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**The expanding commons dilemma for water in the Basin of Mexico**

## Introduction

The storied history of water management in Mexico City has been well documented, and most scholarship places the current crisis in context of historical decisions that set the city on its arguably unsustainable path (Romero Lankao 2010; Tortajada and Castelán 2003; Sosa-Rodriguez 2010). This article frames the story of water management in Mexico City as an evolving, expanding commons dilemma, from the 1300s to the present day (table 1). I use a coupled infrastructure framework from (Anderies, Janssen, and Ostrom 2004)-see figure below- to trace how the resource, resources users, public infrastructure, and its providers, evolve in the management of water supply and flood risk in Mexico City.

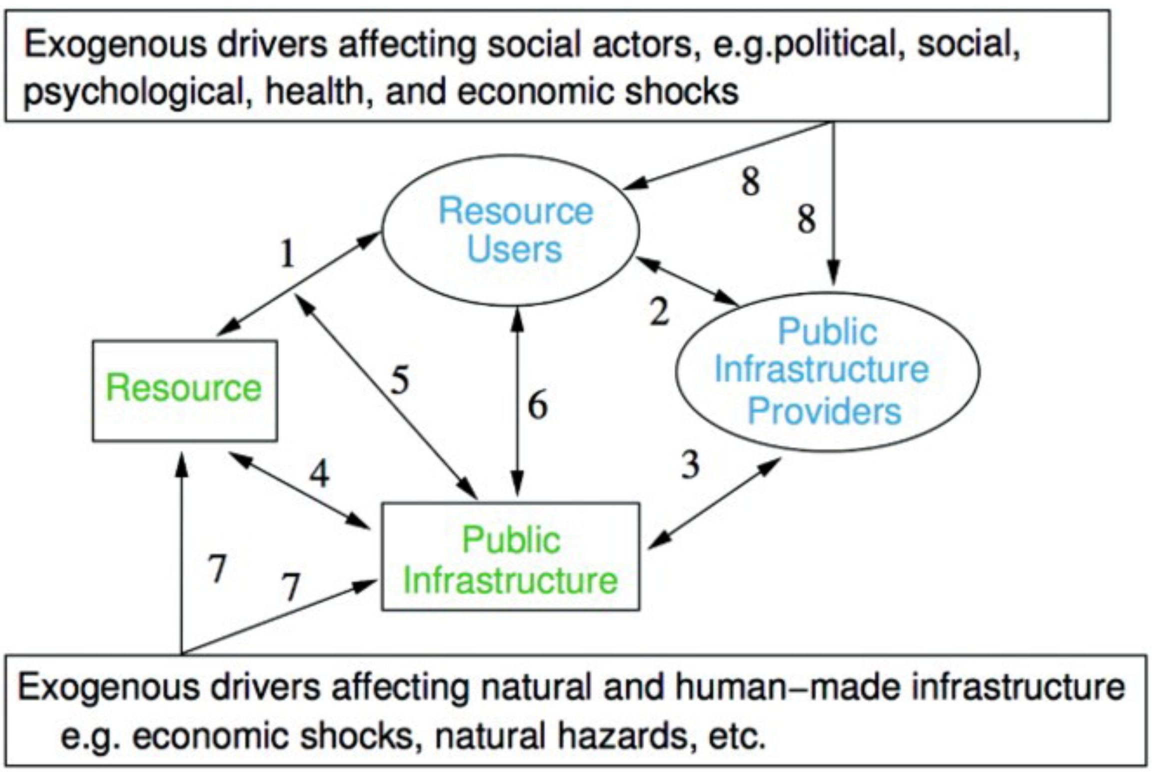


**Figure 1.** Coupled Infrastructure Framework from Anderies et al 2004.

Changes to the coupled infrastructure system are initiated by shifts in mental models of the public infrastructure providers of how to manage variance in the water system. Mental model shifts are a response to perceived feedbacks from the biophysical system (see figure 2a). These feedbacks may be fast (e.g. a major flood event) or slow (the realization that subsidence accumulates over time). In either case, the public infrastructure providers over time manage robustness for increasing dimensions of the system. Managing variance of multiple water risks (both flooding and scarcity) in present day Mexico City introduces a more complex manifestation of robustness-fragility tradeoffs (protecting against high frequency vs. low frequency events), and emerge as *vulnerability transfers* that go beyond risk tradeoffs over time, and extend to tradeoffs over space and to different types of risk altogether. Managing these multiple, interconnected risks is the governance challenge in Mexico City today.

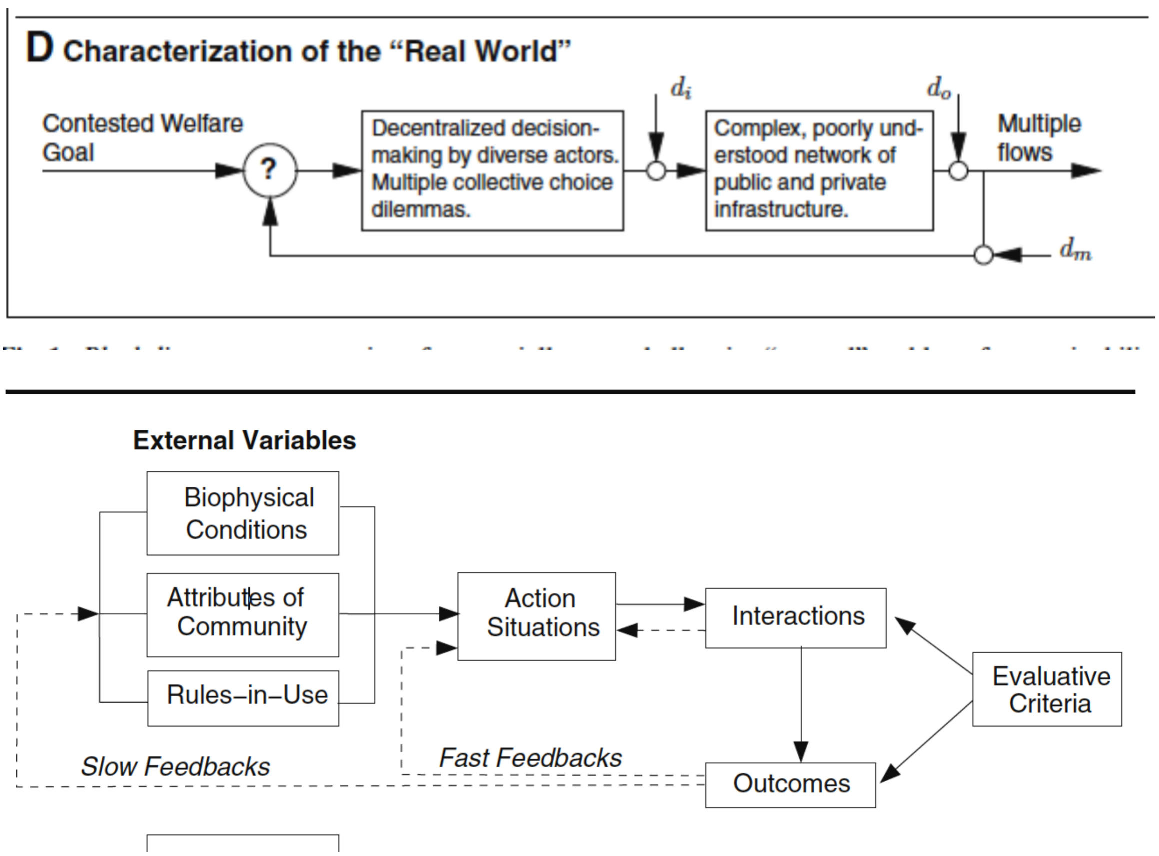


Figure 2a and b-from Anderies 2014. Concepts of how fast and slow feedback influence the "controller" or the public infrastructure providers in an action situation.

## Expanding Dilemmas and Mental Model Shifts

Mexico City, a megalopolis of 22 million, is located at the center of the Basin of Mexico (7000 km$^2$). Prior to Spanish Conquest, water drained from the surrounding volcanic mountains into the basin interior. Tenochtitlan, the predecessor to Mexico City was founded in 1325, improbably located on improved islands in the center of a series of shallow, saline lakes that at that time covered the Valley of Mexico. Early Miztec people farmed in this aquatic environment, developing a system of chinampas, or floating agriculture. Aqueducts brought water from the periphery to the center. The lake was viewed as an essential part of natural infrastructure both for agriculture, defense, and transport.

This system was vulnerable to floods, and a series of extreme events taught the Miztec leadership that in addition to regulating water to prevent scarcity, regulating water to prevent excess was also required. Public infrastructure providers organized the construction of complex flood sluices and dykes. The community experienced structural robustness vulnerability tradeoffs (see Anderies's response to Carpenter et al. 2015), as many floods small are managed, allowing the population to expand near lakeshores. Land, in addition to water, becomes a valued part of natural infrastructure for the Aztecs. However infrequent but high magnitude events kill 10% of the population in one instance, and in another, require the entire capital to be rebuilt.

**Table 1.** Mental Models and SES Representation over time. Notes taken from Hallie Eakin-compiled from (Romero Lankao 2010; Acosta 1993; Garcia 2006; Aragón-Durand 2007, and others)

| Mental Model | Date | Resource | Resource User | Public Infrastructure | Public Infrastructure Provider | Feedbacks |
|---|---|---|---|---|---|---|
| ***Lake water is essential resource for human wellbeing and political security*** | 1324-1382 | Lake Water, Spring water for food, drinking, and as defense | Farmers | Soft: political agreements on water transfers from periphery to center; chinampas maintenance system; human waste management system<br>Built: aqueducts for potable water; *chinampas* construction | Miztecs | Fast-Extreme Flood events in 1382, 1446, 1448-9, 1469, 1499 |
| ***Lake water and spring water is essential resource for human wellbeing and political security***<br>**BUT flood exposure must be controlled** | 1382-1517 | Lake water (*chinampas*, transport, defense)<br>Spring water (drinking water)<br>Land (population residence, agricultural area, building materials) | Farmers | Soft: political agreements on water transfers from periphery to center; chinampas maintenance system; human waste management system; dyke maintenance and water level regulation<br>Built: dykes, sluices for flood control; aqueducts for potable water; *chinampas* construction | Aztecs | Fast: flooding (precipitation extremes) destroy settlements<br>Slow: threaten agriculture (salinization); water scarcity (population growth vs. supply) |
| ***Lake is no longer a resource; represents risk of flooding. Drainage infrastructure and engineered solutions necessary to ensure urban viability*** | 1521-1865 | Potable water (springs).<br>Waste disposal (sewage, lakes).<br>Limited recreation (canals) | Spanish | Soft infrastructure: Legal/financial arrangements with Spain; legal commitments to allocate waste water to agricultural interests north of city<br>Public infrastructure: (half-hearted) dykes/flood barriers; urban drainage system; lake drainage (Tajo de Nochistango) | Spanish | flooding – loss of lives and property; |

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|---|---|---|---|---|---|---|
| ***Flooding represents sanitation risk; population growth and waste disposal urgent concerns. Existing water bodies sanitation threat. Drainage infrastructure (combined sewage/ storm water) required.*** | 1865-1938 | ; Xochimilco provides potable water; Land provides capacity for urban expansion; aquifer now provides potable water | Spanish | Public infrastructure: Urban drainage system; lake drainage; waste system (Gran Canal); well infrastructure<br>Soft infrastructure: limited regulation of well construction, initiation of resource control over watershed and aquifer | Spanish | Risks: water scarcity for growing population; flooding; sanitation Repeated flooding 1819, 1865, 1875, 1879. |
| ***Problem is increasing water scarcity, subsidence, flooding and problems in enabling drainage (loss of gravitational flow). Solution is infrastructural; importation of water from Estado de México; export of waste to Hidalgo (Drenaje Profundo)*** | 1938 - 1985 | Groundwater and Lerma now primary resource (from Edomex and Mex City); Land provides capacity for urban expansion; waste is agricultural resource in Hidalgo; drainage is ag resource in upper lerma | Mexican | Soft infrastructure: Inter-state transfer (Lerma/Cutzamala; Hidalgo/Mexico); well regulation; drainage of Xochimiloco (and then recycling of water from Iztapalapa);<br>Public infrastructure: Groundwater extraction infrastructure; Cutzamala-Lerma; Drenaje profundo… Sewage system and city drainage; pumps…; Green infrastructure: Proyecto Texcoco | Mexican | Subsidence (slow moving) causes Infrastructure (drainage) failures → Flood 1951 (sanitation problem) |
| **Water scarcity… Creating redundancy … Halting urbanization in Suelo de Conservación (zero growth/Banda Dos)… Climate change … Encharcamientos management… Sustainability discourse…** | 1985 to present | Land and watershed provides capacity for urban expansion; aquifer now provides potable water; water from other watersheds critical importance; drainage of city plays fundamental role in flood management | Mexican | Public infrastructure: Lerma-Cutzamala; waste system (Gran Canal, TEO); well infrastructure; pumps/ "rebombeo"; green infrastructure: infiltration; vasos reguladores. [Airport…]<br>Soft infrastructure: Zero growth on suelo de convervación, densification; vote buying, role of delegaciones in water management, *pipas* … | Mexican | Fast: Earthquake of 1985 → Population displacement Chalco 2010… Slow: lack of confidence in water supply |

After Spanish conquest, the Spanish become the new public infrastructure providers. After repeated flooding, the mental model of these public infrastructure providers no longer view the lake as valuable natural infrastructure, but rather a risk to be managed. The lake is used as a waste dumpsite, and as new built infrastructure systems are developed, eventually drained. The Aztec populations were enslaved to dismantle their own built infrastructure system of dykes and forced into labor. The drainage system introduces new systemic health risks, as open channels because a source of cholera and other diseases. Robustness-fragility tradeoffs persist, as extreme floods continue to plague the Spanish.

By the early 1900s, after the Mexican revolution, the drainage tunnel started nearly 200 years earlier to drain the basin was finally completed. Mexico City would come to permanently rely on the public infrastructure system of drainage installed during this time. Water scarcity became the new primary problem as springs began to dry up, and technology to drill wells into the aquifer was introduced. Ground water becomes the focal natural infrastructure to be managed.

By the 1950s, it was clear that solving water scarcity by installing wells had caused subsidence of up to 45 cm/year(Downs et al. 2000) . The more effective drainage system also contributed to subsidence by significantly reducing groundwater recharge. Public infrastructure providers begin to prohibit construction of new wells in the city center in response to the “slow feedback” of subsidence. The new resource of interest becomes surface water of rivers external to the basin (Lerma). In addition to managing the natural infrastructure of the lakes and the aquifer, the scope of intervention for public infrastructure provider moves to rivers external to the city. The beneficiaries of this public intervention are the resources users of Mexico City, not those living near the Lerma River, far from the capital.

As both population and subsidence put pressure on the resource and the built public infrastructure system to supply and drain water, investments to regulate these two risks intensifies. In 1982, another major interbasin transfer is complete, and in 1970 new deep drains are installed to continue to drain the city despite subsidence reducing effectiveness of original channels. With population growth (see figure 3) comes rapid land use change, increasing runoff into an already under capacity sewer system. Public Infrastructure providers begin to recognize land as a valuable part of natural infrastructure essential to regulating water scarcity and flood risk. Efforts to curb urbanization and conserve protected areas with ecosystem services are in place by 2007. New investments in soft public infrastructure are made as the National Water Law creates Watershed Commissions (Consejos de Cuenca) to try and coordinate investments in land, hydraulic infrastructure, groundwater, and surface water management. These commissions become the main public infrastructure providers governing water risks in Mexico City today.

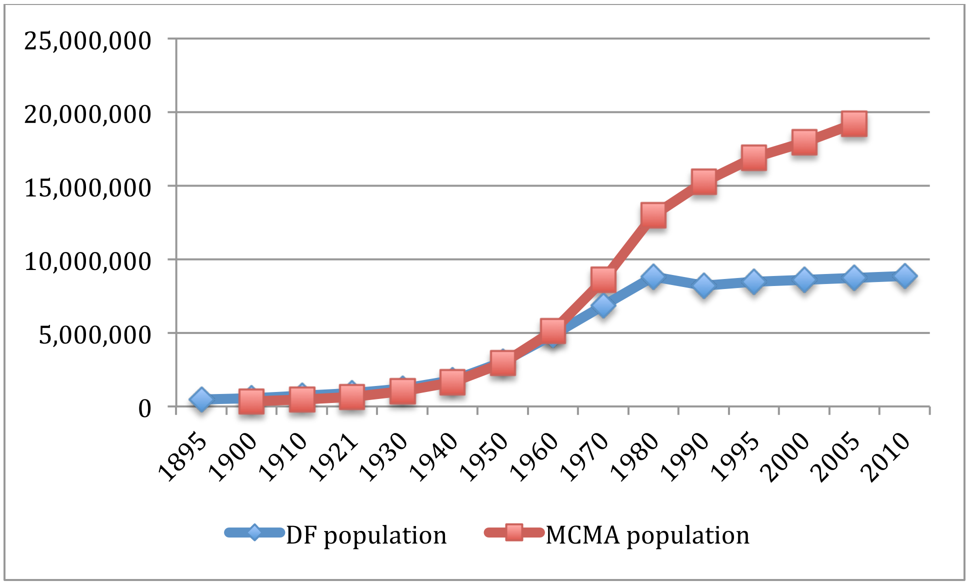


**Figure 3. Population Growth** in DF (Mexico City) and MCMA (Mexico City Metropolitan Area. By Chrissie Bausch

**Wicked Robustness**

While the natural infrastructure of the watershed of the Basin of Mexico, including its land, topography, and aquifers has always regulated water scarcity flood risk, only recently have public infrastructure provider begun to governed it as an integrated watershed system. As control of water revealed new fragilities and risks in the system, public infrastructure providers went from managing variability of water for irrigation, to drinking water supply, to flooding, to subsidence rates, and now manage urban expansion and land use change. Is it possible to manage and control all of these changing variables? Would reducing variance in all these dimensions make the city more resilient or reduce it's safe operating space, like the examples in Carptener et al ( 2015)? Is managing robustness to so many elements a "wicked" problem (Rittel and Webber 1973), or a zero sum game?

Despite efforts to build soft infrastructure (see the IAD- Fideicomiso 1928, or the Consejo de Cuenca) to overcome poor coordination, under provisioning of public infrastructure, and over appropriation of water resources, efforts continue to focus on investments in large infrastructure projects. Each investment increases path dependency on investing in infrastructure, because it must be maintained, as its failure could pose an even greater risk than its absence. As Sosa-Rodriguez(2010) notes, some water risks are prevented (e.g. frequent flooding), while new ones are created (flooding with raw sewage water in the Valle de Chalco). In fact, if the main central drainage tunnel would fail, Mexico City would flood up to 5m in the historic center, and the flood foodprint with cover 217 km$^2$ (SEMARNAT). On the other hand, if the new drainage system succeeds in preventing flood for Mexico City, there is speculation that the city of Tula could be flooded as a result.

Regulating flood risk in Mexico City is not just a classic fragility-robustness tradeoff over time, but it may transfer risk over space, or change the type of flood risk (from just water to raw sewage, introducing new health concerns). Sapountzaki (2007) identifies 5 types of potential vulnerability transfers i) among individuals ii) tradeoffs in increase resilience for the collective at expense of the individual and vice Versa iii) vulnerability to one type of risk can transfer to another type iv) physical risks translate to socio-economic risks, and v) short risks transfer to longer term risks.

The main coordinating body for public infrastructure providers in the basin, the Consejo de Cuenca includes actors from all governance levels (including Hidalgo, the Mexican state where Tula is located), giving it a good vantage point to understand possible risk transfers with making decisions. Two issues arise with this centralized decision-making.

First, the concentration of power and funding for water governance activities in the central Consejo instead of the local Commissions de Cuenca, has made monitoring and sanctioning difficult. While the CONAGUA knows of the existence over 3,000 wells pumping the aquifer without a permit, they do have not capacity to keeps tabs on all 9000km$^2$ of the Cuenca (Interamerican Development Bank 2012). The commissions (only responsible for 500-1000 km2) can play this role.

Second, it is the local commissions de Cuenca that are given responsibilities to restore and protect natural infrastructure for the Basin. However, if they are not given funding and authority to execute this mandate, the soft public infrastructure written into law will not allow them to be public infrastructure providers and stewards of the natural infrastructure.

Finally, one of the actions with little consequences in terms of robustness-fragility tradeoffs is to merely repair the existing leaks in water pipes that cause 40% of water supply to be lost every year (Downs et al. 2000). Repairing leaks could also increase water pressure, facilitating supply to more water scarce locations. However, municipal organizations like SACMEX (Water System of Mexico City) govern maintenance, and are already running debts of several billion dollars a year. There is no funding nor incentive for SACMEX to invest in fixing leaks when its budget appropriations come from municipal assemblies and not the user fees themselves(CENTLI 2009).

**Conclusion**

This article examines how the coupled infrastructure regulating water scarcity and flooding in the Basin of Mexico has evolved over time. Public Infrastructure Providers have changes from the Aztecs, to the Spanish, to the Federal Government, and now to a multilevel watershed governance system involving multiple actors. The common pool resource of interests has grown from water for irrigation and drinking, to include infrastructure for flooding, drainage, and supply. As governments have struggled to control variability to multiple risks in the basin, feedback loops such as subsidence have complicated efforts. Investments in massive infrastructure have influence a path dependency and “stickiness” towards the built infrastructure and the centralization of power in decision-making over water. New exogenous drivers of climate change will further challenge the robustness of built public infrastructure to regulate variance.

Managing risk in the Basin of Mexico remains as challenging know as it did in 1342, when it was first settled. Is the persistence of the city a testament to its resilience? Or a robustness-fragility tradeoff vulnerable to the next extreme event?

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