The Nuevo León State Government under Governor Sócrates Rizzo first proposed the project in 1994 – six years after the Gilbert disaster. Construction only began in 2002 at the end of the Fernando Canales/beginning of the Fernando Elizondo administrations, and concluded in 2004 at the beginning of the Natividad González administration. It took therefore 16 years and four distinct state governors for the project to materialize after the 1988 disaster (Flores Longoria and Maldonado, 2009; Aguilar-Barajas et al., 2015).

Since its inauguration the dam has proved effective on several occasions. The first test came in 2005 with Hurricane Emily: despite copious precipitations of 250 mm, peak flow in the river did not surpass 600 m³/s (Fig. 2) and impacts in the city were modest (Salas and Jimenez, 2014). Neither of the following two named storms (Dean in 2007 and Dolly in 2008) produced any significant peak flows or damages. With Hurricane Alex in 2010 the Rompe Picos dam fulfilled its original purpose: it reduced the peak flow by at least 750 m³/s and prevented flooding in downtown Monterrey and immediate surroundings (Ramírez, 2011; Benavides y Lozano, 2013). Without the dam, peak flow in the Santa Catarina River probably would have equaled or even exceeded the 4,400 m³/s registered during the Gilbert event 22 years earlier (Ramírez, 2011; Leal Diaz, 2012). Fig. 5 presents an aerial view of the dam (facing downstream), the day after the Alex event.

4.2. The Storm Drains Project (2002-2009)

Insufficient and deficient infrastructure to collect and evacuate runoff from even moderate storms had frequently created transit havoc in many parts of the MMA (Barragan, 2008; Flores Longoria and

Fig. 4. Geographical location of the Rompe Picos Regulating Dam. Source: Authors’.
Towards the end of the 1990s, the abundant and critical reporting on the issue (the influential local newspaper El Norte played a significant role in this) reflected a widespread grievance among Monterrey’s residents (Canales Clariond, 2011; Leal Diaz, 2012). This set the stage for a solution involving several state actors: the Storm Drains Project.

The Project initiated in the context of a very restrictive legal, financial and political environment (Canales Clariond, 2011; Aguilar-Leal Diaz, 2012). Clearly, there was no opportunity to prepare for the contingency. Between 1999 and 2000 the federal government’s National Agency for Civil Protection, with the collaboration of various universities and research institutions, developed and implemented Mexico’s first integrated system to deal with meteorological hazards: the Tropical Cyclone Early Warning System (TC-EWS). The TC-EWS was designed to monitor the position and intensity of hurricanes as well as coordinate emergency procedures at the federal, state and municipal level. The basic goals of the system were to have people move out of the path of dangerous storms in advance (a day or two) from vulnerable locations to safer ones, as well as to put in place emergency supplies and materials where potentially needed. In this way, recovery after the impact of a tropical cyclone would be simpler and shorter, improving the resilience of communities. Following the implementation of the TC-EWS nationwide, the number of fatalities associated with tropical cyclones in Mexico diminished dramatically, by one or two orders of magnitude (Magaña et al., 2014).

In 2002, SADM personnel had identified 420 points across the city at risk of flooding from runoff (SADM, 2019). Between 2002 and 2009 about 200kms of main and secondary drain collectors were laid (Fig. 6), reducing by 90-93% the risk of flooding in the city’s most exposed locations (SADM, 2019; Benavides y Lozano, 2013). The equivalent of USD250 million was spent in the process, 80% from SADM’s internal funds and the rest paid for by the federal government. Around 1.2 million people directly or indirectly benefited from the storm drainage project (Flores Longoria and Maldonado, 2009).

In 2007, a new state congress reversed the previous administration’s initiative and devolved responsibility for storm runoff management to the state government and metropolitan municipalities. The decision effectively left the MMA without an integral program to handle storm water and signaled a major step backward in the matter (Barragan, 2013). Such a reversal illustrates clearly the difficulties in building resilience (Aguilar-Barajas et al., 2015) and the non-linearity of the public decision-making process (also identified in the case of Mexico City, see Tellman et al., 2018).

4.3. The national early warning system (1999-2000)

At the time of the Hurricane Gilbert disaster, early warning capabilities were incipient in Mexico. At 22:40 on September 16 1987 the first official bulletin about the storm was emitted; at three o’clock in the morning of the following day, State Governor Treviño got a call to inform him the storm had reached the city (Benavides y Lozano, 2013). This time the city was not taken by surprise and preventive civil protection measures, including evacuation of residents in vulnerable locations and emergency transit restrictions, were put in place in a timely fashion. The relatively low count of fatalities from Hurricane Gilbert certainly can be attributed to this.

The TC-EWS obviously did not emerge in direct response to the Hurricane Gilbert disaster. Disasters of that nature had been a nationwide concern well before then, and continue to be – for example, more than 100 people died when Hurricane Manuel hit the country’s Pacific coast in 2013. In this case the MMA has gained resilience not through its own volition but rather as a consequence of this external context. Due to a number of modifications intended to make it more efficient, in recent years the TC-EWS arguably has lost some effectiveness (Magaña et al. 2014). The National Center for Disaster Prevention...
(CENAPRED) is developing a new, more sophisticated version of the system. The main feature of that new version will be a focus on risk and not solely the characteristics of the hazard.

4.4. Water governance before Hurricane Alex

Prior to the Alex disaster, water governance in Mexico and the MMA did not evolve significantly: it remained fragmented between the three levels of government (federal, state and municipal) and dysfunctional due to the lack of coordination between these actors (Aguilar-Barajas et al., 2016). Meanwhile urban development proceeded with little to no regard for the region’s hydrological reality. In particular, this had led to the obstruction or alteration of natural channels and the occupation of land exposed to flooding despite federal regulations prohibiting its use (Leal Diaz, 2012). Fig. 7 reveals, for example, how in one section of the Santa Catarina River, the width of the channel had been dramatically reduced from 275 m to 165 m by residential development and recreational and commercial activities. This aerial view was captured on May 13, 2009, slightly over a year before Hurricane Alex. It is noteworthy to consider that official state-level development plans at the time (Gobierno Constitucional del Estado de Nuevo León, 2010a) did not refer to the concept of risk management in the face of weather hazards. Moreover, the draft of the state’s first Risk Atlas (Gobierno Constitucional del Estado de Nuevo León, 2010b) was still under review months after the Alex event.

5. Knowledge co-production and urban resilience in the aftermath of Hurricane Alex

With Hurricane Alex, the MMA to an extent demonstrated an increased resilience to floods, in the wake of the resilience building process undertaken after the 1988 Gilbert disaster. The regulating dam upstream from the city, the expanded network of storm drains within the city and enhanced early warning capacities and civil protection protocols, all worked to significantly limit the impacts of the 2010 storm (Flores Longoria and Maldonado, 2009; SADM, 2010b; Leal Diaz, 2012; Benavides and Lozano, 2013; and CERNL 2013). The Alex disaster nonetheless revealed a significant level of social and economic vulnerability (OECD, 2013b) and in its aftermath, a new round of resilience building initiated.

5.1. The immediate reaction to Alex

The immediate reaction to the Alex disaster illustrated well the city’s store of technical capabilities. Piped water offers a case in point. As mentioned earlier, about 1.7 million inhabitants were left without the service (about 37% of total population). Within three days 85% of the MMA’s population had access to the service which was fully re-established within 15 days; at the end of July, tap water was safe to drink again (SADM, 2010a; SADM, 2010b). Repairing the city’s seriously damaged water infrastructure required concerted efforts on the part of the water and sewer authority; for several weeks, crews totaling 2,200 workers using 300 vehicles worked around the clock. During that time, SADM regularly emitted press communiques to inform the public on the progress being made. Another example of rapid rebound was offered by schools: despite many installations having been damaged, children started classes in August on time after their summer holidays (CERNL, 2013).

In parallel with immediate recovery initiatives, the city promptly embarked on a collective and innovative process of collaboration among numerous institutions and sectors of society, to develop solutions to the substantial challenges posed by the damages from the flood. Just three weeks after the disaster, the Nuevo León State Reconstruction Council (CERNL) was formally established.

5.2. Reconstruction: the Nuevo León State Reconstruction Council (2010-2013)

5.2.1. The Council’s architecture and operation

The Council brought together stakeholders from the three levels of
government as well as civil society, mainly from the city’s powerful business sector and main universities and research centers. The state government tasked the Council with guiding and coordinating all reconstruction efforts. Ten work committees were created to handle a wide range of issues: 1) Design and management of a Reconstruction Master Plan and Information System; 2) Financing and transparency; 3) Meteorological risks and water works; 4) Logistics, roadways and mobility; 5) Educational infrastructure; 6) Housing and urban planning; 7) Aid for vulnerable households; 8) Economic recovery; 9) Health; and, 10) Communications. Each committee was to interact with several federal, state and municipal departments and agencies (CERNL, 2013).

The Council soon faced face coordination challenges (CERNL, 2013). In the Mexican context, such problems are not uncommon and derive from the country’s fragmented water governance architecture (Aguilar-Barajas, 2016; Torregrosa et al., 2015; OCDE, 2013c). Coordination among the three levels of governments itself proved difficult and the process surrounding the financing and contracting of public works, convoluted. In particular, access to funds from the FONDEN (Fondo Nacional de Desastres Naturales), a federal entity created in 1996 to provide financial help to states and municipalities affected by natural disasters (OECD, 2013b), was sluggish.

The following illustrates the previous points. When SADM completed the reconstruction of the water and sewerage infrastructure affected by the storm, it could not proceed and carry out maintenance work on the Rompe Picos Dam because of the poor state of the access road (CERNL, 2013). The federal communications and transport ministry, responsible for the rehabilitation of that access road, could not begin work as FONDEN had not released the required funds. The same ministry also complained that reinforcing riverbanks was being made difficult by the lack of progress on the part of the federal water authority as well as the Nuevo León sustainable development secretariat. Meanwhile, work on rectifying the course of the Santa Catarina River came to a halt when engineers realized that the data made available by the federal statistical agency (INEGI) did not meet the spatial resolution requirements previously established (Ramírez, 2011). In order to proceed, new data had to be generated through reconnaissance flights over the river, which had not been originally planned or budgeted for.

5.2.2. Results

The reconstruction of transport infrastructure proceeded gradually, as damages to the city’s two main east-west arteries that follow the course of the river (Constitución on the north bank and Morones Prieto on the south bank), as well as bridges over the river connecting the north and south sides of the city, were extensive. These arteries are fundamental for mobility in the MMA and also play an important economic role in the regional transport network linking the MMA to national markets and Texas. Reconstruction of these arteries and bridges naturally constituted one of the main and most important tasks of the Council.

The new infrastructure put in place, offered significant improvements over what the flood had destroyed in terms functionality, capacity and robustness to withstand future floods (Sisto and Ramírez-Orozco, 2015); for example, elevated bridges replaced the old culverts that had been washed away. Nonetheless, it later became apparent that the two rebuilt arteries lacked sufficient storm drains: in 2013, large pools of water formed in several sections when Hurricane Ingrid dumped copious amounts of rain over the city. State authorities admitted the flaw present in the new infrastructure but argued that the reconstruction budget had not permitted to do more. Since then, people have come to expect water problems on the new roads whenever it rains hard.

In July 2013, three years after the Alex event, the Council disbanded after presenting its final report – cited here as CERNL (2013). That document reported 5,523 actions completed (99.5% of the list of actions contemplated initially) and estimated total reconstruction expenses at 16.9 billion pesos (approximately USD$1.3 billion). In terms of funding, 62% originated from federal sources and 38% from state sources. In terms of spending, 28% of expenses were exercised by federal authorities - nearly all of this went to hydraulic works – and 72% were exercised by state authorities. In that case, nearly all was spent on road works and urban infrastructure; less than 5% of state authorities’ expenses went to education, housing, health and the environment.

Reconstruction expenses amounted to 1.83% of the 2010 state Gross Domestic Product (OECD, 2013b) – note that more than 90% of the state’s economic activity takes place in the MMA. The considerable sums involved motivated many instances of rivalry, bickering, or worse. For the duration of the reconstruction period, the state and federal

Fig. 7. Obstruction of the Río Santa Catarina channel (aerial view, May 13, 2009). Source: Authors’, with data from Google Earth.
administrations belonged to two distinct, antagonistic political parties. Roadside billboards proliferated at reconstruction sites to inform motorists and passengers by which authority (state or federal) was in charge. In the rush to deliver projects, norms and rules (technical, legal and financial) were violated, in some cases leading up to abuse and corruption (Leal Díaz, 2012).

The reconstruction process nonetheless proved successful overall and fairly rapid. This achievement can be credited in part to the work of the reconstruction Council but also to the general social environment that characterizes the MMA. Monterrey has a history of entrepreneurship, innovation and public-private collaboration. This has enabled the city to overcome the multiple challenges described earlier, beginning with the Council’s creation and operation. Monterrey’s experience illustrates well the complex nature of building urban resilience: multiple, varied stakeholders engaged in a web of intricate (and sometimes contradictory) relationships within a rich multi-layered context, with outcomes that do not lend themselves to simple explanations.

5.3. Legacy: the Council’s main recommendations

Knowledge produced within the Council was presented in a systematic and ordered fashion in its final report. The main takeaways in terms of recommendations for increasing resilience to floods consisted in: to build an additional regulating dam in the upper Santa Catarina River Basin to complement the existing Rompe Picos Dam (arguably, two or more additional dams would be of use); to relocate people living in areas at risk of inundation and impede their return (i.e. to enforce existing federal land use laws); to reform and simplify existing regulations on the operations of FONDEN as well as procedures for public works contracts (i.e. to cut red tape); and to reforest the upper basin of the Santa Catarina River to limit runoff downstream and into the city. The MMA Water Fund created for that specific purpose, which gathered stakeholders from government, the private sector, academia and civil society in general, has been working systematically on this issue. In 2016 the Fund purchased 1,200 hectares of land for reforestation in the upper basin and currently in 2018, is in the process of acquiring an additional 1,000 hectares.

Towards the end of its mandate, the Council at the invitation of the state government participated in the creation of a new state Strategic Planning law. A new council for Strategic Planning was also established. The purpose of that civil-governmental body was to craft development policies and monitor their application. Out of this came out the state’s first Strategic Plan for 2015-2030 (CNLPE, 2015). This Plan surprisingly barely mentions risks from weather hazards such as hurricanes and makes no reference to the knowledge produced during the years of the Council’s operation. This illustrates that knowledge about building urban resilience does not simply accumulate over time and may even be lost.

The city to this day still faces significant risk from large storms of the Gilbert or Alex category. Fig. 8 presents areas in the city’s downtown currently classified at risk of flooding from urban runoff (dots) and from the river overflowing (light shaded areas), considering a return period of 1,000 years. Clearly the process of building resilience has not reached completion, but more than eight years after the Alex disaster, complacency appears to be taking hold.

6. Conclusions: lessons learned and the way forward

The MMA has built a degree of resilience to floods through a complex process - drawn out, incremental and non-linear. This process has been conditioned in part by the nature of the hazard the city faces: the infrequency of catastrophic floods has shaped stakeholders’ perception of the risk, fostering complacency and adversely affecting risk management decisions. The 16-year delay after the 1988 Hurricane Gilbert disaster in implementing the city’s foremost element of preventive resilience infrastructure - the upstream regulating dam - is a clear expression of this. So is the absence, more than 8 years after the 2010 Hurricane Alex disaster, of a plan to build the additional regulating dam recommended by the Nuevo León State Reconstruction Council in 2013.

The previous exemplifies how some of the knowledge co-produced in the wake of the 2010 disaster seems to have been, if not lost, at least temporarily forgotten. How to ensure the conservation and continued development of this knowledge raises important questions. At a minimum, this should be an explicit objective of a permanent state development strategy. The experience of the Council may be of great value in this regard, especially the institutionalization of its major recommendations. The continuous updating of the Risk Atlas is another example of what could be done.

The city’s cultural and socioeconomic context has abetted its resilience building process. The immediate reaction to the 2010 disaster revealed the city’s capacity to quickly recover essential functions following a major disturbance and the prompt creation of the Council, its ability to innovate. The relatively rapid and effective reconstruction of the city and the significant work of the Council during that period also reflected that local context - examples of effective multi-stakeholder working groups in Mexico such as the Council are to say the least, not common. Monterrey’s tradition of industry, commerce, higher education and cooperation between the business community and local authorities, has produced an environment that has enabled resilience building. Nonetheless, the institutional capital and knowledge built up in the aftermath the disaster have begun to dissipate to an extent. Most of the recommendations formulated by the reconstruction Council have not translated into concrete action, with the exception of the proposal to reforest the upper Santa Catarina River basin. The MMA Water Fund (FAMM) currently undertaking reforestation work upstream from the city is a notable example of the MMA’s currently dampened but continuing resilience building process.

The wider external political and administrative context in which the city is embedded has made varied contributions. On the one hand, the weak national water governance architecture (understood as the whole social apparatus through which decisions are made) has hampered the coordination of stakeholders’ actions in the aftermath of the 2010 disaster and limited the extent of improvements to infrastructure. On the other hand, the national early warning system implemented after Hurricane Gilbert saved dozens of lives in the city in the 2010 disaster. Monterrey has also benefited from the federal government’s financial contribution to reconstruction – a sound investment for the country as a whole given the city’s strategic importance for the Mexican economy.

The MMA’s history of damages from storms shows that more than “natural disasters” these events are the consequences of inadequate prevention, poor land use planning and insufficient resilience (Leal Díaz, 2012; Zúñiga and Magaña, 2018). In the Mexican context, urban land use patterns are the result of complex social, economic, institutional and political processes involving a multiplicity of actors, at times antagonistic. The current legal framework where federal regulations prohibit development on riverbanks but local authorities manage their own urban development plans and administer construction permits does not help, but the solution to this conundrum requires more than simple regulatory changes. Appropriate mechanisms for effective enforcement of existing regulations are needed. Political rivals must realize that urban resilience is a necessity that transcends any particular agenda, and collaborate towards finding solutions. The public at large also bears responsibility: people need to appreciate the rationale for land use regulations and act accordingly.

Torrential rains and floods pose obvious risks for the MMA but also present significant benefits. In the region’s relatively dry climate, exceptional rains help replenish reservoirs and aquifers that provide water to the city. For example, in mid-2013 after a prolonged dry spell reserved in the MMA’s three reservoirs reached below 20% of their combined capacity; the city was on the brink of a water crisis when Hurricane Ingrid fortuitously appeared to replenish reserves (Sisto et al. 2016). In a future where the MMA has reached a high level of resilience
to storms and hurricanes, these should come to be perceived as benefi-
cial. Resilience and water security are in this way intimately linked for
the MMA and stakeholders will need to refine their perception of risk
and risk management with a view “…to mitigate the losses and improve
the benefits that people experience when they face risk and opportu-
nity…” (World Bank, 2013). This shift in perception would require, first
and foremost, educating stakeholders on the multifaceted issues in-
volved and the advantages of preventive, integral risk management
over a reactive, emergency-based approach. This shared knowledge and
understanding would facilitate the building and sustaining of a social
consensus on policy, including the necessity of adopting a broad urban-
regional system scale that links explicitly urban resilience to

Fig. 8. Areas at risk of flooding risk, Downtown Monterrey (return period of 1,000 years).
Note: areas at risk of flooding from urban runoff (dots) and from the river proper (light shaded areas).
Source: Authors’, based on Atlas de Riesgos AMM (2019).

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