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Water Management in Mexico City Metropolitan Area

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ABSTRACT *Mexico City Metropolitan Area has 20 million inhabitants, with population densities in some areas exceeding 13 500 persons/km^2. The provision of water supplies and sanitation services in an efficient, equitable and timely manner presents a formidable management and investment challenges, which simply cannot be met under the existing conditions. The current approach has been almost exclusively on supply management: demand management practices have received inadequate attention. Unless the current management practices change radically, future solutions will require higher investment costs to transport more water from increasingly distant and expensive sources, with serious adverse economic, social and environmental impacts on the exporting regions and higher land subsidence rates in ZMCM due to ever-increasing groundwater withdrawals, among many others factors. It is essential to formulate a long-term integrated management plan, which does not exist at present, and which considers linkages to policies on urban development (an issue basically ignored thus far), migration, industry, energy, public health and environment. It is not an easy task, but, nevertheless, it is an essential one.*

Introduction

Mexico is a country of contrasts and disparities from economic, social, environmental and cultural viewpoints. Over time, economic and social inequities have become increasingly more acute among the regions. While there are people with access to education, health, water, electricity, roads, infrastructural services, etc., there are many others who lack access even to the most basic services.

In terms of water resources, there is an enormous imbalance between water availability and its use. The main economic activities are concentrated in the central, northern and north–western regions of the country, representing approximately 84% of the GDP, but with a per capita water availability of only 2044 m^3/year. On the other hand, in the south–eastern part of the country, where water availability is 14 291 m^3/year/per capita, only 16% of the GDP is produced. This region has the highest rates of poverty in the country and lacks most types of infrastructural development (OECD, 2002a, 2003; CNA, 2005). This means that in the regions endowed with more natural resources, including water, poverty is more acute due to an unfortunate combination of lack of appropriate policies and

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institutions, which, among other issues, have negatively affected the quality of life of the local populations and the environment in which they live.

At the beginning of the 20th century, approximately 80% of the population in Mexico lived in settlements of less than 2500 people. However, by 2000 60% of the population lived in settlements with more than 15 000 people. The increase in concentration of population in urban and peri-urban areas, many of them living under conditions of extreme poverty, has resulted in increased pollution and other stresses on water resources and infrastructure.

Approximately 30 million people currently live in settlements with less than 2500 people. These heavily marginalized areas have low economic productivity, high unemployment and outmigration rates, and poor access to services like education, health, clean water and sanitation. Malnutrition, low life expectancy and high mortality rate are also the highest in these areas (OECD, 2002b).

In 2005, in terms of water-related services, 89.8% of the population at the national level had access to drinking water and 77.6% to sewerage. However, more than 11 million people still lack access to drinking water and over 22 million do not have access to adequate sanitation, with the rural areas generally lagging behind in terms of having adequate services (Gobierno Federal, 2005). Coverage of water supply, in the present context, refers to the population that have access to piped water in their houses or their properties, and to the population able to obtain water from other houses, properties or from a public source. In terms of sanitation, the Mexican statistics include population connected to a public sewer and septic tank, and those discharging wastes directly to rivers, lakes or ravines. Data are not available on either quality or reliability of the services received.

In the case of the capital city, the increased urbanization and high population growth within Mexico City and the neighbouring State of Mexico resulted in the designation of an area known as Mexico City Metropolitan Area (ZMCM, by its acronym in Spanish). This metropolitan area, with an approximate population of 20 million inhabitants and industries, services and commercial activities that generate 33.2% of the GDP, plays very important roles in the country, both from economic and political viewpoints (SEMARNAT/CNA, 2000). However, it faces escalating demands for services in areas like water, sanitation, electricity, education and health, among many others.

Mexico City Metropolitan Area

Mexico City is the capital of Mexico. It is located in the Federal District at 2240 m above the mean sea level (msl) in the south–western part of the Valley of Mexico. It is surrounded by mountains reaching a height of over 5000 m above msl.

At the beginning of the 20th century, Mexico City was still in the north-central area of the Federal District. However, due to increased urbanization, its 16 boroughs at present cover its entire surface area. In fact, according to the Mexican Constitution, at present Mexico City is equal to the Federal District, and both terms refer to the same location.

At present, approximately 9 million people live in 60 203 ha of urban areas and 88 442 ha of rural or conservation areas (land that is left in its natural state, often for groundwater recharge) (see Figure 1). However, these figures do not represent the reality, since both rural and urban development have taken over a great part of the conservation areas (PNUMA *et al.*, 2003).

The Federal Government, and much of the industries, education and employment facilities and cultural centres of the country are concentrated in Mexico City. However,

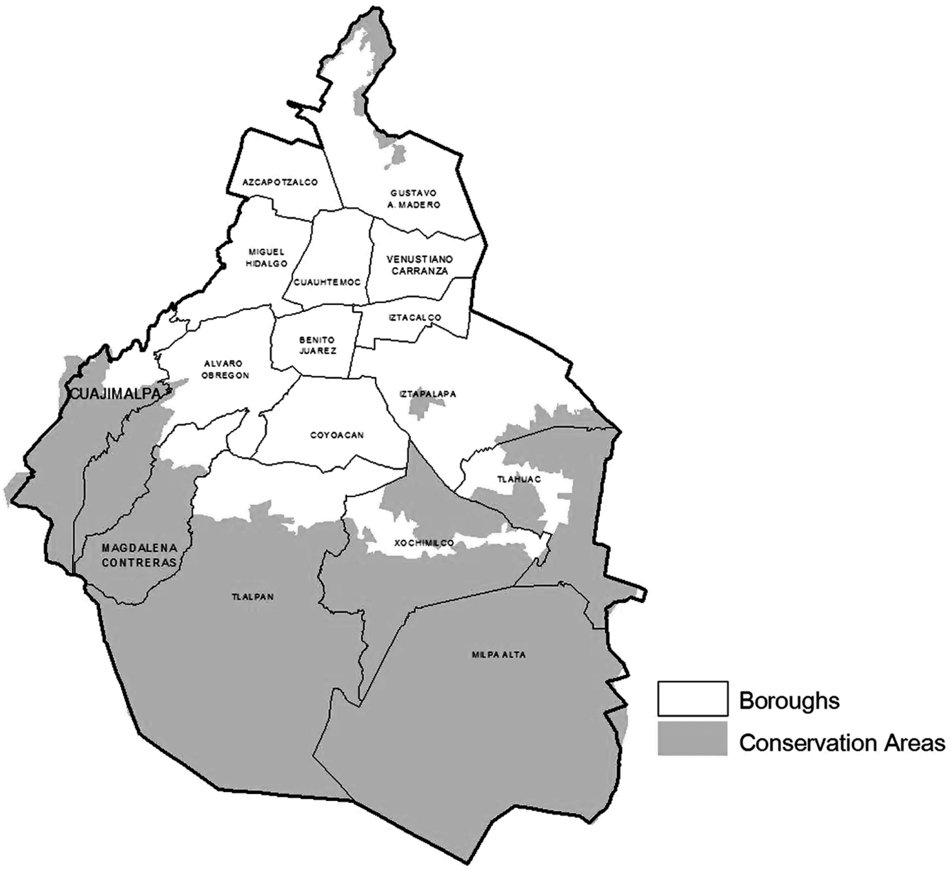

Figure 1. Conservation areas in the federal district. *Source:* Centro de Investigación en Geografía y Geomática 'Ing. Jorge L. Tamayo', Mexico.

the quality of life for the population has decreased significantly in recent years, primarily because of increasing population density, and extensive air, noise and water pollution.

With regard to the ZMCM, in 1990 it included the 16 boroughs of Mexico City and 27 municipalities of the neighbouring State of Mexico. In 1995, it was decided to include within the ZMCM the municipalities of the State of Mexico, which had the highest population as well as economic growth. At present, according to the National Council for Population (CONAPO, 2000), the metropolitan area includes the 16 boroughs mentioned above, 37 municipalities of the State of Mexico and one municipality of the neighbouring state of Hidalgo. However, according to the National Institute of Statistics, Geography and Informatics (INEGI), the ZMCM includes the 16 boroughs of Mexico City and 34 municipalities of the State of Mexico.

The ZMCM covers an area of 4925 km^2 (1484 km^2 in Mexico City, and 3441 km^2 in the State of Mexico), representing about 0.25% of the national area. The population density varies from 13 500 to 131 persons/km^2. The State of Mexico is the most populated area in the country, with 13.1 million inhabitants, followed by Mexico City, with 8.6 million

(INEGI, 2000a). The State of Mexico also has the highest population growth rate of all the states in the country, including Mexico City. During the period 1990–2000, this state had an annual population growth rate of 2.9%, whereas the Federal District had an annual growth rate of 0.4%.

Urban growth in the ZMCM has been very rapid and disorganized, which has resulted in acute environmental deterioration, including water and air quality. The rapidly increasing urban settlements continue invading what used to be protected land, and land use has changed from forestry to agricultural, and finally to urban. This uncontrolled growth in the ZMCM has progressed towards both the State of Mexico and to the rural areas of Mexico City (PNUMA *et al.*, 2003).

The expanding population, as well as the rapidly increasing industrial, services and commercial activities, have represented a formidable challenge for the institutions responsible for providing the necessary services, including water and sanitation, primarily in terms of management, investments and energy consumption. The investments have not only represented high economic costs but also high social and environmental impacts, which have become almost unmanageable (INEGI, 2001).

Historical Development of Mexico City Metropolitan Area[1]

The water supply and wastewater systems in the metropolitan area, as well as in any other locations, cannot be analysed without considering the associated human and geographical environment. They have to be considered in relation to issues such as geography, climate, population growth, urbanization, migration, economic development and social expectations. In the case of the ZMCM, the evolution of the management of water and wastewater systems should be seen as an integral component of a rapidly expanding metropolitan area. Therefore, an overview of the changes that have occurred in the metropolitan area during the last 65 years will provide a better understanding of the water supply and sanitation situation in the region.

In 1940, the Federal District had a population of 1.75 million people, of which 1.6 million lived in the downtown area (what was then known as Mexico City). During this decade, the metropolitan area started to grow mainly as a result of increasing economic activities in the municipalities adjacent to the Federal District.

In 1950, the metropolitan area included Mexico City as it was then, seven boroughs of the Federal District and two municipalities of the State of Mexico. The population was 2.9 million people, living in an urban area of 26 275 ha, with a population density of 113.5 people/ha. Population density was higher in the downtown area compared to the rest of the boroughs, which included mainly rural settlements (less than 2500 people).

During this decade, Mexico City developed primarily towards the north, reaching the limits of the State of Mexico. This resulted in increasing urban activities on both sides of the border, and industrial activities primarily were in this state. The National Autonomous University of Mexico was established in the southern part of the City. This was followed by progressive urban development in this area, with middle and high-income settlements as well as industrial activities. During this period, the government of Mexico City decided not to authorize any additional housing construction. This resulted in formal and informal urban developments in the State of Mexico.

In 1960, the metropolitan area at that time included Mexico City, 15 boroughs of the Federal District and four municipalities in the State of Mexico. The population had increased to 5.1 million inhabitants within an urban area of 41 690 ha, which resulted in a population density of 123.66 persons/ha. This was an increase of almost 73% in terms of population, and more than 58% in urban area, compared with the situation in 1950.

During this decade, Mexico City, as well as the metropolitan area, changed dramatically not only due to population growth, but also due to very rapid urban, road and industrial developments. There was an huge expansion of planned high-rise buildings for low and medium-income families, as well as unplanned settlements. Restrictions for the construction of housing continued in the Federal District, which resulted in an increasing number of informal settlements in the City.

In 1970, the metropolitan area included Mexico City, 16 boroughs of the Federal District and 11 municipalities of the State of Mexico. The population had increased to 8.6 million inhabitants and the urban area had reached 72 246 ha. The urban land used increased by 73% and seven municipalities were added to the metropolitan area, which reduced the population density to 120 persons/ha. This period witnessed a massive urban expansion of both formal and informal settlements within the overall ZMCM.

In 1980, the population in the metropolitan area had increased to 13.7 million (59% compared to 1970) and the urban area by another 89 112 ha (23%) compared to 1970. The population density had increased to 154 persons/ha.

Between 1980 and 1990, the population in the metropolitan area increased to 15 million people and the urban area covered a total of 40 390 ha (11 306 in the Federal District and 29 084 ha in the State of Mexico), with the highest urban growth in the State of Mexico.

From 1950 to 1995, the population of Mexico City increased from 3 to 17 million people (Table 1). In contrast to the previous decades, during the period between 1990–2000, the annual population growth of Mexico City was only 0.4%, compared to the ZMCM, which was 2.9%. The main reason for the growth in ZMCM was immigration from the rural areas and from the medium and small-size cities.

Throughout these decades, the population growth and the planned and unplanned urbanization have resulted in an uneven race for the Federal and the local governments to construct an infrastructure and provide essential services to the population, including water supply and sanitation. An example is the number of houses, which almost tripled in 40 years, with more than 1.7 million in 1990 compared to approximately 600 000 in 1950.

Demographic and socio-economic conditions have had a major influence on the overall urban growth, and land use has depended on the social and economic conditions of the local population. At present, about 67% of the population in the ZMCM can be considered to be at the medium to low socio-economic level, about 15% are in high and medium to high, and 18% in the very low (PNUMA *et al.*, 2003). This means that the land use of the different parts of the metropolitan area reflect the needs and the opportunities of their

Table 1. Average population of Mexico City Metropolitan Area, 1950–95 (millions)

	1950	1960	1970	1980	1990	1995
ZMCM	2 982 075	5 155 327	8 656 851	13 734 654	15 047 685	16 898 316
Mexico City	2 923 194	4 846 497	6 874 165	8 831 079	8 235 744	8 489 007

Source: CONAPO (2000).

population. The wealthier areas have better overall living conditions and more assured access to services (e.g. access to water supply and sewerage, collection of solid wastes, schools, hospitals, road infrastructure, etc.) compared to the less wealthy areas.

Table 2 shows the access in the ZMCM to services such as electricity, water supply and sewerage. More people in Mexico City now have access to such services, compared to the municipalities in the State of Mexico that are part of the ZMCM. This is because Mexico City, being the capital of the country, is much more urbanized than the municipalities, and it has also more economic and political power (Tortajada, 2006).

A large number of high-income houses in Mexico City are not connected to the public sewer because they have been constructed on volcanic rocks, which has made it difficult and expensive to build such an infrastructure. This is especially the case for many settlements in the southern part of the City, most of which have septic tanks that are frequently not properly constructed and managed.

For a region with a population of more than 20 million people, which is steadily increasing, the provision of all services, including water supply and sewerage, has been a challenging task. The responsibilities for water supply and sanitation have been exclusively in the hands of the different levels of governments, whose lack of planning, managerial and human constraints, and political interference, have been obvious throughout the years. In addition, the population in general has not developed any sense of responsibility or interest in participating in the conservation, protection and management of water resources, even though, in the final analysis, water supply and sanitation is for their own benefit and use.

Urban Growth and Conservation Areas

Conservation of the rural areas is fundamental for the water security of Mexico City since it has a direct bearing on groundwater recharge. Rural areas within Mexico City are considered to be conservation areas under the Law of Urban Development.[2] In Article 30.II, the Law defines a conservation area as:

> the land which should be considered as such according to its location, extension, vulnerability and quality; that which has an impact on the environment and on land-use planning; mountains and areas useful for the recharge of the aquifer; hills, valleys and elevations which are natural elements of the land of the City; and land for agricultural and livestock activities, for fisheries, forestry, agroindustry and tourism, as well as rural settlements.

Conservation areas are increasingly threatened because of steady urban growth. Between 1980–2000, 76% (377 000 units) of the new houses that were constructed in Mexico City were located in the seven boroughs with the most conservation areas. Of the 44 rural settlements that still exist in Mexico City, 35 of them (400 000 people) are located in conservation areas.

Expansion of illegal settlements has also become a critical problem for the City. In 2003, there were 804 so-called ‘irregular settlements’ with approximately 60 000 families, living in 2400 ha of land for periods of between 10 and 22 years (SMA Programa de Protección Ambiental del DF 2002–2006, in PNUMA *et al.*, 2003). Some 80% of these

Table 2. Access to services in the ZMCM in urban AGEB[a], 1990

	Total	Downtown	Municipalities in State of Mexico within the Metropolitan Area	Low-income settlements	High-rise buildings	Middle-income settlements	High-income settlements	Other
Number of houses without electricity	54 048	788	6814	40 461	3175	3598	704	329
Percentage of houses without electricity	1.8%	1.6%	2.7%	2.1%	0.7%	0.9%	1.1%	1.7%
Number of houses without sewerage	545 836	2247	96 010	398 218	23 707	17 122	8532	3249
Percentage of houses without sewerage	17.6%	4.5%	38.5%	21.1%	5.1%	4.4%	13.5%	17.2%
Number of houses without tap water	1 115 262	6486	133 878	872 222	61 026	36 341	5309	5932
Percentage of houses without tap water	35.9%	12.9%	53.5%	46.2%	13.2%	9.3%	7.8%	31.5%
Number of private houses	2 147 341	24 075	189 214	1 256 228	375 017	257 919	44 888	9996
Number of rented houses	678 956	20 837	40 903	448 443	53 788	104 927	10 058	5444
Percentage of private houses	69.2%	48.0%	75.7%	66.5%	81.2%	65.8%	76.0%	53.1%
Percentage of rented houses	21.9%	41.6	16.4%	23.7%	11.6%	26.7%	17.1%	28.9%

[a] Urban AGEB refers to geographical areas in settlements consisting of 2500 people or more (all municipalities are included even if population is less than 2500). Land use is for housing, industries, commercial, recreation or any other use, but not for agriculture, livestock or forest.

Source: Resultados definitivos. INEGI, Datos por AGEB Urbana, XI Censo General de Población y Vivienda 1990. Volúmenes del Distrito Federal, Estado de México e Hidalgo, 1992, in: CONAPO (2000).

families are in conservation land, and about 20% of them live in dangerous places such as river beds.

Even though there are urban land-use programmes whose main objective is to control the expansion of rural and irregular settlements in conservation areas, the demand for all types of settlements has been overwhelming. It has simply surpassed any attempts by the public institutions to catch up with the demands for housing and infrastructure, and to provide appropriate services. The net result has been that people often do not have access to even basic services such as electricity, water supply and sewerage, which is especially relevant for settlements in conservation areas. Overall, the demands for housing and infrastructure by all socio–economic levels have continually increased. The unsustainable urban growth and inadequate management have resulted in a mounting pressure on the Federal and local governments to provide more and better services. At the same time, people are now reluctant to live in a polluted and unsafe environment (PNUMA *et al.*, 2003).

Water Availability

The water supply in the ZMCM depends primarily on local groundwater sources and on interbasin transfers. Mexico City, and the most populated 17 municipalities of the State of Mexico, share the same sources of water, as well as the infrastructure for water distribution.

In 2002, the volume of water supplied to the ZMCM was 2.236 MCM/day (1.200 MCM/day from 374 deep wells; 0.071 MCM/day from 18 springs only for Mexico City, and 0.964 MCM/day from 97 sources of water, such as snowmelt in the case of State of Mexico[3]) (INEGI, 2003). The second main source of water is the Lerma-Balsas and the Cutzamala River systems, which will be discussed later. It is estimated that the ZMCM receives 66 m^3/sec mainly for domestic supply, with Mexico City receiving about 35m^3/sec and 31m^3/sec for the State of Mexico (see Table 3). Within Mexico City, the water is distributed to the users through a primary network of 1074 km of pipelines (with diameters of 0.5–1.83 m) and a secondary network of 12,278 km (with diameters of less than 0.50 m). The water supply system comprises 16 dams having a total storage capacity of 2827.90 km^3 (INEGI, 2000b). Data are not available for the municipalities in the State of Mexico.

Table 3. Water supply sources for Mexico City Metropolitan Area

	Federal District (m^3/s)	State of Mexico[1] (m^3/s)	Total (m^3/s)	Percentage
Internal 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
External sources	14.8	6.0	20.8	31.5
Cutzamala	9.9	5.0	14.9	22.6
Lerma	4.9	1.0	5.9	8.9
Total	34.8	31.2	66.0	100.0
Percentage	52.7	47.3	100.0	

[1] Only municipalities which are part of the ZMCM.
Source: INEGI (2003).

In 2000, 95.3% of the population in Mexico City and 84.2% in the State of Mexico had access to water, either with a water connection directly to the house or from common faucets in the neighbourhood (INEGI, 2000a). However, most of the aquifers, springs and rivers which supply water to the ZMCM are located to the west, north and south. Thus, water supply is irregular and unreliable for the people living in the eastern part, who are also most affected by water shortages.

More than 5% of the people living in the metropolitan area still do not have access to water. While some of them receive water from the government in pipes, people have to pay water from private vendors. The cost of water (200 litre-containers) often represents between 6 to 25% of their daily salaries. Poor people who buy water from trucks pay around 500% times more than the domestic consumers. In addition, drinking water for much of the population in the ZMCM comes from 20–30 litre-containers of purified water, which are sold commercially. The reason for this is the near universal distrust of the quality of the tap water. This means that not only people with no access to tap water spend a certain percentage of their income buying bottled water, but also people with access to tap water have to buy containers of water, of which the quality control leaves much to be desired. Indeed, Mexico is the second largest consumer of bottled water in the world, with a consumption of 168.6 l/person in 2004 (Rodwan, 2004).

Main Sources of Water for Mexico City Metropolitan Area

The ZMCM is located in the Valley of Mexico basin, which is surrounded by the basins of Lerma, Cutzamala, Amacuzac, Libres Oriental and Tecolutla rivers (INEGI, 2001). The Lerma and the Cutzamala river basins, together with the aquifer of the Valley of Mexico, are the main sources of water for the metropolitan area. The aquifer of the Valley of Mexico contributes 70%, the Lerma-Balsas river basin 9% and the Cutzamala river basins 21%. The very few surface water bodies that still exist in the basin of the Valley of Mexico provide only 2.5% of water supplied (CNA, 1997a; INEGI, 2000b).

Mexico Valley Aquifer

The annual rate of withdrawal from the aquifers is significantly higher than the recharge rate: 45–54 m^3/s is abstracted each year, but natural recharge rate is only about 20 m^3/s. This mismatch has resulted in a significant over-exploitation, which has contributed to the lowering of the groundwater table by about 1 m per year. Steady lowering of the groundwater level increased the land subsidence rate, initially to 10 cm/year, and later up to 30 to 40 cm/year. The average annual subsidence rate in the area of the International Airport of Mexico City is 20–25 cm, and in the City Centre it is around 10 cm. It is estimated that the central area of the metropolitan area has subsided by 10 m during the past 100 years (Legorreta *et al.*, 1997; INEGI 2001; Gobierno del Distrito Federal *et al.*, 2004).

However, the problems related to water supply in the metropolitan area extend well beyond the subsidence of the City. For example, the water supply and drainage systems have not only become very large and complex, but also obsolete in many areas. Provision of water services varies in the different parts of the City, tariffs are still heavily subsidized, the quality of water supplied is poor, levels of unaccounted for water are unacceptably high and the population wastes enormous amounts of water. People living in wealthy areas use up to 600 litres per capita per day, while the corresponding rate in the poor areas is about 20 litres.

Use of deep wells has resulted in an increase in the iron and manganese content of the water, thus decreasing water quality and making water treatment more expensive. Water infrastructure has become more vulnerable to earthquakes. Over-exploitation is reducing soil moisture in the surrounding mountains, which is damaging forest cover and adversely affecting the ecosystems.

A very high percentage of water is lost from the distribution networks because of leakages and illegal connections. Inappropriate overall management, aged pipes, inadequate maintenance over prolonged periods, poor construction practices and continuing land subsidence, are contributing to high levels of unaccounted for water. It is estimated that more than 40% of water is lost in the network due to leakages, which represents about 130 l/person/day. It is estimated that this volume of water would be enough to provide a service to 4 million people (UNAM, 1997; Secretaría de Obras y Servicios, 2002).

Lerma Valley Aquifer

In 1942, the Lerma Valley project (62 km from Mexico City) was initiated to meet the steadily increasing demands of water in the metropolitan area. The first stage was planned and constructed to bring 4 m^3/sec of water to the metropolitan area. It included the construction of five wells between 50 and 308 m deep for groundwater abstraction, and a 62 km, 2.5 diameter pipe for its distribution. This pipe is laid along the *Sierra de las Cruces*, through the 14 km long *Atarasquillo-Dos Rios* tunnel. Four tanks, 100 m in diameter, and 10 m in depth, were built in Mexico City for storage. This water is then distributed to the City by gravity. The increasing demands for water resulted in the construction of the second stage of the project. Between 1965–75, some 230 deep wells were dug, which increased the volume of water abstracted to 14 m^3/sec. However, due to environmental impacts and social conflicts, the volume abstracted later had to be reduced to 6 m^3/sec (Legorreta *et al.*, 1997).

The political relationship between the authorities of Mexico City and the State of Mexico have been strongly influenced by the social conflicts that have resulted from the interbasin transfer of water from the Lerma Valley to the metropolitan area. The main interest of the Federal and the Mexico City governments has been primarily to guarantee water supply to Mexico City. As a way of compensating the local populations, small projects were constructed in the towns that were adversely affected by the water transfer project. The over-exploitation of the aquifers in the Lerma area has reduced the fertility of the soils. Agriculture has now become mainly rain-fed, and not irrigated as previously. The economy of the region and the life of the population have changed significantly (Legorreta *et al.*, 1997).

Cutzamala System

In 1976, the 'Cutzamala System' was planned to supply water to the metropolitan area from the Cutzamala river, and thus reduce the over-exploitation of the Mexico Valley aquifer. The water is transferred from a distance of 60 to 154 km, and then pumped to a height of more than 1000 m, requiring 102 pumping stations, 17 tunnels and 7.5 km of canals, which makes this project extremely energy-intensive and expensive (CNA, 1997a).

Initially, what later became the Cutzamala System, was planned as a hydropower project, called the Miguel Aleman Hydroelectric System. Cutzamala started by taking advantage of the infrastructures for hydropower generation, but the planned water use was changed. Currently, only 3 m^3/s is used to generate hydropower during peak hours and to satisfy the local energy requirements for the agricultural and industrial sectors (CNA, 1997a). Due to the magnitude of the project, its construction was initially planned in three stages. The first stage has been in operation since 1982 (4 m^3/s), the second since 1985 (6 m^3/s) and the third one since 1993 (9 m^3/s) (CNA, undated, a). During the first stage of the project, water was brought from Victoria Dam and was distributed through a 77 km long and 2.5 m diameter aqueduct, which crosses the *Sierra de las Cruces*. The second and third stages of the project included the construction of both a water treatment plant and a central aqueduct. The implementation of these two stages was very complex mainly due to the height to which the water had to be pumped: 1100 m. The electricity used to pump the total volume of water from the Cutzamala system just to the treatment plant is the equivalent of the energy that is consumed by the city of Puebla, with a population of 8.3 million people (Legorreta *et al.*, 1997). An overview of the infrastructure for Cutzamala System is presented in Figure 2. The elevation at which the different dams and pumping plants of the System are constructed is included.

In terms of investments, according to the EIA carried out for the fourth stage of Cutzalama, the total cost of the first three stages of Cutzamala was $965 million (1996 estimates). If the estimated cost of the earlier hydroelectric plant is added, the total investment cost becomes $1300 million. The cost of the cancelled hydropower system, with a total installed capacity of 372 MW, has been estimated at $325 million, at an average cost of $875 000/MW. The total cost of the Cutzamala System at $1300 million (mainly construction and equipment costs) was higher than the national investment in the entire public sector in Mexico, in 1996, in the areas of education ($700 million), health and social security ($400 million), agriculture, livestock and rural development ($105 million), tourism ($50 million), and marine sector ($60 million). Up to 1994, the Cutzamala System alone represented three times the annual infrastructure expenditure of the Ministry of Environment, Natural Resources and Fisheries for 1996, which was more than $470 million (CNA, 1997a).

The annual energy requirements necessary to operate the Cutzamala System are about 1787 million kWh, representing an approximate cost of $62.54 million. The investment would increase significantly if the costs in personnel ($1.5 million/year) and water treatment process costs were added (CNA, 1997a). If only the operational costs for running the Cutzamala System are considered (about $128.5 million/year), supplying 600 million m^3 of water (19 m^3/s) would mean an average cost per cubic metre of water of $0.214 and an energy consumption of 6.05 kWh/m^3. Hence, the price charged to the consumers, about $0.2/$m^3$, is not enough to cover either the operational costs of the Cutzamala System or the treatment and distribution costs of water to the metropolitan area.

In addition to the construction of the Cutzamala, about 190 so-called 'social projects' were built for the benefit of some of the people living in the municipalities who are mostly affected by water shortages. These projects were built jointly by the National Water Commission of Mexico (CNA) and the communities, and consist mainly of construction, enlargement and rehabilitation of water supply and sanitation systems, as well as construction and rehabilitation of houses, schools and farms. Equally important was the construction and the rehabilitation of roads by CNA, both for Cutzamala and the local

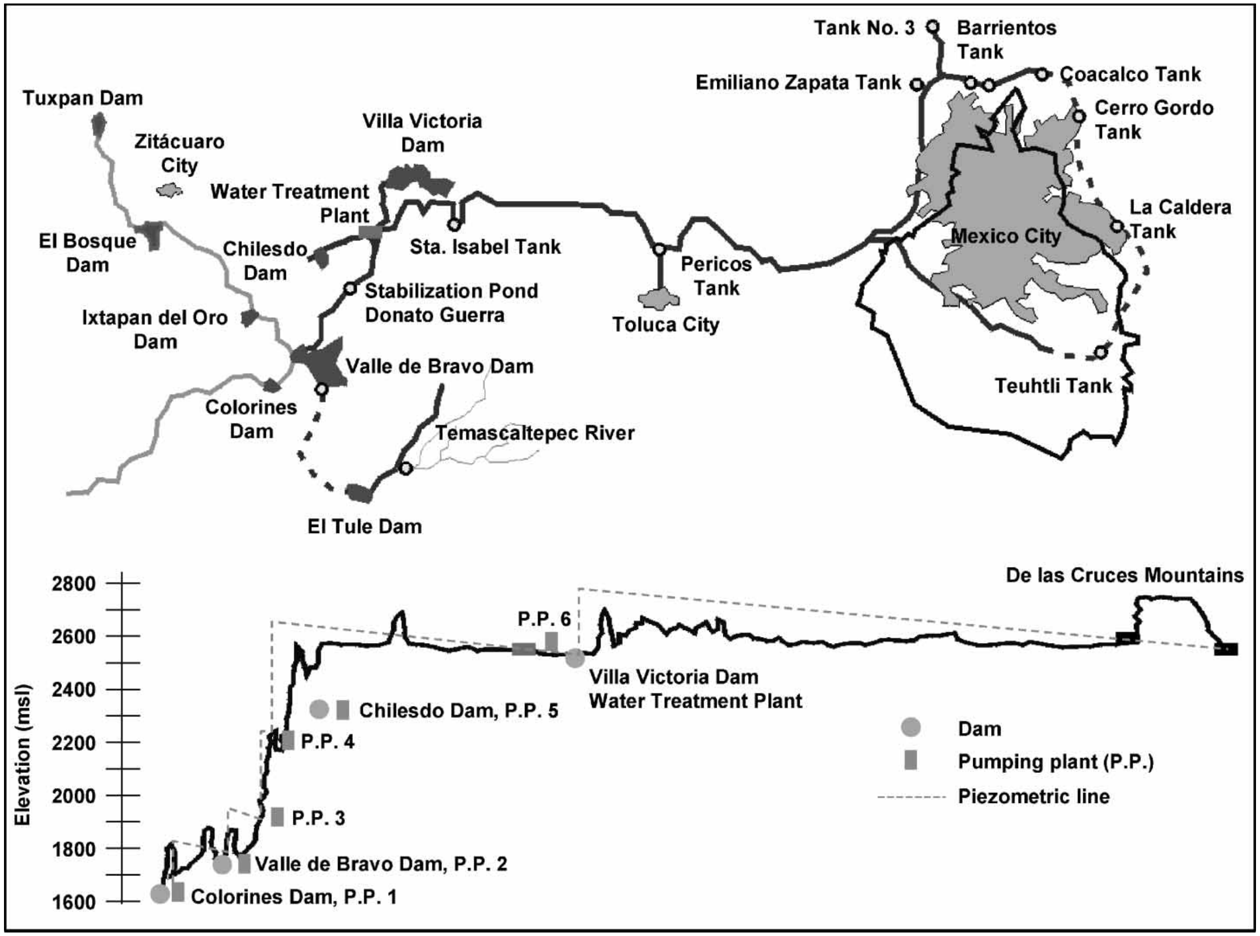

Figure 2. Overview of the infrastructure for Cutzamala System. *Source:* IMTA (1987).

population. In 1996 the cost of these 'social projects' was estimated to be the equivalent of 5% of the direct investment of the Cutzamala, which represented an additional $45 million (CNA, 1997a). A very important issue that has not been resolved as of March 2006, has been the resettlement of the affected communities due to the construction of the Cutzamala project, who after all these years, still have not received the expected compensation.

The programme on drinking water and sanitation of the metropolitan area considered the construction of a fourth stage of Cutzamala which would increase the volume of water transferred to the Valley of Mexico from 0.6 km^3/year (19 m^3/s) to 0.76 km^3/year (24 m^3/s), and the treatment of 1.3 km^3/year (42 m^3/s) of wastewater. The fourth stage of Cutzamala (Temascaltepec project) was to be initiated in 1997. This stage included the construction of a 120 m high dam, 743 m in length at the crest. The reservoir would have a capacity of 65 millions m^3 and regulate an average flow of 5000 l/s. The project envisaged a 15 m^3/s pumping station and the construction of 18 km of canals and 12 km of tunnels (CNA, 1997a). The water would flow to the Valle de Bravo Dam through a 18.75 km long and 3.5 m diameter tunnel. According to official figures, the initial investment was estimated to be $502 million. Once the fourth stage of the Cutzamala is operational, the volume of water will increase only by 5 m^3/sec of water, from 19 to 24 m^3/sec (Tortajada, 2001).

As of March 2006, the Temascaltepec project has not yet been started because of serious social constraints. The population of some of the villages of Temascaltepec are afraid that the construction of the tunnel will dry up springs (El Naranjo, La Huerta, El Sombrero y El Chilar) and will affect the agricultural production of the area (maize, sugar cane, banana, tomato, melon and peas). Even though the local people who would be affected by the project are against the project (Legorreta *et al.*, 1997; Agua Latinoamérica, 2004; La Jornada, 15 July 2004; El Universal, December 2005), authorities consider the development of Temascaltepec river to be of the utmost importance for the development of not only Mexico City, but also of the State of Mexico as noted in the Development Plan of the State of Mexico 1999–2005 (Government of State of Mexico, 1995).

For years, studies have indicated that if the leakages in the distribution system in the ZMCM 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 that is being planned with very high economic, social and environmental costs would not be necessary. However, this type of rational planning and management continues to be absent in the relevant water management institutions.

In addition to Cutzamala, the other sources of water that the Federal Government has identified for potential contributions to the water supply of the metropolitan area are the Amacuzac, Tecolutla and Atoyac rivers (Gobierno del Distrito Federal *et al.*, 2004). The Amacuzac river project would include the construction of a 185 m high and 450 m wide dam, with an inundated area of 67 km^2, and a storage capacity of 4000 MCM. The dam would be located in the borders between the states of Morelos, Guerrero and Puebla. Water distribution from this site to the ZMCM would require the construction of a 160 km long aqueduct, and, depending on the final design, either two pipes of 4.5 m of diameter or three pipes of 3.5 m diameter. Water would have to be pumped to a height of 1825 m, requiring a generating capacity of 4000 MW. The annual electric power consumption for this system is estimated to be 5% of the annual national electric power production, representing 16.5 million barrels of oil per year. It is claimed that this project will make it unnecessary to abstract 50 m^3/sec of groundwater from the Valley of Mexico aquifer any more. The rational is that the groundwater would be used only during periods of severe droughts or when the other water distribution systems were not working due to maintenance activities (Tortajada, 2004; CCE and CMIC, 2000).

Under these conditions, it will certainly be more economical, socially acceptable and environmentally desirable to consider first demand management practices such as a reduction in the unaccounted for losses, water pricing and other water conservation practices, before embarking upon extremely expensive new water development projects, with high social and environmental costs. It has been estimated that each cubic metre of water from the Cutzalama river required an investment of $23 million. This estimate would increase by a factor of four if the source of water were the Amacuzac river (INEGI, 2001).

Basically, governmental institutions in the past have ignored the potential social conflicts and disruptions that could result from interbasin water transfers. In addition, no authoritative analyses have been made on the nature of the beneficiaries and the people who may have to pay the costs. Surprisingly, even the EIA for the fourth stage of the Cutzamala System (CNA, 1997a) does not consider any social costs. As with most of the EIA that are carried out in Mexico, mostly physical technical factors are considered: social issues are conspicuous by their absence (Tortajada, 1999, 2001). In 2003, the government of the State of Mexico took the government of Mexico City to court and demanded compensation of $2.2 billion due to damage caused by over-exploitation of the aquifers and excessive abstraction of water to the detriment of people in the State of Mexico. The decision of the Supreme Court was expected to set precedents for similar cases in the future. However, in October 2005, the newly elected Governor of the State of Mexico publicly declared that he would withdraw the court case, since he preferred to work with the Federal and Mexico City governments to find an amicable solution.

Aqueducts: 'Cutzamala-Macrocircuito' and 'Cutzamala-Aquaférico'

The Federal Government, as well as the government of the State of Mexico and CNA, initiated the construction of two distribution lines in 1980 to ensure a more efficient distribution of water from the Cutzamala System. Mexico City was constructing a water distribution system known as *Aquaférico* which would come from the west, and would supply water to the southern and eastern parts of ZMCM.

In the State of Mexico, the water distribution system is known as *Macrocircuito*. The construction was planned around most of Mexico City towards the north, carrying water to the northern, southern and eastern parts of the City (CNA, undated, a). The first stage of this system was inaugurated in October 1994. Both the first and the second stages are now in operation and provide a continuous supply of 4 m^3/s. This has benefited around 1.4 million people, with a supply of 250 l/capita/day. The operation of the third and fourth stages planned to increase water availability by an additional 7 m^3/s (total volume of 11 m^3/s), benefiting 4 752 000 inhabitants who live in the eastern and northern parts of the State of Mexico, with approximately 200 l/day/person (CNA, undated, b, c, d; CNA, 1997b). The system includes the construction of two pipelines, with a total length of 168.28 km. This is in addition to 58.28 km of pipelines that have already been constructed. The two pipelines will require a surface area of 336.56 ha, plus 71 ha for the storage tanks (CNA, 1997b).

The total investment costs for *Macrocircuito* between 1987 and 1997 were $78 million, while the estimated cost for the third and fourth stages (1997–2000) were expected to be approximately $190 million, making a total investment of $268 million. This amount represents almost half of the total public sector budget at the national level for 1995 ($563 million) in the areas of urban development, ecology and drinking water (CNA, 1997b).

The projects were expected to be completed by 2000, but so far the construction has progressed very slowly (CAEM, 2003; Reforma, 9 November 2004).

Wastewater Management

The soil of Mexico City is basically clay, and thus susceptible to compaction. Accordingly, the higher the volume of water abstracted, the higher is the rate of land subsidence (CNA, 1997a). The sinking of the City has resulted in extensive damage to its infrastructure, including the water supply and sewerage systems and degradation of the groundwater quality. It has also required the construction of costly pumping stations to remove wastewater and stormwater from the City.

At the beginning of the last century, the sewerage system (Great Sewerage Canal) used to function by gravity. However, this system was disrupted by subsidence, and, by 1950, the uneven settlement of the sewerage network made it necessary to pump wastewater from the small sewerage lines to the level of the main wastewater collector of the City, thus significantly increasing both maintenance and operation costs. The Great Canal has been affected by land subsidence so much, that at present the first 20 km have almost totally lost their inclination. In addition, continually increasing the population in the metropolitan area has rendered the wastewater collection and treatment capacity insufficient.

Accordingly, in 1967, a decision was taken to build another main collector for wastewaters for both Mexico City and the State of Mexico as a combined sewage and stormwater network (Deep Tunnel Sewerage System (hereafter noted as Deep sewerage)). A system of 60 km of sewerage interceptors and deep collectors were constructed along with a new artificial exit from the basin of Mexico in 1975. By 1997, there were 153 km of tunnels in operation. The Deep Sewerage had to be constructed up to 200 m below the ground level to ensure that it will not be affected by land subsidence (DGCOH, undated, 1990; Domínguez, 2000).

The Deep Sewerage has more than 80 interceptors and carries an average annual flow of 48 m^3/s of wastewater and 14 m^3/s of stormwater through primary and secondary networks. The primary network is 50 km long and 6.5 m in diameter, and it is connected to the secondary network, transporting municipal and industrial wastewater, and stormwater through 3.1 m to 5 m diameter tunnels (INEGI, 1999). The Deep Sewerage system stores, transports and disposes wastewater and stormwater through four artificial channels located at the northern end of the basin of Mexico. The system includes 66 pumping stations, regulatory tanks for flow control, storm tanks, 111 km of open canals, rivers which are now used for transporting wastewater, 16 dams and lagoons. The average volume of wastewater and stormwater that is discharged into the ZMCM sewerage system is 2897 MCM (INEGI, 2001). In 2004, this was 2260.23 MCM, of which less than 10% is treated. No information about the percentage of wastewater that is treated in the State of Mexico is available.

A new interceptor was constructed during the period 1998–2000 for the Great Canal. It is to transport stormwater from Mexico City downtown by gravity and thus alleviate the threat of floods in this part of the City. The interceptor is a 1000 m long and 3.1 m diameter-tunnel built 20 m below the ground level, with a capacity of 35 m^3/s (DGCOH, undated, 2000).

Since the City is located within a naturally closed hydrologic basin, it is especially vulnerable to floods. Throughout history, artificial channels had to be constructed to take wastewater and stormwater from of the City. The rainy season in the metropolitan area is characterized by high intensity storms of short duration. The average annual rainfall in the City is 800 mm: 500 mm in the eastern part and around 1000 mm towards the southern and western parts (Domínguez, 2000). The main collector of the Deep Sewerage was designed to carry about 200 m^3/s of water over a 45-hour period. However, it has carried up to 340 m^3/s. Such sudden fluctuations in the amounts of water that have to be drained create major operational and maintenance problems.

The floods in Mexico City can be explained due to the difference in levels between some parts of the City and the Great Canal, as well as the inability of the sewerage system to quickly pump out all the water during the rainy seasons. For example, due to the subsidence in the City, downtown is 7 m below the highest point of the Great Canal (Legorreta *et al.*, 1997). Since the secondary sewerage network is insufficient to carry high volumes of storm and wastewater, severe problems have been encountered in those parts of the City that are above the east interceptor where the Great Canal has lost its gradient. On many occasions wastewater has also flooded the streets in these areas, but for only for short durations.

Some 30 years ago, the Great Canal could discharge 90 m^3/s. At present, it discharges only 12 m^3/s. Due to this increasing inefficiency, the Deep Sewerage did not receive proper maintenance until 1995, when the heavily silted primary sewerage network could be cleaned. In May 2005, the Water System of Mexico City initiated monitoring activities to check the status of different sections of the main sewerage network of the Deep Sewerage, especially in terms of the infrastructure and level of siltation. The risks presented by sulphuric acid and methane to human beings were nullified by adding a chemical (*Albisol*) to reduce both the acid and the methane to negligible levels. The main findings were that the percolation of water to the tunnels was minor, that the concrete walls of the tunnel had not deteriorated seriously, and that siltation was not serious enough to prevent water from flowing out the network system.

The Master Plans for Drinking Water and for Sewerage for the Mexico City (DGCOH, 1997a, 1997b) outlined the different types of strategies, including infrastructure, necessary to improve the supply, storage and transportation of drinking water in the City, as well as the storage, transportation and disposal of wastewater and stormwater out of it. However, these plans also noted that, in addition to very high investment costs, the infrastructure would also require several years to construct. This means that in spite of the importance of the infrastructure as part of a water and wastewater management strategy for the Mexico City, this is not the only alternative available.

One example is the so-called ‘reuse’ of wastewater produced in the ZMCM. The disposal of untreated wastewater has become a serious problem for the metropolitan area, especially when the high volume and the nature and levels of pollutants contained therein are considered. The problems created by the current effluent disposal practices are now affecting neighbouring areas of the region, where wastewater is discharged. This has created very significant health and environment-related problems and concerns.

Globally, ZMCM is now by far the largest single producer and exporter of wastewater that is used for agricultural purposes. Since the beginning of 20th century, wastewater from the

City has been diverted to the Mezquital Valley, in the nearby state of Hidalgo, located 109 km north of Mexico City. Otherwise a semi-arid region, the Valley has become an important agricultural area by using this untreated wastewater, with 110 000 ha of official and unofficial command area, and more than 50 000 water users in the different irrigation districts.

In the Mezquital Valley, the main crops grown are alfalfa and maize, representing some 60–80% of the total irrigated area. Cultivation of higher-value crops is forbidden by law due to health considerations. This practice of wastewater irrigation has provided added nutrients to soils and it has been a source of water for economic activities. However, for many years, it has also represented a very high risk to the health of not only the population who live and work in the irrigation districts, but also to the consumers (IDRC, 2002).

In 1996, the Inter-American Development Bank approved a $1.035 billion project for the Mexico Valley Sanitation Project. Unfortunately, this much-needed project did not proceed for several reasons, mainly economic and political. In 2004, the Mexico City Water System, Water Authorities from the State of Mexico and National Water Commission were working jointly with the Inter-American Development Bank and the Japanese Bank for International Cooperation to develop the terms and references to prepare three tenders to build four wastewater treatment plants. The total budget for this project was approximately $1 billion, of which IDB would contribute $365 million for the collectors system and JBIC would provide $670 million for the wastewater treatment plants (STAT-USA, 2004). No public information is available as to what has happened to these projects. The disturbing fact continues to be that more than $60 m^3/s$ of wastewater continues to be discharged with no treatment whatsoever.

The continuous transfer of wastewater over a century and the excessive irrigation by the farmers in the Mezquital Valley to counteract its salinity, have resulted into groundwater recharge of the local aquifer. The groundwater level table has gone up and several springs have appeared, which have become a source of water for the local population. Unfortunately, no serious and reliable study is currently available on the quality of groundwater or the springs in the Valley, as well as their overall impacts on human health and the environment.

Clearly, long-term and rational planning is urgently needed in the ZMCM including an efficient systemic strategy for drinking water and wastewater management. There is an urgent need to formulate coordinated policies for the development and management of the metropolitan area as a whole. To date, there are no signs that this is likely to occur in the near future. As the National Population Council (CONAPO, 2000, p. 79) has noted: “there is no long-term planning for the ZMCM in terms of urban development, including provision of services such as housing and infrastructure”. This lack of systemic planning is contributing to increasingly disorganized development of the metropolitan area, which will require a never-ending provision of services such as water supply and sanitation. In addition, technical, managerial and administrative capacities to provide such necessary services is simply not available at present.

Water Pricing Policies

In the ZMCM, drinking water is charged per cubic metre and its price increases with the highest consumption levels. Within the metropolitan area, there is no uniform policy for water pricing. It is decided independently by the governments of Mexico City and the State of Mexico, and even by the few water utilities that operate in some of the municipalities in the State of Mexico.

One of the main problems for the local governments in terms of cost-recovery has been that there were, and still are, numerous water connections that are not registered, and thus consumption through them is neither recorded nor charged. In 2000, it was officially estimated that there were about 2.5 million water connections in the ZMCM: 67% domestic, 16% commercial and 17% industrial (INEGI, 2001). However, these figures represent only approximately 64% of the existing connections, the rest are illegal.

Another reason why water consumed is not charged in the metropolitan area is because most houses do not have meters. In fact, only 49% of the legal connections are metered. In addition, water users currently pay only 24% of the operational, maintenance and administration costs. It is estimated that in 1997, only 43.6% of water was billed at the national level (INEGI, 2000b).

In the case of the Mexico City, the local government has recognized the limitations it faces to provide water to its population. Some of the main problems that have been identified include a deficit of water availability of 3000 l/sec; leakages of more than 30% because of poor conditions of the networks; unreliable water supply received by at least 1 million people; the number of people with no access to water is increasing; and, as of January 2004, Mexico City had not had new sources of water for the previous eight years (Gobierno del Distrito Federal, 2003).

Even though the government expects the implementation of stage four of the Cutzamala System, it has acknowledged that this project, if and when it is implemented, will take several years to be completed. This situation forced the government of Mexico City to develop a strategy to improve the current situation in terms of providing drinking water to the City. The importance of using economic instruments to improve water and wastewater management is slowly being realized. Water can no longer be considered as a public good that is to be supplied by the State to all the users at highly subsidized prices. The strategy for water management currently includes legal and institutional reforms; participation of the private sector for specific activities, such as billing, meter-reading and leakage repairs; and modifications of the pricing mechanism.

A census of water users was carried out between 1994 and 1996. It included all properties and taps that existed in the 16 boroughs. Users were identified and a users' register was prepared. In addition, water consumption was measured (which was virtually non-existent before) by installing meters in more than 90% of the properties. Even though Mexico City has not received additional volumes of water since 1995, the programmes of meter-reading and detection and repair of leaks claim to have saved 2.8 m^3/s of water, with which it has been possible to provide more people with drinking water (Marañón, 2004). Table 4 shows some indicators that illustrate the improvements that have been recently achieved.

In terms of perceptions of the users on the quality of water services, the main complaints are about poor water quality, reliability of the service, and pricing (Marañón, 2004). While the differences in opinions may be considered normal within such a large population, the fact remains that there is a very high percentage of poor people in the City and hence particular attention must be given to the problems to ensure that poor people have access to water in a fair and equitable manner.

The evolution of the tariffs structure for the domestic sector is shown in Table 5.

For the State of Mexico, drinking water is also priced volumetrically. Prices also increase with higher consumption levels, as is the case for Mexico City. However, in some municipalities, the tariffs also vary by area depending upon their dominant socio–economic

Table 4. Efficiency indicators for drinking water supply in Mexico City, 1996 and 2001

Indicators	1996	2001
Volume of water delivered	686.6 million m^3	752.2 million m^3
Volume of water produced	1096.9 million m^3	1087.0 million m^3
Number of meters installed	737.2 thousand	1255.9 thousand
Number of users billed	1477.5 thousand	1769.1 thousand
Amount of water billed	$1.1 million	$ 3.2 million
Amount of water that was paid	$1.7 million	$ 3.8 million

Source: Marañón (2004).

Table 5. Evolution of domestic water tariffs, Mexico City, 1996–2002 (1996 = 100)

Consumption (m^3)	1996	1997	1998	1999	2000	2001	2002
10.1–20.0	100.0	96.0	81.0	82.9	76.1	72.9	73.4
20.1–30.0	100.0	172.8	169.4	162.6	149.4	143.1	144.2
240.1–420.0	100.0	293.0	275.5	292.7	306.6	319.7	322.7
420.1–660.0	100.0	582.1	613.3	653.6	684.5	714.0	720.7
660.1–960.0	100.0	978.7	1049.9	1138.1	1192.0	1243.0	1254.7

Source: Financial Codes of Mexico City, 1996–2002; and National Index of Prices for the Consumers, Bank of Mexico, in: Marañón (2003, 2004).

conditions. Various socio-economic strata have been defined within each municipality, and the people at the higher strata have to pay higher charges compared to the lower strata.

The overall efficiency of water management in the municipalities that are part of the ZMCM is considered to be very low. For example, only 22.5% of domestic consumers pay for water as do 48.7% of non-domestic consumers. Furthermore, water charges in the State of Mexico are still based primarily on fixed rates. Accordingly, demand management practices have been mostly ignored by the institutions concerned. Table 6 shows selected efficiency indicators for 14 municipalities of State of Mexico, where information is available.

Overall, neither Mexico City nor the State of Mexico have carried out serious studies on tariff structures. Accordingly, pricing has played only a minor role for managing water in the ZMCM.

Table 6. Efficiency indicators for 14 water utilities in the municipalities of the State of Mexico which are part of the ZMCM, 2002

Average rate for domestic users (metered)	$0.5/m^3
Amount billed	$44.5million
Average rate for domestic users (fixed rate)	$0.5/m^3
Amount billed	$132.7 million
Non-domestic users (metered service)	$2/m^3
Amount billed	$32.9 million
Non-domestic users (fixed rate)	$4.3/m^3
Amount billed	$134.8 million
Total payment by domestic consumers	22.5%
Total payment by non-domestic consumers	48.7%

Source: Comisión del Agua del Estado de México (2002), in: Marañón (2004).

There are many constraints to improve access to water, quality of water supplied and overall water services. These constraints include issues such as: management continues to be very centralized, hierarchical and bureaucratic; pricing structures have not been properly developed; management and technical expertise available to manage water and wastewater systems are inadequate; users have very little say on how water is managed; and lack of transparency.

A strategy for water management in Mexico City was launched in 1992 as an effort to promote major structural changes. The idea was that water could no longer be considered as a public good (and, as a result, subsidized heavily by the State), but as an economic good. The institutions concerned faced a severe crisis because of deterioration of infrastructure and economic conditions, inefficiency, and a pricing system based primarily on fixed tariffs. It was also necessary to eliminate heavy subsidies because of financial reasons and also to promote water conservation. In addition, due to economic constraints, it was not possible to expand and improve the supply to the poorest neighbourhoods (CADF, 1993, pp. 2–3 in Marañón, 2004). As part of this strategy, private sector companies were invited to participate in different activities such as distribution of drinking water, metering, billing, customer support and maintenance of the secondary networks.

For detailed analysis of the participation of the private sector in managing water in Mexico City, detailed information can be found in CCE and CMIC, 2000; Marañón 2003, 2004; Martínez Omaña *et al*., 2002; Sistema de Aguas de la Ciudad de México, 2005; Tortajada, 2005, 2006.

Concluding Remarks

Based on the analysis presented in this paper, it is evident that the management of water resources in the ZMCM is very complex and at present inefficient. There appears to be an uneven race between the water and sanitation needs of an increasing population, and the planning, investments, technology and management needs required to construct, operate and maintain all the necessary systems efficiently.

The problems of water quantity and quality in the ZMCM are multidimensional and are directly linked to the societal expectations, regional economic development policies and steady increases in population. The government policies have attempted to promote the development of other urban centres to alleviate poverty and to provide improved standards of living as well as quality of life. However, even though the population growth rate in Mexico City during the later part of the 20th century has declined compared to the rates witnessed in the earlier decades, the growth rates in the adjacent municipalities of the State of Mexico that are part of the metropolitan area are expected to increase even further. Accordingly, the problem is likely to remain complex in the foreseeable future. Unless the current trends and management practices change, the future solutions will require very high investment costs to transport more and more water from increasingly distant and expensive sources. In turn, there will be important economic, social and environmental implications for the exporting regions, higher land subsidence rates due to ever-increasing groundwater withdrawals, a reduction in the quality of the groundwater abstracted, and higher investments to cover operation and maintenance costs, not to mention the decreasing quality of life of the population living in the region.

One constraint stems from the fact that the demand for living spaces from the continually increasing population has contributed to major changes in land-use practices.

Concrete and asphalt now cover areas that are needed for groundwater recharge. The southern area of the City is a good recharge area since the soil is broken basalt. However, this area is now heavily urbanized, and hence is also one of the main sources of groundwater contamination because of the absence of a sewerage network, which cannot be economically constructed due to the presence of volcanic rocks. Housing complexes are thus built only with septic tanks that are mostly not properly constructed and maintained and, therefore contribute to groundwater pollution.

Changes in land use have also contributed to higher volumes of stormwater discharges to the sewerage system, requiring increasing capacities in the system. The risk of aquifer contamination is enhanced because of disposal of untreated industrial wastewaters directly into the sewerage system, inadequate wastewater treatment facilities, leakages from the sewerage networks, and solid waste illegally dumped in landfills, unlined sewerage canals and watercourses.

There has been evidence of low water quality in the aquifer for several years (National Research Council *et al.*, 1995; UNAM, 1997; Mazari-Hiriart *et al*., 2000, 2001). Total and faecal coliforms, as well as bacteria responsible for gastroenteric diseases and acute diarrhoeas, have been found in groundwater in the southern and western parts of the City. Some studies show that the highest contamination of groundwater is in the centre of the Mexico City (Mazari-Hiriart, 2001). The gastroenteric diseases, resulting from the consumption of polluted water, are the second major reason for child mortality (278 per 100 000) in the country, the third leading cause of death for children in the State of Mexico (450 per 100 000); and the fourth in Mexico City (157 per 100 000).

A major limitation to analysing water problems of the ZMCM, or indeed any part of Mexico, is that of data reliability and accessibility. Official data are often inconsistent, which is a major constraint for decision-making, since decisions have to be taken based on conflicting or no information. The public have very limited access to information available at the institutions which, in addition, is often contradictory from one year to another, from one location to another or even from the same source.

It is obvious that the current approach to the management of the water supply and wastewater in the metropolitan area is neither efficient and equitable, nor sustainable. In order to fulfil the needs of an expanding population in terms of water quantity and quality, and to simultaneously maintain a proper balance between the people, natural resources, environment and health, it is necessary to formulate and implement a long-term integrated management plan, which does not exist at present. This should explicitly consider the needs and interests of the different social and economic sectors in both Mexico City and State of Mexico, and also the numerous existing inefficiencies in management can be overcome. Water allocations for the different consumers need to be systematically planned and be better organized. More efficient institutional arrangements and coordination between the governments of both the regions of ZMCM are essential. Joint and more efficient institutional mechanisms are needed to substantially improve the existing practices. The relevance and importance of public involvement and consultations in preparing and implementing such plans should not be underestimated. Such stakeholders' participation is now conspicuous by its absence.

The current policies on tariff structures need to be reassessed. At present, there is one tariff, based on the volume of water consumed, for the great majority of the people, irrespective of their socio-economic status or the place where they live. Since a poor family can have 10 people living in the same house, they often pay more than a rich family of only 2–4 persons. A new, realistic and equitable tariff structure needs to be developed which will promote water conservation, improve the financial self-sufficiency of the water institutions and explicitly consider access to water by the poor, perhaps with targeted subsidies.

Finally, there is no doubt that there is an enormous potential for improvement in the existing and proposed practices for water management in the Metropolitan Area of Mexico City. However, a policy that considers exclusively the water sector is unlikely to be successful. It needs to concurrently consider linkages to policies on urban development (so far an issue that has been completely ignored), migration, industry, energy and the environment. It will not be an easy task, but nevertheless, it is an essential task.

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Notes

1. This section is based mainly on information from National Population Council, Demographic and Urban Scenarios of the Metropolitan Area, Mexico, 2000.
2. The Law of Urban Development of Federal District was published on the Official Magazine of Federal District (Gaceta Oficial del Distrito Federal) on 29 January 1996; and on the Official Newspaper of the Country (Diario Oficial de la Federación) on 7 February 1996. It has been modified three times: on 23 February 1999 and published on Gaceta Oficial del Distrito Federal. No. 25; on 29 January 2004, published on Gaceta Oficial del Distrito Federal No. 8-TER, and on 29 January 2004, published on Gaceta Oficial del Distrito Federal No. 8-TER.
3. Figures include only the municipalities of the State of Mexico where information was available.

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