Water Scarcity, Flooding, and Public Infrastructure in Mexico City

December 11, 2015

1 Part I: System Structure - Collective action

Mexico City, a megalopolis of 22 million, is located at the center of the Basin of Mexico. For over 600 years, catastrophic flooding and access to potable water have challenged the city's residents, motivating extensive investments in hard infrastructure to supply the city with fresh water, or to protect the city from periodic flooding. The case study catalogues an action situation involving residents and their local, city, state, and federal governments that formally and informally govern land, water, and the built infrastructure that regulates water supply and flood risk.

The key resources (natural infrastructure) in the system are the hydrology, topography, aquifer (shared), and land (private) that make up the Basin of Mexico watershed. The key resource relevant to the commons dilemma faced by the city is water, regulated by built infrastructure (common-pool) that extracts, exports, dams, and moves water into and out of the city. The main social dilemma is the over appropriation of groundwater and land for urbanization and under provision of public infrastructure to effectively regulate urbanization and aquifer extraction (soft) and repair leaking pipes that breaks as subsidence increases (built).

This case study is an addition to the original Common-Pool Resource (CPR) database.

The Commons Dilemma

Potential over appropriation / poor coordination of appropriation

Ground water over appropriation has existed for at least the past 80 years, when the city began drilling the artisanal aquifer in 1937. Current extractions to replenishment rates are 1.6 to 1. While many wells in the city limits were closed after the 1950s, regulated, together with unregulated and illegal drilling has continued outside the city borders and in the watershed area. While soft public infrastructure of water laws and basin commissions that span local to national actors are present, monitoring illegal extraction is insufficient. Of the 6,000 detected wells in the basin, only 3,000 are legally registered. Lack of legal support and funding to local sub basin commissions, especially in rural areas of the Basin, limits their ability to monitor and sanction municipal governments in the State of Mexico who often sell permits illegally. Over exploitation of the aquifer leads to subsidence, reducing the function of built infrastructure and exposes residents to new flood risks. Poor coordination of appropriation of surface water from rivers outside the Basin of Mexico into the city has resulted in major social conflicts, as rural communities along the Cutzamala river have no potable water supply, yet see major federal investments carrying water from the river far away to Mexico City.

In addition to water, land has also been over appropriated due to extensive and unregulated urbanization from 1950-2000. Irregular settlements, covering an estimated 9000 ha, are often located in parks and protected areas where there is less control and undefined land tenure. While local governments are not legally permitted to carry city water supplies to these settlements, in some cases, local politicians skirt these laws and either regularize or bring water infrastructure to the settlement in exchange for votes. Urbanization degrades the both ability of the aquifer to recharge and the soil to mitigate floods via infiltration. However, new payments for ecosystem services programs attempt to compensate farmers in upstream portions of the watershed for the affordances they provide by conserving the land.

Potential under-provisioning of public infrastructure

The underprovision of built infrastructure has historically been a problem in Mexico City, in part because increasing rates of population growth and subsidence can overburden destroy the water supply and drainage system, which requires increasing investments to maintain. The city requires a drainage capacity of 315m3/s, but currently only has capacity for 165m3/s (compared to 280m3/s in 1970). Financing for mega infrastructure projects was previously thwarted by poor coordination between state, local, and federal actors in the watershed, whose disagreements in the Fideicomiso 1928 (see rules-in-use) from 1996-2002 caused both the Interamerican Development Bank and Japanese government to take back promised loans (360 and 410 million, respectively), which would have been designated for major infrastructure repairs. The Fideicomiso was reinstalled in 2007 and has since successfully pooled local, state, and federal funds to support critical infrastructure projects, including a new major flood drain.

While the Fideicomiso supports mega infrastructure projects, maintenance of local supply and drain pipes continues to be underfunded. This is in part because the price of water does not cover operating costs. SACMEX, the city water authority in charge of this maintenance, typically runs a budget deficit of over 5 billion dollars a year. This under investment comes at a high cost- an estimated 30% of the water in the supply system is lost in leaky pipes.

Finally, local residents free ride off the water supply and drainage system. Irregular settlements often illegally connect to the city's flood drainage system, reducing its capacity and performance. Clandestine water extraction for the surface supply system by farmers in near the Cutzamala supply pipe reduces the amount of water available to city residents. While there is no sanctioning or monitoring for these behaviors, the impact on flooding and water supply is unknown.

1.2 Biophysical Context (IAD)

Natural infrastructure (NI):

Mexico City is located at the center of the Basin of Mexico (9000 km^2), a naturally closed depression or *endorheic* basin. 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. Since the time of Spanish conquest, the State has funded major biophysical transformations by draining lakes, deforesting and urbanizing the watershed, extracting drinking water from thousands of wells, importing drinking water from 9 watersheds 100 km away (McDonald et al 2014), and constructing over 10,000 km^2 of drainage networks to pump flood and waste waters out of the city, draining into another watershed which then drains towards the city of Tula.

Water from the aquifer accounts for 60% of the city's water supply, and is a scarce resource. Continuing to pump the aquifer has increased subsidence rates, which range between 5-45 cm/year. Some portions of the city have sunk by 7 meters over the past 100 years. Continued depletion of the aquifer also decreases water quality, due to both natural minerals and cracks in the soil, allowing waste water to contaminate the aquifer.

Watershed topography creates natural asymmetries in water access and flood risk. As water is pumped from lower elevation, decreased water pressure in the system means that communities at higher elevations have lower water pressure, and some days receive no water supply. While communities at lower elevations have less problems with water scarcity, they experience higher flood risk when the drain system is overwhelmed, and experience greatest rates of subsidence, which can destroy the private infrastructure of their homes.

Hard human-made infrastructure:
Well and pipes are primarily used to bring water from the aquifer and distant watersheds to the city and into peoples homes. All residential and industrial wastewater (only 8% treated) is combined in the same infrastructure as stormwater and pumped out of the Basin through the Gran Canal and the "Deep Sewage" system (Drenaje Profundo). Both systems were designed to be gravity operated, but increasing land subsidence now requires fuel-intensive pumping to drain sewage and flood water. Subsidence rates of up to 60cm in Valle de Chalco caused major flooding in 2010 and 2011, when a combined rain and sewage canal burst. Ironically, earlier attempts to build levees in this region only served to increase subsidence due to the increased weight of concrete, and were rendered maladaptive. All built infrastructure regulating water supply and flooding is public and government regulated. Some small-scale public infrastructure (held at the communal level), such as pumps to remove floodwater from neighborhoods is present. Private infrastructure in the form of cisterns, or water supply tanks, can increase water supply to individual homes by allowing them to store water on days they don't receive public supply.

1.3 Attributes of the Community (IAD)

Social Infrastructure

The governance of water resources for the Basin of Mexico spans multiple governance levels and involves many overlapping actors, the most essential are outlined in the rules in use. The main role of each is outlined in the Mexican Constitution and the National Water Law, though additional laws (or lack of them) to regulate land use also influences water supply and flood risk. Civil society is active, and regularly protests due to lack of water or after major flooding events if concerns are not addressed. Some clientelistic relationships (e.g. exchanging a resource, like water, for political support) are present in irregular settlements and communities of higher water scarcity. Politicians looking to gain votes will bring water trucks to fill cisterns in homes on days that water supply is unavailable. Residents typically complain that corrupt governance and mismanagement is partially to blame for flooding and scarcity problems.

Human Infrastructure

Innovative proposals to solve the water crisis, from rainwater capture, to conservation, to green infrastructure, have been supported by universities and NGOs in the city. Mexico City residents include prominent intellectuals, architects, and scientists working to solve water issues. The government has yet to fund and support some of the innovations on a large scale. Many communities have deep experience in collective action to solve their own flood and water risks, in part due support from organizations formed in the rubble of the 1986 earthquake.

1.4 Rules in Use (IAD)

Position Rules:

The Federal government (CONAGUA, Consejo Nacional de Agua) is responsible for administering water from the aquifer and surface water from other basins. They also operate major dams and infrastructure projects, including the large drainage system of Mexico City, and regulate well permits.

The Fideicomiso 1928 is a financing mechanism meant to span 3 government scales to fund major water projects in the Basin of Mexico. There are 2 voting representatives from Mexico City, 2 from Mexico State, 2 from the Federal Secretary of Finance, and 2 from CONAGUA, who presides the group. There is one representative from National Public Works department who has voice but no vote. Funding comes from member groups, and from the sale of bulk water (e.g. water from inter basin transfers and wells sold to operating organisms to distribute).

The Consejo de Cuenca coordinates decisions across all government scales. It brought actors together to write the essential "water protocol" for the basin, which designates how drains and pump stations will be operated in a major flood event. The consejo should advice operating organizations to set fair water prices. This includes actors from the States of Mexico, Tlaxcala, and recently, Hidalgo (the state the receives the Basin of Mexico's flood and sewage water). The Consejo is in charge of distributing water from their own set of wells (called the PAI) and the Cutzamala interbasin transfer.

The "Operating Organizations" (SACMEX in Mexico City, and CAEM elsewhere in the State) are responsible for local water distribution, maintenance of pipes, payments for services, operation of wells, and supply of local rainwater and treated grey water. SACMEX is in charge of one of the interbasin transfer systems, the Lerma.

Delegations (only in Mexico City) are local elected governments in Mexico City that support SACMEX by distributing water to local communities.

Metropolitan Comission of Drainage and Water (CADAM) oversees storage and filtration of rain water, and treatment of wastewater.

Comsiones de Cuenca are present in subwatersheds of 500-1000km2. In support of Conagua, they can check well permits and monitoring illegal drilling, maintaining forested slopes, reducing contamination in industry and agriculture. Representation must at least 50% by civil society, no more than 35% by state and municipal government, and the rest is federal representation.

Comites Tecnico de Agua Subterranea (COTAS) monitor local aquifers. There are 4 major aquifers below Mexico City, but only one COTA has been formed (for Cuautitlan).

Many other organizations regulate land use through Forestry (SEMARNAT, CONAFOR), Agriculture (SAGARPA, SEDEREC, SEDATU), Housing (SEDUVI) which are not covered here.

Boundary Rules: public infrastructure providers are appointed or hired by the government that has been voted into power.

Choice Rules: These are complex due to overlapping governance roles. For example, Comisiones de Cuenca *may* monitor and sanction illegal drilling, but often do not have financial or personnel support to complete this role. Conagua *may* intervene with the Consejo de Cuenca or Organizatopms like SACMEX in emergencies, extreme scarcity, or overexploitation. SACMEX *must not* supply water to irregular settlements until they are legally registered. Delegations *may* pay private water providers to supply homes with water in times of water scarcity.

Aggregation Rules: None specified except for Fideicomiso, which votes on projects (assuming majority wins?) and SACMEX budget appropriations, which is approved by Mexican City Assembly.

Scope rules: Conagua is supposed to limit the amount of water pumped in each well concession (but this often does not occur). Households have no limit on water use, though the price increases non-linearly with usage.

Information Rules: The Federal Institute for the Access to Public Information obligates

Conagua to publish minutes from meetings and technical and financial information from Fideicomiso 1928.

Payoff Rules: The price of water per cubic meter in Mexico City is about 3 pesos (even though it costs SACMEX between 5-11 pesos, which is why they run several billion dollars of deficit every year). Residents of Mexico City spent around $2 per day, and in the rest of the watershed, $7/day.

Farmers who maintain forest cover are paid for their ecosystem services, $1500/ha/year. This payment comes from water user fees ($30 million/year, or 3.5% of the CAEM state water revenue, funding nearly 17,000 ha).

1.5 Summary

While major efforts to form soft infrastructure necessary to fund large projects (Fideicomiso 1928) have helped address some of the under provisioning of public infrastructure, the dynamics of subsidence and continued exploitation of the aquifer continue to threaten the built infrastructure system for drains and supply. Efforts to fix leaks in pipes could significantly reduce the amount of water needed from wells, and help slow subsidence. However, the low (subsidized) price of water, and the fact that organizations responsible for fixing pipes are not required to be financially sustainable (e.g. SACMEX gets all of its money from Mexico City congress and remains billion of dollars in debt) removes incentives to fix existing infrastructure problems. In addition, the role of local Comisiones de Cuenca could play an important role in monitoring illegal wells, but lacks the support to do so. Furthermore, potential innovations in protecting natural infrastructure and preserving water (reforestation, infiltration etc) is left to the local, underfunded Comisiones. If given more power, Comisiones could help protect natural infrastructure for the system. The water governance system in Mexico City currently under values land resources, and under provides for existing built infrastructure. This under provisioning threatens sustainability of the system, and exacerbates scarcity and flooding.

2 Part II. Dynamic Analysis - Robustness

2.2 Shocks, Capacities, Vulnerabilities

...to and of the Resource (link 7 to R):

The main pressure on the resource is increasing urbanization. This can cause the conversion of forested lands in the upper watershed to urban land covers, further reducing infiltration to recharge the aquifer and increase runoff, which can tax the sewer system and increase flooding. Increasing population can also increase the demand for water resources.

...to and of the Public Infrastructure (link 7 to PI):

The main threat to public infrastructure (in addition to increased subsidence with water withdrawls) is climate change. Increasing storm intensities will overwhelm the already inadequate flood drainage system. If a major storm would destroy or render ineffective the main flood drain, there would be up to 5 meters of flooding in the center of the city. According to SEMARNAT, over 217 km2, or 10% of the urban metropolitan area, would be covered in floods. This would cause devastating impacts.

...to and of the Public Infrastructure Providers (link 8 to PIP):

Public Infrastructure providers are chosen (hired or appointed) by the government, and so are subject to political whim (e.g the privatization of water). In addition, major disasters often inspire changes or major infrastructure investments, and could influence public infrastructure providers. Other unexpected shocks include corruption and clientelistic behavior. PIPS can abuse they power by trading a resource like water for more votes, or gain money by illegally selling a well permit or land for urbanization.

...to and of the Resource Users (link 8 to RU):

Population growth is the other major potential shock that could increase demand for water.

2.3 Robustness Summary

The chronic nature of the problem raises the specter of increasing vulnerability under a changing climate. Flood vulnerability and exposure is only expected to increase with climate change projections (Romero Lankao 2010). Vulnerability in this context is a product of complex socioecological system (SES) dynamics, rather than a simple aggregation of the sensitivity, exposure, and capacity of a city's neighborhoods, businesses, and institutions. Endogenous dynamics, such as independent and uncoordinated decision-making about changes to infrastructure and landscapes by actors adapting to a specific spatial or sectorial vulnerability in the water system, in combination with exogenous changes in climatic conditions, are likely to produce nonlinear outcomes. Consequently, actions meant to mitigate risk can be rendered unintentionally transformative or maladaptive. In Mexico City, as in many megacities, risks are addressed in fragmented and sectorial ways: one dimension of risk is prioritized over others, tradeoffs among risks are ignored, and adaptations can, over time, exacerbate vulnerability, rather than reduce it.

3 Case Contributors

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