Water Management for a Megacity: Mexico City Metropolitan Area
Author(s): Cecilia Tortajada and Enrique Castelán
Source: *Ambio*, Vol. 32, No. 2 (Mar., 2003), pp. 124-129
Published by: Springer on behalf of Royal Swedish Academy of Sciences
Stable URL: http://www.jstor.org/stable/4315348
Accessed: 12/07/2011 00:09

Article Cecilia Tortajada and Enrique Castelán

Water Management for a Megacity: Mexico City Metropolitan Area

The paper presents an overview of the present situation of the Mexico City Metropolitan Area (MCMA). The analysis indicates an urgent need to radically improve the current water supply and wastewater management practices, to become sustainable. The MCMA is one of the most rapidly growing urban centers of the world, with a population of about 21 million people, a very high rate of immigration and numerous illegal settlements. In order to meet the increasing water demand, successive governments have focused almost exclusively on supply management and engineering solutions, which have resulted in investments of hundreds of millions of USD and the construction of major infrastructure projects for interbasin water transfer. Environmental, economic and social policies associated with water management are mostly inadequate and insufficient, which is resulting in increasing deterioration in the environment, health and socioeconomic conditions of a population living in one of the largest urban agglomerations of the world. Surprisingly, however, no long-term strategies on demand-management, reuse, conservation, and improved water-management practices have been developed so far.

INTRODUCTION

Mexico City Metropolitan Area (MCMA) is located in a natural closed basin called Valle de Mexico, at 2240 m above sea level (m a.s.l.). It includes the Federal District and 34 municipalities of the State of Mexico. Mexico City, the capital of Mexico, is located in the Federal District (Distrito Federal, DF), surrounded by mountains, reaching an altitude of over 5000 m a.s.l. The State of Mexico is the most populated area in Mexico (13 million inhabitants according to reports), followed by Mexico City, with almost 8.6 million people (1).

The metropolitan area is one of the most rapidly growing urban centers in the country, with a surface area of 4902 km^2, about 21 million inhabitants (accounting for 18.4% of the total population of Mexico). The quality of life of the population living in the MCMA area has decreased dramatically in the recent years, primarily due to high population density (ranging from 131 ind. km^{-2} up to 18 075 ind. km^{-2}) and extensive air, water, and soil pollution. Historically, the city has faced severe water problems, which have become more acute due to a continuous increase in the population and the contamination of surface and groundwater in and around the city (2). Figure 1 presents an overview of population growth and water demands in the MCMA.

At present, 95.3% of the population in DF and 84.2% in the State of Mexico have access to water, either by water connection directly to houses or from common faucets in the neighborhood (3). The per capita water supply in Mexico City is about 364 L cap^{-1} day^{-1} in Mexico City and around 230 L cap^{-1} day^{-1} in the State of Mexico, which would represent an average daily consumption of 297 L cap^{-1} day^{-1} in the MCMA as a whole. However, the actual amount received by each individual is significantly less, because this average includes water use by industries and services, leakages of more than 40%, unauthorized uses, and differences in distribution patterns in the different areas of the metropolitan area (2, 4).

Since most of the water sources which supply water to the MCMA are located to its west, north and south, the water supply is somewhat irregular and unreliable for the population living in the eastern part, which is currently most affected by water shortages. More than 5% of the people living in the metropolitan area still have to buy water from either public or private water trucks. The cost of water (200 L containers) represents from 6 to 25% of daily salaries (5). At present, poor people who buy water from trucks pay about 500% more than do registered domestic consumers.

The water supply of the metropolitan area depends mainly on the local groundwater sources and on the transfer of surface waters from more and more distant basins. In order to meet part of the water needs of the population, a total volume of 2453 x 10^3 m^3 day^{-1} is abstracted from 414 wells (1476 x 10^3 m^3 day^{-1}), 30 springs (76 x 10^3 m^3 day^{-1}) and 93 sources of snowmelt (900 x 10^3 m^3 day^{-1}) (3). The second main water source is the Lerma-Balsas and Cutzamala river basins.

In Mexico City, water is distributed to the users through a primary network of 882 km of pipelines and a secondary network of 12 042 km (2). The water supply system includes 16 dams having a total storage capacity of 207 527 x 10^3 m^3 (3). Information on the infrastructure for water distribution for the State of Mexico is not available.

At present, the National Water Commission (*Comisión Nacional del Agua, CNA*) supplies about 24 m^3 s^{-1} of water to the metropolitan area. CNA is also responsible for constructing and operating distribution systems to transfer water from other basins to the basin of the Valley of Mexico. It operates also some of the existing deep wells, while others belong to the State of Mexico and Mexico City governments (6). The distribution system has become so huge and complex that the water extracted from wells in one part of the MCMA does not necessarily enter the system within the same service district.

There are 24 wastewater-treatment plants in Mexico City and 41 in the municipalities of the State of Mexico which are part of the metropolitan area. These 65 plants have an installed capacity of 10 174 L s^{-1} (6412 L s^{-1} in Mexico City and 3763 L s^{-1} in the State of Mexico). Some 1 637 000 x 10^3 m^3 of wastewaters are produced annually in Mexico City alone, of which no more than 9% are treated. There is no information available on the wastewater that it is produced in the State of Mexico (2). It is not known whether all the treatment plants are currently functional, or the extent to which their capacities are used.

However, irrespective of the numerous infrastructures that have been constructed to provide clean water and dispose of the wastewaters of the MCMA, there are still no strategies for integrated management of the infrastructures as a whole within the metropolitan area, including practices as basic as regular and timely maintenance. For example, in June 2000, heavy rains, and the lack of maintenance by the water authorities of the La Compañía river (now a wastewater canal) in the eastern part of the MCMA, resulted in the flooding, with wastewater, of 80 ha of a very poor urban area, damaging nearly 1200 houses and affecting 6000 people who lost all their property, and were subject to health risks. The cost for cleaning the area, support to some of the families, and repair of the canal was calculated at approx. 55 million pesos (USD 6 million). Additionally, one of

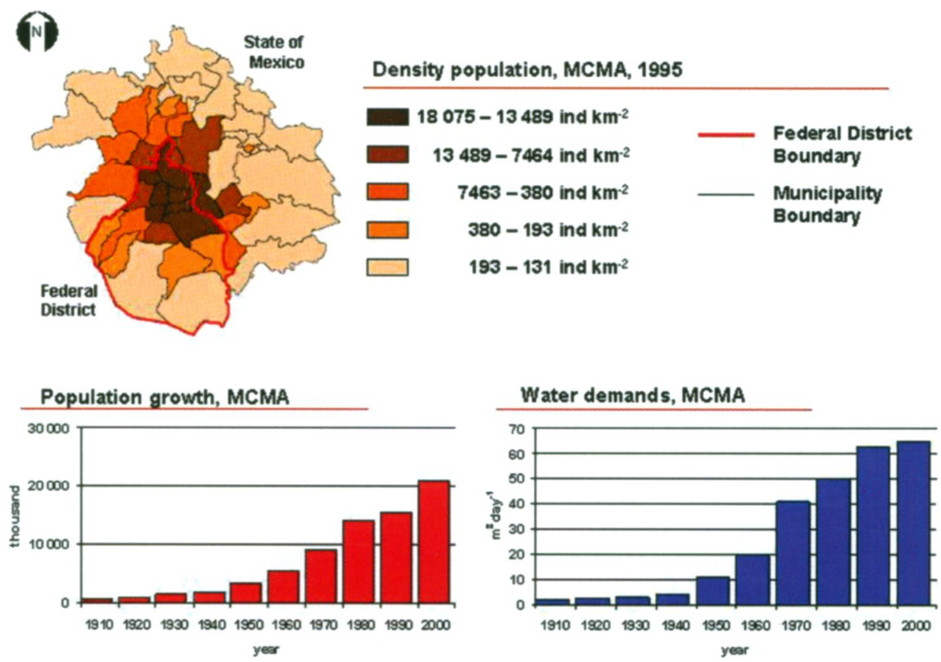


Figure 1. Population growth, population density, and water demands in the MCMA, 1999.

the main highways to the MCMA (Puebla Highway) was closed for about 10 days. There are records that show that the municipality and the local water utility warned CNA of cracks in the canal and demanded maintenance work during the preceding 2 years. These warnings were not heeded, and the much-needed maintenance work was never carried out. As a result, the canal walls collapsed and the entire area, including the houses, were flooded with wastewater. The Human Rights Commission after reviewing the situation, recommended that appropriate staff members should be held administratively and legally responsible for the negligence. Not surprisingly, no action was ever taken in this regard (7).

There is an urgent need for all the stakeholders involved and interested in the sustainability of the MCMA and its large population to develop a long-term regional strategy which includes socioeconomic development, poverty alleviation, quality of life, and water and wastewater management. However, real stakeholder participation, for all practical purposes, is conspicuous by its absence. While this is an important issue, it is beyond the scope of the present paper. The present paper is an in-depth analysis of the size and complexity of urban water and wastewater-management problems in one of the largest megacities in the world.

MAIN SOURCES OF WATER SUPPLY TO THE METROPOLITAN AREA OF MEXICO CITY

The MCMA is located in the Valley of Mexico basin, which is surrounded by the basins of Lerma, Cutzamala, Amacuzac, Libres Oriental, and Tecolutla rivers (8). The Lerma and the Cutzamala river basin, together with the aquifer of the Valley of Mexico, are the main sources of water for the population living in the metropolitan area. The aquifer of the Valley of Mexico contributes with 70% (45 $m^3\ s^{-1}$), the Lerma-Balsas river basin with 9% (6 $m^3\ s^{-1}$) and the Cutzamala river basins with 21% (19 $m^3\ s^{-1}$) (3, 4). The design for Cutzamala is for 19 $m^3\ s^{-1}$, but it delivers only 14 $m^3\ s^{-1}$.

The Aquifer of the Mexico Valley

The annual rate of withdrawal from the aquifer of the Mexico Valley is significantly higher than the recharge rate: 45 $m^3\ s^{-1}$ is abstracted but the natural recharge rate is only 20 $m^3\ s^{-1}$, leaving an overexploitation of 25 $m^3\ s^{-1}$ (9). The overexploitation of the aquifer has contributed to the lowering of the watertable by about 1 m each year, which has resulted in land subsidence at the rate of 10–40 cm yr^{-1} in some parts of the city. At present, the average annual subsidence of the City in the area of the city centre is 10 cm, and 20–25 cm at the International Airport of Mexico City. It is estimated that the central area of the metropolitan area has subsided by 10 m during the last 100 yrs (2, 10).

The problems related to water supply in the metropolitan area extend beyond the subsistence of the city. The entire hydraulic system, for example, has become not only very large and complex, but also obsolete in many areas. Water distribution to the population varies in the different parts of the city, the tariffs are still very highly subsidized, and the population wastes enormous amounts of water. People living in the richer areas consume up to 600 L $cap^{-1}\ day^{-1}$, while the corresponding rate in the poor areas is about 20 L $cap^{-1}\ day^{-1}$ (11). Deep well drilling has resulted in the increase of substances like iron and manganese, decreasing water quality and contributing to more expensive water purification. The urban infrastructure has become more vulnerable to earthquakes. The overexploitation is draining soil humidity in the surrounding mountains, which is damaging forest resources and reducing ecosystem integrity (12).

A very high percentage of water is lost from the distribution networks due to leakage from old pipes, absence of proper maintenance over prolonged periods, poor construction and management practices, and continuing land subsidence in the metropolitan area (2, 4). It is estimated that the amount lost would be enough to provide water for more than 4 million people (9). In 1994, about 42 242 leakages were repaired in the water supply distribution network; 33 463 leakages in 1995; and 41 246 leakages in 1996 (13).

Aquifer of Lerma Valley

In 1942, the Lerma Valley project (62 km from Mexico City) was initiated to increase water availability in the metropolitan area. The first stage brought 4 $m^3\ s^{-1}$ of water to the metropolitan area. It included the construction of 5 wells between 50 and 308 m deep for groundwater extraction, and a 62 km, 2.5 diameter pipe, for water distribution. This pipe goes along the *Sierra de las Cruces*, through the 14 km *Atarasquillo-Dos Rios* tunnel. Four storage tanks each of 100 m in diameter and 10 m in depth were built in Mexico City to receive the water of the Lerma project. This water was later distributed to the MCMA by gravity. The increasing demand for water in the metropolitan area, resulted in the construction of the second stage of the project. Between 1965–1975 some 230 deep wells were constructed increasing the volume of water distributed to 14 $m^3\ s^{-1}$. However, due to environmental impact and social conflicts, this volume has been reduced to 6 $m^3 s^{-1}$ (8, 12).

The political relationship between the authorities of Mexico City and the State of Mexico has been strongly influenced by social conflicts which have resulted from the interbasin transfer of water from the Lerma Valley to the metropolitan area. The overexploitation of the aquifers in the Lerma area has resulted in reduced agricultural productivity, and irrigation has given way to rainfed agriculture. The economy of the region and the life of the population have changed drastically because of these modifications. In spite of this, the main interest of the Federal and the Mexico City governments continues to be primarily to increase water availability to the metropolitan area. As a way of compensating local populations, small infrastructural projects have been constructed in the villages which have been affected by the Lerma project, without much impact. (8, 12).

Cutzamala System

In 1976, the Cutzamala System (*Sistema Cutzamala*) Project was planned to supply water to the metropolitan area from the Cutzamala river, and to reduce the overexploitation of the Mexico Valley aquifer. The water has to be transferred from 60 to 154 km away and pumped to a height of more than 1000 m, which makes this operation extremely energy-intensive and expensive (4).

Initially, what later became the Cutzamala System, was planned as a hydropower project, Miguel Aleman Hydropower System. Cutzamala was started by taking advantage of the infrastructures that already were constructed for hydropower generation. The planned water use was changed. Currently, only 3 $m^3 s^{-1}$ are used to generate hydropower during peak hours, to satisfy local energy requirements, mainly for agricultural and industrial sectors.

Due to the magnitude of the project, its construction was initially planned in 3 stages. The first stage has been under operation from 1982 (4 $m^3 s^{-1}$), the second from 1985 (6 $m^3 s^{-1}$), and the third one from 1993 (9 $m^3 s^{-1}$) (14). During the first stage of the project, water was brought from the Victoria Dam and was distributed through an aqueduct 77 km long and 2.5 m wide, which crosses the mountain *Sierra de las Cruces*. The second and third stages of the project included the construction of a water purification plant and a central aqueduct. The implementation of these 2 latter stages was very complex, mainly due to the height to which the water had to be pumped. In the case of the Colorines Dam, water has to be pumped to a height of 1100 m (15) (Fig. 2). The electricity that is used to pump the total volume of the Cutzamala system to the purification plant is equivalent to the total energy consumed in the city of Puebla, with a population of 1.5 million people (8, 12).

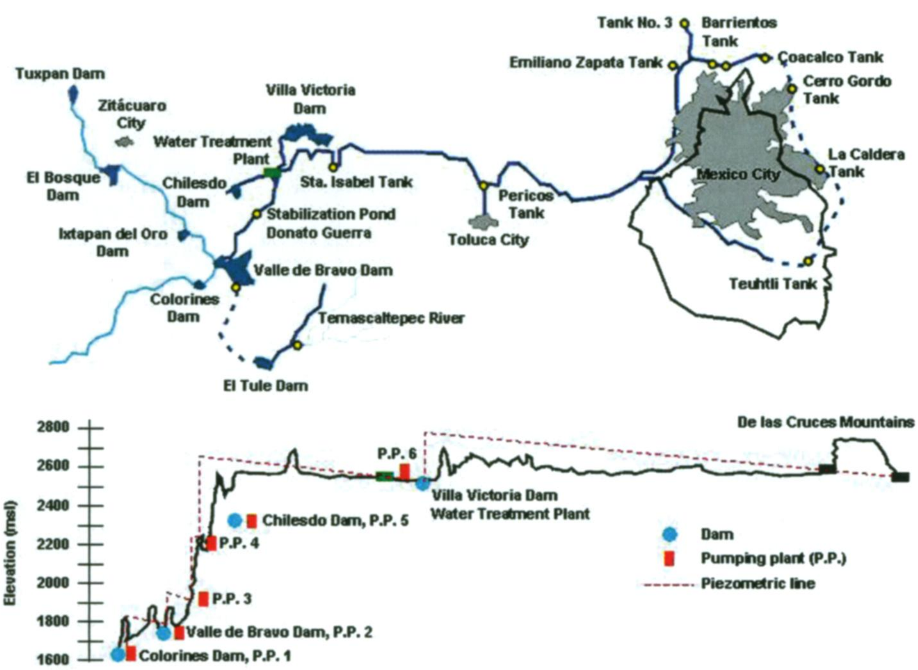
The Cutzamala System utilizes 7 reservoirs which store a total volume of 790–840 x 10^6 m^3 of water. It includes one pipeline, a regulatory reservoir, a 127 km long aqueduct, with 21 km of tunnels, 7.5 km open canal, and one water-treatment plant (24 $m^3 s^{-1}$ capacity) (16). Six pumping stations are necessary to raise water by 1300 m, requiring a total energy of 1650 kWh yr^{-1} (4). The water is first treated at the source in the Los Berros treatment plant (prechlorination, alum coagulation/flocculation, gravity sedimentation, and rapid sand filtration) and then it enters the Cutzamala System (17). One of the most important dams in the system is Valle de Bravo dam, which stores approximately 394 x 10^6 m^3 of water, but receives discharges of wastewater from the urban areas nearby and it is infested with aquatic weeds, which affect the water quality (8).

In 1997, the fourth stage (Temascaltepec project) was expected to be initiated. This stage included the construction of a 120 m high dam, with a 743 m long crest. The reservoir would have a capacity of 65 x 10^6 m^3 of water to supply an approximate flow of 5000 L s^{-1}. It included construction of a 15 $m^3 s^{-1}$ pumping station, and construction of 18 km of canals and 12 km of tunnels (4). The water would be distributed to the Valle de Bravo dam through a 18.75 km long and 3.5 m diameter tunnel. The tunnel would be 160 to 700 m deep, depending on geographical conditions. According to official figures, the initial investment is estimated at USD 502 million. Once the fourth stage of the Cutzamala is operational, the volume of water would increase only by 5 $m^3 s^{-1}$, from 19 $m^3 s^{-1}$ to 24 $m^3 s^{-1}$ (18, 19).

The government has not been able to start construction of the project due to serious social problems (4). The population in the villages of Temascaltepec insist that the construction of the tunnel will dry up several springs, like *El Naranjo*, *La Huerta*, *El Sombrero* and *El Chilar*, which would affect the agricultural productivity of the area, and thus the incomes of the local farmers. The area is a major producer of maize, sugarcane, banana, tomato, melon, and peas, with important markets in Mexico City and Toluca, the capital of the State of Mexico. Not surprisingly, all the people who would be adversely affected by the project are against it. From past experience, they know that their incomes and lifestyles, as well as the development of the region, will be irreversibly affected negatively. The CNA has tried to convince them by constructing some small infrastructural projects, but so far the people are more interested in their own welfare, rather than in the population of the metropolitan area (8).

In the past, governmental institutions have generally ignored the potential social conflicts which could result from interbasin transfers. Nor have they carried out analyses of the nature of the beneficiaries of the project and identification of the people who may have to pay the cost, and how they can be properly compensated. Most surprisingly, even the Environmental Impact Assessment (EIA) for the fourth stage of Cutzamala System (4) does not consider any of its social impacts. As for most EIA stud-

Figure 2. Overview of the Infrastructure for Cutzamala System. The elevation at which the different dams and pumping plants of the System are constructed is presented (15).



ies carried out in Mexico, it considers almost exclusively technical factors; social issues are conspicuous by their absence (20, 21).

According to the EIA study carried for the Cutzamala system, the total investment cost of the first 3 stages was USD 965 million (1996 estimates). If the estimated costs of the facilities from the previous hydroelectric plant that would no longer be used are added, the total investment cost becomes USD 1290 million. The cost of the cancelled hydropower system, having a total installed capacity of 372 MW, has been estimated at USD 325 million (4).

The total surface affected by the construction of the Cutzamala System during the first 3 stages is approximately 710 ha, with a land value of USD 3.55 million. One of the main adverse socioeconomic impacts of the Cutzamala has been the relocation of the affected communities, who, as of November 2001, had not received the expected compensation. About 190 so-called social projects have been built to benefit some of the people living in the municipalities that are most affected by water shortages. These projects were built jointly by the CNA and the communities, and consist mainly of construction, enlargement and rehabilitation of both water supply and sanitation systems, as well as construction and rehabilitation of houses, schools, and farms. Equally important is construction and rehabilitation of roads by CNA, both for Cutzamala and for social benefit. The cost of these so-called social projects was estimated in 1996 to be equivalent to 5% of the direct investment of the Cutzamala, which would represent an additional USD 45 million (4, 20).

It is worth noting that the total cost of the Cutzamala System at USD 1300 millions (mainly construction and equipment costs) was higher than the national investment in the entire public sector in Mexico for the year 1996, including education (USD 700 million), health and social security (USD 400 million), agriculture, livestock and rural development (USD 105 million), tourism (USD 50 million), and the marine sector (USD 60 million). Up to 1996, the Cutzamala System alone represented 3 times the annual infrastructure expenditure of the Ministry of Environment, Natural Resources and Fisheries for 1996, at around USD 470 million (4, 20).

The annual energy requirements to operate the Cutzamala System are about 1787 million kWh, which represents an approximate cost of USD 62.54 million. The investment would increase significantly if the investment costs in personnel (USD 1.5 million yr^{-1}) as well as the water-treatment process costs are added (4, 20).The energy consumed by the system, plus the energy that could have been produced if the system was operated as a hydropower plant as was originally planned, would have met the electricity needs to some 2.59 million people.

Additionally, unofficial estimates indicate that about 20% of the energy that is produced at the national level is used to pump imported sources of water up to the metropolitan area, and afterwards, pump the wastewater up from the sewage network to the wastewater channels (previously rivers!) to take the wastewater out of the city. There are estimates which indicate that the energy used to pump water in and out of the metropolitan area is more than 50% of the energy produced at peak operation (750 MW) by the thermoelectric generating plant of the Valley of Mexico, and more than 30% of the energy produced at peak operation at each Chicoasen (1200 MW) and the 2 nuclear generators at Laguna Verde (1280 MW) (21).

If only the operational costs for running the Cutzamala System are considered (about USD 128.5 million yr^{-1}), supplying 600 million m^3 of water (19 m^3 s^{-1}) would mean an average cost per cubic meter of water of USD 0.214 and an energy consumption of 6.05 Kwh m^{-3}. The later figure represents more than 7 times the consumption of power in the locations near the metropolitan area. The price charged to consumers, about USD 0.2 m^{-3}, is not enough to cover either the operational costs of the Cutzamala System, or the purification or distribution costs of water to the metropolitan area. According to the EIA study (4, 20), for the fourth stage of Cutzamala, the minimum water price per m^3 to cover the expenses should be over USD 0.3 dollars m^{-3}. It would be even higher if the treatment and distribution costs were included.

Studies indicate that if the leakages in the distribution system within the MCMA were repaired, there would be no need to construct the fourth stage of the project. This means that the additional water supply of 5 m^3 s^{-1} that is being planned with very high investment, social and environmental costs, would not be necessary. However, this type of efficient planning and management is basically absent in Mexico at present (20).

Official sources (2) indicate that the cost to transfer 1 m^3 s^{-1} from Cutzamala system to the metropolitan area is approximately 310 million pesos or USD 33 000 at June 2001 conversion rate, due to investment and operation costs. How long the federal and state governments can spend such amounts, is something that only time will tell.

In addition to Cutzamala, the other source of water that the Federal Government has identified for potential contribution to the water supply of the metropolitan area is the Amacuzac river basin, with 50 m^3 s^{-1} (12, 21). This project would include the construction of a 185 m high and 450 m wide dam, with an inundated area of 67 km^2, and 4000 x 10^6 of storage capacity. The dam would be located between the states of Morelos, Guerrero, and Puebla. Water distribution from this site to the metropolitan area would requires the construction of a 160 km long aqueduct, with a capacity of 50 m^3 s^{-1}, and either 2 pipes of 4.50 m diameter or 3 pipes of 3.5 m diameter; depending on the final design. This system would pump water to a height of 1825 m, and would require a capacity of 4000 MW. The annual electricity consumption for this system is estimated to be 5% of the national annual electricity production level, representing 16.5 million barrels of oil per year. With this water project, it is expected that it would not be necessary to extract groundwater from the Valley of Mexico Aquifer. All the wells for water distribution in the Valley of Mexico would be used only during severe droughts, or when the other water-distribution systems were not working for maintenance purposes (12, 22).

In order to improve water supply to all areas of the MCMA, the Federal and state governments planned to enlarge the Cutzamala distribution system by constructing 2 aqueducts (Macrocircuit and Aquaférico); and 4 wastewater-treatment plants, and by covering 86 km of the present uncovered main sewage line in the MCMA. The investment cost would be about USD 1800 million over a $3^1/_2$ year period (11). In 1998, the newly elected government of Mexico City cancelled the plans for the construction of the projects to supply drinking water and for sanitation purposes. Several issues were considered in reaching this decision. First, the investment costs for treating the wastewater and transferring it hundreds of kilometers from the source to the Mezquital Valley, where raw water at present is used for irrigation, are extremely high. Second, Mexico has not developed a cost-effective technology to treat wastewater and reinject it into the aquifer. Third, construction of only the treatment plants, without proper water-resource management and planning, would not solve the acute sanitation problems of Mexico City and Mezquital Valley.

DRAINAGE SYSTEMS

The soil of Mexico City is basically clay, and thus susceptible to dewatering and compaction. Accordingly, the higher the volume of water abstracted, the higher the rate of land subsidence (4). The sinking of the city has resulted in extensive damage to the infrastructure of the city, including water supply and sewage systems (pipe fractures and the loss of the hydraulic gradient) and groundwater contamination. It has also resulted in the construction of costly pumping plants to remove both wastewater and rainwater from the city.

Because of being located within a naturally closed hydrologic basin, the MCMA is particularly vulnerable to flooding. Throughout history, artificial channels had to be built to transport wastewater and rainwater out of the city. The rainy season in the metropolitan area is often characterized by intense storms of short durations, which could produce up to 70 mm of rainfall in 3 hours, representing nearly 10% of the total annual precipitation.

At the beginning of the last century, the sewage system (Grand Drainage Canal, *Gran Canal del Desagüe*) used to work by gravity. However, the original gravity-fed system was disrupted by the subsistence of the city and by 1950 the uneven settlement of the sewage network made it necessary to pump wastewaters up from the small sewage lines to the level of the main wastewater collector, thus significantly increasing both maintenance and operation costs. The *Gran Canal* has been affected by the subsidence of the city so much that at present, the first 20 km have almost totally lost their inclination (17, 23) (Fig. 3).

Continually increasing population in the metropolitan area rendered sewage collection and treatment capacity insufficient. Accordingly, in 1967, it was decided to build another main collector for wastewater for both Mexico City and the State of Mexico as a combined sewage and rainwater network (Deep Drainage, *Drenaje profundo*). A system of drainage interceptors and deep collectors were constructed along with a new artificial exit from the Basin of Mexico in 1975. At present, the *Drenaje profundo* has more than 80 interceptors. This system had to be constructed up to 300 m below the ground level so that it was no longer affected by the subsidence (24), thus increasing its costs very significantly. The main collector (*emisor central del Drenaje profundo*) was designed to carry about 200 $m^3 s^{-1}$ of water over a 45-hour period, even though it has carried up to 340 $m^3 s^{-1}$ (17). Such sudden fluctuations in the amounts of water that have to be drained can create serious problems for the design and operation of the infrastructure.

The *Drenaje profundo* carries an annual average of both rainwater (14 $m^3 s^{-1}$) and wastewater (48 $m^3 s^{-1}$) through primary and secondary networks. The secondary network is used to transport municipal, industrial and rainwaters in pipes of up to about 6.5 m in diameter (2). The primary network is connected to the secondary network which stores, transports, and disposes of the wastewater outside of the city through 4 artificial channels located at the northern end of the basin (9, 17) (Fig. 4). The floodings in the city can be explained due to the difference in levels between some parts of the city and the *Gran Canal*, as well as the inability of the overall sewage system to pump all the water out of the city in rainy season. For example, due to the subsidence of the city, downtown is 7 m below the highest point of the *Gran Canal*, which makes it difficult for the water to be pumped out of the area (18).

In addition, the secondary sewage network is insufficient to carry sudden high volumes of rainwater. There have been severe problems in those parts of the city which are above the east interceptor, where the *Gran Canal* no longer has a gradient. Occasionally, both rainwater and wastewater come out on the streets for short periods. Some 30-years ago, the *Gran Canal* could discharge 90 $m^3 s^{-1}$; currently it discharges only 12 $m^3 s^{-1}$. Due to the increasing inefficiency of the *Gran Canal* system, the *Drenaje*

Figure 3. Subsidence in Mexico City. The lines in the figure on the left show the level in meters that the several areas of the city have subsided during the last 100 years. (Source: 23). The figure on the right shows the progressive subsidence of the city between 1910 to 1990, which has affected the gravity drainage system in such a way that it has lost almost all its pendent. The result has been that it has been necessary to pump rain- and wastewater up to the level of the main drainage collector, increasing both maintenance and operation costs. (Source: 17).

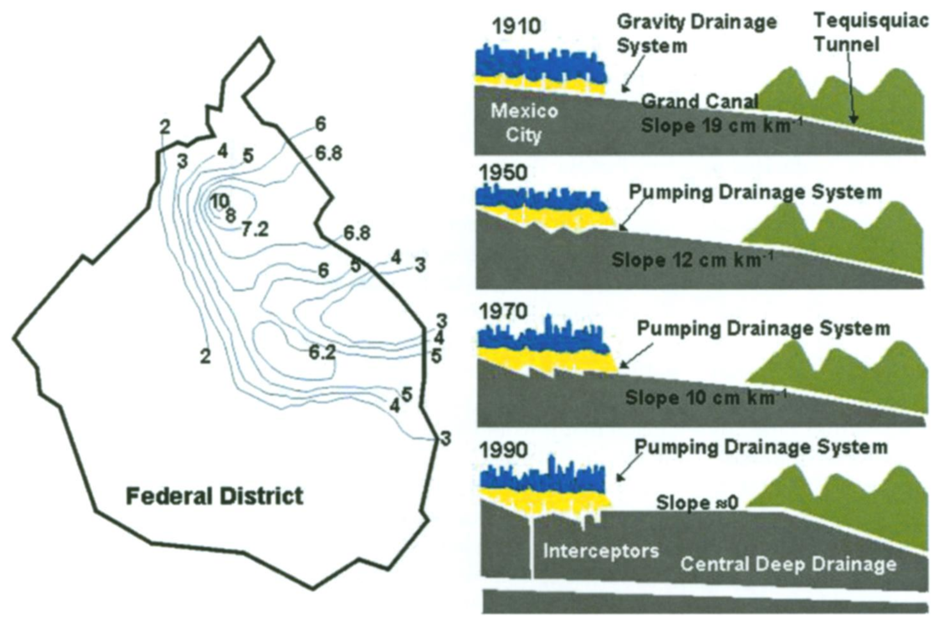
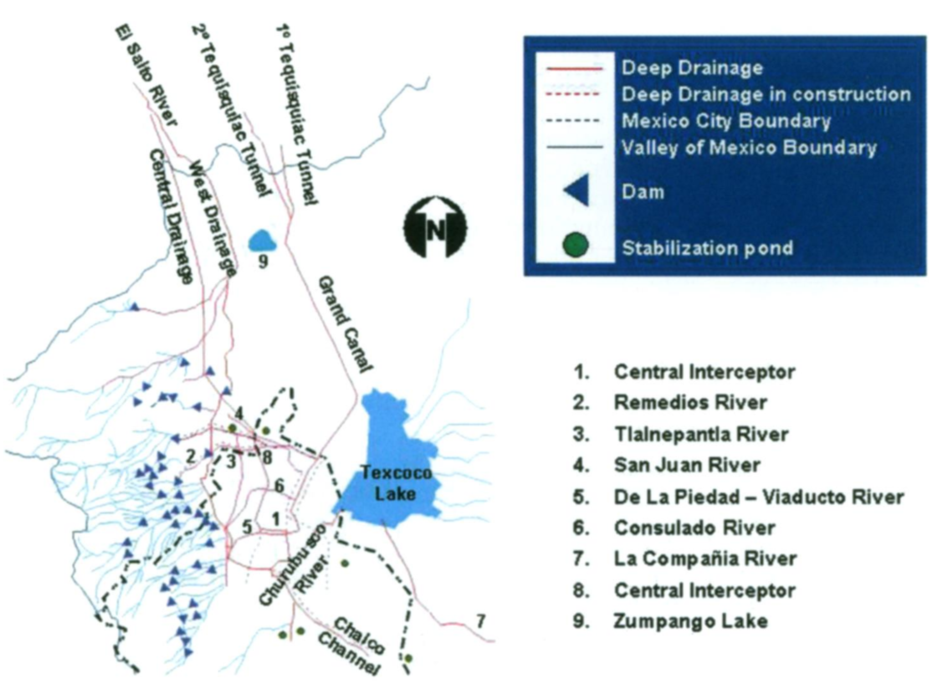


Figure 4. Deep Drainage System of the Mexico City Metropolitan Area. (Source: 9, 17).



profundo has to be used permanently. Accordingly, it has not received maintenance during the last 2 years (24), despite the severe risk that such poor management practices entail.

It is clear that the *Gran Canal* is already inadequate, and thus long-term sustainable solutions need to be found. Infrastructure construction is necessary, but is only a partial solution. Additionally, financial resources are not always available, and construction invariably takes time.

CONCLUDING REMARKS

The current water supply and wastewater-management problems of the Mexico City metropolitan area can be directly linked to the lack of long-term regional economic development policies, poor and inappropriate management practices, and the absence of any serious attempt to formulate and implement a viable wastewater-management plan. Continual increases in population have also made the problems more complex. The solutions should include policies to reduce future population growth rates in the metropolitan area, and preparation of a long-term, implementable water and wastewater-management plan for the MCMA, as well as the region as a whole. In theory, past government policies have attempted to promote the development of other urban centers to discourage further growth in the existing major cities. However, in reality, the Federal Government is still not willing to "give away" financial resources and, most importantly, allocate decision-making power to other levels of government. This situation is valid for the water sector as well.

Construction of infrastructural projects *ad infinitum* to bring more and more water to the metropolitan area is neither sustainable, nor economically feasible, nor is it environmentally and socially desirable. With the existing poor-management practices, investment costs would skyrocket to transport more and more water from increasingly distant and expensive sources, higher operating costs would be incurred for energy, land subsidence will accelerate due to increasing groundwater withdrawals, the quality of groundwater abstracted will decline, higher subsidies and higher investments would be necessary to cover operation and maintenance costs, etc. This represents a never ending vicious circle. The quality of life is likely to improve for the rich, but continue to worsen for the poor.

Because of the neglect of proper wastewater treatment and disposal practices in the past, the cost of implementing a proper wastewater-management system is going to be astronomical in the future. Not surprisingly, nearly all of the streams within the metropolitan area have now been transformed into wastewater-drainage channels. Even if the mindsets of the senior water managers change, and the necessary investments for wastewater management can be found, adequate human capacity in the country to manage water quality is still to be developed (25).

Long-term planning, with a new management mindset, is urgently necessary for the MCMA. Demand management practices must receive rapid attention, as should water quality and wastewater-management practices. New cadres of managers, with a broader vision and more professional and management expertise are necessary. Most regrettably, however, there are no signs that the authorities are searching for new long-term cost-effective solutions, which could simultaneously consider both hard and soft options. On the contrary, all the signs indicate that progress is likely to continue to be incremental, as has been the case in the past, and business-as-usual will likely to be the order of the day, until a catastrophic water-related crisis hits the region. If the present trends continue, that crisis may not be very far off.

References and Notes

1. INEGI 2000. *Agenda Estadística, Estados Unidos Mexicanos*. Instituto Nacional de Estadística, Geografía e Informática. México, 186 pp. (In Spanish).
2. INEGI 1999. *Estadísticas del Medio Ambiente de Distrito Federal y Zona Metropolitana*. Instituto Nacional de Estadística, Geografía e Informática. México, 231 pp. (In Spanish).
3. INEGI 2000. *Cuaderno Estadístico de la Zona Metropolitana de la Ciudad de México*, Instituto Nacional de Estadística, Geografía e Informática. México, 227 pp. (In Spanish).
4. CNA 1997. *Diagnóstico Ambiental de las Etapas I, II y III del Sistema Cutzamala*, México, 156 pp. (In Spanish).
5. Restrepo, I. (ed.). 1995. *Agua, Salud y Derechos Humanos*. Comisión Nacional de Derechos Humanos, México, 409 pp. (In Spanish).
6. CNA No date. *Planta Potabilizadora Madín*. Gerencia de Aguas del Valle de México. Unidad de Información y Participación Ciudadana. México, 8 pp. (In Spanish).
7. *Comisión Nacional de Derechos Humanos 2001*. Recomendación 16/2000. (In Spanish). (http://www.cndh.org.mx).
8. Legorreta, J., Contreras, M.C., Flores, M.A. and Jiménez, N. 1997. *Las Cuencas Externas, Agua y mas Agua para la Ciudad*. Red Mexicana de Ecoturismo. (In Spanish). (http:www.planeta.com)
9. UNAM (eds) 1997. "*Environmental Issues: The Mexico City Metropolitan Area*," Programa Universitario del Medio Ambiente, Departamento del Distrito Federal, Gobierno del Estado de México, Secretaría de Medio Ambiente, Recursos Naturales y Pesca, ISBN 968-36-4812-6, México, 123 pp.
10. Legorreta, J., Contreras, M.C., Flores, M.A. and Jiménez, N. 1997. *El Hundimiento de la Ciudad, Agua y mas Agua para la Ciudad*. Red Mexicana de EcoTurismo. (In Spanish). (http:www.planeta.com).
11. Tortajada, C. 2000. Water supply and distribution in the metropolitan area of Mexico City. In: *Water for Urban Areas*. Uitto, J.I. and Biswas, A.K.(eds). United Nations University Press. Tokyo, pp. 112–134.
12. Castelán, E. 2001. Water management in the Mexico City Metropolitan Area: The hard way to learn. In: *Frontiers of Urban Water Management/Deadlock or Hope?* Proc. UNESCO/World Water Council, Marseille, France, 9 pp.
13. Sánchez, M. 2000. *El Servicio de Agua en la Zona Metropolitana de la Ciudad de México*. Cuadernos de Investigación. Vol. 1. México, 57 pp. (In Spanish).
14. CNA No date. *Subsistema Chilesdo, Tercera Etapa Sistema Cutzamala*. Gerencia de Aguas del Valle de México. Unidad de Información y Participación Ciudadana. México, 6 pp. (In Spanish).
15. IMTA 1987. *Visita al Sistema Cutzamala*. Boletín No. 2, Instituto Mexicano de Tecnología del Agua. México. 23 pp. (In Spanish).
16. CNA No date. *Planta Potabilizadora Los Berros, Sistema Cutzamala*. Gerencia de Aguas del Valle de México. Unidad de Información y Participación Ciudadana. México, 6 pp. (In Spanish).
17. National Research Council, Academia de la Investigación Científica, A.C. and Academia Nacional de Ingeniería, A.C. (eds) 1995. *Mexico City's Water Supply: Improving the Outlook for Sustainability*. National Academy Press, Washington, D.C., 221 pp.
18. Tortajada, C. 2000. Environmental impact assessment of water projects, *Water Resources Develop. 16*, 73–78.
19. Castelán, E. 2000. *Análisis y Perspectiva del Recurso Hídrico en México*. Third World Centre for Water Management. Mexico, 98 pp. (In Spanish).
20. Tortajada, C. 1999. *Environmental Sustainability of Water Management in Mexico*. Third World Centre for Water Management, Mexico, 155 pp.
21. Escurra, E., Mazari-Hiriart, M., Pisanty, I. and Aguilar, A. 1999. *The Basin of Mexico, Critical Environmental Issues and Sustainability*. UNU Press. Tokyo, 216 pp.
22. Frias, M. No date. *Abastecimiento de Agua para el Valle de México*. Proyecto Nacional para el Tercer Milenio. (In Spanish). (http://www.mexicotm.com).
23. *Secretaria del Medio Ambiente del Gobierno del Distrito Federal 2000*. Uso Eficiente del Agua en el Distrito Federal, su Tratamiento y Reutilización, Reunión sobre el Día Mundial del Agua "El Agua y la Ciudad de México", 22 Mayo, 2001, 28 pp. (In Spanish).
24. Domínguez, R. 2000. Las Inundaciones en la Ciudad de México, Problemática y Alternativas de Solución. *Revista Digital Universitaria, UNAM, Vol. 1*, No. 2. (In Spanish). (http://www.revista.unam.mx).
25. Tortajada, C. 2001. Capacity building for the water sector in Mexico: An analysis of recent efforts. *Water Internat. 26*, 490–498.

26. First submitted 21 March 2001. Accepted for publication after revision 30 Nov. 2001.

Cecilia Tortajada is Vice-President of the Third World Centre for Water Management, Mexico, and a member of the Executive Board of International Water Resources Association. Her work focuses on sustainability of water management in developing countries, water policies and institutions, and environmental and social impacts of development projects.

Enrique Castelán is a Senior Researcher at the Third World Centre for Water Management, Mexico. His work focuses mainly on sustainability of water resources management in developing countries, including decentralization and public-private partnership.

Their address: Third World Centre for Water Management, Avenida Manantial Oriente 27, Los Clubes, Atizapan, Estado de Mexico, 52958, Mexico.
E-mail: thirdworldcentre@att.net.mx