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Adapting to Impacts of Climate Change on Water Supply in Mexico City

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Background note

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Building resilience: Adaptation mechanisms and mainstreaming for the poor

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Description of Mexico City

Location, population and territory

Mexico City is one of the largest cities in the world. Located in a closed basin of 9,600 km^2, Mexico City spreads over a surface of 4,250 km^2 at 2,240 meters above the sea level. The city has 18.6 million inhabitants, concentrates 18 % of country's population and generates 35% of Mexico's gross domestic product on a surface equivalent to less than 0.3% of the national territory. As a metropolitan area, the city comprises the 16 *Delegaciones*[1] of the Federal District (DF) and 34 municipalities of the State of Mexico[2],[3] for a total of 50 geopolitical and administrative units who must coordinate among themselves in terms of urban planning, public services provision, and overall city management.

[Figure 1: map of Mexico City basin]

Urban growth and Poverty

Mexico City's population had an exponential growth in the 20th century. Natural population growth but mainly migration fostered by the rapid industrialization and an economic strategy based on intensive use of workforce, led to the expansion of the city. In 1520, the city had 30,000 inhabitants and reached a population of 541,000 inhabitants by 1900. Compared to 1900, by 1930 the population had more than doubled and the urban area multiplied by three. Between 1940 and 1970 the population grew at an average of 5% per year before descending its growth rate to a 1.7% per year in the 1990-2000 decade. Population projections estimate that Mexico City will continue to expand and will have 22.6 million inhabitants by 2030[4].

[Figure 2: Mexico City population and urban area 1600-2005]

[Figure 3: Mexico City per municipality: population, growth and urban density 1990-2000]

Along the 20th century the pattern of urban growth in Mexico City has been heterogeneous and without formal planning, creating a city of notable differences in terms of access to public services. Attributable to the rapid growth and to the lag on allocation of sufficient resources, the local and federal authorities have been unable to invest and build up the city infrastructure for public services provision, mainly in the water and wastewater treatment sectors, at the pace required. For instance, in 2000, nearly 5% of the population in the DF and 15% in the conurbated municipalities of the

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[1] *Delegaciones* is the plural of *delegación*, an administrative unit of the Federal District. A *delegación* is equivalent to what in other countries is known as borough.

[2] As defined by Ministry of Social Development. The Metropolitan Environmental Commission (CAM), a coordination body comprised by the government of the Federal District, the government of the State of Mexico, and the federal Ministry of the Environment and Natural Resources, define the Mexico City Metropolitan Area as the urban area integrated by the 16 Delegaciones, 27 municipalities of the State of Mexico and one municipality of the state of Hidalgo.

[3] By 1941, the city area comprised what currently are 4 delegaciones around the downtown, and in 1971 the city was equivalent to the 16 delegaciones of the Federal District. By 1995, 34 municipalities from the State of Mexico were also considered as part of the Mexico City Metropolitan Area.

[4] CONAPO (2000). "Proyecciones de la Población por municipios y por localidad 2000-2030". Available at: http://www.conapo.gob.mx/micros/proymunloc/index.html

State of Mexico still did not have access to water, neither through a water tap in the house nor through a shared faucet in the neighborhood[5]. As the gap between services needs and provision increased or persisted, highly excluded and marginalized human settlements appeared during the last 60 years in different areas of the city but mainly to the east and south east.

The World Bank estimates that 4.8% of Mexico City population lives in extreme poverty[6] and 25.8% in moderate poverty[7], which add to an estimated of 5.7 million inhabitants. On the other hand, according to the National Population Council (CONAPO) and its Marginalization Index 2000, only 1.4% of the Mexico City population lives under medium, high or very high marginalization, whilst the Human Development Index 2000, calculated at municipal level by CONAPO, estimates that nearly all the DF and the conurbated municipalities of the State of Mexico have a high or medium high human development[8]. Although aggregated data are helpful in terms of describing the general situation, do not reveal the exact location of the underserved population and the city poor; disaggregated information, if possible at the block level, is needed for a detailed mapping of services provision. Brief description on Marginalization Index per AGEB? (figure 4).

[Figure 4: Mexico City marginalization index, 2000]

[Figure 5: Mexico City Human Development Index, 2000, municipal level]
[Table municipalities-HDI-Marginalization Index]

Water availability and supply in Mexico City

Water demand in Mexico City

Mexico City consumes nearly 62 m^3/s; around 35m^3/s are consumed by the DF and 27 m^3/s by the conurbated municipalities of the State of Mexico[9].

The overall water demand for Mexico City has continuously increased due to population and industrial activities growth. Based on the dynamics of the population, it is expected that the water demand in the DF will show a minor growth compared to the forecasted growth in the conurbated municipalities of the State of Mexico.

Forecasts to 2015 indicate that the urban demand will reach 51.8 to 62.2 m^3/s while total demand, where agriculture and industries consumption are included, will be between 63.5 to 74.5 m^3/s, a 20% increase in total demand compared to 2000.

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[5] Tortajada, C. (2006). "Who Has Access to Water? Case Study of Mexico City Metrpolitan Area". Background paper for the Human Development Report 2006. Available at: http://hdr.undp.org/hdr2006/background_docs.cfm

[6] Extreme poverty as defined by the national poverty line; closely equivalent to an income of USD$2 per day.

[7] World Bank (2004). "La Pobreza en México. Una evaluación de las condiciones, las tendencias y la estrategia del gobierno". World Bank, México. Page. 98.

[8] CONAPO (2000). "Indice de Desarrollo Humano por municipio, 2000". Anexo Estadístico. Available at: http://www.conapo.gob.mx/00cifras/6.htm

[9] Castelan, E. (2002). "Water Management in the Mexico City Metropolitan Area: The Hard Way to Learn". Research Report 7 en. Third World Centre for Water Management. Mexico.

Currently, the water supplied to the Mexico City basin is used in agriculture (47.8%), urban consumption (45.8%) and industries (6.4%). At the urban level, it is estimated that the Mexico City citizens have an average consumption between 125 to 230 liters per inhabitant per day, which adds to a daily total consumption between 2.4 to 4.3 millions of m^3 per day considering the data on 2005 population. However, given the great differences in terms of water provision, the consumption per capita differs among municipalities and *delegaciones*. Whilst some areas may have a per capita consumption above 300 liters per person per day, other barely reach over 100 liters per capita per day; the difference does not reflect an environmentally-led or more conscious consumption, but an unreliable water provision service with a coverage not reaching the entire city population.

Water supply and water sources

At present, the city water is supplied from three main water sources. The Mexico City valley aquifer, located underneath the city, is the main water source by supplying 66 to 70% of total volume; the remaining volume is imported from two out-of-the-basin sources: the Lerma valley aquifer, located at 20 kilometers of the city, which supplies 9 % of total supply, and the Cutzamala system, 127 kilometers away, which supplies the remaining 21 to 25%. In 2002, the volume of water supplied to Mexico City reached 2.2 millions cubic meters per day[10].

The DF government has estimated shortages (demand minus supply) of 15%[11]. Underserved or impoverished areas that already experience water cut offs or a total lack of supply, may face the burden of water shortages. Many of these areas, such as areas of Iztapalapa in the DF, Ecatepec in the State of Mexico, or neighborhoods in Tlalpan, already experience water shortages and people must buy water from water trucks, which is a more expensive option in terms of cost per cubic meter.

Shortages may be associated to some extent with leakages. Nearly 40% of the supplied water is lost on pipelines and network leakages. Poor maintenance and pipelines fractures due to terrain consolidation, soil subsidence and earthquakes are the main causes of the leakages.

The supply network in the DF includes 13,000 kilometers of primary and secondary pipelines, 295 water storage tanks, 31 potabilization plants and 12 chlorination plants. A new potabilization plant (200 l/s) will be installed in 2007. There is no public data available on the State of Mexico water supply network. As a matter of fact, the supply networks of the DF and of the municipalities in the State of Mexico are not interconnected.

	DF (m^3/s)	**State of Mexico (m^3/s)**	**Total (m^3/s)**	**Percentage**
Within the basin sources	**20.0**	**25.2**	**45.2**	**68.5 %**
Wells	19.0	24.8	43.8	66.4 %
Springs and rivers	1.0	0.4	1.4	2.1 %

[10] Tortajada, C. (2006). "Who Has Access to Water? Case Study of Mexico City Metropolitan Area". Background paper for the Human Development Report 2006. Available at: http://hdr.undp.org/hdr2006/background_docs.cfm

[11] Downs, T. et al. (2000). "Sustainability of least cost policies for meeting Mexico City's future water demand". Water Resources Research, Vol. 36, No. 8, pp. 2321-2339. August 2000.

External sources	**14.8**	**6.5**	**21.3**	**32.0 %**
Cutzamala	9.9	5.5	15.4	23.1 %
Lerma	4.9	1.0	5.9	8.9 %
Total	**34.8**	**31.7**	**66.5**	**100 %**
Percentage	52.7 %	47.3%	100%	

Sources:
Tortajada, C. (2006). "Who Has Access to Water? Case Study of Mexico City Metropolitan Area". Background paper for the Human Development Report 2006. p. 15.
CONAGUA (2006). "Estadísticas del agua en México 2006" Chapter 4, pp. 111.

In recent years, there are evidences of a lowered quality in the water extracted from the Mexico City basin aquifer; studies performed by Mexican scientists detected the presence of total and faecal coliforms as well as bacteria responsible for gastroenteric diseases and acute diarrheas[12,13] in different well samples in Mexico City, suggesting aquifer contamination from surface sources. The inflow of wastewater mixed with leaks from broken water pipes and faulty boreholes construction are considered as possible causes of aquifer contamination.

Other studies on the hydrogeology and hydrochemical conditions of the aquifer have also detected water contamination on boreholes up to 250m depth, particularly in the form of high concentration of iron, manganese, sodium, and total dissolved solids.

Conditioning of water availability: Mexico City basin characteristics

From a geological point of view, the Mexico City terrain is a complex one. From the surface down, the soil consists of semipermeable lacustrine deposits, ranging from 0 to 400 meters that alternate with clay layers and volcanic sandstones; volcanic and pyroclastic material, ranging from 0 to 2000 meter, that constitutes the main aquifer in the southern part of the valley; and alluvium deposits, found primarily along the basin mountain flanks, that constitutes the main aquifer system[14]. Given that 66% of the supply comes from the Mexico City aquifer, the terrain characteristics are relevant for understanding aquifer recharge, the groundwater flow system including vertical inflow, as well as the aquifer chemical composition[15], being the later a determinant of purification cost per cubic meter. Also, the terrain characteristics determine the presence of natural barriers to the inflow of surface contaminants. Nowadays zones where aquifer

[12] Tortajada, C. (2006). "Water Management in Mexico City Metropolitan Area". Water Resources Development, Vol. 22, No. 2, pp. 353-376, June 2006.
[13] Cifuentes, E. Suarez, L., Solano, M., Santos, R. (2002). "Diarrheal Diseases in Children from a Water Reclamation Site in Mexico City". Environmental Health Perspectives. Vol. 110, No. 10, October 2002. pp. A619-A624. Children's Health Articles.
[14] Marín, L.E., Escolero-Puentes, O., Trinidad-Santos, A. (2002) "Physical Geography, Hydrogeology, and Forest Soils of the Basin of Mexico", in Fenn, M., de Bauer, L, Hernández-Tejeda, T. (2002). "Urban Air Pollution and Forests. Resources at Risk in the Mexico City Air Basin". Ecological Studies 156. Springer-Verlag, New York. Pp. 47-49.
[15] Huizar-Alvarez, R. Carrillo-Rivera, J., Angeles-Serrano, G., Hergt, T., Cardona, A. (2004). "Chemical response to groundwater extraction southeast of Mexico City". Hydrogeology Journal. 12:436-450.

recharges occur are systematically being urbanized[16] and all the rivers that used to discharge to the central lakes of the basin are now connected to a drainage system[17].

[Figure 6: Geology of Mexico City]   [Figure 7: Geological section]

Water availability
Water availability depends on the precipitation, the surface run-off and the aquifer recharge. About 70% of the rain falling in the Mexico City basin evaporates and the remaining runs-off on the surface or goes to lower layers of the terrain, down the aquifer. Surface run-off not used. Reduction in water availability due to overexploitation of the aquifer and the loss of aquifer recharge areas.

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[Table 4: Water availability]

Water balance
Annual precipitation of 746 mm (226.7 m^3/s)[18] and an estimated evapotranspiration of 163.2 to 179 m^3/s. Calculated recharge is a maximum of 19m^3/s. The estimations from a variety of studies are shown in the table. Groundwater exploitation rate of 51.3 m^3/s. Mean annual evaporation is 1,524mm. Aquifer annual recharge of 788 hm^3, and 2,071 hm^3 per year are pumped from the aquifer[19].
[Table 3: Mexico City water balance]

Climate change scenarios

Current climate

Documentation of past climatic records provides information of climate before being influenced by anthropogenic global warming and climate change. Studies on climate and climate variability in Mexico of the last 600 years, since the Aztec period, (Appendini and Liverman, 1994; Ezcurra, 1991; Hunt, 2002, INE, 2004, etc.) suggest the alternation of wet years and the occurrence of floods in the Mexico City basin, (i.e. during the wet years of 1440s) followed by drought episodes that in some cases were severe and extended for 10 or more years. Modeling of climate variability of the last 10,000 years also suggest that natural occurring droughts were caused by rainfall anomalies of up to -2.1 mm/day with a reduction in annual mean rainfall between 20 to 40% and a reduction of moisture influx from the Pacific Ocean[20]. Another study by Mendoza et al. identified a total of 136 droughts that took place between 1450 and 1900

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[16] Marín, L.E., Escolero-Puentes, O., Trinidad-Santos, A. (2002) "Physical Geography, Hydrogeology, and Forest Soils of the Basin of Mexico", in Fenn, M., de Bauer, L, Hernández-Tejeda, T. (2002). "Urban Air Pollution and Forests. Resources at Risk in the Mexico City Air Basin". Ecological Studies 156. Springer-Verlag, New York. P. 65
[17] CNA. (2003). "Plan Hidráulico Regional 2002-2006. Aguas del Valle de México y Sistema Cutzamala. Región XIII". Comisión Nacional del Agua, August 2003. page 36.
[18] Birkle, F., Torres Rodríguez, V., González Partida, E. (1998). "The water balance for the Basin of the Valley of Mexico and implications for future water consumption". Hydrogeology Journal. 6: 500-517.
[19] CNA. (2003). "Plan Hidráulico Regional 2002-2006. Aguas del Valle de México y Sistema Cutzamala. Región XIII". Comisión Nacional del Agua, August 2003. page 36.
[20] Hunt, B.G., Elliot, T.I. (2002). "Mexican megadrought". Climate Dynamics, Vol. 20, pp. 1-12.

in Mexico City[21]. Recent studies from the National Waters Commission on the geographic extension of droughts between 1948 and 1996 showed that the Mexico City basin continues to be exposed to drought periods.

[Figure 8: Droughts in Mexico 1948-1996]

In principle, such events may occur again at anytime whenever the natural circumstances leading to a drought are present, but now influenced or modified in frequency or magnitude by global warming and climate change.

Records from the National Meteorological Service with data collected over the last 50 years indicate that the mean annual precipitation in the Mexico City basin is around 705 mm per year and the monthly mean temperature is 15.6°C.

The rain season starts by the end of May and ends by mid October, following a bell shape on the rain distribution over the year. January and December are the driest months while July exhibits a mean precipitation of 155 mm. However, the rain distribution on the basin varies. The mean annual precipitation in the south of the city is 692mm whilst Tula, a small city in the northwest of the basin, receives 536mm. The north and northeast of the basin tends to be drier than the south.

Scenarios for Mexico City: DF and the State of Mexico

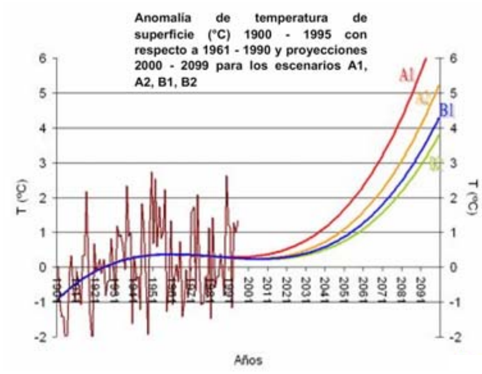
Since the early 1990s, General Circulation Models have been used for climate modeling on research of global warming impacts in Mexico. Results from such models (Liverman, Hadley) and from climate change scenarios prepared by the UNAM[22] in 2006 for each state, predict an increase in the ambient mean temperature of up to 4°C and a decrease in mean precipitation of up to -20% in the area of Mexico City by 2080.

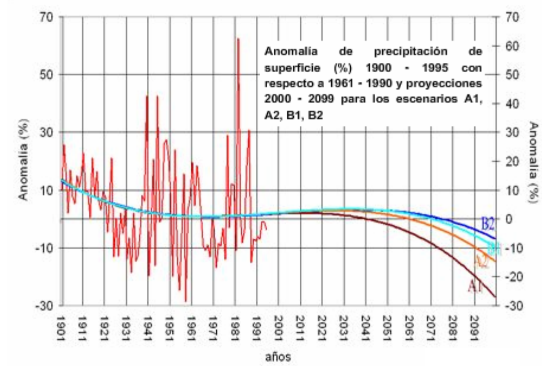
DF	**2020**	**2050**	**2080**
Temperature	+ 0.8°C to + 1.2°C	+ 1°C to + 2°C	+ 2°C to + 4°C
Precipitation	+ 5% to - 5%	+5% to -15%	- 5% to - 20%
State of Mexico	**2020**	**2050**	**2080**
Temperature	+ 0.8°C to + 1.2°C	+ 1°C to + 2°C	+ 2°C to + 4°C
Precipitation	- 5% to - 10%	- 5% to - 10%	- 5% to - 20%

Federal District

[21] Mendoza et al. (2005). "Historical droughts in Central Mexico and their Relation with El Niño". Journal of Applied Meterology, Vol. 44, May 2005, pp. 709-716.

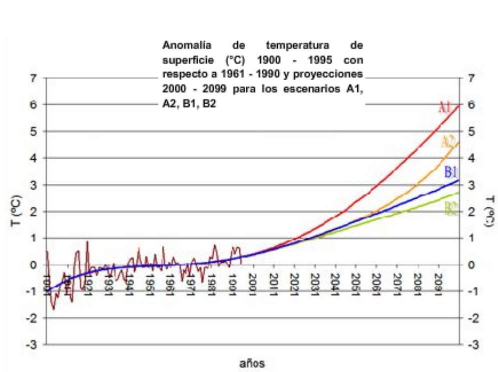
[22] Four scenarios per variable were prepared: A1-high GHG emissions, rapid economic development, rapid population growth; A2-Medium-high GHG emissions, regional economic development; B1-low GHG emissions, tendency towards an environmentally sustainable development; B2-medium-low GHG emissions, tendency towards a more environmentally sustainable regional development.

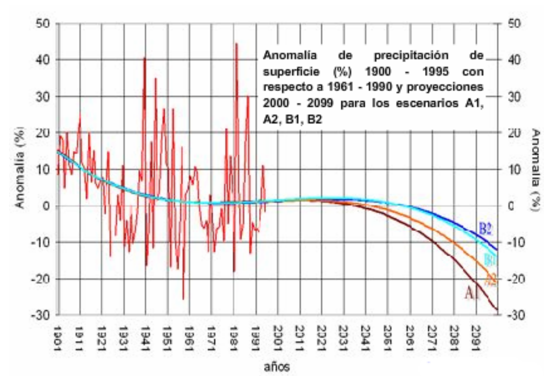




(a) temperature (b) precipitation

State of Mexico





(a) temperature (b) precipitation

Expected/predicted climate change impacts in water sector in Mexico City

A decrease in precipitation and an increase in temperature may modify the Mexico City water balance by increasing the evapotranspiration rate, decreasing the precipitation runoff and aquifer recharge rates, and decreasing, overall, the water available for Mexico City. Such changes imply additional stress to the already limited water sources. From modeling of changes in water availability under climate change scenarios, Mexican scientists estimate a variation between +30.8% and -65.7% on the annual water runoff per capita[23]. These scientists also predict a medium to high vulnerability in the availability, storage, and consumption of water in the Mexico City basin area.

The changes or reductions in water availability may cause, bring back or prolong social conflicts between municipalities or between people and authorities on access to water, water use, or water consumption. Three main reasons have been identified in Mexico as critical factors on the occurrence of water related social conflicts: 1) aggravation of water shortages, a trigger that strains the competition for the resource; 2) public rejection to government decisions that may be perceived as unpopular (e.g. subsidies reduction, increase in tariffs, scheduled reductions in water supply); and 3) additional causes related to local (geographic or sectorial) circumstances, e.g. recurrent drought periods affecting local agricultural activities, lack of infrastructure, or inequitable supply. Between 1990 and 2002, 60 % of the all the water-related social conflicts that

[23] Mendoza, V. Villanueva, E., Maderey, L. in Martinez, J. Fernandez, A. (2002). "Cambio climático: una visión desde México". SEMARNAT-INE. P. 217.

took place in Mexico and that were reported by the media occurred in geographic areas with overexploited aquifers, and 49% of all the water-related social conflicts over the same period took place in Mexico City; the most recurrent non-violent expressions of the conflicts were in the form of demonstrations, streets blockades, facilities occupation, and damages to infrastructure[24]. Insufficient wastewater discharge capacity and associated wastewater floods, inadequate or lack of water supply infrastructure, water shortages, damages caused to dwellings by land subsidence, poor water quality, and opposition to water tariffs were amongst the most common topics used as arguments during social conflicts.

But the effects of changes in water availability can also generate problems outside the Mexico City basin; for instance, peasants in rural areas near the Cutzamala system modified their economic activities, from rye, wheat and livestock to maize, which can be grown under both irrigated and rainfed conditions, because of a reduction in water availability on the area, a reduction due to exploitation of the aquifer for supplying Mexico City, which is located over a hundred kilometers away[25].

The health sector may be also affected by changes in the water balance of the Mexico City basin, mainly in the form of an increase in the incidence of water-related diseases and may influence the origin, intensity and distribution of the diseases. A substantial body of literature details the effects of climate change in human health, including changes distribution and incidence of vector-borne and other infectious diseases[26,27,28,29]. In Mexico, hemorrhagic dengue, acute respiratory disease, heat waves, and exposure to excessive cold, as well as epidemics associated with extreme weather events such as floods, hurricanes and other water-related natural disasters, have been identified as the main impacts of climate change in the health sector[30]. For instance, insects and insect-borne disease, such as malaria, have been reported at high elevations in Mexico and in the Mexico City basin up to 50,000 cases were reported between 1984 and 2002[31]. Water related diseases due to water quality and to parasites and bacteria proliferation on food and water when having higher ambient temperatures are another example; acute diarrhea disease, due to increase in ambient temperature, is the fourth cause of death among children below 1 year old in Mexico. In addition, mortality associated to heat waves is also important: between 14 and 55 cases were reported between 1979 and 2003 in the Mexico City basin.

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[24] Sainz, J., Becerra, M. (2003). "Los conflictos por el agua en México". Gaceta Ecológica, Núm 67, April-June. Mexico. pp. 61-68

[25] Appendini, K. Liverman, D. (1994). "Agricultura policy, climate change and food security in Mexico". Food Policy, Vol. 19. pp. 149-164

[26] Haines, A. Kovats, R.S., Campbell-Lendrum, D., Corvalan, C. (2006). "Climate change and human health: impacts, vulnerability, and mitigation". The Lancet. Jun 24-Jun30, 2006. Vol. 367. pp. 2101-2109.

[27] WHO. (2003). "Climate change and human health: risks and responses". World Health Organization. France.

[28] McMichael, A., Woodruff, R., Hales, S. (2006). "Climate change and human health: present and future risks". The Lancet. Vol. 367. March 11, 2006. pp. 859-869.

[29] Kovats, R., Bouma, M., Hajat, S., Worrall, E., Haines, A. (2003). "El Niño and health". The Lancet. Vol. 362. November 1, 2003. pp. 1481-1489.

[30] National Institute of Public Health, National Institute of Ecology. (2006). "Estudio diagnóstico sobre los efectos del cambio climático en la salud humana de la población en México". Final report. September 2006. Available on: http//www.ine.gob.mx/cclimatico/estudios_cclimatico.html

[31] INE, INSP. (2006). "Estudio diagnóstico sobre los efectos del cambio climático en la salud humana de la población en México". Research project final report. September 2006. Available at: http://www.ine.gob.mx/cclimatico/estudios_cclimatico.html

As if disease was not enough, changes in water consumption and use due to climate change may cause discomfort in the Mexico City citizens. Bioclimatic conditions could be altered by climate change[32] in a city were dwellings and buildings are not designed for a warmer ambient. Even new dwellings built in the last 10 years are equipped with small water tanks (up to 400 liters) limiting the water storage capacity of the house and preventing people from storing water for longer periods of time. To some extent, these dwellings and its occupiers rely on the public water supply almost on a daily basis. As a response, people are forced to build underground cisterns, install an additional water tank, or fill and keep containers or buckets with water.

Climate change adaptation in Mexico City

Based on the climate change scenarios and the current situation of the water supply sector, it is evident that Mexico City needs some solutions in order to improve supply coverage and water quality not to mention to guarantee water supply under climate change scenarios. The development of a climate change adaptation strategy, at least in the water sector, is a must.

Throughout the years, Mexico City population has implemented different measures to adapt to the effects of changing climate conditions associated with precipitation, as in the case of floods and droughts. For instance, during wet years in the 16^{th}, 17^{th}, and 18^{th} centuries, the construction of dykes were a common measure used to prevent floods in the Mexico City basin; when the population realized that dykes were not sufficient and the Spaniard practices after the Aztec conquest were promoted, further actions were taken. Between the 16^{th} and 20^{th} century four major hydraulic works, the first of which was inaugurated in the 17th century and the last in the 20th century, drained the basin. The main objective of the hydraulic works was to control the floods in the emerging city, floods that in some cases reached a height of 3 meters in the 19th century[33].

[Figure 9: map of Mexico City hydraulic works 15^{th}-19^{th} centuries]

However, such measures used to adapt to climate variability, through artificial channels for the valley, desiccated the lakes and a new and extended terrain became available for the city to grow. With the city expansion, small neighboring towns all around the city were engulfed, creating a metropolitan area. Meanwhile, the desiccation of the central lakes, the loss of forest cover in the surrounding mountains, and the construction of sewerage systems that took the rainwater, the rivers, and the wastewater out of the basin reduced the amount of run-off water available for use and for the recharge of the basin aquifer, and eventually resulted in land subsidence in some parts of the city and in the need for new water sources.

In some way, water management in the Mexico City basin during the last 4 centuries may be presented as an example of climate change maladaptation, as it represents changes in natural or human systems that inadvertently increased the vulnerability to

[32] Jauregui, E. Cervantes, J., Tejeda, A. (1997). "Bioclimatic conditions in Mexico City-an assessment" Int. J. Biometeorol. Vol. 40. pp. 166-177.

[33] DGCOH-DDF. (1991). "Drenaje profundo: cuarta salida artificial para el desalojo del agua de la ciudad de México". Ingeniería hidráulica en México. Vol. VI, núm. 3, II Epoca. Septiembre-diciembre de 1991. p. 68.

climate stimuli[34]. By the time the measures were taken, the effects of climate variability were the ones of concern.

Now the question arises: how to adapt to climate change impacts on water supply in Mexico City? A large list of drawbacks complicates the answer. The lacustrine system is now extinct; the city aquifer is overexploited; the availability of water may be reduced by city growth; the rainfall is not used in any way as a water source or for aquifer recharge; about a third of the water supplied comes from sources located up to 130 kilometers away and up to a kilometer below the city level; the bulk of the wastewater is not treated and reused; the supply systems loses about 40% of the liquid due to pipe leakages and poor maintenance; and nearly 5% of the city population do not have access to water. Hence, how to adapt to the impacts of climate change on water supply in Mexico City?

A number of measures or actions for adaptation to climate change may be reported, some of which are taken by the Mexico City citizens, and some that could be taken in the next 10 or 20 years (before a water crisis arrives). The measures can be classified as anticipatory, planned, or reactive, following the types of adaptation as defined by the IPCC; together the measures look for reducing the vulnerability, and improving the resilience and the adaptive capacity of the water supply system.

At the household level, people has opted for containers or buckets to store water that has a basic use at home, (e.g. personal hygiene, human consumption, or food preparation). The volumes stored are relatively small (from 20 to 200 liters) but the option is flexible in the sense that more buckets or containers can be added. Whenever water is available or when it rains people fill their containers. The use of containers or buckets has been a choice among poor people who live in under-served parts of the city and where water is not available on a daily basis.

Another measure has been the use of underground cisterns for water storage of volumes equivalent to up to two weeks of household supply. However, the measure requires additional economic resources for the family to build the cistern or bury a bigger water tank as cistern, and to install additional pipes inside the dwelling or even a pump. The measure also implies an increase in energy consumption at the household level whenever a pump is added to the dwelling water system.

The shortages in water supply have also fostered some changes in water use and water consumption patterns; for instance, the reuse of the shower water in the WC for the discharge of feces or for floor cleaning in the house is spreading as a water reuse method. More conscious citizens who are in the position to do so, turn off the shower for some minutes while taking a bath, whilst others change the WC water tanks and install water saving technologies.

Not all the adaptation measures are or should be taken at the household level. Local authorities are responsible for water supply and wastewaster treatment. Water works such as pipelines substitution to reduce leakages and the use of earthquake and land movements resistant pipes are some of the measures in the hand of the local authorities.

[34] IPCC-TAR, (2001). "Climate Change 2001: Impacts, Adaptation and Vulnerability". IPCC Third Assessment Report, Cambridge University Press.

Adaptation to climate change inevitably has policy implications.

Policy implications

Water management in the city has been reformed in the last 15 years. In the DF, water management migrated from a supply side control to a demand management approach. By 1989 reforms to the water management legislation were introduced and the supply service was privatized; the DF Water Commission granted concessions to four private companies as administrators of the DF water systems[35]. The companies have been confronted with aquifer overexploitation, expensive and recurrent maintenance of the system, and low tariffs. On the other hand, customers have neither an incentive to pay fees nor is there a punishment for failure to pay.

Modifications to the regulations on water management in the metropolitan area have to consider several issues to improve coverage and guarantee supply.

Regulations for water management in the metropolitan area

- Transparency on water system performance and finance of concessions to private companies
- No more exploitation permits; permanent measure that should be kept for a period of time long enough to protect the aquifers
- Official definition of the volume considered as basic human right for public provision
- Construction codes /regulations with water saving technology in infonavit and fovisste dwellings
- Infonavit incentive for these houses, discount for people as incentive for the buying
- Reforestation afforestation activities in the hills and mountains around the city, and within the city (local climate regulation and water capture and infiltration)
- Texcoco lake recovery with treated wastewater
- Guidelines for water capture at dwelling level

Tariffs

Tariffs are supposed to reflect the cost of water extraction, purification, and distribution, and in some cases, treatment. In Mexico City water has been a highly subsidized good that turned into an economic asset until 1990s, when legal reforms were made to the water management system, in an effort to lowering the level of subsidies, achieving financial self-sufficiency and establishing prices as a function of relative scarcity of water[36].

The cost per cubic meter in Mexico City is estimated in US$1.34 but the highest fee charged to consumers averaged US$0.34 per cubic meter in 1997[37]. Water is a highly subsidized good. Reductions in water pricing in Mexico City has been used as a political asset when contending for political control of the city. As a result, the citizens

[35] Wilder, M. (2006). "Paradoxes of Decentralization: water Reform and Social Implications in Mexico". World Development, Vo. 34, No. 11. pp.1977-1995.
[36] Marañon, B. (2003). "Potable Water Tariffs in Mexico City: Towards a Policy Based on Demand Management?". Water Resources Development, Vol. 19, No. 2, p. 233.
[37] Cautelan, E. (2002). "Water Management in the Mexico City Metropolitan Area: The Hard Way to Learn". Third World Centre for Water Management. Research Report 7 en, 2002.

take for granted the provision of water and have benefited in the past from a fixed rate tariff. It was until the 1990s when the pricing policy established differences in rates between different types of users, and instituted consumed volume and ranges as the reference for charging customers[38]. Despite such effort, tariffs have not been sufficient to cover the costs of water utilities not the mention the costs of wastewater treatment.

The water reforms initiated in 1989 led to the privatization of the water sector in the DF. The private sector, through four companies servicing the four zones in which the DF was divided for water provision, has been providing technology, organization and international experience while the government decides on volumes and delivery times and keeps control of the tariffs[39]. The private sector participation has brought up to date the register of users in the DF, has increased water metering coverage, and has improved efficiency in terms of service and of billing and collection. Although overall improvements have been made, by no means they consider the possible effects of climate change in the water supply system.

Three main actions are considered as adaptation measures that could be taken in Mexico City to prepare the city to the effects of climate change in water supply:

1. Adjust tariffs to reflect the real cost of water supply and the opportunity cost of not having water in the near future due to climate change. A recent study suggest that people is willing to pay more than double current water bills or up to over $US 60 every two months[40].
2. Recover the cost and invest in supply and treatment infrastructure as means to reduce leaks in pipelines and treatment of additional wastewater volumes.
3. Define a tariff system based on a baseline of water (certain volume) conceived as a human right in order to provide water in enough volume per person for basic needs, and any increments of additional consumption be charge at more expensive rates.

Infrastructure

- Rain harvesting at dwelling level
- treatment for public use at city level
- Reduce leakages on supply system
- Improve water supply coverage
- Control for urban growth

Adaptation measures can also take place on other sectors, including health and forestry. From the linkages between access to water and prevalence and incidence of infectious and vector-borne diseases, it is advisable to consider additional measures to adapt to impacts of climate change in the water supply in Mexico City.

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[38] Marañon, B. (2003). “Potable Water Tariffs in Mexico City: Towards a Policy Based on Demand Management?”. Water Resources Development, Vol. 19, No.2, pp. 233-247.
[39] Marañon, B. (2005). “Private-sector Participation in the Management of Potable Water in Mexico City, 1992-2002”. Water Resources Development, Vol. 21., No. 1, pp. 165-179.
[40] Soto-Montes de Oca, G., Bateman, I. (2006). “Scope sensitivity in household’s willingness to pay for maintained and improved water supplies in a developing world urban area: Investigating the influence of baseline supply quality and income distribution upon stated preferences in Mexico City”. Water Resources Research, Vol. 42, W07421, doi:10.1029/2005WR003981.

The adaptation measures may focus on health sector preparedness to water-related infectious and vector-borne diseases. The availability of drugs for infectious diseases on hospitals and clinics in the Mexico City area should be kept in level to current and expected demand given the plausible scenarios on water supply and modifications due to climate change. In addition, the health sector should work on providing information to citizens on water storage and mosquitoes reproduction cycle, use of mosquito nets on windows or around beds, and use insecticide or insect repellent, assuming that mosquitoes may live in the Mexico City basin and that a number of vector-borne cases, including dengue, have been reported in the last 20 years. Along with the information dissemination, fumigation campaigns may take place in the city as took place during the 1940s decade, mainly in neighborhoods where conditions for mosquitoes reproduction exist.

Considering the fact that water supply will have a close link with climate conditions, the health sector could incorporate meteorological data as part of the epidemiological early warning system currently operating, as predictor of water-related diarrhea and other infectious diseases outbreaks.

The forestry sector could also implement different adaptation measures with positive feedback on the water supply system. Deforestation and urbanization have been identified as major causes of the reduction on aquifer recharge rates. Meanwhile, water from temporary streams and springs in the upper parts of the city are presently intercepted and channeled into the water distribution system. As a result, forests are losing soil humidity which in turn reduces water availability for trees and vegetation. A reduction in soil humidity increases the trees stress, its susceptibility to plagues and diseases, and its death rate. Vast areas of surrounding forests are dying from lack of water, a situation exacerbated by air pollution, which causes damages to leaves, reducing the photosynthetic capacity of trees. The loss of forest coverage increase soil erosion and water run-off and reduces the area available for aquifer recharge.

Hydrogeological studies have already identified areas suitable for water capture and aquifer recharge[41]. The Governments of the Federal District and of the State of Mexico could use such information to implement forestry programmes, under payment for environmental services, to incentive forest protection on the surrounding hills and mountains. These types of programmes have proved successful in other parts of the country where deforestation and the loss of soil cover has been a major problem. Also the local authorities or the local legislature could delimit protected areas for aquifer recharge around or within the city, as hydrogeologic reserve zones where strict land-use controls are enacted and enforced; such areas could include the mountain ranges around the city like Santa Catarina, Sierra de las Cruces, Monte Alto ranges, and Guadalupe.

Illegal logging and forest fires have also reduced the forest surface of the surrounding mountain ranges. Law enforcement is a measure to reduce illegal logging while satellite detection of hot spots during the dry season may help reduce or control the outbreak of forest fires.

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[41] Marín, L.E., Escolero-Puentes, O., Trinidad-Santos, A. (2002) "Physical Geography, Hydrogeology, and Forest Soils of the Basin of Mexico", in Fenn, M., de Bauer, L, Hernández-Tejeda, T. (2002). "Urban Air Pollution and Forests. Resources at Risk in the Mexico City Air Basin". Ecological Studies 156. Springer-Verlag, New York. P. 47-53.

Annex: tables

Table 1. Mexico City population and surface of urban area.

	Federal District		State of Mexico		Metropolitan area	
Year	Population	Surface of urban area (km^2)	Population	Surface of urban area (km^2)	Population	Surface of urban area (km^2)
1600	58,000					5.5
1700	105,000					6.6
1800	137,000					10.8
1845	240,000					14.1
1900	541,516					27.5
1910	720,753					40.1
1921	906,063					46.4
1930	1,229,576					86.1
1940	1,757,530					117.5
1950	3,050,442		59,000		3,000,000	
1960	4,870,876		309,000		5,200,000	
1970	6,874,165		1,783,000		8,700,000	683
1980	8,831,079		4,904,000		13,800,000	980
1990	8,235,744		6,812,000			
2000	8,605,239	730.98	9,204,232	3,531.55	17,809,471	4,262.5
2005	8,720,916	1,486.0	9,850,522		18,851,438	

Sources:
Ezcurra, E. (1990). "De las chinampas a la megalópolis. El medio ambiente en la cuenca de México". Fondo de Cultura Económica. Serie La ciencia desde México. No. 91.
INEGI (2000). XII Censo General de Población y Vivienda
-------- (b) (2005). Conteo de Población y Vivienda 2005.
-------- (c) (1996). Estados Unidos Mexicanos. Cien años de Censos de Población.
-------- (d) (2001). Indicadores sociodemográficos de México (1930-2000).
Molina, L.T., Molina, M.J. (2002). "Air Quality in the Mexico Megacity. An Integrated Assessment". Kluwer Academic Publishers. Pp.62-74.

Table 2. Mexico City population, urban area, and HDI, disaggregated by municipality (2000).

	Municipality	Surface of urban area (km^2)	% of Mexico City urban area	Population	% of Mexico City population	Human Development Index
Federal District	Azcapotzalco	33.56	0.8%	441,008	2.5%	0.8523
	Coyoacán	53.67	1.3%	640,423	3.6%	0.8809
	Cuajimalpa de Morelos	29.13	0.7%	151,222	0.8%	0.8398
	Gustavo A. Madero	85.86	2.0%	1,235,542	6.9%	0.8392
	Iztacalco	23.05	0.5%	411,321	2.3%	0.8475
	Iztapalapa	112.92	2.7%	1,773,343	10.0%	0.8256
	Magdalena Contreras, La	18.68	0.4%	222,050	1.2%	0.8417
	Milpa Alta	3.97	0.1%	96,773	0.5%	0.7902
	Alvaro Obregón	69.74	1.6%	687,020	3.9%	0.8508

	Tláhuac	28	0.7%	302,790	1.7%	0.8184
	Tlalpan	71.2	1.7%	581,781	3.3%	0.8588
	Xochimilco	62.75	1.5%	369,787	2.1%	0.832
	Benito Juárez	26.4	0.6%	360,478	2.0%	0.9136
	Cuauhtémoc	32.38	0.8%	516,255	2.9%	0.8671
	Miguel Hidalgo	46.07	1.1%	352,640	2.0%	0.8788
	Venustiano Carranza	33.6	0.8%	462,806	2.6%	0.847
State of México	Acolman	86.88	2.0%	61,250	0.3%	0.798
	Atenco	94.67	2.2%	34,435	0.2%	0.7791
	Atizapán de Zaragoza	89.88	2.1%	467,886	2.6%	0.839
	Coacalco de Berriozábal	36.5	0.9%	252,555	1.4%	0.8478
	Cuautitlán	37.3	0.9%	75,836	0.4%	0.8215
	Chalco	234.72	5.5%	217,972	1.2%	0.7729
	Chiautla	20.13	0.5%	19,620	0.1%	0.7728
	Chicoloapan	60.89	1.4%	77,579	0.4%	0.7843
	Chiconcuac	6.94	0.2%	17,972	0.1%	0.7384
	Chimalhuacán	46.61	1.1%	490,772	2.8%	0.7638
	Ecatepec de Morelos	155.49	3.7%	1,622,697	9.1%	0.8039
	Huixquilucan	143.52	3.4%	193,468	1.1%	0.8409
	Ixtapaluca	315.1	7.4%	297,570	1.7%	0.8089
	Jaltenco	3.96	0.1%	31,629	0.2%	0.8127
	Melchor Ocampo	15.19	0.4%	37,716	0.2%	0.7982
	Naucalpan de Juárez	149.86	3.5%	858,711	4.8%	0.8379
	Nezahualcóyotl	63.44	1.5%	1,225,972	6.9%	0.8149
	Nextlalpan	42.49	1.0%	19,532	0.1%	0.765
	Nicolás Romero	233.51	5.5%	269,546	1.5%	0.7958
	Papalotla	3.59	0.1%	3,469	0.0%	0.7874
	Paz, La	26.71	0.6%	212,694	1.2%	0.7897
	Tecámac	153.41	3.6%	172,813	1.0%	0.8082
	Teoloyucán	31.52	0.7%	66,556	0.4%	0.796
	Teotihuacán	82.66	1.9%	44,653	0.3%	0.7790
	Tepetlaoxtoc	172.38	4.1%	22,729	0.1%	0.7582
	Tepotzotlán	208.83	4.9%	62,280	0.3%	0.8078
	Texcoco	418.69	9.8%	204,102	1.1%	0.8024
	Tezoyuca	10.90	0.3%	18,852	0.1%	0.7962
	Tlalnepantla de Baz	83.48	2.0%	721,415	4.1%	0.8403
	Tultepec	19.02	0.4%	93,277	0.5%	0.8142
	Tultitlán	71.08	1.7%	432,141	2.4%	0.8158
	Zumpango	244.08	5.7%	99,774	0.6%	0.7861
	Cuautitlán Izcalli	109.92	2.6%	453,298	2.5%	0.8419
	Valle de Chalco Solidaridad	46.36	1.1%	323,461	1.8%	0.7666
	TOTAL	**4,250.69**	**100%**	**17,809,471**	**100.0%**	

Sources:
Government of the State of Mexico. Regiones y Municipios.
http://www.edomexico.gob.mx/r_edomex/regiones.asp
Goverment of the Federal District. Secretaría de Desarrollo Social
INEGI (2000). XII Censo General de Población y Vivienda
UNDP. (2005).

Table 3. Mexico City water balance, according to different authors

Authors	Year	Area of study	Annual precipitation	Evapotranspiration	Aquifers recharge	Surface runoff	Availability
CNA	1991	Mexico City basin			23 m^3/s		
Birkle, Torres-Rodriguez, González P.	1995	Valley of Mexico basin	226.7 m^3/s (746 mm)	163.2 – 179.1 m^3/s (72-79%)	29.1 m^3/s	19 m^3/s	48.1 m^3/s
Birkle, Torres-Rodriguez, González P.	1995	Mexico City Metropolitan Area	80.8 m^3/s	54.4 – 59.8 m^3/s	13.4 - 18.8 m^3/s	7.6 m^3/s	21 – 26.4 m^3/s
CONAGUA	2006	Mexico Valley, Hildago, and Tlaxcala	737 mm		61.4 m^3/s	63.3 m^3/s	124.7 m^3/s

Table 4: Water availability

Year	Water availability	Population	Availability per cápita	Authorized exploitation volume	Consumption		Source		Déficit
					Urban Agriculture Industry		Aquifer….. Reuse……. Cutzamala system……	45m^3/s	
2006 Mexico Valley, Hildago, and Tlaxcala	124.7 m^3/s	20,489,583	192 m^3/hab/año	148.6 m^3/s	Urban Agriculture Industry	68 m^3/s (61.2 m^3/s) 71.1 m^3/s 9.36 m^3/s	Aquifer….. Reuse……. Cutzamala system……		
2006 Mexico City metropolitan area									

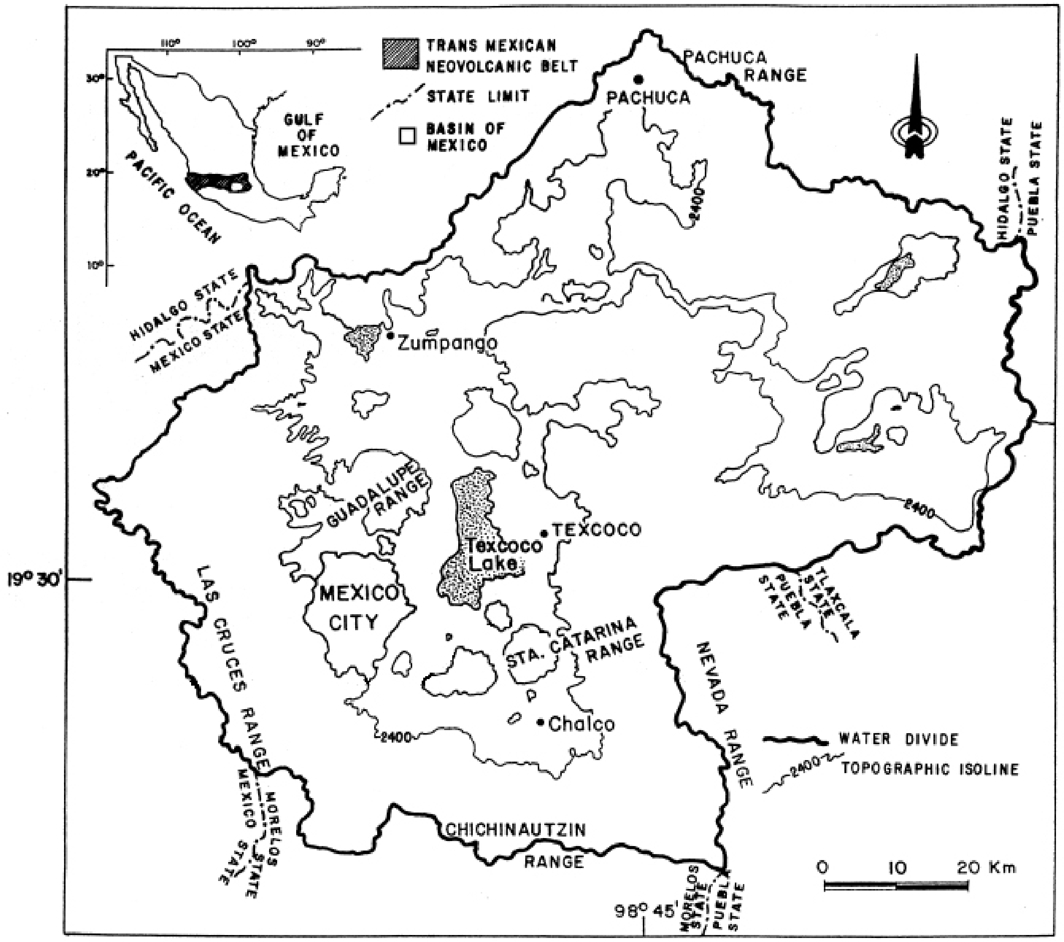
Source: CONAGUA (2006). "La gestión del agua en México". Pp. 150-154.

Table 5 : Water supply in Mexico City

Year	Water availability	Authorized exploitation volume	Consumption		Source		Déficit
			Urban Agriculture Industry		Aquifer….. Reuse……. Cutzamala system……	45m^3/s	
2006 Mexico Valley, Hildago, and Tlaxcala	124.7 m^3/s	148.6 m^3/s	Urban Agriculture Industry	68 m^3/s (61.2 m^3/s Mexico City) 71.1 m^3/s 9.36 m^3/s	Aquifer….. Reuse……. Cutzamala system……		
2006 Mexico City metropolitan area			Urban Agriculture Industry	8.24 m^3/s			

Annex: figures

Figure 1: the Mexico City basin.



Source: Gonzalez-Moran, T., Rodriguez, R., Cortes, S.A. (1999). “The Basin of Mexico and its metropolitan area: water abstraction and related environmental problems”. Journal of South American earth Sciences. 12. pp. 608.

Figure 2: Mexico City population and urban area 1600-2005

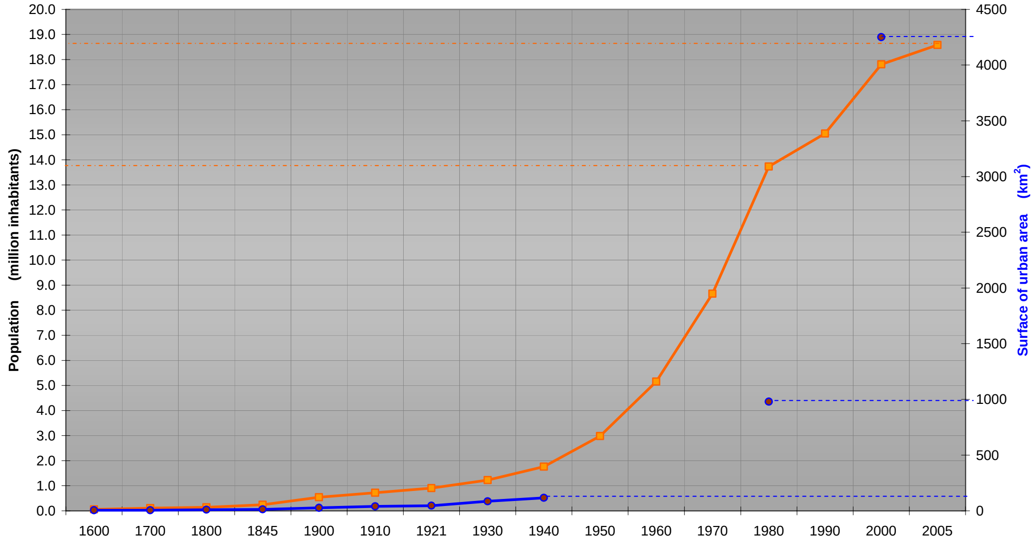
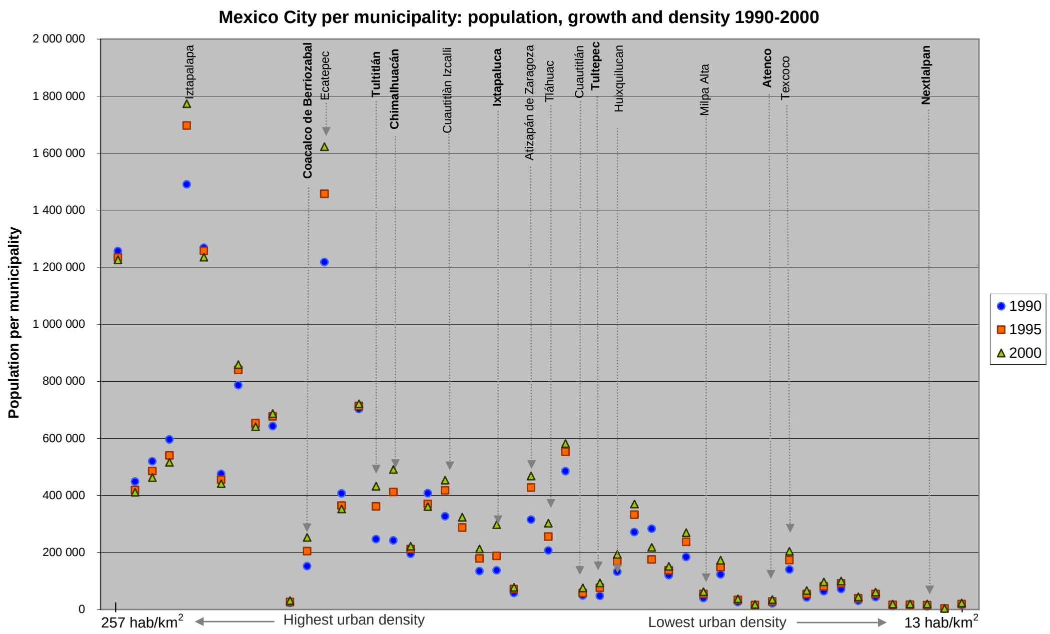
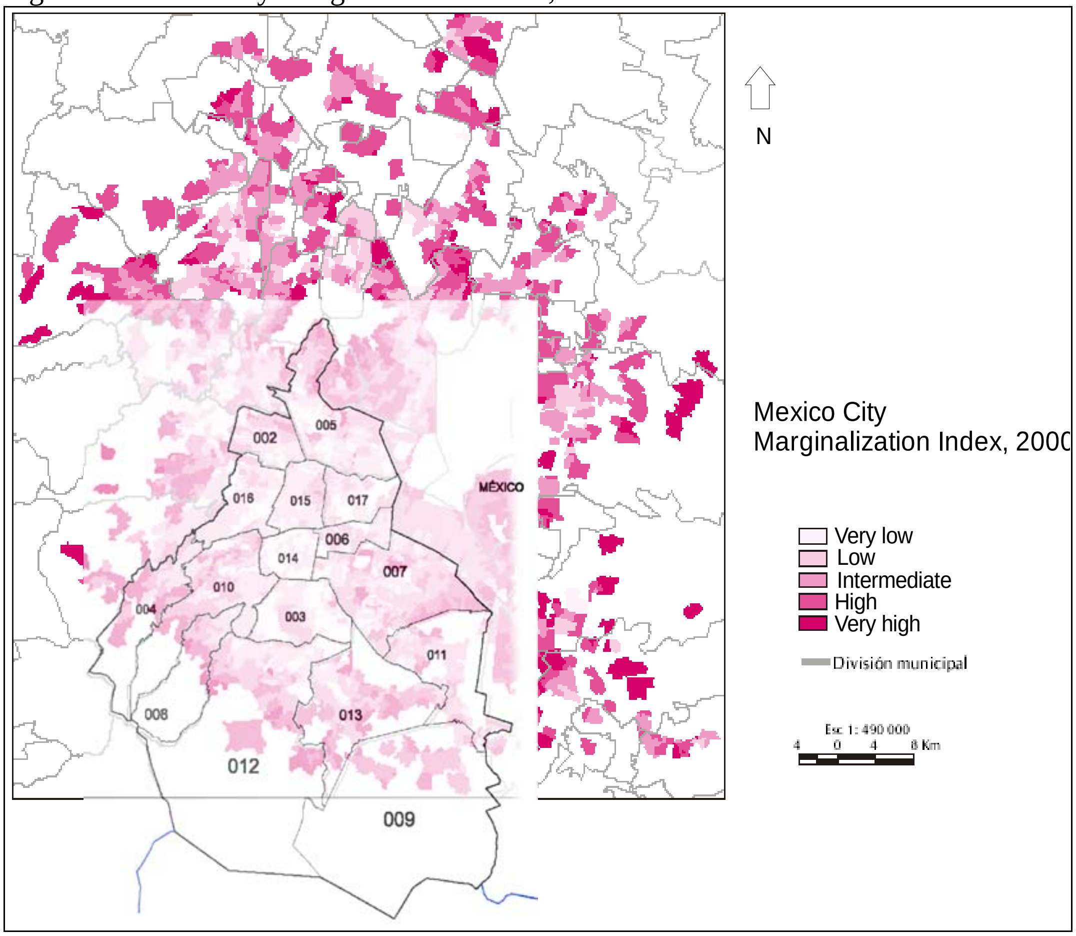


Figure 3: Mexico City per municipality: population, growth and urban density 1990-2000



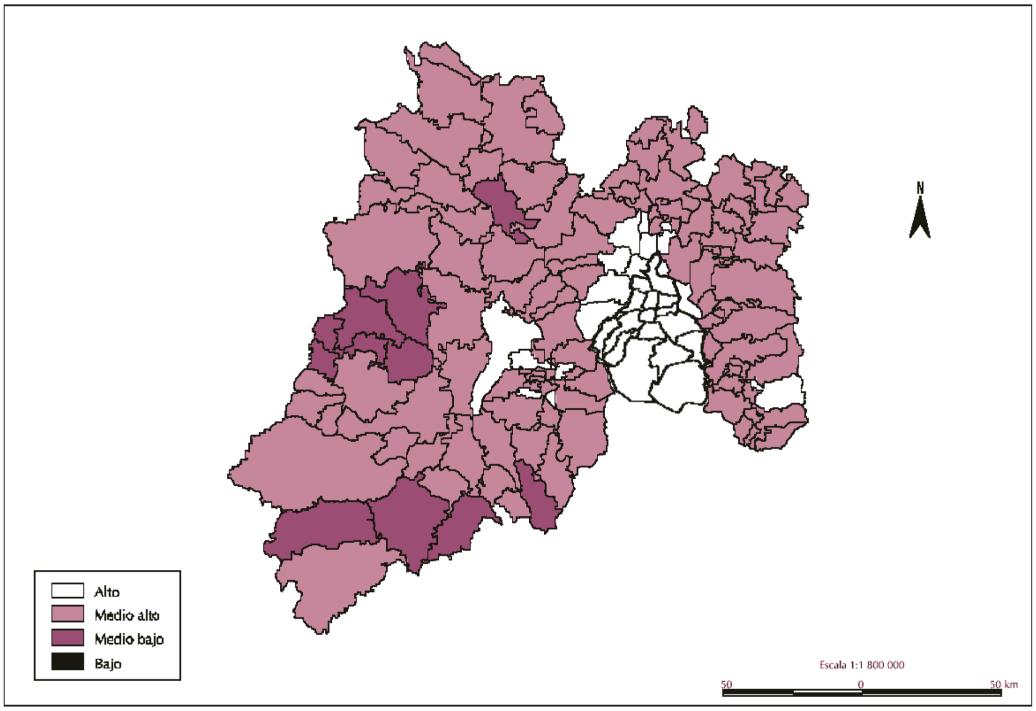
Note: The municipalities to the left are those with a higher urban density in terms of inhabitants per km^2 whereas those in the right have the lowest density. A number of municipalities, mainly from the State of Mexico, showed an annual population growth rate higher than 3% and even higher than 5%, almost twice the national average for the same period. In bold the municipalities with a mean annual growth rate higher than 5%; the other municipalities named in the graph have growth rates between 3 and 5 %.

Figure 4: Mexico City Marginalization Index, 2000.



Note: Estimated by the National Population Council, the Marginalization Index is estimated based on 8 variables, one of which is access to potable water at dwelling level. The estimation is disaggregated at the Basic Geostatistical Area (AGEB), a unit equivalent to 20 to 40 blocks of the city. The other variables are: percentage of the population 15 years and older illiterate; percentage of population 15 years and older who did not finish primary school; percentage of dwellings without bathroom; percentage of dwellings without electricity; natural log of average dwellers per room in a dwelling; percentage of dwellings with dirt floor; percentage of occupied population who receive a salary equivalent to up to two minimum wages.

Figure 5: Human Development Index at municipal level, 2000.

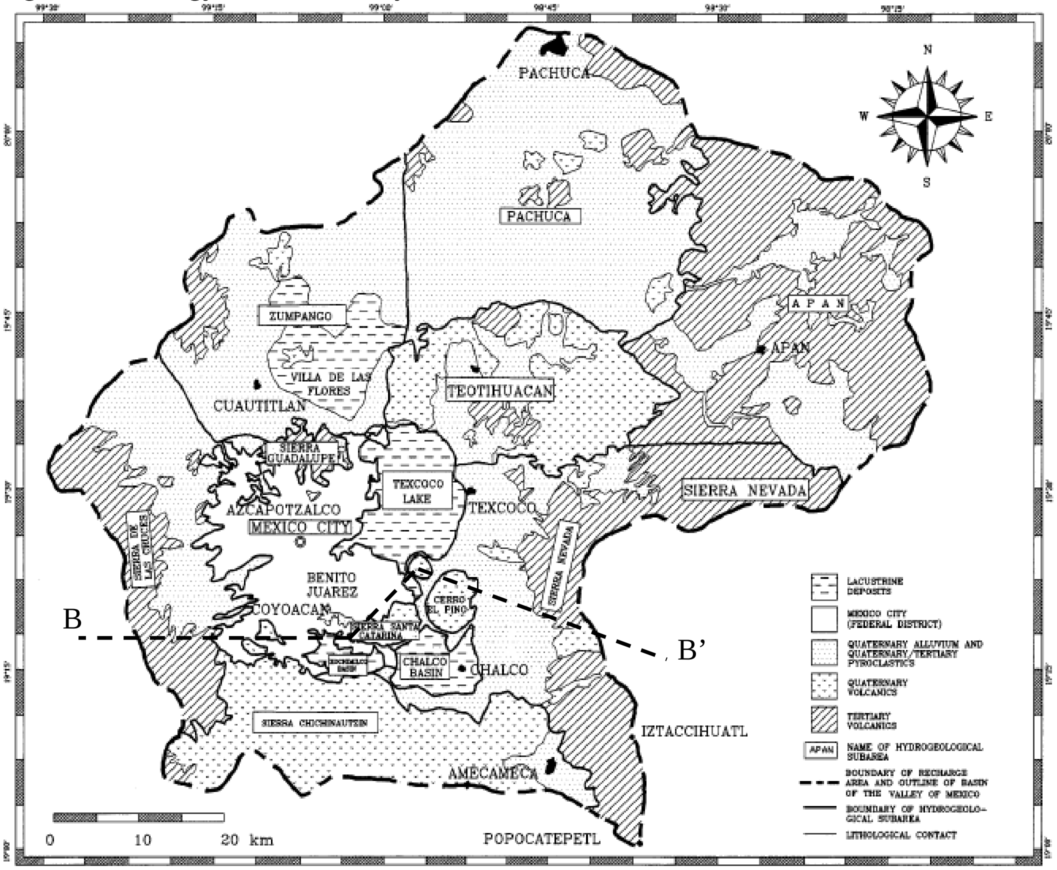


Fuente: estimaciones de CONAPO con base en los resultados del XII Censo General de Población y Vivienda, 2000.

Source: CONAPO (2000). “Indice de Desarrollo Humano, 2000”. Anexo Estadístico, Mapas. Available at: http://www.conapo.gob.mx/00cifras/6d.htm

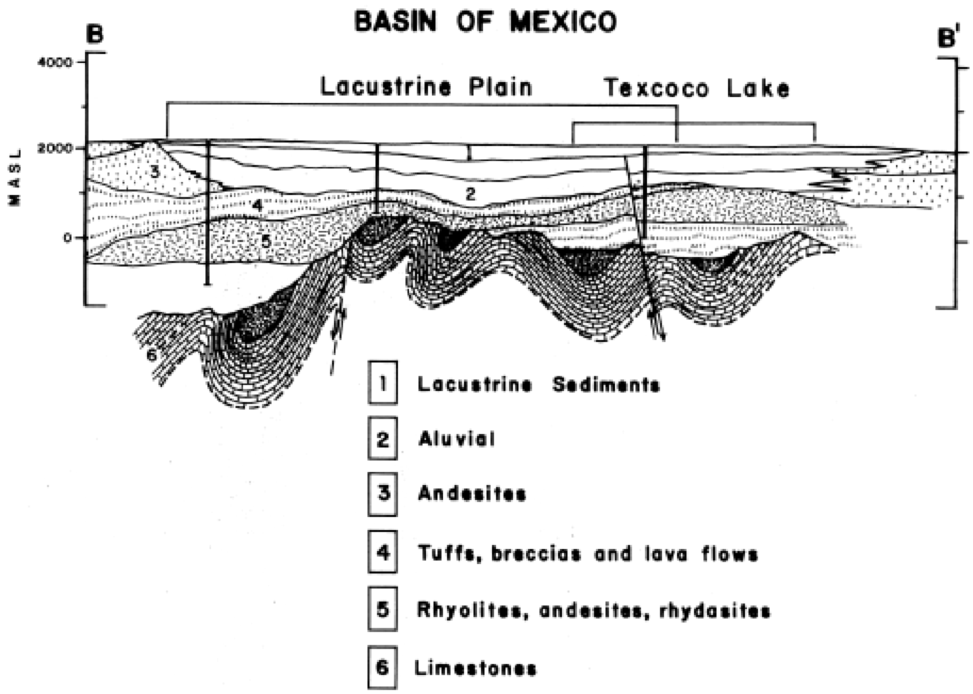
Notes: The map shows the Human Development Index at municipal level of the DF and all the municipalities of the State of Mexico.
White- High Human Development Index
Light red: Medium high Human Development Index
Dark red: Medium low Human Development Index
Black : Low Human Development Index

Figure 6: Geology of Mexico City



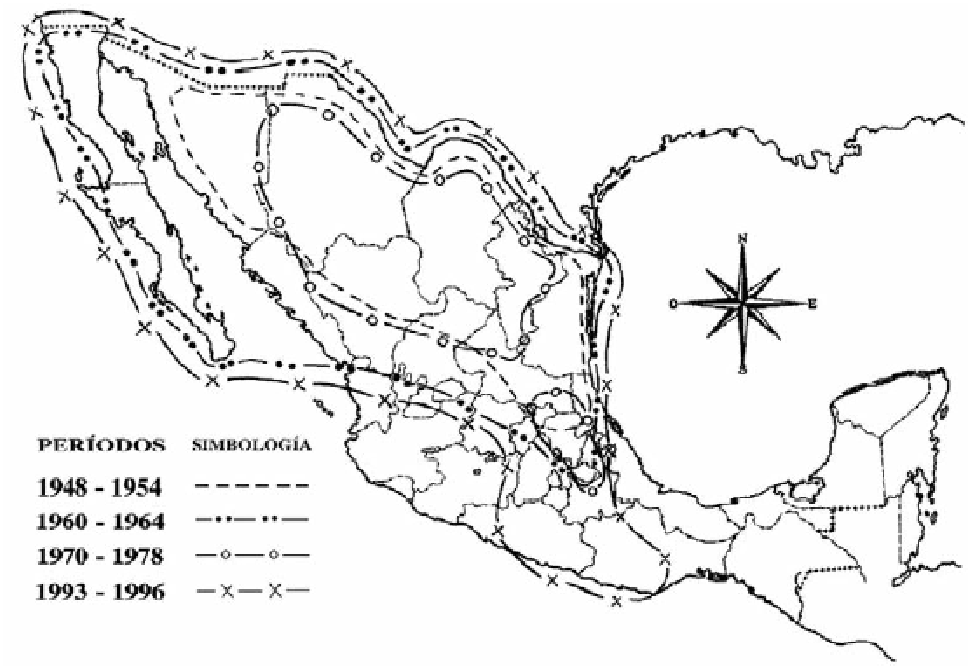
Source: Birkle, F., Torres Rodríguez, V., González Partida, E. (1998). "The water balance for the Basin of the Valley of Mexico and implications for future water consumption". Hydrogeology Journal. 6: 500-517.

Figure 7: Geological section



Source: González-Morán, T., Rodríguez, R., Cortes, S.A. (1999). "The Basin of Mexico and its metropolitan area: water abstraction and related environmental problems". Journal of South American Earth Sciences. 12: p. 610

Figure 8: Droughts in Mexico 1948-1996]



Fuente: CENAPRED. Sequías de la Serie Fascículos. Secretaría de Gobernación.

Source: CONAGUA (2006) “Estadísticas del Agua en México”. Chapter 3. page 44.

Figure 9: map of Mexico City: hydraulic works 15th-17th centuries.