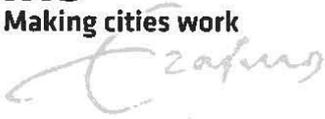


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of Erasmus University Rotterdam

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**Thesis**

**Title: Water-Energy-Climate Nexus CDMX:** A study of the urban water cycle and potential savings, towards a resilient and low carbon city.

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**Water-Energy-Climate Nexus CDMX**

A study of the urban water cycle and potential savings, towards a  
climate resilient and low carbon city.

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## Summary

Global urbanisation is rapidly developing, with an expected seven billion urban residents by 2050. This rapid growth will put considerable stress on both water and energy resources in cities. While there is much research at the national and regional levels on the energy implications of water supply (the urban water-energy-climate ‘nexus’), there is relatively little at the city scale. In this paper, a city-level study of the urban water-energy-climate nexus is presented for México City (CDMX). It is shown that at present 50% of CDMX water (city total c.  $1000 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ ) comes from a local aquifer with a further 30% deriving from energy-intensive surface sources which are pumped over considerable topography. The water supply system consumes currently 90% of the water system energy demand (city total c.  $2500 \times 10^6 \text{ kWh yr}^{-1}$ ), and is responsible for the majority (90%) of the CO<sub>2</sub>e emissions (city total c.  $750\text{--}2000 \times 10^6 \text{ kg CO}_2\text{e yr}^{-1}$ ). In the wastewater sector, 80-90% is discharged with no or little treatment, with corresponding low energy demand. The small fraction that is treated accounts for the vast majority of energy use in the wastewater sector. This study also shows the uncertainty in energy demand and CO<sub>2</sub>e emissions when reliant on secondary data as it’s considerable over/under-estimated energy used compared with primary data. Three water savings measures are assessed for their impact on energy and CO<sub>2</sub>e emissions reductions. Considerable reductions in water supply volumes and concomitant energy consumption and CO<sub>2</sub>e emissions are possible. However the extent of implementation, and the effectiveness of any implemented solutions depend on financing, institutional backing and public support. Additional climate impacts are explored taking particular attention to water security, flood capacity enhancement and CO<sub>2</sub> abatement to evaluate adaptation-mitigation interrelations. This work adds important city-level quantification of the urban water-energy-climate nexus, allowing operators and policy makers to discern which water-system elements are responsible for the greatest energy use and climate impact, and are therefore better equipped to make targeted operational decisions.

## Keywords

Water, Energy, Climate, Nexus, Adaptation, Mitigation, Mexico City.

“In an ever growing consumerist era, world population is exponentially growing and living in cities. Water and energy are the most important services, responsible for most of the cities consumables and livelihoods. Unsustainable resource use fulfils humanities greatest markets, steering our devolution to scarcity crisis. Being the ecological footprint the result of a fragmented system that overlooks potential interlinked synergies to enhance cities resource resiliency.”

## Acknowledgements

The present thesis, is the result of a first experience of the kind. Therefore, great efforts towards exploring a topic lightly know in the country was made. By the ending of the document, different material was used, mostly due to the great effort of Mexico City and international actors that pressure the megacity to lower their footprint and act against climate change. Consequently, excellent material (correspondent citation in place) has been added to this thesis with the efforts of other people, for which I´m thankful. I foresee great future on the city climate resilience.

I would like to additionally, thank all the people supporting my thesis. Among them; my supervisors that showed great motivation and strong guidance to a barely explored topic, adding academic relevance that has been able to further mould my view of the city. Now, as an integrated organism that shifts rapidly, where it´s true complexity lye on integrated actions and decisions able to overcome fragmentation in the different sectors that conforms it.

To my girlfriend, that has not only been a loving partner but also a great support. She has been able to stand by my side in this difficult and long process, always giving great advice and patiently standing repetitive conversations about the topic.

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## Abbreviations

IHS	Institute for Housing and Urban Development
Ad-Mit	Adaptation/Mitigation
BAU	Business As Usual
CONAGUA	National Water Commission
CDMX	Mexico City
CDE	Cumulative Energy Demand
CO <sub>2</sub> e	Carbon Dioxide Equivalent
GDP	Gross Domestic Product
CMM	Centro Mario Molina
GHG	Greenhouse Gas Emissions
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LDC	Least Developed Countries
MBSL	Meters Below Sea Level
MASL	Meters Above Sea Level
MW	Municipal Water Storage
ODE	The Organisation for Sustainable Energy
UWC	Urban Water Cycle
UWECN	Urban Water-Energy-Climate Nexus
RHA	Hydrological Administrative Region
RW	Rainwater Storage
TW	Treated Rainwater Storage
WSM	Water Saving Measures
ZMCM	Mexico City Metropolitan Area

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# Chapter 1: Introduction

## 1.1 Background

*“Water is at the core of sustainable development. Water resources, and the range of services they provide, underpin poverty reduction, economic growth and environmental sustainability.*

*From food and energy security to human and environmental health, water contributes to improvements in social well-being and inclusive growth, affecting the livelihoods of billions”*  
(UNESCO, 2015)

The world runs on water. Every community and ecosystem on earth depends on water for sanitation, hygiene, and daily survival (Gleick, 1994, 1998, 2000, 2003). Clean, reliable water supplies are vital for industry, agriculture, and domestic use. Yet the world’s water systems faces formidable threats. More than a billion people currently live in water-scarce regions (Moe, 2006), and as many as 3.5 billion could experience water scarcity by 2025, (UN, 2014a, 2015). Yet world population continues to increase, as well as their necessity to feed, being agriculture the baseline on the food chain, and currently leading the water use globally. Water availability is crucial to all economic activities and humanity, but not equally distributed geographically. Still many cities can’t ensure enough water for their population, forcing them to explore different solutions towards water quantity and quality. All know methods for achieving water need energy, either for convey, treat, drink or use in any of the activities that requires it. Energy created from sources either extremely water intensive or fossil fuel dependent. Producing environmental footprint, like; erosion, degradation, pollution, scarcity, land use change, ecosystems deterioration or even species extinction. The increasing environmental footprint degrades freshwater and coastal aquatic ecosystems, forestry and resource availability, all recognized to contribute to climate change (IPCC, 2007; UN, 2015a). Climate change phenomenon is poised to shift precipitation patterns and speed glacial melt, altering water supplies and intensifying floods and droughts (World Resource Institute, 2015), it will increase climatic temperatures and risk ecosystems equilibrium.

World urbanization faces enormous challenges for proper placement of its growing population. Presently, one third of the world population lacks of basic infrastructure services like freshwater supply, sewage collection-treatment systems and reliable-sufficient and clean energy, (World Bank, 2012; UN 2014, 2015; Scott, 2015). History has taught us the process for countries to achieve development, in which water and energy plays a major role towards providing services and consumables to its population. In the learning curve we have understood the environmental damage that we are creating because the unsustainable use of resources and profit oriented scope to achieve such development, (OECD, 2002). As world urbanization continues to grow, more energy is necessary towards sustaining population demands. Most of the energy in present days is produced in centralized systems (hydroelectric, coal, diesel, nuclear, etc), normally far from people’s livelihoods for safety reasons, resulting on massive infrastructure that is capable of moving energy for miles towards urban areas. This extensive infrastructure grids inevitably deteriorates over time and demand constant maintenance, costs that are not always fully address by cities managers resulting on catastrophic amounts of energy loss in the transition, meaning that the energy lost accounts for a production chained towards an obsolete, inefficient, costly and pollutant system to deliver the service. Consequently energy production accounts for most of the Greenhouse Gas Emissions (GHG) emitted to the atmosphere enhancing climate change phenomenon that poses multiple threats to water availability and may increase the frequency, intensity and severity of extreme weather events, (IPCC, 2007). Against this backdrop, 97 percent of the world energy produced today needs water, a precious resource that is vital for the planets ecosystems and humanity’s survival. Fresh water has a similar story where is being pumped out from its source to supply cities around the world for produce, provide and consume services and goods. Normally freshwater

in most countries is delivered by grids that are facing similar problems from the one's in the energy sector, as the infrastructure that keeps the services "running" is exponentially deteriorating over time, and has resulted on enormous transition losses as it moves from source and through the cities hidden and aged infrastructure, towards their end-use and treatment, cycle that demands energy in all of its stages. Furthermore, the Intergovernmental Panel on Climate Change 5th Assessment, projects that for each degree of global warming, approximately 7% of the global population will be exposed to a decrease of renewable water resources of at least 20% (IPCC, 2007, Döll et al., 2014; Schewe et al., 2014), indicating the interlinked paradigm on water-energy and climate.

Meanwhile world population is estimated to continuously grow, cities around the globe are rapidly expanding (Cohen, 2006). In this rapid urbanization, land savings have become essential to the long term sustainability of over-populated cities (Haiyan, 2008; Fazal, 2000), endangering the quantity and quality of the world's water sources, risking its depletion. And so the big challenge that the world urbanization faces today is how to find water-energy-land and food security for its population in a clean, efficient and sustainable approach, with a continuous and reliable delivery of the services and consumables depending on this four sectors. For many years, the respond towards achieving better management of resources while lowering their environmental footprint have been astonishing, with energy efficiency measures and innovative production/operation technologies that are fossil fuel free around the world. Still the transition towards clean technologies is not sufficient and the energy sector stresses pressure towards providing sufficiently to fulfil population needs, demanding more from the water sector. Meanwhile, world urbanization demands more land for accommodating the coming generations, endangering groundwater capacity to naturally recharge. Land that competes over best practices and uses, as recently ecosystem services have been strongly proven (Pearce et al., 2006; Defra, 2007; Farley, 2010) and for generations largely damaged worldwide, raising major concerns towards environmental crisis, strengthening the paradigm to achieve world sustainability. Bounded together towards uncertain reliability to depend of better management and practices onwards its uses over the different sectors and their inter-linkages. Many have discussed over better resource management to ensure the world's capacity to support humanity (Gleick, 1998; Meadows, 2005; Hopkins, 2008; Read, 2013) stressing the effects of an "overshoot" worldwide that is consuming resources over their capacity to self-replenish, while polluting the environment and ecosystems that provide balance to nature.

## 1.2 Problem Statement

World population growth will increasingly take place in cities, estimates are that 70 percent of population will live in cities by 2050, (UN, 2015). Over the coming decades, the level of urbanization is expected to increase in all regions, currently 59 countries are already more than 80 percent urban. The most highly urbanized countries are Belgium 98 percent urban, Japan 93 percent urban, Argentina 92 percent urban and the Netherlands 90 percent, (UN, 2014b). World cities are bounded to provide services like water to the growing population. Water over exploitation and poor water management is stressing the resource availability and security to sustainably provide population needs in future. In order to provide water services in cities electric energy is required and normally highly dependent, establishing an inter-linkage between two services (water service and electric energy service). Both resources are established by centralized systems to extensive infrastructure grids from source to end-use, much of the water and energy is wasted in the cities service cycle due to inefficient management of the resource, accounting for great environmental losses related to water scarcity and carbon emissions. Sharing great potentiality to correlatively abate their footprint by exploring their efficiency measures and saving options for a better resource management.

*“However, rapidly aging and costly infrastructure, population growth and increasing urbanization call to question current water management”*, (Larsen, pp 1, 2016).

Understanding their nexus (inter-relationships) is vital to ensure water-energy security. More than 68 percent of world energy is produced by burning fossil fuels, process that needs water for a direct or indirect purpose, accounted for more than 45 percent of the current total water use in the industrial sector, (UN, 2014b). Around 10 percent of the world energy is currently being used in the water sector. The energy and water consumed in cities have a strong connection with environmental and climatic degradation. Their use, and relationship will grow exponentially as well as the population in cities, creating enormous pressure on both water and energy availability, exponentially creating more equivalent CO<sub>2</sub> emissions. **Since there is no replacement, water security looks more crucial than energy security**, stating the importance to study saving measures in cities service cycle, as it is a strong and growing user.

Exploring this connection (urban water-energy-climate nexus) in one of the most populated cities in the world (Mexico City), which has an extremely complicated water management due to the population size, great water losses in a leaky system, urban sprawl, decreased recharge areas and lack of awareness, being some of the factors that significantly risk the city water sources. Currently, the complexity of the water systems have created a crisis that may affect over 23 million habitants in both Mexico City and Metropolitan Area, with a water capacity per capita of 5,367 ft<sup>3</sup>/person/year, meanwhile the country capacity per capita is 140,623 ft<sup>3</sup>/person/year, (100 Resilient Cities, 2016). This disparity is a clear indicator of great stress in the city's water system. The overexploitation of the groundwater sources has caused land subsidence it has been determined that in the last 6 decades the city centre has sunk over 10 meters (UNAM, 2008), in consequence great damage to the city infrastructure including piping and sewage systems, being one of the reasons for the great leaking in the city (40-50%). In order to fulfil the water demand, water importation has proven efficient to deliver the vital resource to the thirsty population (50%), brought from neighbour basins at an incredible high electric costs and equivalent CO<sub>2</sub> emissions, due to the energy production typology used in the country. Importing water from basins with an altitude difference of 1,100 m total, have consequences towards the environment, impacting over the species diversity, and also the local livelihoods; affecting economic, health and equity of the surrounding population. Being the urban water-energy-climate (CO<sub>2</sub>e) nexus the main objective of this research's.

### 1.3 Research Objectives

The research study aims to analyse the urban water cycle at Mexico City (CDMX). The interlinkages between energy and water services referred to as the water-energy nexus, (Gleick, 1994; CEC, 2005; Cooley et al.; Yang, J., 2008; Bennet et al.; USGS, 2010; Kenway, P., 2011; Cooley & Wilkenson, 2012; Lenhart J., et al., 2013; Mo, W. et al.; WWAP, 2015). The main objective of the research is to analyse the current business as usual (BAU) scenario of the water use in the service cycle, the energy involved in the different urban water cycle (UWC) processes, and the Carbon Dioxide Equivalent (CO<sub>2</sub>e) emissions related to the energy used. Two different scenarios will be compared; the first with BAU projections towards 2025, and the second projection; with water saving measures, also towards 2025. Providing useful information for interested actors to understand CDMX water availability towards the coming years (water security), different Water Saving Measures (WSM), and how they may influence the Adaptation/Mitigation (Ad-Mit) respond of the city.

## 1.4 Provisional Research Question

**To what extent does the water-energy-climate nexus influences CO<sub>2</sub>e emissions at the urban water cycle in CDMX?**

- 1.1 What is the water-energy-climate nexus in the urban water cycle in CDMX?
- 1.2 What are the current flows in the urban water cycle in CDMX, how much energy does it use, and equivalent CO<sub>2</sub> emissions produces, in BAU scenario?
- 1.3 What are the implications of WSM on carbon emissions, and how are they influencing the adaptation mitigation respond of the city to climate change?

## 1.5 Significance of the Study

Many countries in the world today face water scarcity, and many more project in a short period of 10 years to have scarcity in their business as usual scenarios, leading to potential conflict among people and countries, (UN, 2015b). World urbanization, population growth and consumer behaviours are increasingly pressuring the remaining freshwater sources, stressing demand over water intensive sectors like; agriculture, food security, energy production, manufacturing of goods and services, drinking water, sanitation services that reflects on cities health, and water to maintain diversity in ecosystems. However all (water) dependant sectors have identified potential savings, mostly due to the poor management of resources. Increasing urgency to manage trade-offs and maximize co-benefits across multiple sectors. Water use has been widely studied around the world, however it is relevant to bring further analysis to the city level, as projections show that world population is be living in urban areas like never before and will exponentially grow in the coming years.

The sector to apply and analyse this research is at the city level, specifically the **urban-water service cycle** that has projections to increase their demand extraordinary mainly due to human activities and urban population growth. Meanwhile the relevance of this study is to contribute to an enhanced understanding of integrated urban water models at the urban level and the interrelations with energy and environment sectors that encompasses different aspects of the urban water cycle in cities. The specific contributions of this thesis are subdivided into water distribution system, urban drainage system, urban water-energy-climate nexus, cities adaptability and mitigation potential to climate change by forecast development, combining three different topics for an integrated assessment widely referred as the water-energy-climate change nexus. A subsequent critical discussion is to reflect how forecasting urban water management and saving measures have potential to ensure water and energy availability in the years to come, meanwhile reducing CO<sub>2</sub>e emissions to the environment. Unfortunately megacities already project scarcity and conflict, making them perfect target to analyse urban studies as they are the first struggling to ensure the citizens livelihoods due to their complexity.

By studding the urban water cycle I intend to enhance to academic knowledge over better resource management the urban water area and the energy involved. However, climate change has a role to perform in this nexus as the savings from both sectors have a strong influence on the indicators of the cities respond to the phenomenon.

## 1.6 Scope and Limitations

The scope of the research is exclusively; the urban water conveyance, drainage and treatment systems (urban water cycle) in Mexico City. The BAU scenario will be established by data collection, and projected until the year 2025. The WSM scenario, will be projected by implementing WSM; established by literature review, academics, and experts opinions in the urban water cycle of CDMX. A subsequent discussion will be performed on the data; analysed over water security, energy dependency and a CO<sub>2e</sub>, in an overall analysis over both scenarios. The limitations of the study are over primary data, as it is challenging to obtain, due to different factors updated data may differ among sources in all the sectors. Another limitation is the scope itself, as only the selected city (CDMX) will be analysed and wider information will be neglected, being the water management in this city strongly linked with the region and neighbours basins.

A comparison between megacities in urban [Water-Energy-Climate Nexus \(UWECN\)](#) is not part of the scope of this research, but interesting for further studies.

## Chapter 2: Literature Review / Theory

### 2.1 World Urbanization

*“Understanding the demographic changes that are likely to unfold over the coming years, as well as the challenges and opportunities that they present for achieving sustainable development” (UN, p.7, 2015a).*

According to world population prospects by UN, currently, the world population reached 7.3 billion (UN 2015a), showing an overall of one billion people added in a 12 year span, with an overall 83 million additional people added to the world every year. Distributed approximately as following; in Asia 4.4 billion representing 60 percent, in Africa 1.2 billion representing 16 percent, Europe 738 million representing 10 percent, Latin America 634 million representing 9 percent, and the remaining 5 percent are in North America (358 million) and Oceania (39 million). The most populated countries are China with 1.4 billion representing 19 percent and India with 1.3 billion representing 18 percent of global population. In 2005 world population was growing by 1.24 percent and has slightly decreased to 1.18 percent per year implying a slower growth than the recent past. Future projections over population growth are estimated as following; by 2030 will reach 8.5 billion, further increase to 9.7 billion by 2050 and 11.2 billion by 2100, growth that will mostly occur in urban areas, coming up to 70 percent of the total population by the end of the century, meaning that around 7 billion people or equivalent of today's entire population will be living in cities (Read, 2003; UN, 2014a, 2015a). Although Asia holds most of the population by continent, future projections look up towards Africa that has a growing rate of 2.55 percent annually (2015), indicating that by 2050 half of the world's population growth will be held among the African countries with 1.3 billion people added in 35 years, the anticipated rapid population increase in Africa assumes a decrease of children per woman from 4.7 (2015) to 3.1 (2050), expected to be the world's region experiencing substantial growth in their population projected over 25 percent by 2050 and 39 percent by 2100. Asia closely follows with 0.9 billion people and expected to fall up to 54 percent by 2050 and 44 percent by 2100. In contrast Europe is projected to decrease its population by 2050. (As for the projections it has been acknowledge a degree of uncertainty among the world population and presented based on the medium projection variant, assuming increase/decline of fertility and life expectancy depending on different countries present average). Regardless of uncertainty among fertility in Africa the young people currently on the continent ensure a major role in shaping the world's size and distribution of population over the coming years.

More than 50 percent of the world population lives today in cities, of which 30 percent live in slums, expected to grow to 40 percent by 2050 and around 93 percent is accounted to developing countries. **Least Developing Countries (LDC)** constituted by 48 countries according to United Nations hold an average population growth of 2.4 percent annually, representing an overall of 954 million inhabitants (2015) and expected to double in size with 1.9 billion by 2050 and is to increase to 3.2 billion by 2100, 27 of this countries are in Africa. World urbanization will mostly be in the poorest countries and hold's major concerns to human rights and quality of life with problems like hunger, health, education, basic services and infrastructure for the growing societies.

TABLE POPULATION OF THE WORLD AND MAJOR AREAS, 2015, 2030, 2050 AND 2100, ACCORDING TO THE MEDIUM-VARIANT PROJECTION

Major area	Population (millions)			
	2015	2030	2050	2100
World	7 349	8 501	9 725	11 213
Africa	1 186	1 679	2 478	4 387
Asia	4 393	4 923	5 267	4 889
Europe	738	734	707	646
Latin America and the Caribbean	634	721	784	721
Northern America	358	396	433	500
Oceania	39	47	57	71

Source: United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision*. New York: United Nations.

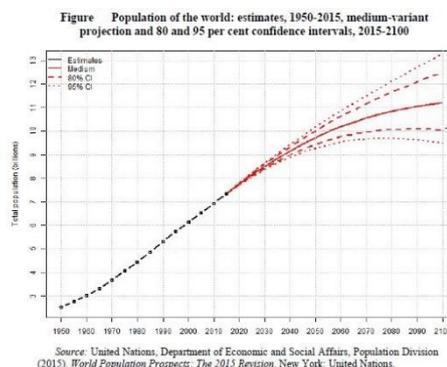


Figure Population of the world: estimates, 1950-2015, medium-variant projection and 80 and 95 per cent confidence intervals, 2015-2100

**Table 2. 1: Current world population (millions) by continent, and future projections until 2100**

Source: UN, (2015a)

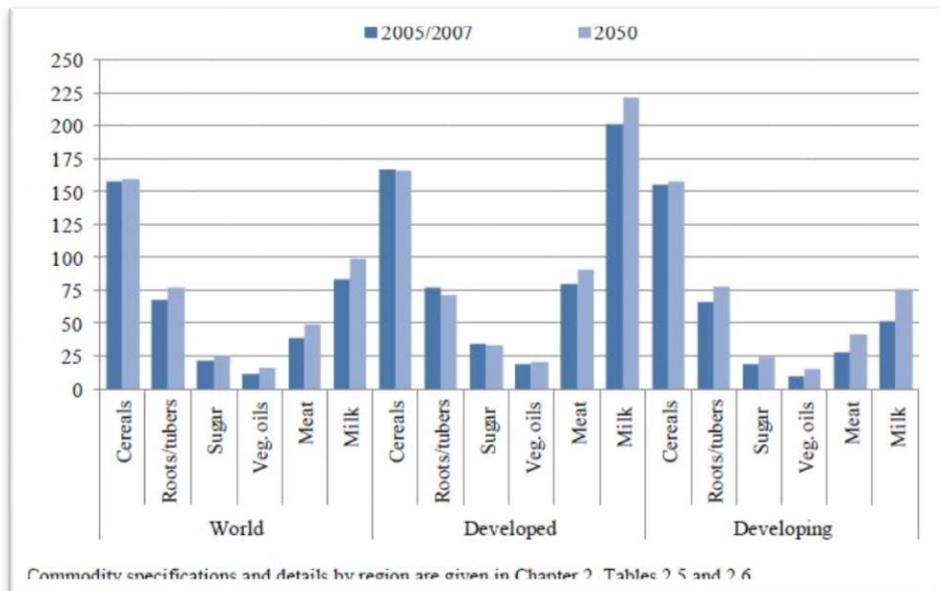
**Graph 2. 1: Current world population (billions), and future projections until 2100**

Source: UN, 2015a.

The urbanization process experienced today, has been reflected in the size and quantity of urban establishments. It has been estimated that mega-cities with more than 10 million habitants have grew from 2 in 1950 to 28 in 2014 and according to UN by 2050 up to 41 mega-cities will be established globally. Presently Tokyo is the most populated city in the world with 38 million habitants, followed by Delhi with 25 million, Shanghai with 23 million and closely Mexico City, Mumbai and Sao Paulo with 21 and 22 million, (UN, 2015a). As a result of this unprecedented urbanization, poverty characterizes most of this settlements as low income and lack of access to services like water, energy and transport are common and the per capita emissions are consequently lower. It is estimated that by 2020 cities will cover around 2.7 percent of global available land equivalent to 3.5 million km<sup>2</sup> (Schneider, Friedl and Potere, 2009), 80 percent of global gross domestic product and 2/3 of world energy (Newman et al., 2009). The world urbanization has been determined in 3-7 percent annually, being China number one in expansion (Seto et al., 2010), this phenomenon is linked to similar economic growth, energy, water and other resources, as well as the GHG emissions. The rising global GDP is mostly accounted over 380 cities generating overall 60 percent (McKinsey Global Institute, 2013; Seto et al., 2014) and 1/5 of the world population, the most wealthy, consumes 85 percent of overall consumables services and natural resources (Davies et al., 2008). GDP grew on average by 3.5 percent/year from 1960/12 (World Economics, 2014) in expense of an environmental cost, compromising the ecosystems and the natural replenish cycle for satisfying the world's growing demand (MEA, 2005). Rising per capita consumption and demographic growth are solid drivers that pressure the water sector and is expected to further increase and worsen (Susnik, 2015). The fast growing population, consumption behaviour and governance failures around the world have increased the pressure on water resources and has consequently produced serious impacts on our social and economic well-being (Cooley et al. 2013), as to its quality and availability is compromised, (Dias et al., 2006).

Water-related problems like droughts, flooding and severe water pollution is related to this economic-demographic growth and frequently affecting the most vulnerable as the world climate continue to change. Furthermore, we have realized that water is the key vector on human survivor throughout the phenomena, it is the core of sustainable development linked to climate change, agriculture, food security, health, equality, gender and education. Poverty and social equity are main concerns on the access to water supply over the household level as it's critical for human development, and interventions over this sector instantly benefits their livelihoods through better health, increased productivity and time-savings. Rapid growth in urban areas is related to slum development, which in many cases lacks access on water and sanitation infrastructures that usually has a huge toll on health, well-being and loss to economic activities. In many places aquifers, rivers and lakes are being overexploited to depletion, and reflects the excessive water consumption to fulfil humanity needs (McDonald et al., 2014), with devastating consequences for the environment and future generations to come, were the worst and most severe consequences compromises water availability, quality and demand affecting all levels of livelihoods mostly food supply as it represents the biggest consumer of freshwater worldwide. Predictions on food supply (Not relevant for the objective of the thesis, but relevant for the state of the art research) remark the trembling path towards continuity, as water security is yet a future goal. A key question expressed by the interested stakeholders like FAO, IPCC, and UNESCO among others, is whether the quantity and quality of freshwater will suffice for the growing needs upon food security, stating for example that agricultural activities now a days accounts for around 70 percent of fresh water withdrawals in the world and has primer concern over the sector towards freshwater scarcity as the overall agricultural demand will grow on 1.1 percent per year towards 2050, making global agricultural water demand unsustainable and calls of better management over the sector in order to reduce water losses and increase productivity and efficiency. Meanwhile, world diet also changes and per capita consumption increases, consumption that will demand more livestock products, mostly in rapid developing economies that has been adopting western diets, like China and Brazil, that moved quickly towards this diets, pressuring even more on land and water resources both in quantitative and qualitative terms, followed consequently by soil degradation, salinization of irrigated areas and competition on other land uses, (FAO, 2011).

Developed countries that has passed through industrialized process are already acquiring strategies to achieve water security (efficient irrigation, closed water systems for energy reactor cooling). Over the last 30 years the human footprint has slowly showed (positive) effects by implementing new technologies, consumers awareness, reformed institutions and international agreements, however some undeveloped countries are struggling throughout the industrialized processes were economic growth is to be acquired and their footprint still far from decreasing. As stated before water demand is strongly influenced by population growth and consequently by urbanization, food and energy security, among others. It is projected on WWAP (2015) report that global demand on water will increase by 55 percent, mainly due to manufacturing, electricity generation and domestic use. However economic arguments can be relevant for preserving ecosystem services as its valuation demonstrates benefits on their conservation, being vital for decision maker's agendas.



**Graph 2. 2: World food consumption**

Source: UN, 2015a.

## 2.2 Current Water Situation

Freshwater is the planet's bloodstream in both bio and social sphere, humanity's dependency on it is proven at every level of our livelihoods. It is critical to acquire sustainable development, as it's an essential resource that nearly steers all social, economic activities, and the planet's well-being. The last decades have produced enormous amounts of data that support climate change and the world's over-use of resources (IPCC, 2007; World Resource Institute, 2015), consequently environmental depletion has made us understand that the world has exceeded its carrying capacity (Dwight W., 2003; Meadows, 2005; Diaz, 2006; ), creating an ecological footprint and defined as; the required/consumed resources and total emitted/absorbed emissions of the planet by the global population, stretching the non-renewable resources to critical levels, (Susnik, 2015). The current global footprint is already affecting climate change and availability of resources as it influences the spatial distribution of water resources and its availability. Consequently enhancing vulnerability to already climate risk livelihoods, (UNESCO, 2015); the frequency and intensity of water-related disasters, will continually grow parallel to global temperatures, (IPCC, 2014; World Resource Institute, 2015).

Ocean and sea water comprise 97 percent of all water in the planet, only 3 percent is freshwater. This vital resource for humanity is unequally distributed around the globe as follows. Around 68.7 percent of the world's freshwater remains frozen, locked up in ice-caps and glaciers unavailable for human use, however around 30.3 percent is stored underground in aquifers, meanwhile the rest 1 percent is surface water stored in lakes, rivers, swamps etc.,. About 110,000 km<sup>3</sup> of fresh water precipitates from rain worldwide, around 43,000 km<sup>3</sup> of this renewable freshwater flows through rivers and thought that about 9,000 km<sup>3</sup> is available for human activity, however more than 6,000 km<sup>3</sup> is being currently withdrawn from all sources (Gleick, 1999). The increasing population consuming rates, have been stressing the world's natural resources capability to replenish in most of the sectors, affecting not only the livelihoods of people but affecting seriously the ecosystems well-being. Groundwater supplies are decreasing over 20 percent, the world's aquifers are being over-exploited (Gleeson et al., 2012) mainly disrupting the ecosystems and enhancing deforestation which have consequences on the cyclic replenish aqueducts levels, bringing closer a crisis as the finite supply has been nearly tapped dry. Above one-third of the world's population lives in freshwater scarcity, over 80 countries (countries that will increase drastically population within the years to come)

(WWAP, 2015), according to United Nations definition of freshwater scarcity as consumed above 10 percent of the natural capacity to self-replenish, (UN, 2014b). Bringing to the attention the world's capacity to sustain humanity suggesting the overshoot limits of the Earth's support capacity to the ecosystems and environment (Dwight, 2003; Meadows, 2005). Many authors have showed the total water use, hidden behind goods (Hoekstra; Aldaya; and Chapagain, 2011), to help understand the global importance of the resource as well as our strong dependency and urgent management over globalized use of water. They stress the hidden water footprint<sup>1</sup> over diverse sectors to produce, manufacture and deliver services around the world, trading not only the product itself but the water footprint among countries, (Hoekstra 2011).

Human activities consume and pollute water, currently unsustainably in most countries due to **food production (agricultural and live-stock), industrial and domestic sectors**, to fulfil humanity necessities for goods and services paying little attention to the fact of overall resource consumption and natural replenishing rate. World water use is defined in this three sectors. For example; Most of the industrial process need water; worldwide its accounted for being the second largest water consumer. Including energy production that uses it for cooling down their generators (coal, oil, gas, biomass and nuclear), they may not only consume water heavily but also pollute it to a point it becomes unusable for any purpose. Unfortunately, around 97 percent of the global energy produced in the year 2010 (20,300 TWh) relied on heavy water dependant methods. Two thirds of the energy come from coal, gas, and oil fired power plants, all identified as heavy water users, (Olsson, 2012). Less than 3 percent of energy producers are onwards a real definition of sustainability, like wind turbines and solar panels that are capable of not using exorbitant amounts of water for producing energy. Unlike, biofuels (1.9% of total global energy produced), geothermal (0.3 % of total global energy produced) and hydro plants (15.8 % of total global energy produced) they all have great water consumption and produce massive environmental degradation. Stating the unsustainable competition for water, between “uses and users” which eventually may led to inequity over access to services, developing conflicts on local economies and livelihoods. Even as the planet's endowment of water is expected to remain constant, human appropriation on water sources already passes 50 percent by some measures, it is expected to increase further (Postel et al. 1996). Moreover, the world's water is increasingly becoming degraded in quality, raising the cost of treatment and threatening human and ecosystem health and diversity (Palaniappan et al. 2010). Furthermore, the physical availability of freshwater resources does not guarantee that a safe, affordable water supply is available to all. At least 780 million people do not have access to clean drinking water, some 2.5 billion people lack access to safe sanitation systems, and 2–5 million people—mainly children—die as a result of preventable water-related diseases every year (Gleick 2002; UN 2009; WHO and UNICEF 2012).

## 2.3 Identifying the Urban Water-Energy-Climate Nexus

The benefits of the interrelation of water and energy policy implementation, has been largely proven (Gleick, 1994, 1998, 2000; CEC, 2005; Cooley et al.; Yang, J., 2008; Bennet et al.; USGS, 2010; Kenway, P., 2011; Cooley & Wilkenson, 2012; Vidal, P., et al.; Davies G. et al.; Lenhart J., et al., 2013; Mo, W. et al.; WWAP, 2015). The annual review of energy and environment article (1994), establishes the innovative employment of water-energy cycle, analyses the intensity of the water sector cycle from extraction through treatment, distribution and end use. Policy implementation and planning for governmental institutions on regulatory terms are to perform managing savings of water and energy resources and call for joint

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<sup>1</sup> The water footprint of a product is the volume of fresh water used to produce the product, summed over the various steps of the production chain. (Hoekstra 2011).

innovative optimization on operation for the integral management of both resources. The urban water life cycle assessment (LCA) among developed countries is relatively consistent, and normally conformed of a water body either in surface or underground sources. In this paper, three process are defined (supply, sewage and re-use) and broken down as following: Water extraction (withdrawal), water treatment (potabilization) and convenience (pumping) together stablish the beginning of the water cycle and will be referred in this paper as supply, being the process to reach users. After end-users, water is disposed to the wastewater collection system (sewage) which is pumped to treatment plants, and is typically discharged back to water bodies. Water re-use refers to sewage water that received previous treatment before being used once more instead of being discharged. Present at all steps of the urban water LCA, energy is involved, energy that commonly is produced by burning fossil fuels, liberating CO<sub>2</sub> to the environment. This section is able to recognise the urban water-energy-climate nexus and provide a wider extend of the topic.

Urban population will continue to grow, people living in cities need both water and energy services. Urban expansion and densification is the immediate respond to overpopulated cities. The water resource implication for urban population growth is around 64 billion m<sup>3</sup> per year, on a already stressed resource (INNERS, 2013). A global challenge is how to sustainably provide the communing population with suitable water and energy services to offer a quality of life. This issue is much more complex than it may initially appear as it is well known that water and energy, especially in urban areas, are intimately linked (Kenway et al. 2011; Sanders and Webber, 2012; Lenouvel et al. 2014; Lenhart et al. 2015). As they grow, neighbourhood's demand better infrastructure and services that need massive investment to deploy and operate, the supply grids that over time become obsolete for their enormous loses and expensive maintenance. Meanwhile, overlapped by build methodology water infrastructure has become the bloodstream of the city, as the water travels from one corner to the other in order to fulfil basic needs of users. However, the water cycle requires energy in all of its process, and is very resource inefficient. In UK, during withdrawal, treatment and supply of clean drinking water, pumping alone equates to 60 percent of the total energy used in the urban water cycle (INNERS, 2013). Meanwhile leaky systems lowers the efficiency of the operation and threatens the availability and security of water sources, resulting in water and energy waste in the systems grid. More than 40 percent of global water is lost in the grids, meaning that 40 percent of the global carbon emissions emitted by the urban water cycle is produced by water losses, (Olsson, 2012). At present, 12 percent of primary energy consumption in the US is related to the water sector (Sanders and Webber, 2012), other estimates state that around 8 percent of global energy use is in the water sector, energy from produced from burning fossil fuels, (Olsson, 2012; WWAP, 2012). Water sensitive policies are vital to overcome sectors fragmentation. Water savings may adopt many measures to ensure urban water security, like: recycled water use, pricing reforms, leakage-pressure reduction and water saving campaigns. However, off-grid technologies like rain harvesting, and in-sight treatment systems may reduce the municipal dependency of individual users. This methods lowers water use from buildings and public areas, cutting down the Life Cycle Assessment (LCA) process, reducing water supply (withdrawal and conveyance) in grids. They unfolds a series of interrelated co-benefits, being precisely the kind of synergies the urban water-energy-climate nexus represents, and may dramatically enhance water security and environmental preservation of urban areas, as less water is conveyed in the LCA less energy is used, and less CO<sub>2e</sub> is emitted.

Water energy usage has been studied mostly in national, regional or global values. The world Energy Council (2010) reports global average values for primary energy extraction, the DOE (2006) reports global average for water used for electricity production. Meanwhile at national and regional levels, a general overview of their inter-relationships has been studied, (Fthenakis and Kim, 2010; Rasmussen, 2012; Sanders and Webber, 2012; Davies et al. 2013; Koch et al. 2014). However, local-level information at city scale is barely explored while some cities have been explored (Kenway et al. 2014; Lenouvel et al. 2014; Lenhart et al. 2015; Jiang et al. 2016),

generally information is scarce, meanwhile more studies are needed to address the topic at mega-cities, name given to those highly populated cities that have passed 10 million habitants. The registered number of mega-cities has grown from 3 in 1975, 14 in 1995, 19 in 2007, to 22 in 2015 and it is projected to reach over 27 in 2025, (Parrish, 2009; UN, 2016). They are the engines of economy, innovation and cultural interactions, but today they concentrate all problematic of cities including; health, mobility, pollution, sprawl, resource scarcity and inequity. According to the World Cities Report, 2016 (UN, 2016), the top urbanized 600 cities hold 1/5<sup>th</sup> of the world's population, produce 60 percent of global GDP, consume 60/80 percent of energy and generate 70 percent of GHG emissions to the environment primarily by burning fossil fuels, developing countries population will double, and cities could triple land area currently covered by 2030. Yet, greater population density could act in favour and allow more efficient use of resources. Hence, unprecedented opportunity lies upon finding localized solutions to megacities problematic, in this case [Mexico City \(CDMX\)](#). A perfect example of urban complexity, a laboratory of innovation that may overcome institutional fragmentation for an integrated resource efficient agenda. To this end, this thesis presents a detail study into the urban water cycle of Mexico City, in order to provide city-level information on the water-energy nexus, showing the strong relation and fragile dependency among each other. The consequent information is connected with [carbon dioxide equivalent \(CO<sub>2</sub>e\) emissions](#), posing further debate on the urban expansion, resource consumption and climate change, (WWAP, 2014).

## **2.4 Ada/Mit Co-benefits in the Urban Water-Energy-Climate Nexus**

When studying the urban water cycle in a climate change framework several factors need to be understood and analysed in order to provide full understanding of the service implications. In this study it reveals consequent energy use and the equivalent carbon dioxide emissions (CO<sub>2</sub>e) in it's different processes (supply, treatment/re-use and sewage). However, climate change phenomenon is enhanced by different anthropogenic activities including carbon dioxide emissions (IPCC, 2007), it is understood they distortion ecosystems balance causing change in the environmental conditions, including weather; temperature and precipitation standards (UN, 2015a). As stated before urban population has grown and will continue growing due to different social factors, being cities currently major contributors to CO<sub>2</sub> emissions worldwide, (Fischedick et al., 2012; Balaban and de Oliveira, 2013; Sims and Dhakal, 2014; Lucon et al., 2014; Revi et al., 2014). Therefore, the great importance of carbon mitigation at urban level is evident. However, climate change effects and impacts are already being felt in urban areas, this study is interested in floods and droughts, being both related to water. Consequently, to reduce pre-existent or new vulnerabilities in urban areas worldwide efforts are being developed for urban-climate adaptation, that may involve different actors to interact at the city level to develop climate policies, spatial planning and cross-sectoral decision-making at different urban sectors and levels of governance, (Piper and Wilson, 2009). The relationships between adaptation and mitigation across the urban sector is widely studied (Callaway, 2004; McEvoy et al., 2006; IPCC, Klein et al., 2007; UNFCCC, Saavedra and Budd, 2009; Barnett and O'Neill, 2010; Döpp et al., 2010; Pacteau and Jossaume, 2013), it's joint implementation is imperative to develop strong solutions as the city responds to climate change effects, and to avoid complications in planning and decision-making in cities (Piper and Wilson, 2009). This section recognises water saving measures to reduce water-energy consumption, and abate CO<sub>2</sub>e emissions. Meanwhile, enhancing urban climatic resilience (Molyneaux, L., Wagner, L., Foster, J., 2015), establishing co-benefits in the interrelations between adaptation and mitigation (Ad-Mit), see [table 2.2](#).

Adaptation-Mitigation Interrelations

Urban Water-Energy-Climate Nexus		City Respond to Climate Change		
Water Saving Measures		Water Security	Flood Capacity Enhancement	CO2 Emissions Abatement
1	Rainwater harvest on buildings by off-grid technologies	Water source relief	Delay and capture rainwater	Lowers systems energy consumption
2	Rainwater harvest and retention on public space by promoting eco-system services and water sensible infrastructure	Water source relief	Delay and capture rainwater	Lowers systems energy consumption
3	Recycle water use	Water source relief		Technology implementation to produce clean energy
4	Water leakage/loss reduction in grids	Water source relief		
5	Up-date technology in the urban water cycle service			Lowers systems energy consumption
6	Reform on water pricing, according to water consumption and based tariffs	Water source relief		
7	Water savings campaign	Water source relief		

**Table 2. 2: Selected WSM for the local context (CDMX) and interrelation with the city respond to climate change.**

Source: Author, 2016.

1 and 2.- Rainwater harvest for non-essential uses is vital to achieve urban water sustainability, cutting down all cost involved in the LCA. Although, rainwater harvesting and treatment technologies need to be supported by clean energy, produced preferable by solar/wind in-sight technologies cutting down all energy related costs, and adding extra values to Ad-Mit potential. Cities that have stressed sewage systems, may flood during rainy seasons. By capturing rainwater and separating it from the sewage system, cities enhance their climatic resilience (Venema & Rehman, 2007; Isla Urbana, 2009; UNAM, 2014a and 2014b; Valdez, C., et al. 2016). Different techniques are to capture rainwater, until now we uncovered rainwater harvesting by buildings but other techniques are used in countries like Netherlands. In the city of Rotterdam a climate proof initiative had to be developed, as some locations in the city are under 6 meters below sea level (mbsl). They are implementing the so called water-squares, they are public spaces design for people by people, in a participatory approach. The innovative part of this place making, relies on the climatic characteristics added to the design. The water-squares are dynamic water storages that are design to capture and retain rainwater from streets, pavement and buildings by a grid system that allocates the water to a specific place and may benefit a whole block. This harvested water has the property of retaining rainfall, allowing sewage systems to process storm water, as it creates “pools” for a determinate time, then they automatically drain after the sewage system reduced its rainy flows. This water may also be used in public areas. This measure represent all three categories (water security, flood capacity enhancement and Co<sub>2</sub> emissions abatement) towards the city respond to climate change.

3.- Recycled water use is strong measure (World Bank, 2012), as it reduces water resource use and enhances water availability. This measure represent two categories (water security and Co<sub>2</sub> emissions abatement) towards the city respond to climate change. However, by treating sewage water with the correct technology is possible to generate energy from biological waste (Fthankis, et al., 2010; Noyola, A., et al., 2016), example. In Denmark in the Aarhus locality. As we speak (2016) they are building a water treatment plant first of its kind, as it is able to create 50 percent more energy that it uses out of all wastewater entries from the city. “This will

be through entirely new technologies that exploit the green energy-production potentials in wastewater”<sup>2</sup> (state of the green, 2016).

4.- Water leakage/loss reduction in grids is fundamental in order to achieve a sustainable urban water cycle (CONAGUA, 2015; SACMEX, 2015). This issue is always given in the infrastructure and it has become a great problem in urban areas as it is extensive and costly to maintain. This measure represent one category (water security) towards the city respond to climate change.

5.- Up-date technology in the urban water cycle is of great importance as new technologies are able to bring energy efficiency and lower carbon emissions, (World Bank, 2012).

6.- Pricing reforms have proven efficient to reduce water supply/waste and to promote equity among users, (Olsson, 2012). The prohibition of flat tariffs has basically ruled out non-volumetric pricing schemes and tariffs, the combination of fixed charge covering a given volume of consumption and volumetric charges has drastically lower water use among consumers in France, UK, AU and USA (among others), as water prices have significantly increased and water bills gain importance at households. Moving towards efficient prices will result in an increase of welfare, environmental promotion and equity (more benefits), (Dinar and Subramanian, 1997; Swallow and Marin, 1998; Kim, 1995; Renzetti, 1999; Sage, 1999; OECD, 1999; Garcia, R., and Reynaud, A., 2004; Olsson, 2012).

Consumption (m <sup>3</sup> )	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

**Table 4. 1: Evolution of domestic water tariffs in CDMX, 1996-2002**

Source: Marañon, 2004.

*“Prices are derived from an accounting system that emphasizes historical rather than economic costs and they are based on artificial unit costs. The water price is in general set such as the expected revenues from water sales cover the forecasted expenses. This is very close to an average-cost pricing. Moreover, the accounting observed cost may not correspond to the true economic cost. The marginal costs of supply and factors that may be expected to influence them are neglected in the rate-setting exercise. In order to be efficient, the marginal price of water faced by consumers must be equal to the marginal social cost. It is clear that the full economic cost of water and the cost of the water utilities may not coincide for two main reasons. First, unless water is purchased from a regional wholesaler, it is typically assigned no value. Thus, the price faced by consumers represents more the cost of treating, storing and delivering water rather than the value of water itself. Second, prices may reflect the costs of delivery but they may not incorporate the social cost of water treatment once consumption has taken place. This is especially the case when sewage treatment is administered by a separate utility or municipal department. However, these fees are computed in order to balance water agencies’ budgets. They may significantly differ from environmental social marginal damages.” (Garcia, R., and Reynaud, A., pp: 7, 2004).*

<sup>2</sup> Treatment plant able to produce 50 percent more energy that it produces. Available at: <https://stateofgreen.com/en/news/first-water-treatment-plant-in-the-world-generates-50-electricity-surplus>.

7.- Water savings campaign is a measure (strategy) to reduce water use, that involves best uses and techniques (Olsson, 2012). This measure represents one category (water security) towards the city respond to climate change.

All of the interventions mentioned previously reduce, alleviating and diminishing stress on overwhelmed capacity flows of the highly centralized sources on both water and energy infrastructure grids to deliver the service. But also, reduce the maintenance costs, environmental degradation and resource depletion, while enhancing water-energy security, (service reliability), and a more resource efficient management by the city administration. Mitigation benefits are also deducted, as potential CO<sub>2</sub>e emissions are abated from the energy that has been spared from the urban water LCA.

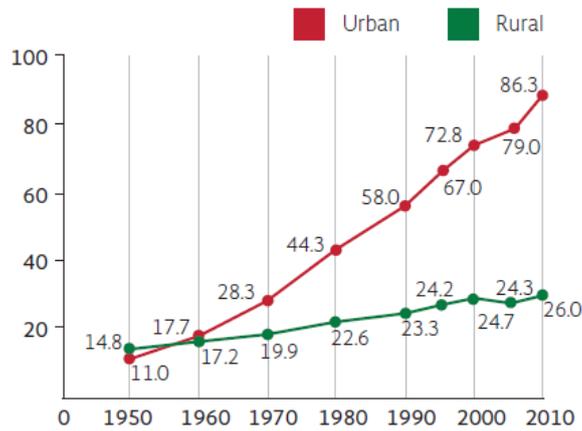
## 2.5 Conceptualizing the Country and Region

México’s continental surface corresponds to 1,964 million km<sup>2</sup>, constituted in 32 states, the country capital and most populated urban area is; México City (formally, Distrito Federal). Two thirds of the countries territory is considered arid or semi-arid with annual variations from less than 500 mm to over 2000 mm in the humid areas, the variation relies according to its topography. The country holds an overall population of 119.21 million habitants with a growth rate of 1.32 (2014) percent and a population density of 61 hab/km<sup>2</sup>, (INEGI, 2015). Since the mid-20<sup>th</sup> century the population is abandoning rural and congregating in urban areas, around 56.9 percent of the total population is living in cities in contrast with the 13 percent in 1900 and future projections of 80 percent by 2050 (UN, 2104b). It is estimated that 46.2 percent of the population (55.3 million people) is living in poverty, enlarging the urbanization over the outskirts of the cities where public infrastructure not always arrives on time. The previously mentioned factors, have altered the natural environment and is propitiating further degradation and enhancing climate change phenomena. Posing stress over the natural resource, those providing goods and services to the population. “The concentration and the accelerated growth of the population in urban localities have led to stronger pressures on the environment and on institutions, due to the increasing demand for services” (CONAGUA, pp: 16, 2015).



**Figure 2. 1: Mexico’s population by state**

Source: INEGI, 2014.



**Graph 2. 3: Mexico’s rural-urban population growth**

Source: INEGI, 2014.

## 2.6 Hydrological Administrative Region XIII (RHA)

In the 60’s the Mexican Hydrological Secretariat divided the country in different hydrological zones by their resources in to 37 regions, in order to manage the water resources properly and to ensure accessibility from all states of the federal republic. Some decades later CONAGUA regrouped all the RHA into 13 in order to reduce and better control the resources. An RHA is formed by a group of hydrological and hydrographical basins, it considers the municipal geographical borders, and a joint regulatory frame of the states involved. The RHA number XIII corresponds to Water of the Valley of Mexico, constituted by 105 municipalities from 3 different states (México, Hidalgo, Tlaxcala), and the 16 delegation of **Mexico City (CDMX)** formally **Distrito Federal (DF)** and yet divided in 2 sub-regions; Valle de México and Tula, see figure 2.2 & table 2.2



**Figure 2. 2: RHA XIII.**

Source: CONAGUA, 2014.

Entidad federativa	Delegaciones y municipios	Población 2013 (habitantes)		
		Urbana	Rural	Total
DF	16	13 184 501	56 684	13 241 184
Hidalgo	39	7 431 713	526 987	7 958 700
México	62	928 874	657 618	1 586 492
Tlaxcala	4	26 769	2 359	29 128
<b>Total</b>	<b>121</b>	<b>21 571 857</b>	<b>1 243 647</b>	<b>22 815 504</b>
<b>Subregión de planeación</b>				
Tula	36	16 316 208	757 292	17 073 500
Valle de México	85	5 276 761	465 244	5 742 004
<b>Total</b>	<b>121</b>	<b>21 592 969</b>	<b>1 222 535</b>	<b>22 815 504</b>

Fuente: Proyecciones de la Población de México 2010-2050, CONAPO.

**Table 2. 3: RHA XIII Municipal Division**

Source: CONAGUA, 2013

The total surface of the RHA XIII (Mexico State, Hidalgo, Tlaxcala and Mexico City) is of 18,229 km<sup>2</sup> and holds 19.21 percent of the total national population with 23 million people in 105 municipalities, being the smallest and most populated RHA of the country. It is considered to be one of largest urban areas in the world, commonly compared with others of its kind like; New York, Sao Paulo or Seul. In the early 1980s the valley was expected to become the largest urban area. A number of factors kept that from happening including falling birth-rate due to family planning policies, from extraordinary 5.5 percent in the 50's to 4.0 percent in the 70's till 1.6 percent in the 90's. The breakdown of the RHA XIII per state is as following; Mexico City has a total surface of 1,485 km<sup>2</sup> with a total population 8.84 million habitants, with an average density 5,974 h/ km<sup>2</sup>, divided in 16 delegations. State of México has a surface in this RHA region of 8,310 km<sup>2</sup>, with a total population 12.37 million habitants, with an average density 1,468 h/km<sup>2</sup>, divided in 62 municipalities. In the other hand, Hidalgo has a total surface in this RHA region of 7,943 km<sup>2</sup> with a total population 1.66 million habitants with average density 210 h/km<sup>2</sup>, divided in 39 municipalities. Finally Tlaxcala has total surface in this RHA region of 490 km<sup>2</sup> with a total population 81,376 habitants, with an average density 166 h/km<sup>2</sup>, divided in 4 municipalities. The last 3 (Mexico State, Hidalgo and Mexico City) forms the [Valley of Mexico Metropolitan Area \(ZMVM\)](#), see table x5. As stated before the RHA XIII has been sub-divided in: The sub-regions; Valle de México has a total surface of 9,739 km<sup>2</sup>, with a total population 21.68 million habitants with average density 2,226 h/km<sup>2</sup>, holding 53.4 and 94.3 percent of total surface and regional population ([CONAGUA, 2014](#)). Meanwhile the sub-region Tula has a total surface of 8,490 km<sup>2</sup>, with a total population 1.319 million habitants with an average density 155 h/ km<sup>2</sup>, holding 46.6 and 5.7 percent of the total surface and regional population. See figure 2.3 & 2.4



mechanisms to ensure hydraulic sustainability and security for the future generations. Entails detailed lines of actions that are rated and adjusted every two years for optimum performance of each action. The main reforms seek modernization on the different pillars of the hydraulic development for the country, and it's fundamentally linked with the program PHN 2014-2018 under a vision of deep transversal transition, Its main goals are: Build up institutional capacity, secure hydraulic security in natural disasters, strengthen service security in all its sectors, increase institution technical, scientific, and technological capacity, secure the water supply for the different sectors to ensure economic growth in the country (agriculture, industry, energy and tourism, among others) and finally consolidates a competitive Mexico in the international water management.

## **2.8 Water Infrastructure**

RHA XIII has a vast infrastructure network, in fact it's unique location needs articulation between 5 states and from differential altitudes, variations from 1100-2300 m from sea level. It's extension still is its biggest deficiency, as along the decade's lack of maintenance and overwhelming use has deteriorated it, due to the enormous water loss and increased use the region sustainability has been compromised. Current strategies to alleviate the water stress in the region includes; a campaign of maintenance of leaks in the system, being equivalent up to 20 percent of the total water use, being the part of a realistic solution to achieve sustainability. Other measures include water importation from different basins, a solution that has been implemented for more than half century stating a clear initiative to acquire the necessary resource from distant sources, a solution that has given clear results. However the environmental damage that it has created is too high to actually call it solution as many sectors have been environmentally stressed with high droughts, more frequent in areas where basins, lakes and rivers are being over-exploited, causing further damage to economic growth as most of the agriculture and cattle in the region depends of the water being piped to fulfil the services of growing urbanization. Conflict between states are currently present as equity among regional livelihoods are not present, stressing more the need of a real sustainable solutions in an inclusive framework.

The RHA XIII system operates with the following over all infrastructure:

- 121 water dams,
- 102 ha of irrigated agricultural land
- 62 potabilization plants
- 120 municipal water treatment plants
- 379 industrial treatment plants
- 533 km of aqueducts and piping in the primary network

## 2.8.1 Dams

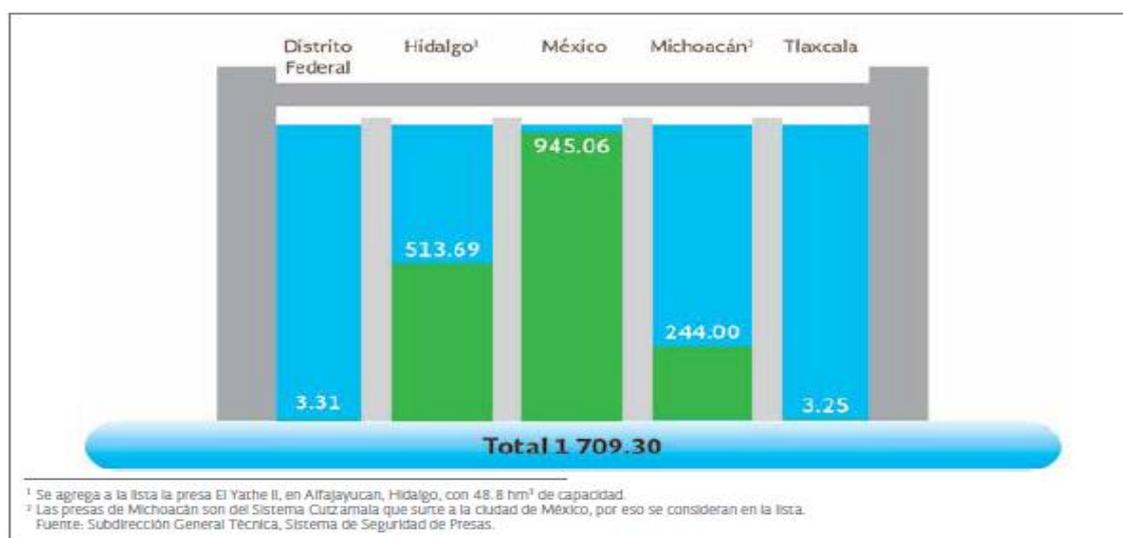
The total water dams are 121 distributed as following; Mexico City (DF) 23, Hidalgo State 41, Mexico State 50, Michoacán<sup>3</sup> State 2, and Tlaxcala 4. The total water retention (capacity) is of 1709 hm<sup>3</sup>. See table 2.3 & graph 2.4.

Entidad federativa	No. total de presas	No. de presas operadas por CONAGUA	No. de presas operadas por otro organismo	Capacidad (hm <sup>3</sup> )
DF	23	2	21	3.31
Hidalgo <sup>1</sup>	41	6	40	513.69
México	50	32	18	945.06
Michoacán <sup>2</sup>	2	2	0	244.00
Tlaxcala	4	0	4	3.25
<b>Total</b>	<b>120</b>	<b>41</b>	<b>83</b>	<b>1 709.30</b>

<sup>1</sup> Se agrega a la lista la presa El Yatze II, en Alfajayucan, Hidalgo, con 48.8 hectómetros cúbicos de capacidad.  
<sup>2</sup> Las presas de Michoacán son del Sistema Cutzamala que surte a la ciudad de México, por eso se consideran en la lista.  
Fuente: Subdirección General Técnica, Sistema de Seguridad de Presas.

**Table 2. 4: RHA XIII, water dams by state and operational institution administration**

Source: CONAGUA, 2013



**Graph 2. 4: RHA XIII, water capacity in dams by state (hm<sup>3</sup>)**

Source: CONAGUA, 2013

## 2.8.2 Irrigation

In the RHA XIII the agriculture sector is compelled of 7 different irrigation districts (DR), Sub-region Tula holds 41 percent of the total irrigation area, Alfajayucan 32 percent, Zarco 15 percent and 12 percent from the rest of the districts. In the previous year 2011-2012 the overall water used for the 7 irrigation districts was determined over 414 hm<sup>3</sup>, equivalent to 44.9 m<sup>3</sup>/s. See table 2.4 & figure 2.5.

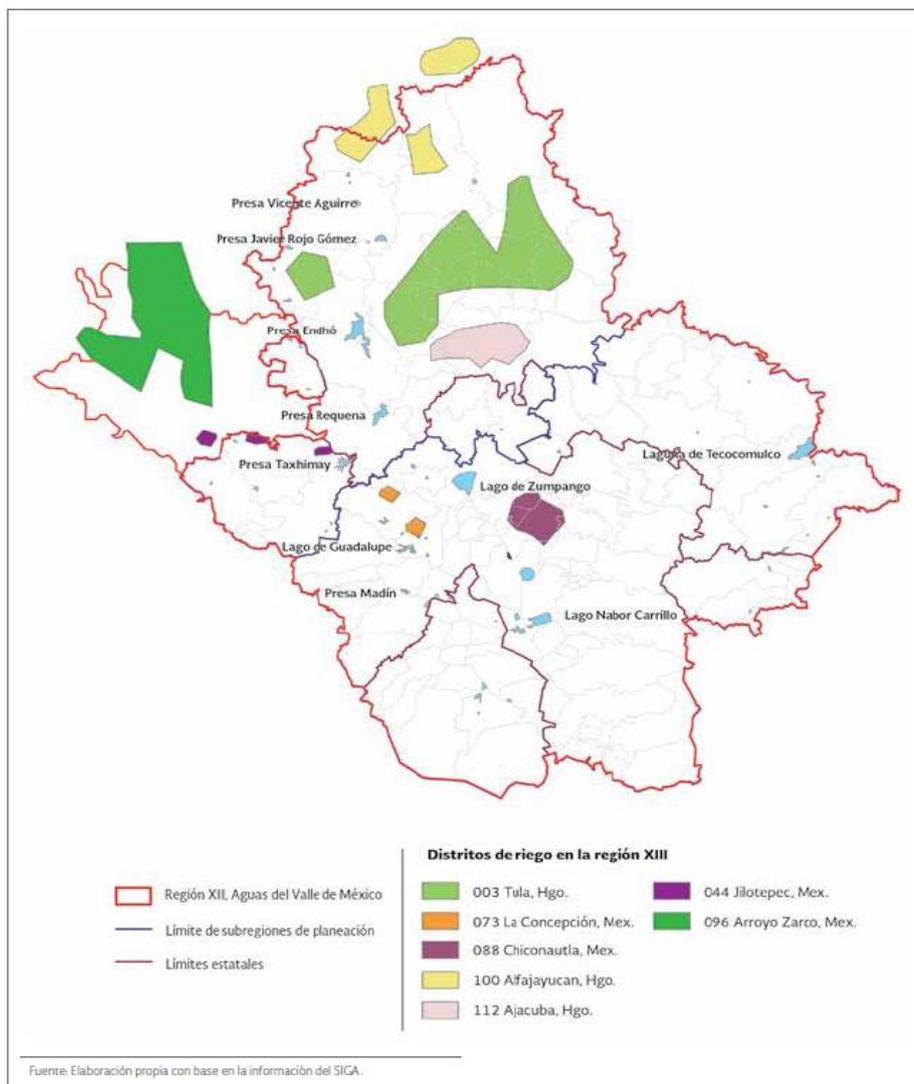
<sup>3</sup> Michoacán dams are represented in this table as they operate also in the Cutzamala System, even doe it belongs to other RHA.

No.	Distrito de riego	Superficie física regada en el año (ha)			Lámina bruta media (cm)	Volumen distribuido (miles m³)	Usuarios
		Un solo cultivo	Dos cultivos	Total			
003	Tula	45 777	5 004	50 781	180	914 119	36 717
044	Jilotepec	2 701	0	2 701	56	15 230	2 245
073	La Concepción	495	0	495	68	3 356	440
088	Chiconautla	2 454	0	2 454	84	20 570	1 828
096	Arroyo Zarco	5 971	0	5 971	42	25 107	5 813
100	Alfajayucan	28 633	0	28 633	169	483 957	25 186
112	Ajacuba	6 142	0	6 142	67	40 946	1 845
	<b>Total</b>	<b>92 172</b>	<b>5 004</b>	<b>97 176</b>	<b>155</b>	<b>1 503 285</b>	<b>74 074</b>

Fuente: Elaboración propia con base en la información de las Estadísticas agrícolas de los distritos de riego. Años agrícolas 2006-2012.

**Table 2. 5: RHA XIII, water capacity in dams by state (hm3).**

Source: CONAGUA, 2013



**Figure 2. 5: RHA XIII, water capacity in dams by state (hm3)**

Source: CONAGUA, 2013

### 2.8.3 Potabilization

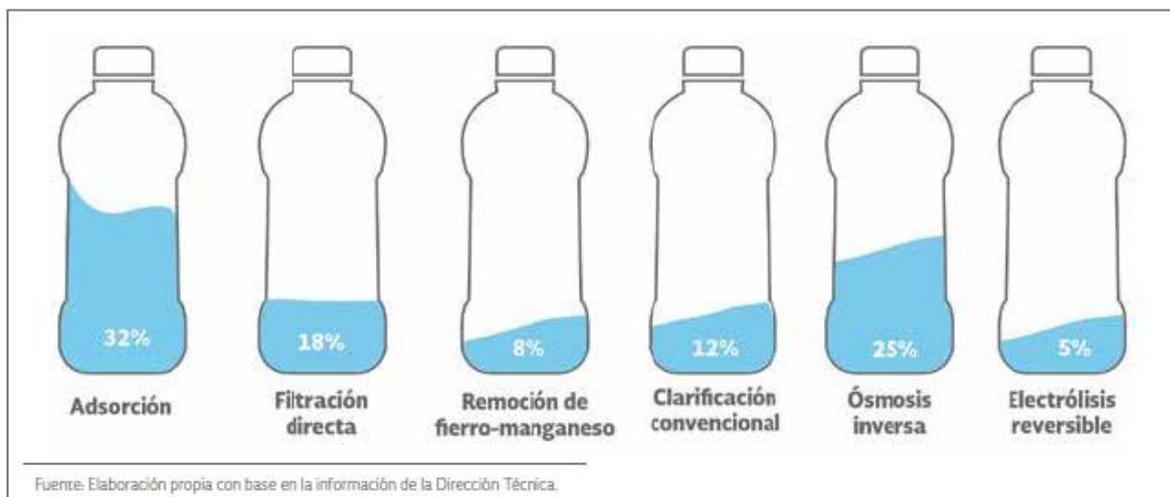
The potabilization plants in the RHA XIII are 62 with a total capacity of 6,275 l/s an overall 4.4 percent of the capacity installed in the country. The biggest in the region is Los Berros, located in Mexico State, it belongs to the Cutzamala System and sanitises an important quantity of the water supplied for the ZM Toluca and Mexico, and it has a capacity of 24,000 l/s, See table 2.5. The process used the most to treat the water are by absorption, osmosis and filtration, see graph 2.5. Water treated and supplied in the network is not in drinkable standards and is mostly not consumed by the population before boiling, costume that has lost popularity in recent years but still is to be considered towards the nexus due the total amounts of energy it uses. It is to be understand that drinking water is mostly distributed by the private sector and the city is entirely dependent of their supplying capabilities.

Entidad federativa	No. de plantas en operación	Capacidad instalada (l/s)	Caudal potabilizado (l/s)
DF	39	4 593	3 422
Hidalgo	19	282	282
México	4	1 400	1 157
<b>Subtotal</b>	<b>62</b>	<b>6 275</b>	<b>4 861</b>
Los Berros		24 000	14 410
<b>Total</b>		<b>30 275</b>	<b>19 271</b>

Fuente: Inventario nacional de plantas municipales de potabilización y de tratamiento de aguas residuales en operación 2012.

**Table 2. 6:** RHA XIII, water potabilization plants by region and capacity.

Source: CONAGUA, 2013



**Graph 2. 5:** RHA XIII, water potabilization by process.

Source: CONAGUA, 2013

## 2.8.4 Re-Use and Treatment

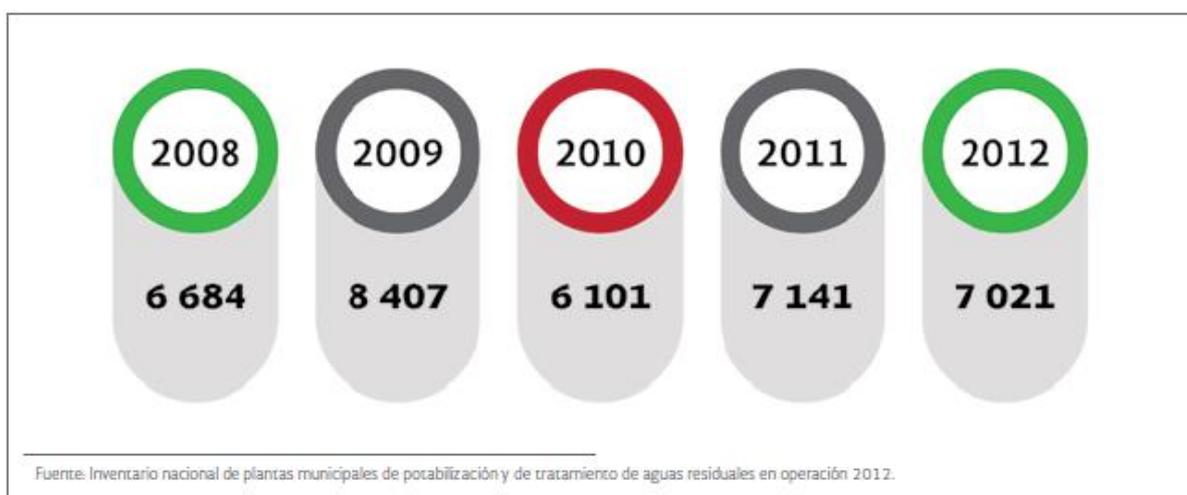
With around 7 percent of the water treated in 2013 and mostly used for industrial purposes, the untreated water is partially used in crop irrigation (that has caused health problems) or discharged to rivers. A total of 120 treatment plants consolidate the regional treatment sector, treating around 7,021 l/s in the municipal sewage system collection (see table & graph 2.6). Water being the central and key objective to achieve the current environmental, economic and social development goals in Mexico, water re-use has been considered vital to reduce the exploitation of the aquifers, as indicated in the survey that I have conducted to a team of experts from the Technical sector of water management and operational institutions (CONAGUA and SACMEX), as well as academic professional in the social and urban studies from UNAM. The survey revealed that it is among top priorities (2/8) in the water savings inventory (see table 3.3), only passed by leak reduction program. However update in the water treatment plants is required (Noyola, 2016), in technological equipment to perform optimal, a necessity to reduce the energy consumption of the treatment plants to abate costs and GHG emissions to the atmosphere.

Entidad federativa	No. total de plantas	Capacidad instalada (l/s)	Caudal tratado (l/s)
DF	28	6 771	3 063
Hidalgo	6	147	147
México	78	5 251	3 740
Tlaxcala	8	80	71
<b>Total</b>	<b>120</b>	<b>12 249</b>	<b>7 021</b>

Fuente: Inventario nacional de plantas municipales de potabilización y de tratamiento de aguas residuales en operación 2012.

**Table 2. 7: RHA XIII, municipal water treatment plants by state.**

Source: CONAGUA, 2013



**Graph 2. 6: RHA XIII, water treated per year (l/s).**

Source: CONAGUA, 2013

## 2.8.5 Industrial Water Treatment Plants

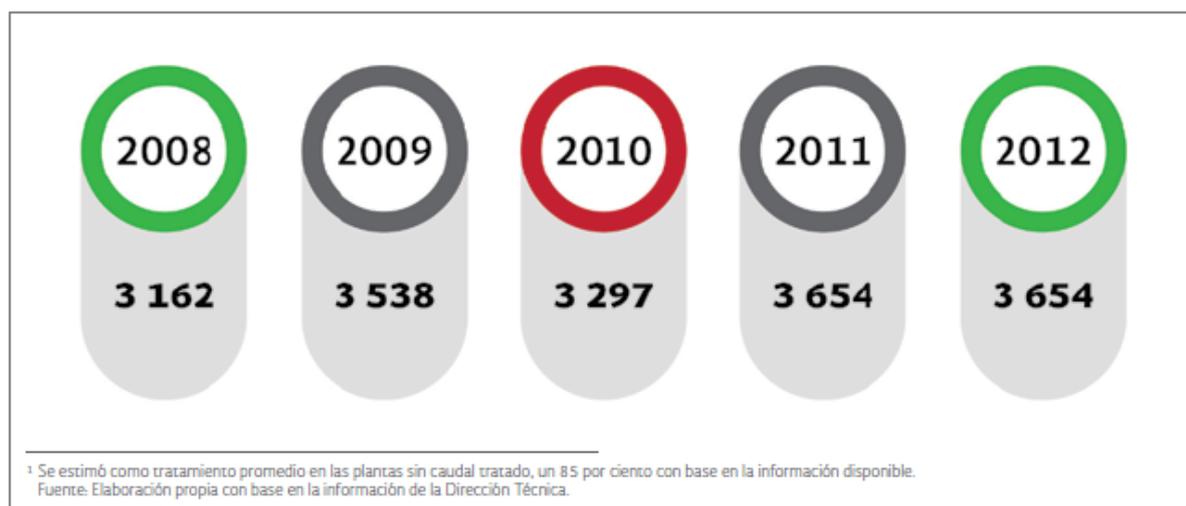
A total of 358 treatment plants were registered operationally active in 2012, with 84 percent of efficiency, and total water treated of 3,652 l/s in the region. In Mexico City 162, Hidalgo 35, Mexico State 158 and Tlaxcala 4, (See table 2.7 & graph 2.7).

Entidad federativa	No. total de plantas	No. de plantas en operación	Capacidad instalada (l/s)	Caudal tratado (l/s)
DF	163	162	587	499
Hidalgo	44	35	1 074	992
México	171	158	2 631	2 141
Tlaxcala	6	4	24	20
<b>Total</b>	<b>384</b>	<b>359</b>	<b>4 316</b>	<b>3 652</b>

Fuente: Dirección Técnica.

**Table 2. 8: RHA XIII, industrial water treatment plants by state (l/s).**

Source: CONAGUA, 2013

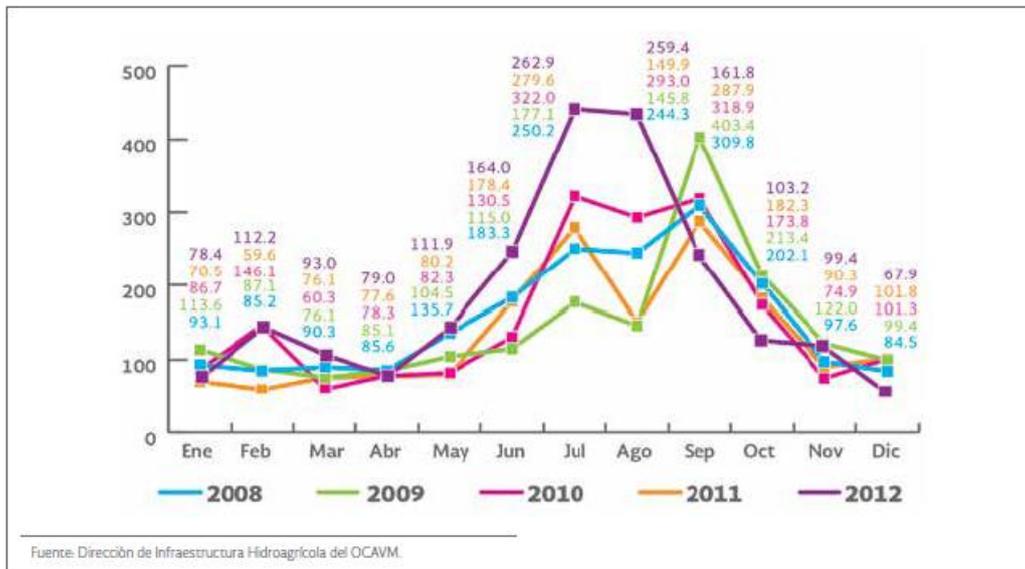


**Graph 2. 7: RHA XIII, industrial water treated per year (l/s).**

Source: CONAGUA, 2013

## 2.8.6 Collection Network (Sewage)

In 2012 the total amount of water flowing through the sewage system was around 51 m<sup>3</sup>/s or 1,578 hm<sup>3</sup>, depending on monthly variations according to rain season, being the strongest from Jun-Oct (see graph & table 2.8). The region has unique and complex sewage systems that cross more than 4 states towards the Gulf of Mexico to prevent cities flooding. Mostly due to lack in natural drainage of the region, and highly urbanized areas. The endorheic basins lost their capacity to store water as the former in-land lake system has been compromised by deforestation and urban sprawl which covers the permeable area, preventing the aquifers from fully taking advantage of the rainwater to recharge its levels. The most important and safe keeper of the region is the deep sewage system, some sections are buried over 200 m from the city level safe from land subsidence, making it one of the most complex sewage systems in the world, (see figure 2.6 & table 2.8). The RHA XIII has a total sewage coverage of 97.82 percent, it is higher than the national average. The rural areas are the most affected in sewage infrastructure.



Entidad federativa	2008		2009		2010		2011		2012	
	hm³	m³/s								
ZMVM	1 797	57	1 681	56	1 804	57	1 578	50	1 578	50
Resto de la región	65	2	61	2	65	2	56	2	561	2
<b>Total</b>	<b>1 862</b>	<b>59</b>	<b>1 743</b>	<b>58</b>	<b>1 868</b>	<b>59</b>	<b>1 634</b>	<b>52</b>	<b>1 594</b>	<b>51</b>

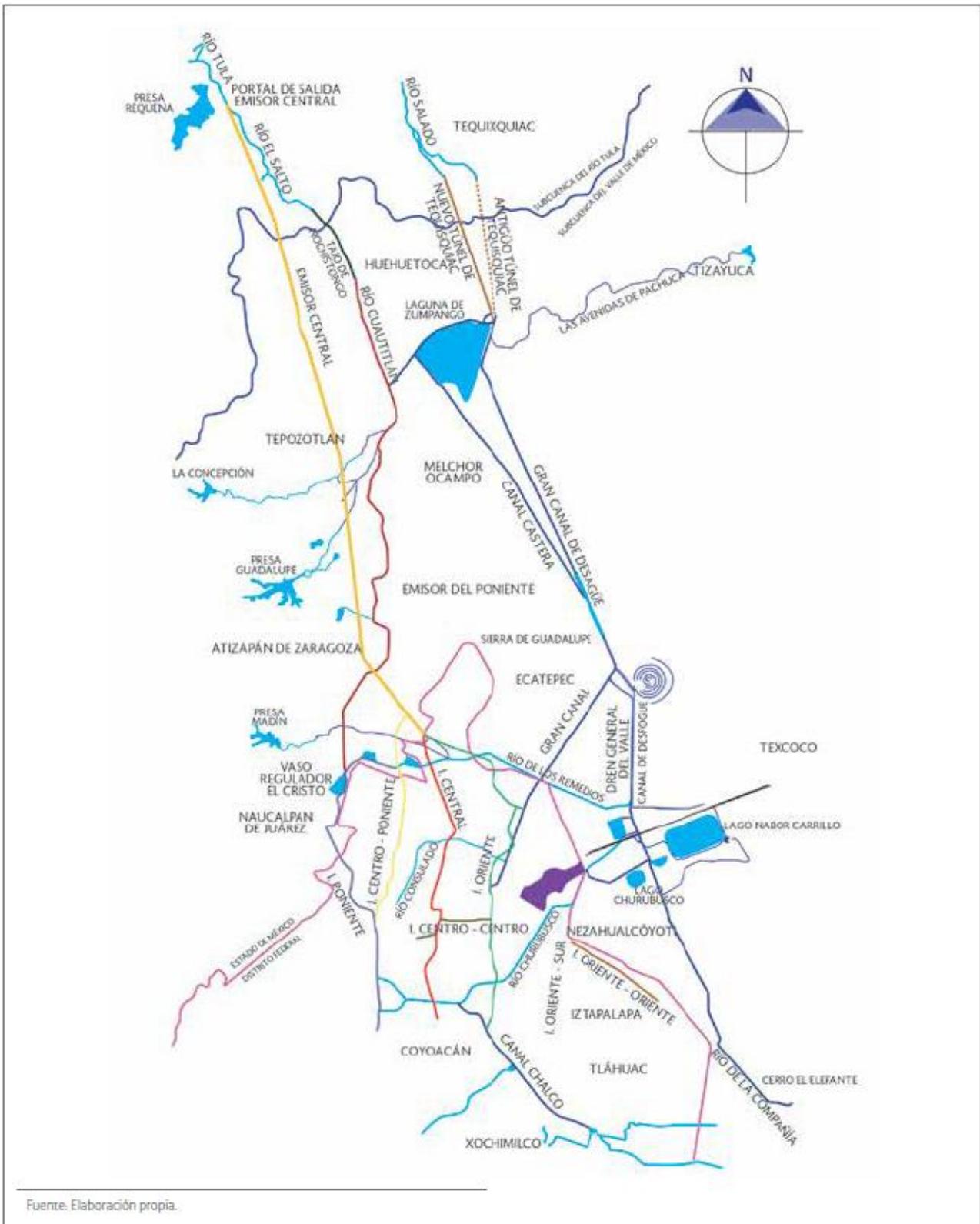
<sup>1</sup> Las cifras fueron redondeadas para fines ilustrativos.  
Fuente: Dirección de Infraestructura Hidroagrícola del OCAVM.

**Graph 2. 8: RHA XIII, monthly water collection from sewage system.**  
Source: CONAGUA, 2013

Nombre del túnel	Diámetro (m) <sup>1</sup>	Capacidad de conducción (m³/s)	Profundidad promedio (m)	Longitud proyecto (km) <sup>1</sup>	Longitud operación (km) <sup>1</sup>	Periodo de construcción	No. de lumbreras
Emisor Central	6	220	40-220	50	50	1967-1975	23
Interceptores Central	5	90	22-41	22	16	1967-1975	15
Oriente	5	85	20-50	28	28	1967-1975 1987-1990	22
Oriente-Sur	5	80	20-25	14	14	1990-1997	9
Centro-Poniente	4	40	22-51	16	16	1975-1982	9
Poniente	4	25	12-35	16	16	1960	27
Centro-Centro	5	90	26	4	4	1986-1988	4
Oriente-Oriente	5	90	20	7	3	1997	6
Iztapalapa	3.1	20	10-16	5	5	1994	6
Canal Nacional-Canal de Chalco	3.1-3.2	20	10-18	16	12	1987	10
Obrero Mundial	3.2	20	16	1	1	1987	3
Gran Canal	3.1	90	—	1	1	—	—
Indios Verdes	3.1	—	15-28	3	—	—	—
Ermita	3.1	—	12-16	7	—	—	—
Cuautepec	3.1	—	—	2	—	—	—

<sup>1</sup> Las cifras fueron redondeadas para fines ilustrativos.  
Fuente: Documento Compendio de los Servicios Hidráulicos de la Ciudad de México, junio 2007 SACM.

**Table 2. 9: RHA XIII, Deep Sewage System by component.**  
Source: CONAGUA, 2013



**Figure 2. 6: RHA XIII, Deep Sewage System by component. Illustrated.**

Source: CONAGUA, 2013

## 2.9 Surface Water

### 2.9.1 Cutzamala System

Is an outstanding and extremely expensive project to transfer water resources from the neighbouring basins to meet the population needs of [Mexican Valley \(VM\)](#). Water importation has become a popular and necessary solution due to the growing population demand, and the severe exploitation of the local aquifers. Consequently this overuse will reduce with neighbour contributions, and it is operated by OCAVM. The construction of this system goes back to 1982 when the first stage was operational with 4 m<sup>3</sup>/s from Villa Victoria Dam, in 1985 second stage went operational with additional 6 m<sup>3</sup>/s from Valle de Bravo Dam, and third stage in was ready in 1993 with additional 9 m<sup>3</sup>/s from the sub-systems Chilesdo (5 m<sup>3</sup>/s) and Colorines. In the year 2012 the average supply flow was 14.48 m<sup>3</sup>/s in benefit of 3.8 million habitants from Toluca and Mexico State as well as Mexico City.

The system is composed from: 7 storage reservoirs; Tuxpan with a storage capacity of 5 hm<sup>3</sup> at 1,751 [meters above sea level \(masl\)](#), El Bosque with the storage capacity of 202 hm<sup>3</sup> at 1,741 masl, both located in Michoacán. Colorines with a storage capacity of 1.5 hm<sup>3</sup> at 1,629 masl, Ixtapan del Oro with storage capacity of 0.5 hm<sup>3</sup> at 1,741 masl, Valle de Bravo has a capacity of 394.4 hm<sup>3</sup> at 1,768 masl, Villa Victoria's capacity is of 186 hm<sup>3</sup> at 2,545 masl and Chilesdo with 1.5 hm<sup>3</sup> capacity at 2,396 masl, all the previous are located in the State of Mexico. In total the convenience system consists of 6 pumping stations, of which 4 of them operate with capacity of 24 m<sup>3</sup> each, 1 with a 20 m<sup>3</sup> capacity and the last with a 5 m<sup>3</sup> capacity. "Going thru surge tanks and regulation shafts. The former provides the volume and dynamic head required for engine start up; the later counteracts the water-hammer effect on the pressure steel pipeline connecting the pumping station to the regulator shaft, thereby eliminating said effect in the remaining stretch of the aqueduct. Both are cylindrical structures of reinforced concrete, with height varying from 37 to 58 m, inner diameters of 10 m and walls up to 1.6 m thickness, equivalent to a 20 story building", ([Haddad, 1991; pp:2-3](#)). The system operates at 1600 masl up to 2,700 masl to the oscillating tower, overcoming 1100 km difference in altitude, the final stage for delivering the water is by gravity. The treatment plant Los Berros treats the water in 6 different modules with a singular capacity of 4 m<sup>3</sup>/s total of 24 m<sup>3</sup>/s. The continuous operation of the plant (all year around) has develop great decadence on the operation capacity and has increased the water loses, thereby the related costs of the water conveyed true the steep highs. Currently studies and action plans are being determined towards maintenance of the treatment plant that will permit a capacity of 14.7 m<sup>3</sup>/s in service near to 5 million habitants. The Analco-San Jose tunnel crosses the Sierra de las Cruces, forming the watershed between the Valleys of Toluca and Mexico and conveys the already purified water to the North and South Branches named the Macro-Circuit; The North Branch (91 km long divided in 4 different construction stages) developed to supply Mexico and Toluca State and South Branch (33 km long with tunnel diameters of 3.1-4 m) to supply Mexico City. The components of the infrastructure include 127 km of long aqueduct, 21 km of tunnels and 7.5 km of open canals. The completion of the works required 90 different companies (1991), specialized in different construction activities such as roads, channels, aqueducts, tunnels, etc. making the Cutzamala one of the most complex water importation systems in the world, ([see figure 2.7, 2.8 and table 2.9](#)). To convey the water from 127 km, energy is necessary to activate all devices, and it comes from Infernillo-Nopala System via a sub-station Donato Guerra.

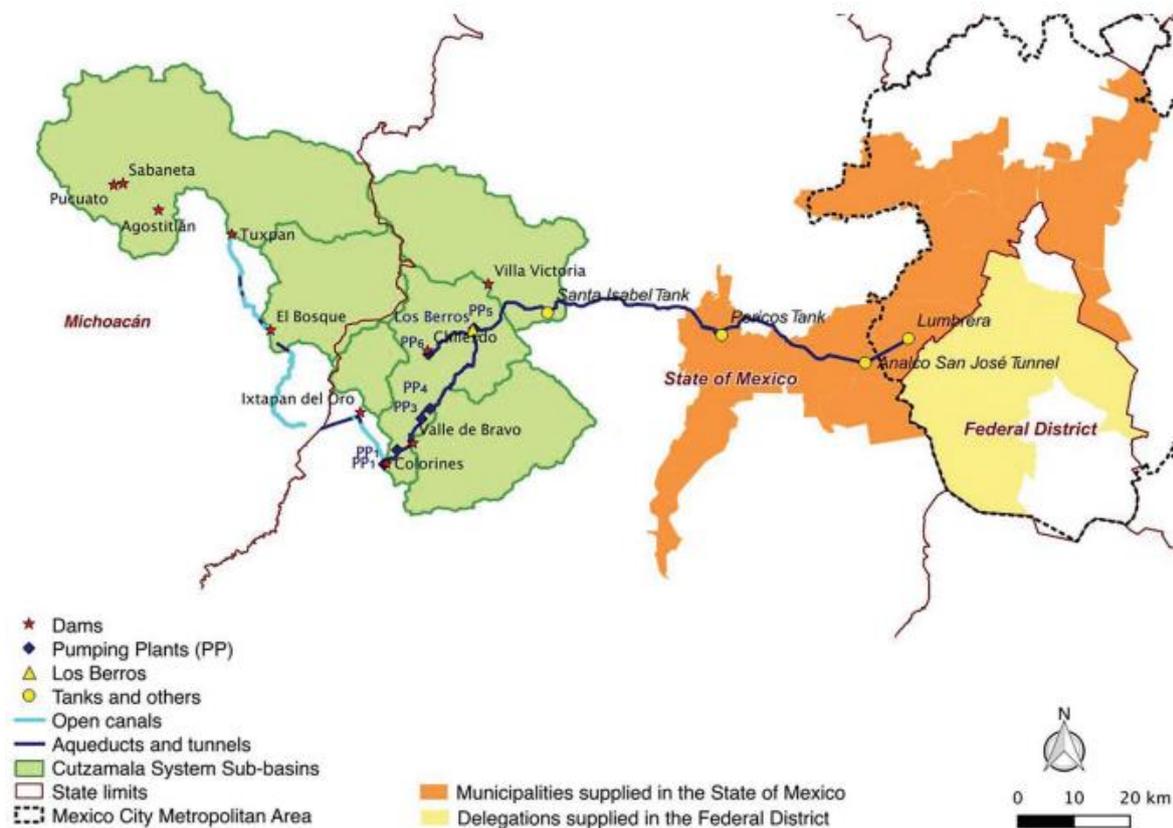
The electrical operation cost of the entire system (pumping, treatment, etc) has been determined in 80 percent of total system costs, or 1,29 TW/h or 0.56 % of the total energy produced in the country, the same amount that the City of Puebla consumes ([World Bank, 2013](#)). Another source back from 2003 has estimated that the energy requirements to operate the Cutzamala System where in that period 1,787 million kWh, with a total cost of USD 62.54 million. The previous electricity amount plus the energy originally planned in the hydroelectric plant, could

have benefit around 2.6 million people. Additional estimations consider an operational cost of completely running Cutzamala System (about USD 128.5 million yr<sup>-1</sup>) to supply 19 m<sup>3</sup> would mean an average cost of USD 0.214 per m<sup>3</sup> and energy consumption of 6.05 Kwhm<sup>-3</sup>.

Año	Distrito Federal		Estado de México		Total	
	Volumen hm <sup>3</sup> /año	Gasto medio m <sup>3</sup> /s	Volumen hm <sup>3</sup> /año	Gasto medio m <sup>3</sup> /s	Volumen hm <sup>3</sup> /año	Gasto medio m <sup>3</sup> /s
2006	303.53	9.61	177.26	5.61	480.79	15.21
2007	303.90	9.72	174.56	5.58	478.46	15.30
2008	306.25	9.57	179.47	5.61	485.72	15.19
2009	244.60	7.74	155.38	4.92	399.97	12.66
2010	266.85	8.45	165.84	5.25	432.69	13.70
2011	296.46	9.09	182.17	5.80	478.63	14.89
2012	272.54	8.62	190.96	5.79	463.50	14.41

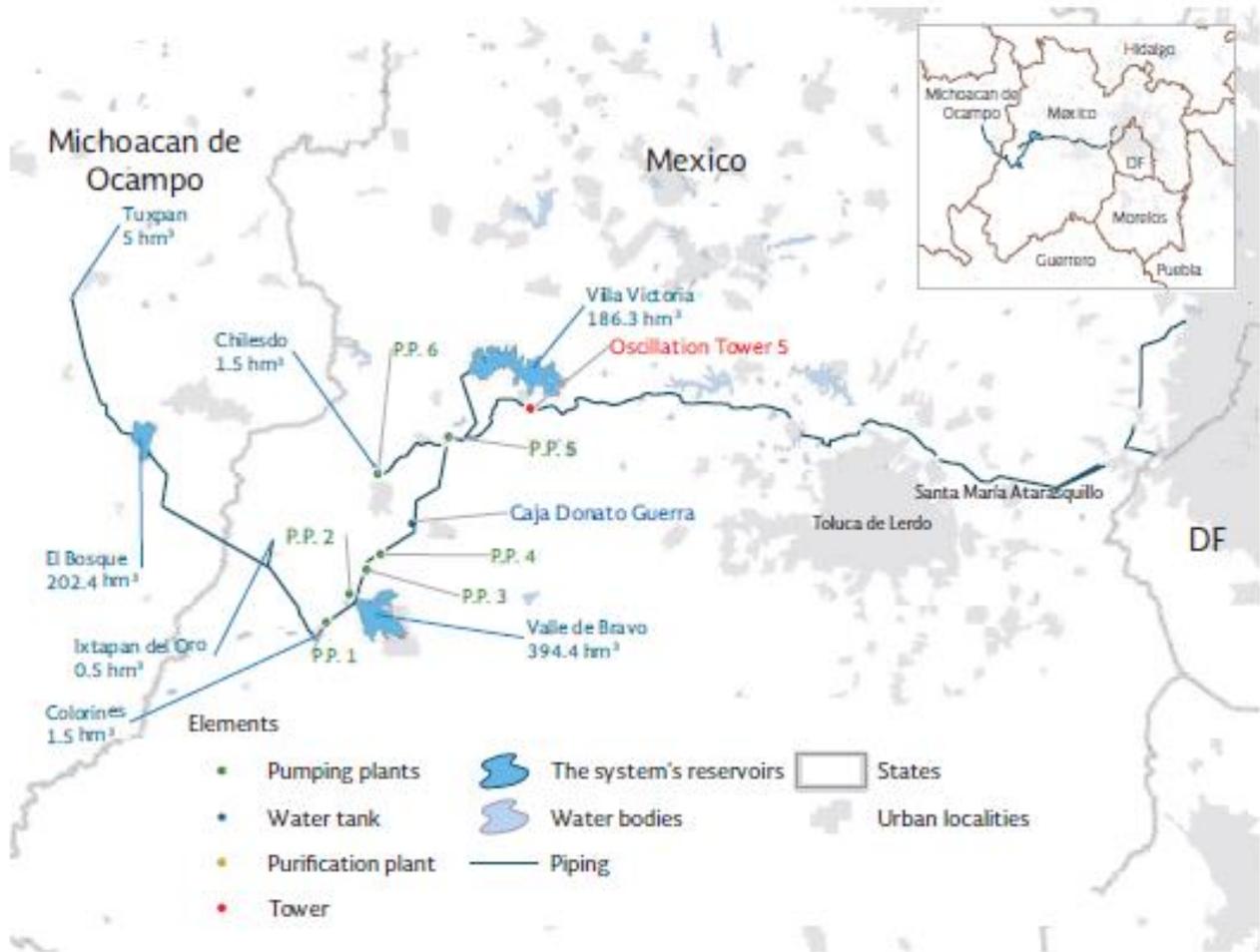
Fuente: Dirección de Agua Potable, Drenaje y Saneamiento.

**Table 2. 10: RHA XIII, Cutzamala System flows by year.**  
Source: CONAGUA, 2013



**Figure 2. 7: RHA XIII, Cutzamala System infrastructure, location**  
Source: World Bank, 2013.

## Plant



## Cross-section

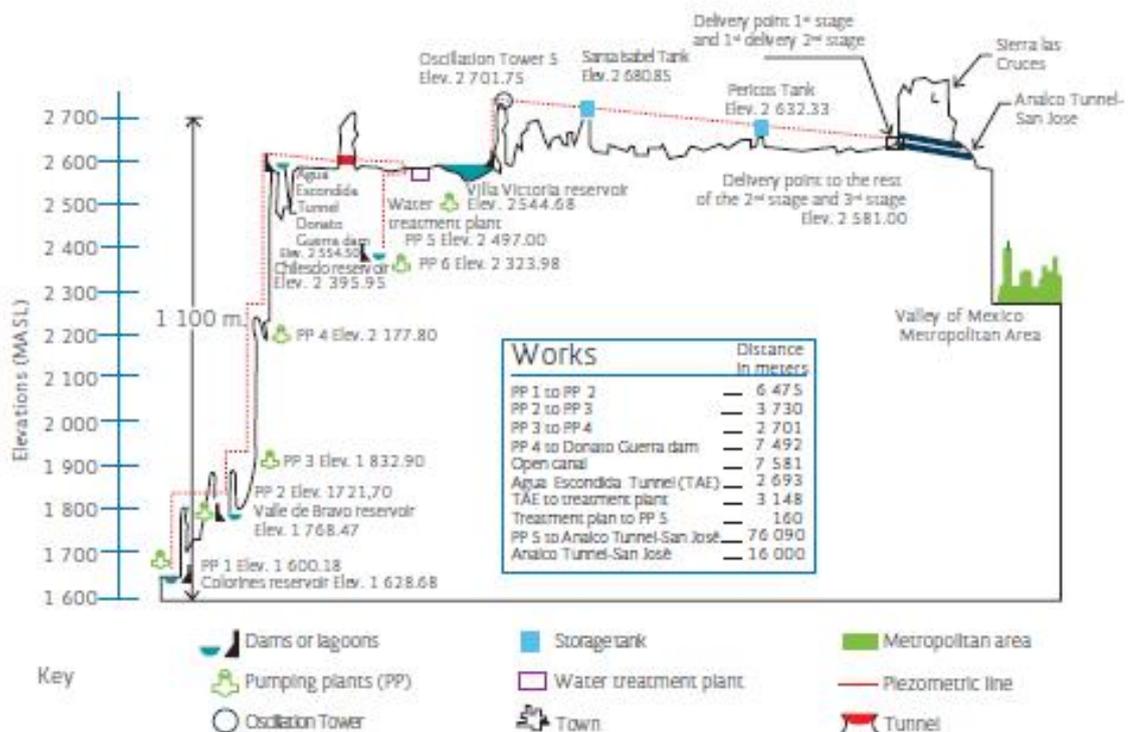
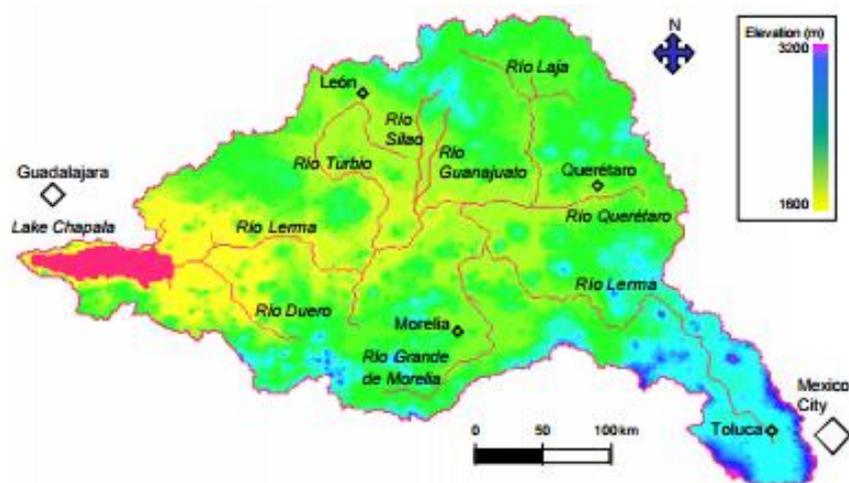


Figure 2. 8: RHA XIII, Cutzamala System infrastructure, location and highs.

Source: CONAGUA, 2015

## 2.9.2 Lerma System



**Figure 2. 9: Lerma origin-destination by highs and location.**

Source: Mestre, 2001

Lerma River is originated in Mexico's central high plateau at 3000 masl and ends in Chapala Lake 1510 masl, the largest lake in Mexico and water provider of the third biggest city Guadalajara its Metropolitan Area. The lake has suffered severe decrees in water levels due to the exploitation not only by the neighbour regions but also due the exploitation from the water source by ZMVM (Mestre, 2001), see figure 2.9. Upper Lerma started operation 1951, (4 m<sup>3</sup>/s to 14 m<sup>3</sup>/s in 1975) the water is withdrawal from the Lerma Aquifer and conveyed to Mexico City throe the tunnel Atarasquillo-Dos Ríos (14 km, total 62 km to CDMX in 2.5 m diameter pipes), since the period 2003-08 the flow was reduced to 6 m<sup>3</sup>/s, due to environmental impact and social conflicts, (Tortajada, 2003; World Bank, 2013), currently an average of 4.1 m<sup>3</sup>/s are supplied from the system (2008/12), from which 1 m<sup>3</sup>/s is supplied to Mexico State and the rest to CDMX. The overexploitation of the river has edge the agriculture of the region to reduce productivity and lead the way to rained agriculture, changing the economy of the region dramatically, (CONAGUA, 2013). However constructions of little impact where done to the villages and communities affected, not improving sufficiently the situation. The infrastructure supporting the system includes 4 storage tanks each of 100 m diameter and 10 m depth, build in CDMX.

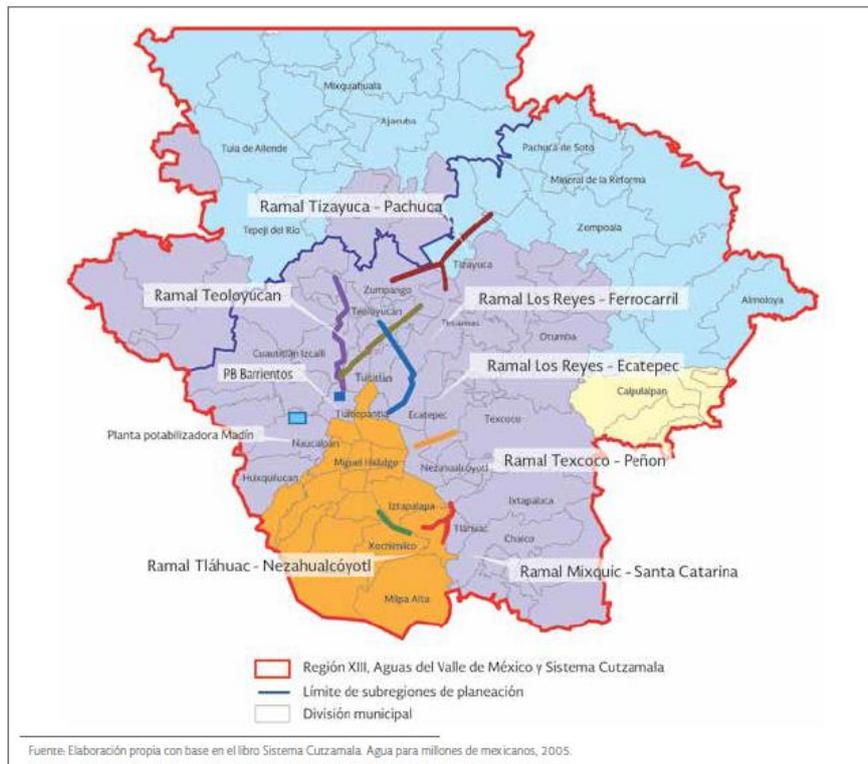
## 2.9.3 Future Importation Projects

There are currently other sources being considered for importing water, like Tula System in the state of Hidalgo with 7 m<sup>3</sup>/s, or Tecolutla-Necaxa System with primary contemplated costs of 23 billion, the Temas River (4.5m<sup>3</sup>/s) that has been in conflict for 10 years due to population apposition, likewise the Temascaltepec System (6 m<sup>3</sup>/s) with primary costs of 18 billion, considered the fourth stage of the Cutzamala System. It is to convey water to the Valle de Bravo Dam, the project includes the construction of 120 m high dam, a 15 m<sup>3</sup> pumping station, 18 km of canals and 12 km of tunnels 160-700 deep depending on the topographic conditions, (CONAGUA, 1997). The government was not able to start the project due to the population opposition for they insist that many springs will dry up, severely affect the agricultural activities of the region's products like; tomato, banana, sugarcane, maize, melon and peas with important markets in CDMX. All the previous mentioned and the ones currently operating, have generally ignored the potential social conflicts that results from interbasin transfers. Surprisingly the environmental assessment have not been performed or have not consider social impacts, (Tortajada, 2003).

## 2.10 Ground Water

### 2.10.1 Immediate Action Plan (PAI)

It has been operational since the year 1974, initially operating the south water well system. Currently integrated by 7 well batteries, formed by 219 wells, that withdrawals water in 2 different states; Hidalgo and Mexico and also from Mexico City. It is pumped by 6 plants and has a potabilization plant in Madín, both located in Naucalpan, Mexico State. Currently PAI system delivers water to 28 delegations and municipalities in the region. It is considered that 94 percent of the total water supplied by this systems has underground (aquifer) sources and the rest 6 percent is supplied from the Madín treatment plant. It's supplied by the PAI System through 7 branch systems called ramales, from which Santa Catarina and Nezahualcóyotl deliver 1 m<sup>3</sup>/s to Mexico City, meanwhile the rest remains in Valle de Mexico. Together Valle de Mexico Aquifers, PAI and SACAM Aquifers deliver the water to the capital city population from all underground sources. [See table 4.1](#)



**Figure 2. 10: RHA XIII, PAI System and the seven branches it operates.**

Source: CONAGUA, 2013

No.	Delegación / Municipio	No.	Municipio	No.	Municipio
	<b>Distrito Federal</b>		<b>Estado de México</b>		<b>Estado de México</b>
1	Azcapotzalco	1	Atizapán de Zaragoza	11	Nextlalpan
2	Gustavo A. Madero	2	Chicoloapan	12	Nezahualcóyotl
3	Iztapalapa	3	Coyotepec	13	Tecámac
4	Venustiano Carranza	4	Cuautitlán	14	Teoloyucan
5	Tláhuac	5	Cuautitlán Izcalli	15	Tepetzotlán
	<b>Hidalgo</b>	6	Ecatepec	16	Tequixquiac
1	Tizayuca	7	Hueyoptla	17	Tlalnepantla
2	Tolcayuca	8	Jaltenco	18	Tultepec
		9	La Paz	19	Tultitlán
		10	Naucalpan	20	Valle de Chalco Sol
				21	Zumpango

Fuente: Dirección de Agua Potable, Drenaje y Saneamiento.

**Table 2. 11: PAI, source and location.**  
Source: CONAGUA, 2013

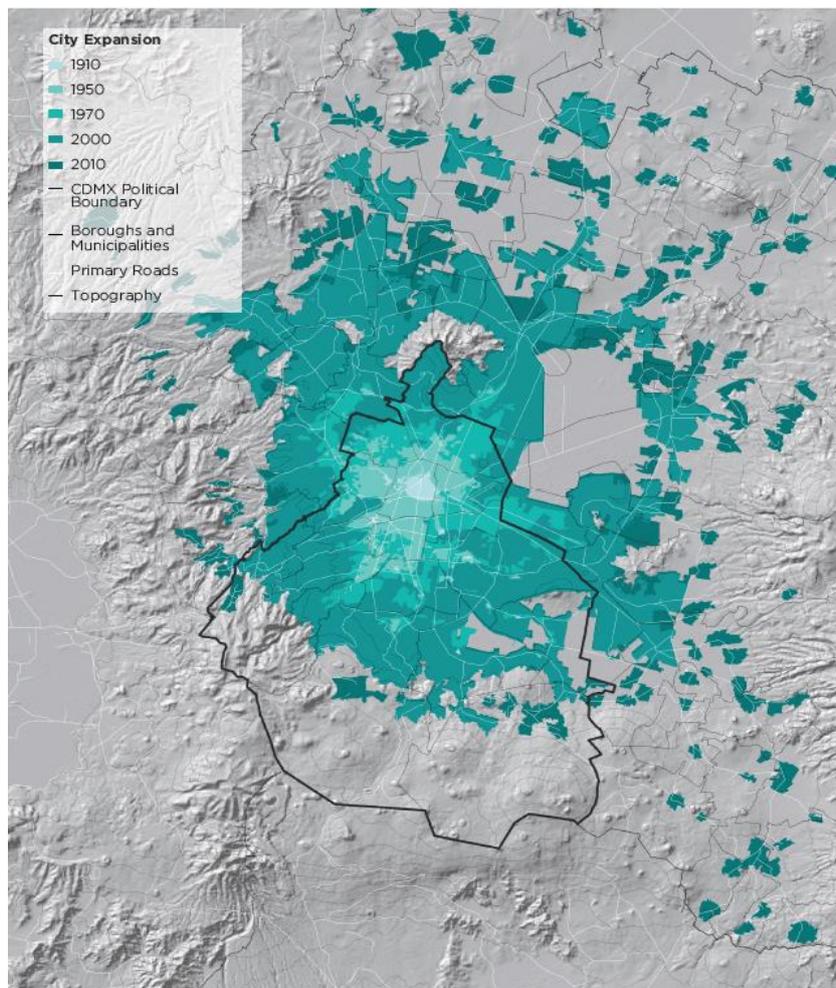
## 2.11 Conceptualizing Mexico City (CDMX) History

The city was founded by the Aztec empire in 13th century (see figure 2.13), commonly known as Tenochtitlan, sitting in an island on the inland lake system reachable by canoe and wide causeways to the mainland, being the largest city of the Pre-Columbian Americas. After Spanish colonization became the New Spain by hand of Hernando Cortés in the early 15th century. The territory was formally occupied by an interconnected lake system of more than 1,100 km<sup>2</sup>, forming the basin from Sierra Chichinautzin to the northern areas (see figure 2.12). After the new capital emerged population considerably grew, depth of the lake fluctuated and the city was subject of periodic flooding's, fight that Mexicans still have today. As consequence of little land availability, flooding and health issues, a massive operation started to drain the wetlands taken place since previous decades, changing completely the scenery and water availability in the region (that today is highly regretted as it developed consequences). After the inland lake system was gradually drained, unique engineering sewage infrastructure has been placed ever since, it hinders water bodies to the Panuco River preventing the megacity flooding. After Independence from the Spanish rule, the city continued with great artificial drainage to convey water from the city to the near watersheds, the engineering efforts continue currently. The remaining of the lake system are still to be found at Xochimilco, Tláhuac and Ateco municipalities. The valley is surrounded by mountains on all four sides, creating a basin with an opening on the north side, trapping the pollution created by industry and over 5 million vehicles, meanwhile in rain seasons the water gathers towards the city in a natural flow according to the geological composition of the region, greatly enhancing risk to livelihoods due to extreme flooding. Other climatic events like heatwaves and earthquakes are recorded in history, which effects are greatly enhanced due to water scarcity.

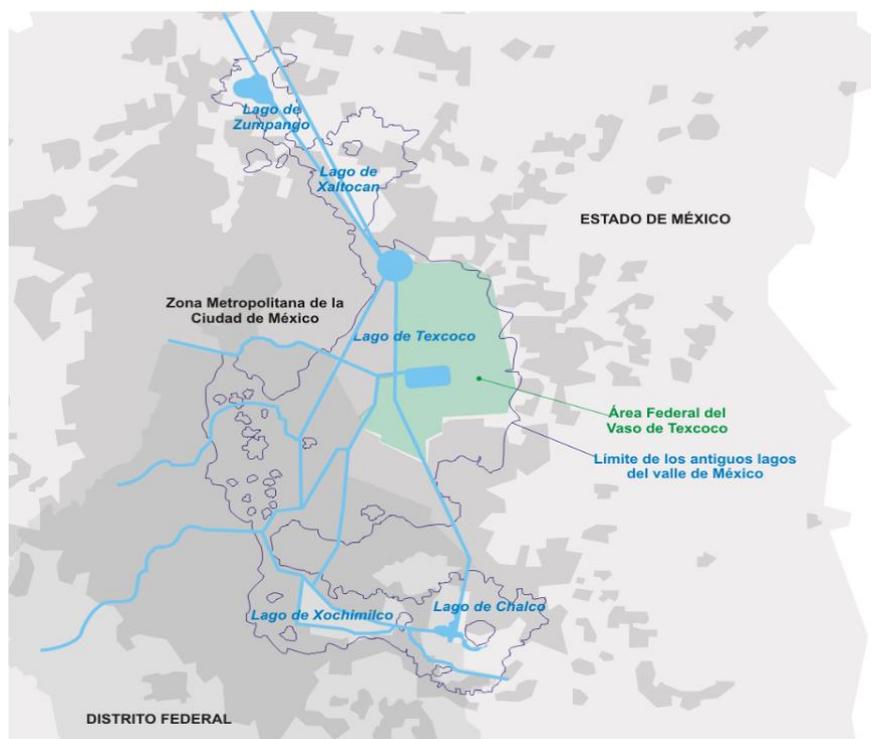
*“The compositional characteristics of the geology of the Mexico City Basin are important factors in understanding the historical and the current relationship the City has with water. They explain the way this region operates, with a special condition which is quite different from other lake systems. The Mexico City Basin is endorheic: It is a closed drainage basin that retains water and allows no outflow to other external bodies of water, such as rivers. It stores the water from rain and streams that run down from the surrounding mountains, and then very slowly infiltrate into the ground, due to a thick layer of impervious sediment called the aquitard”, (De Urbanisten, pp: 37, 2016). See figure 2.11*





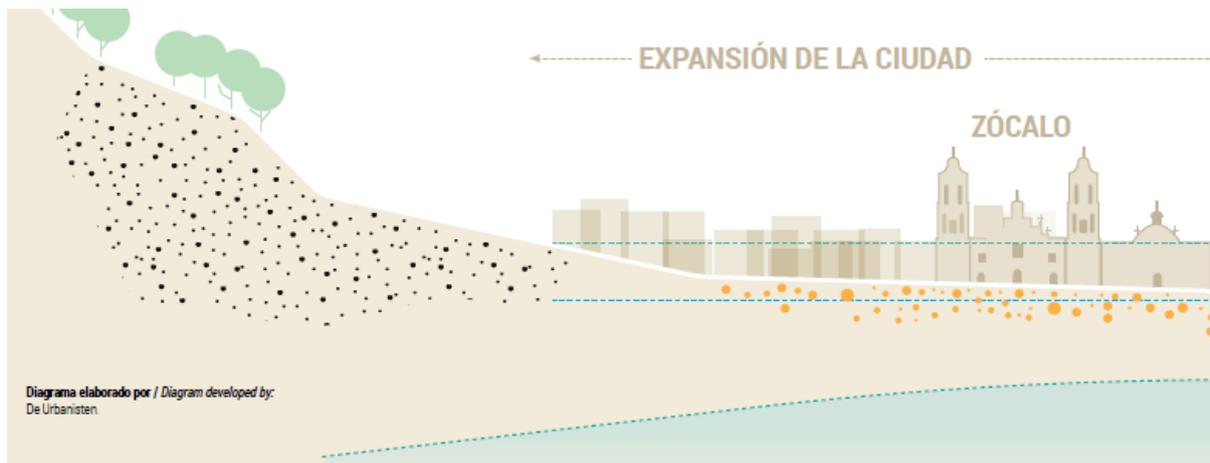


**Figure 2. 14: City expansion from the 1950 to 2010.**  
 Source: 100 Resilient Cities, 2016.



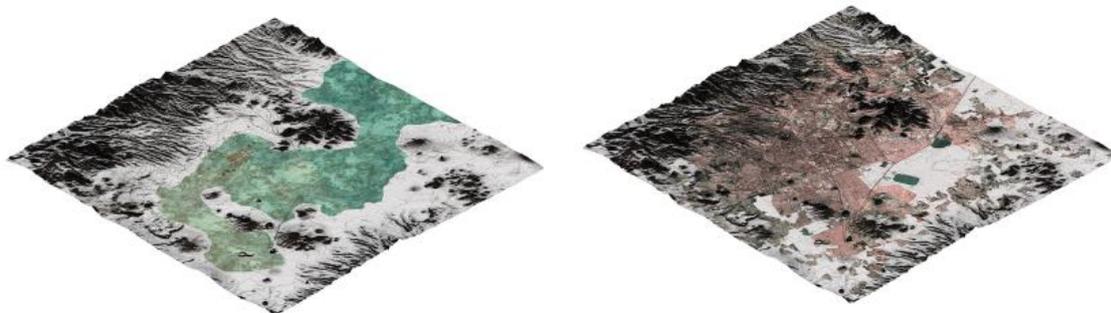
**Figure 2. 15: Urban sprawl illustration and basins urbanization.**  
 Source: <https://metrhispanico.com/tag/americas-latina/page/2/>

“From the 16th to the 19th centuries, giant drains, pits, and tunnels were built as flood protection, draining the lakes and carrying excess rainfall water out of the Valley of Mexico Basin. This type of flood protection ended with the construction of the “Great Sewage Canal.” During the 1960s, 80 kilometres of rivers were covered and replaced with roads, a development that reflected the thinking of the times but resulted in a host of water-related issues. Population growth increased demand for this vital resource, which is why new, huge hydraulic works were built at a regional level. Lerma System, which opened in 1952 and expanded in 1976 with the Cutzamala System, was built to import water from neighbouring basins, while new projects, such as the deep sewage system that was completed by 1975, were built to drain grey water out of the Valley of Mexico Basin.” (100 Resilient Cities, pp: 24, 2016), see figure 2.15.



**Figure 2. 16: Mexico City geological conformation and natural water cycle.**

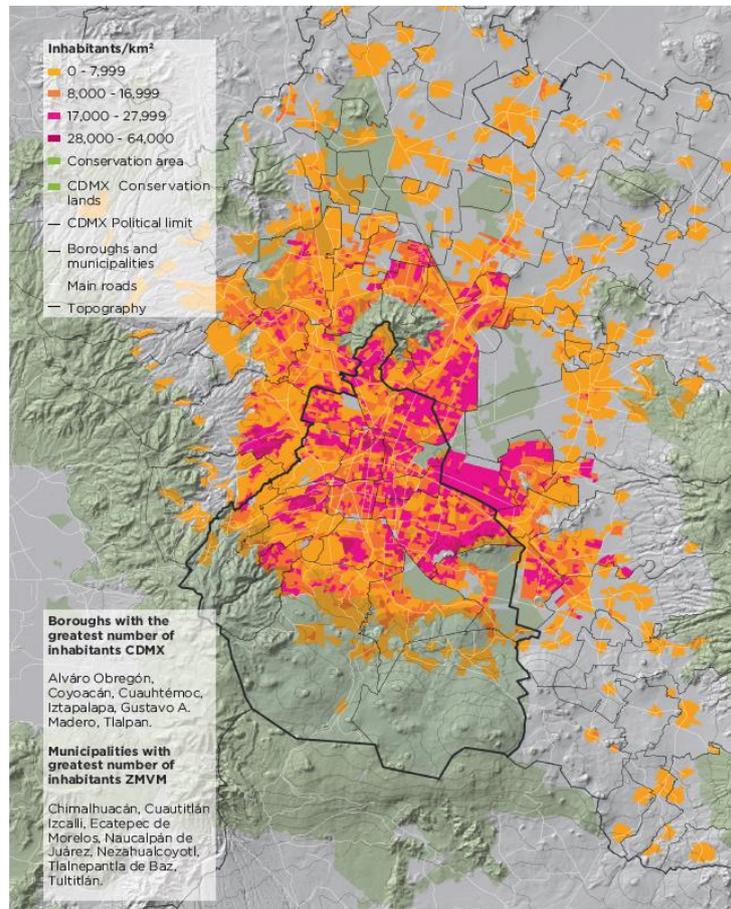
Source: De Urbanisten, 2016



**Figure 2. 17: From lakeside to megacity, years 1500 to 2016.**

Source: 100 Resilient Cities, 2016

“Over time Mexico City has experienced a great social and environmental transformation, becoming the centre of economic, political, and social-cultural activities. A strong trend of population growth and expansion of its territory have given rise to pressing issues, such as intense demand for natural resources, inequality and social marginalization, informal settlements, waste generation, degradation of natural resources, and pollution. These issues, however, have also generated a strong link between the Metropolitan Area of the Valley of Mexico and the Megalopolis, due to intense collaboration and integration at urban, socioeconomic, and environmental levels in the region. To build resiliency, the past must be considered so that risks related with the city’s history are better understood. For example, while the fact that most of the City is located on top of what used to be a lake must be considered, future scenarios must take into account the fact that social and environmental transformation continues to take place. Knowledge of both the past and the present is the foundation for a better understanding of the potential risks and unforeseen events that the City and its inhabitants may face.” (100 Resilient Cities, pp: 23, 2016)



**Figure 2. 18: Population density map.**

Source: 100 Resilient Cities, 2016.

The great density that the city holds has developed complexity in most of the city sectors (land, public space, water, transportation, air, waste and energy) plus 4.2 million people living outside CDMX commute every day to their jobs in the capital (see figure 2.20 & 2.21), posing great stress over the city services and environment creating one of the most congested transit systems in the world. Transportation in ZMVM is estimated to generate 46 percent of total polluting emissions a consequence of a fast developed city growing to the periphery, it developed completely a car oriented city. Together with profit oriented policy development to benefit automobile companies, resulted on 5 million vehicles circulating every day, and worst is the 3.8 percent annual growth, that it will continue to impact the cities air quality and cause health related diseases to the population. More and more public transportation system is becoming essential to the city mobility; the implementation of a great metro system, bus rapid transit, emerging cycling lines and mechanisms to block automobile use (parking payment, policy for cars not to circulate every day, gasoline cost increase, among others) are showing to be effective against the automobile era showing hope to reduce impact.

*“In order to understand Mexico City’s hydrological cycle, it is important to highlight that all the aforementioned variables are interconnected in one way or another. All the layers of the previous should be understood as parts of a whole cycle. What happens in the hills has consequences in the plains: the loss of the infiltration in the mountains negatively affects the water volume of the aquifer and increases the pressure on the availability of drinking water; draining all water out of the Basin as quick as possible –in addition to reducing the aquifer’s volume– accelerates the subsidence phenomenon.” (De Urbanisten, pp: 106, 2016). See figure 2.11, 2.22 & 2.25*

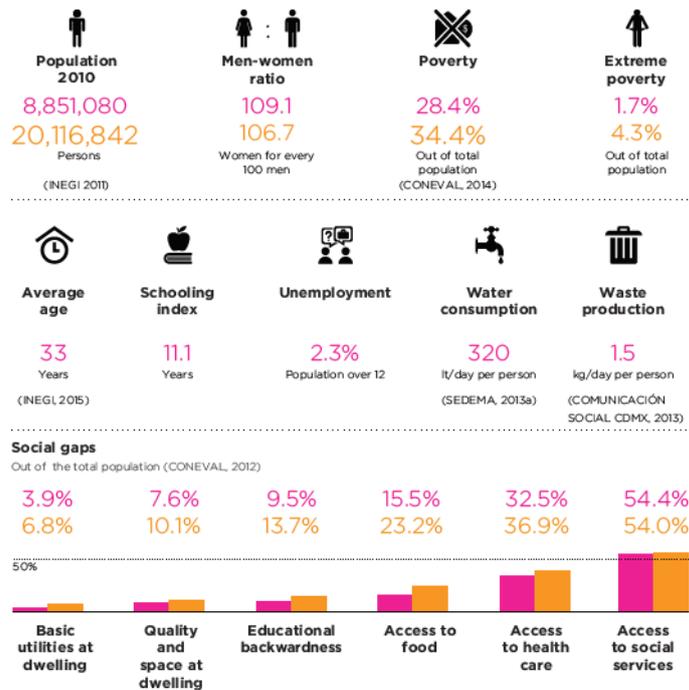
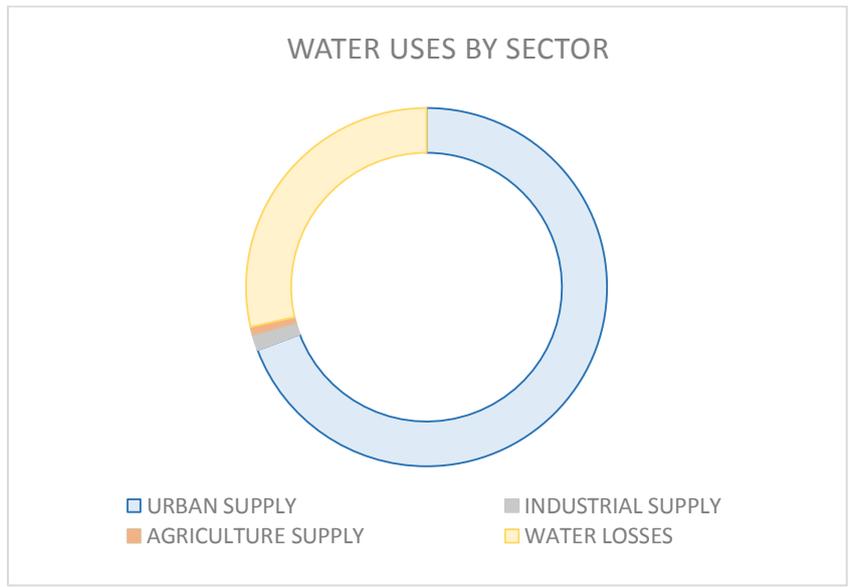


Figure 2. 19: General data for CDMX and ZMVM.

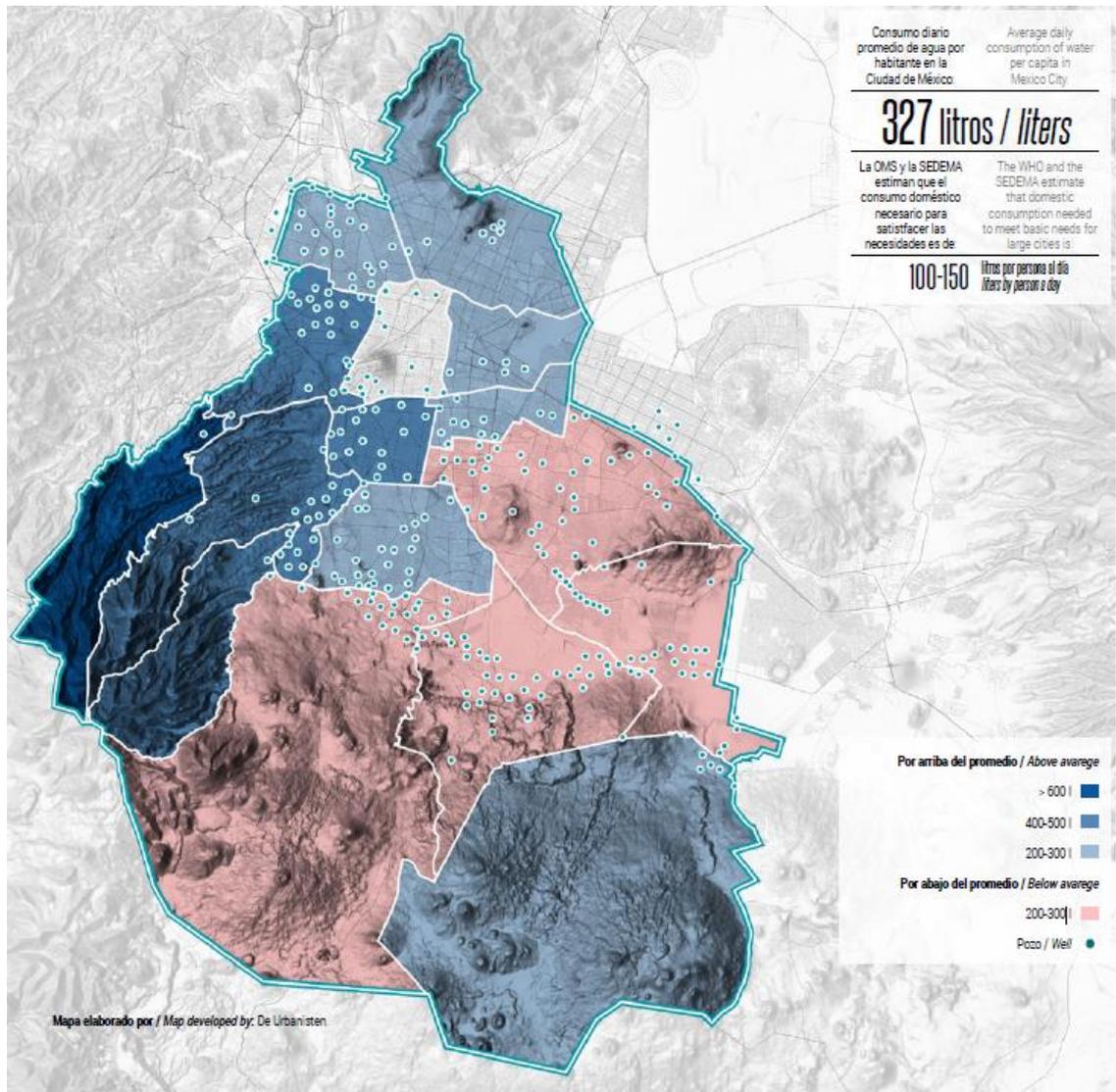
Source: 100 Resilient Cities, 2016.

## 2.13 Water Uses

Water supply for CDMX is regulated by The Public Registration and Water Rights, in 2015 they authorized 182 titles that registered an overall withdrawal of 1,123 hm<sup>3</sup> or 35.6 m<sup>3</sup>/s. A correspondent 72 percent belongs to underground water sources and the rest 28 percent to surface water sources, according to SACMEX (2016) reports. They also establish different uses, urban supply represents 97 percent of total water use, meanwhile industrial 2 percent and agricultural 1 percent, (not considering water losses). The previous data is important to understand that the great population living in Mexico City uses most of the water, and it is the most important sector to perform water-energy-carbon savings. Second, agricultural and industrial activities does not take place inside the city, meaning that both important sectors commute their goods in order to supply the city. And third, as much as 4.5 million people from the city peripheral, are working and commuting inside impacting all services. Being most important that CDMX cannot be seen a singular unit, it's to be understood as a dynamic and complex organism and has challenges beyond the city or region that affects in larger scales. At present, 98 percent of the population in CDMX have access to water supply with an approximate per capita use of 364 l/cap/day of which 97 percent have accessibility to sewage system. However the actual amount of water is lower than the previous number as the average includes all uses, like industry, services and even lost in leakages, (CAN, 1997; INEGI, 2000). Most of the water that supply the MCMA are located either west, north or south and for the population on the Easter part have irregular and unreliable supply and are affected often with water shortages (see figure 2.24). More that 5 percent of the population in the metropolitan area buy's water from water trucks to fulfil their basic needs, paying as much as 500 percent more money than a regular municipality user (Tortajada, 2003). Consequently México City has to understand the limitation of their water sources as they have been using them unsustainably for the last 50 years (Valdez, 2016). The Nexus referred in this paper is strongly represented in this megacity and seems only to get worse if not considered.



**Graph 2. 9: Water uses by sector in CDMX, 42 percent of the total is lost in leaky pipes.**  
Source: Author, 2016.

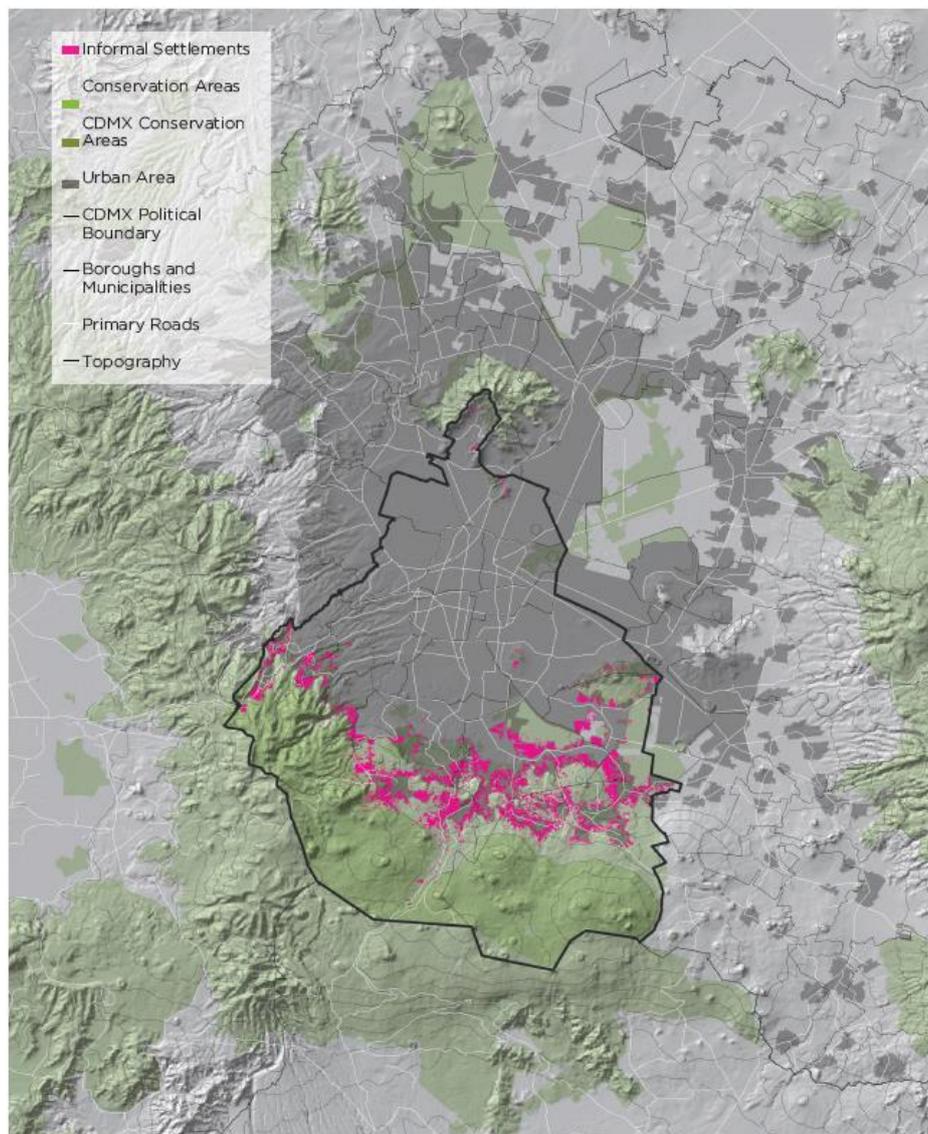


**Figure 2. 20: Mexico City water consumption per capita.**

Source: De Urbanisten, 2016

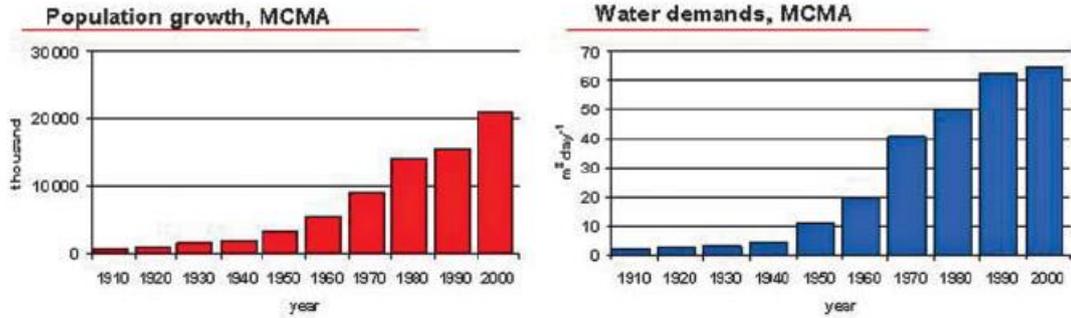
## 2.14 Water Related Problems

The quality in people's livelihoods is severely questioned in different areas in MCMA, primarily due to population growth, inequity, sprawl, pollution and resource depletion. They are related with extensive air, water and soil pollution, [graph 2.10](#) shows an overview of population growth and water demand in the MCMA. In the unmeasured growth 2 main problems are identified related to water resources; water scarcity ([see figure 2.24](#)) and overcapacity drainage. Both have related sub-problems in the region like; loss of infiltration capability due to high-urbanization factors ([see figure 2.23](#)), that summed up with location typology greatly increase risk over livelihoods by extreme flooding's in rainy season ([see figure 2.33](#)), as less water filtrates to the aquifers more flows are to be handled in the sewage system, consequently water availability for the population decreases. Despite significant efforts of the local and federal levels of government, water security in CDMX and ZMVM is at great risk due to several degradation of the water resources. Among the factors that contributed to arrive to such scarcity are; population growth and urban sprawl, leaky grids, poor water management, political unwillingness, lack of awareness, absolutely no water saving measures or policies. The following figures show a strong relation with inequality and water services availability due to peripheral urbanization and distance to the city centre.



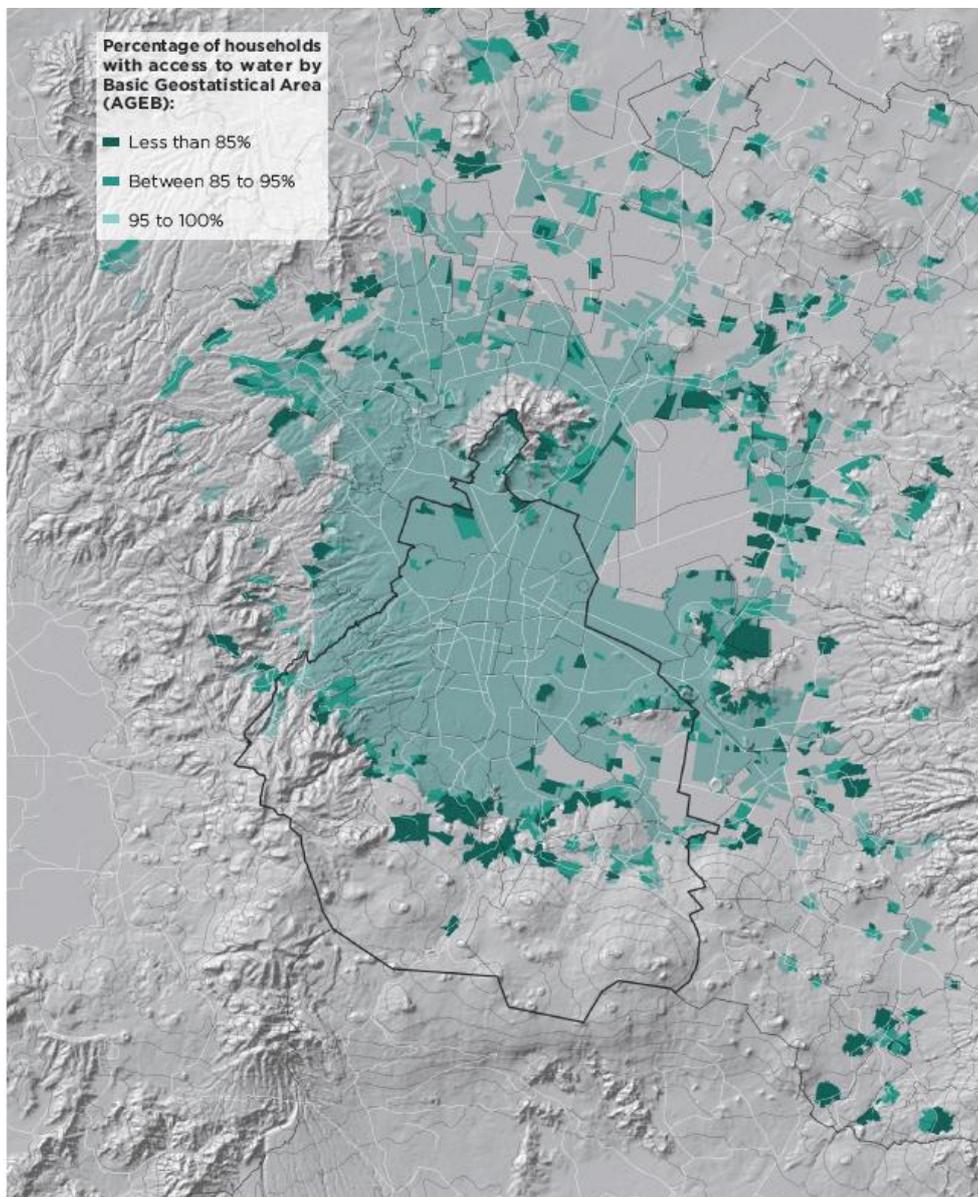
**Figure 2. 21: Expansion of the informal settlements in aquifer recharge and conservation areas.**

Source: 100 Resilient Cities, 2016



**Graph 2. 10: Population density in ZMVM by municipality and delegation. Relation of population growth and water demand.** Source: World Bank, 2013.

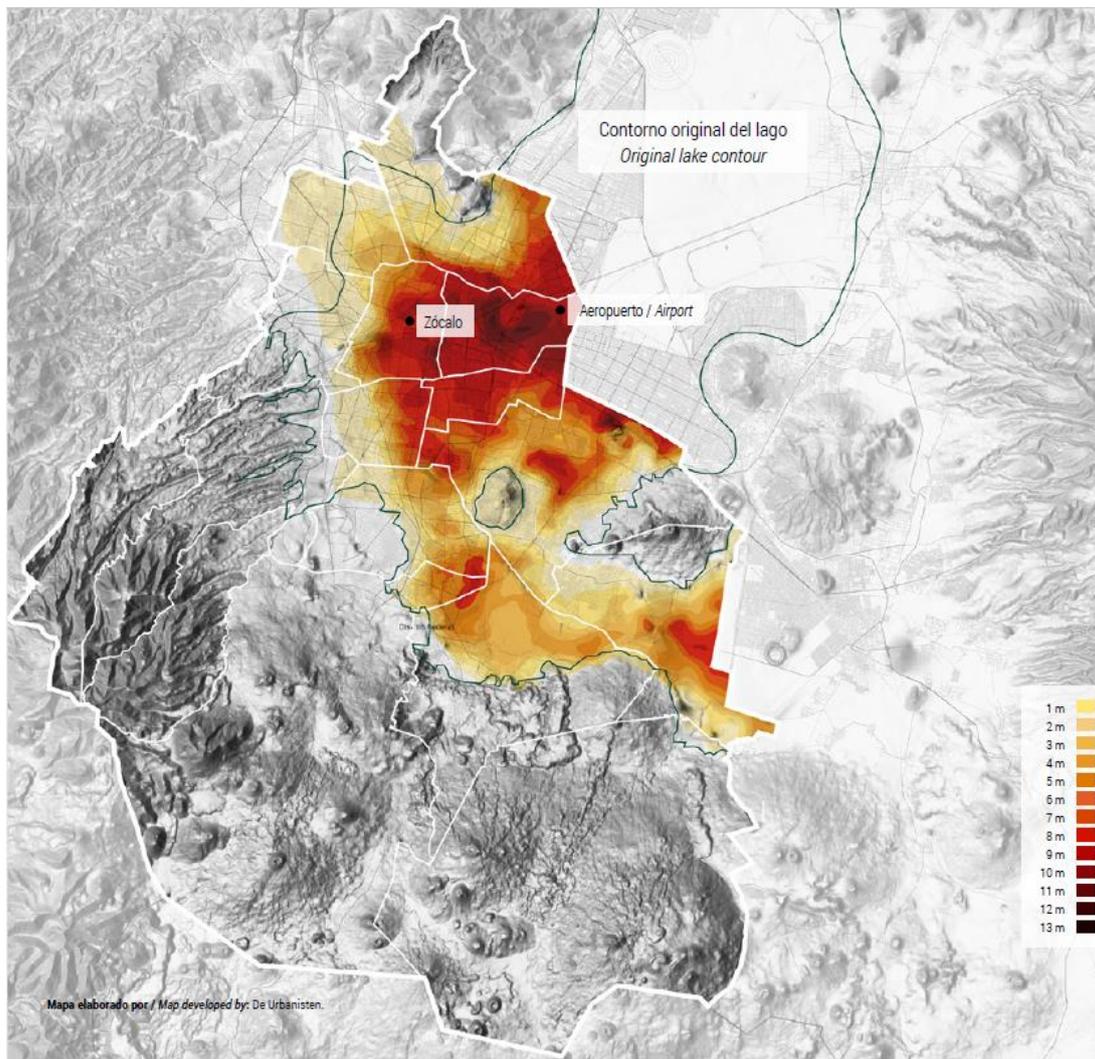
*“In the area of hydraulic resources, the city faces a high degree of vulnerability over the availability of water due to the effects of climate change, in addition to the rising demand for water, the increased degradation of aquifers and catchment areas, among other factors. The distribution of volumes in 2013 for the city were distributed for the following uses: public supply, 97 %, industrial self-supply, 2.9 %, and agricultural sector, 0.1 % “(Gobierno, 2015).*



**Figure 2. 22: Water availability in the ZMVM.** Source: 100 Resilient Cities, 2016.

## 2.15 The Sinking Megacity

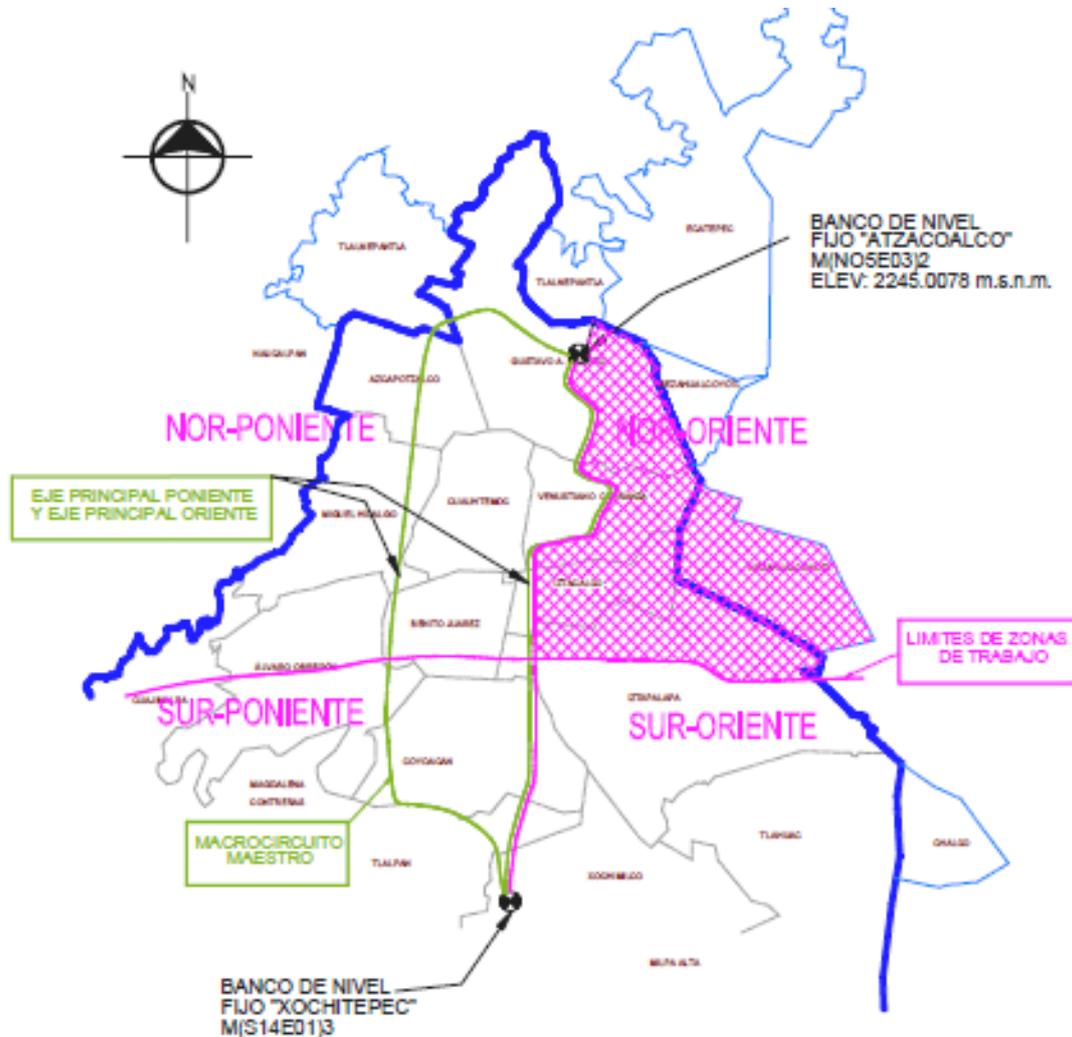
The mega-city of Mexico is located as stated before, in an endorheic basin surrounded by mountains, over-exploited aquifers have consequently led to land subsidence causing the city to sink up to 15 to 36 cm every year in some neighbourhood's especially in the city centre, (see figure 2.25). In the last 6 decades the city centre has sink over 10 meters (UNAM, 2008; SACMEX, 2014; CONAGUA, 2016), damaging the city's infrastructure including water networks and drainage systems, being one of the main reasons for water losses, compromising the entire water infrastructure bringing further degradation to the environment and discontinuity to population access to water, especially in low income areas, (like Tláhuac and Iztapalapa where water is to distributed daily by water trucks). The phenomenon was first discovered by Roberto Gayol more than 80 years ago and proven in 1947 by Nabor Carrillo, he was the first to stablish a relation between subsidence and soil consolidation by water extraction.



**Figure 2. 23: Mexico City subsidence since 1862 to 2001.**

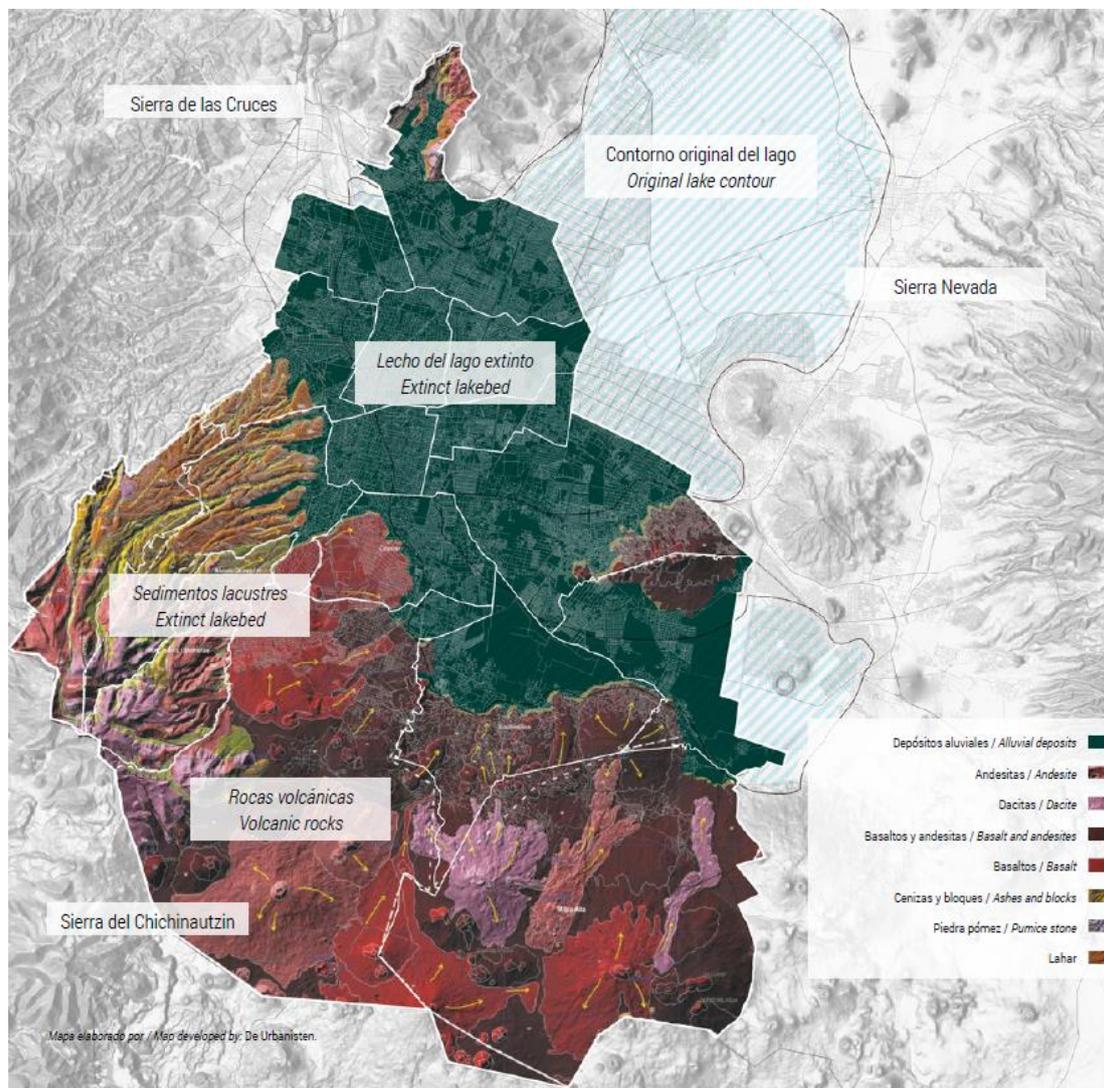
Source: De Urbanisten, 2016

In order to level the territory, bank levels were created dividing the city in 4 areas: Noreast, Norwest, Southeast and Southwest, (see figure 2.27). The principal axis starts in Atzacolco and ends in Xochitepec with 49 km total (UNAM, 2008). The bank levels are deep pillars created to overcome the land subsidence, mostly needed in the lake sediments area where the city sinking takes place. The following figure shows the soil typology diversity and gives a visual understanding of the current urbanization on top of the lakebed. The undeniable relation between underground water extraction and land subsidence due to the soil typology is clearly proven at this point. And the major population density is also located in these areas and corresponds to the water wells system built for water extraction, (SACMEX, 2016).



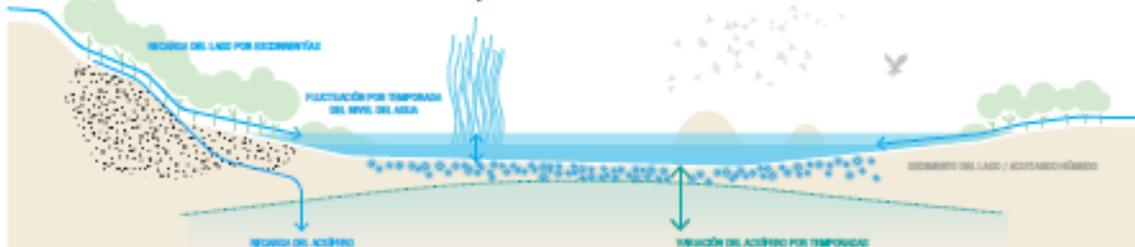
**Figure 2. 24: Bank level by axis.**  
Source: UNAM, 2008.

“The geological base of the Mexico City Basin is composed of two entities of a very different nature. First, the mountains, hills and slopes are formed by rocks of volcanic origin like basalts and andesite’s. On the other hand, the plains are formed by the typical sediments of a lake bed that have been dragged and dropped by the water to the bottom of the Basin. These are mostly clays, silts and sands. Importantly, the City is primarily built on top of this layer”, (De Urbanisten, pp: 70, 2016). See figure 2.27



**Figure 2. 25: Mexico City soil composition.**  
Source: De Urbanisten, 2016

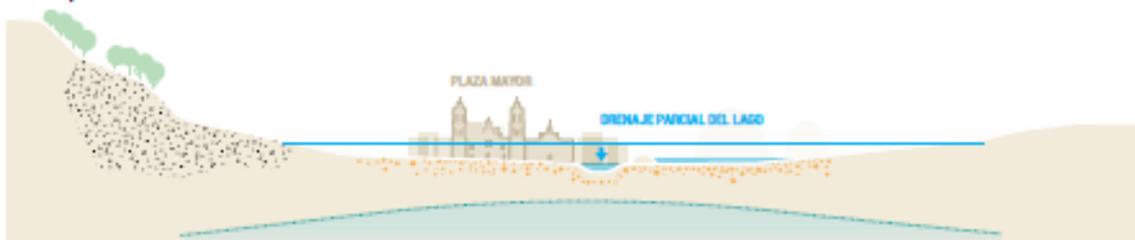
Antes de los asentamientos humanos / Before human settlements



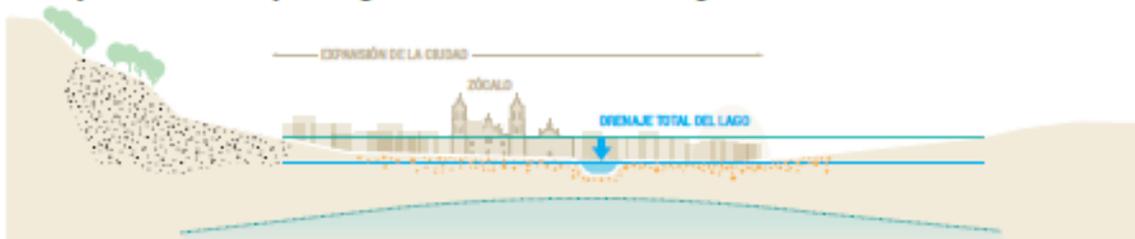
Tiempos mexicas / Mexica times



Tiempos coloniales / Colonial times



Drenaje de la Cuenca y los lagos / Basin and lakes drainage



Época moderna / Modern times

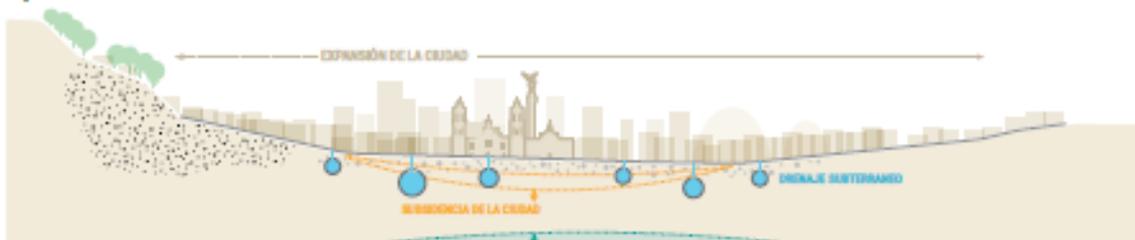


Figure 2. 26: Lake-city relationship.

Source: De Urbanisten, 2016

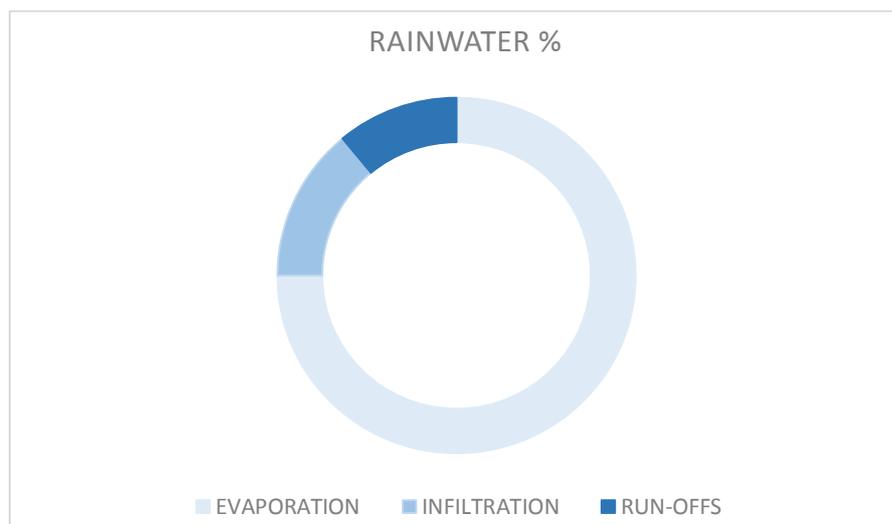
## 2.16 Climate

Most of the territory has subtropical highland, sub-humid (87%) climate due to the location and altitudes ranging from the city altitude at 2,240 m to surrounding mountains and volcanos that pikes up to 3,900 m over se the sea level. The average temperature variation from 12 to 16°C, the lowest recorded currently is -4 to 34 C. The overall precipitation is concentrated in summer months from June to October in rain season, with average 820 mm every year. The rainwater runoffs lean mostly to evaporation of an average 75 percent, mostly due to lack of recharge areas, 14 percent average soil infiltration and 11 percent runs off via canals and rivers.



**Figure 2. 27: Climate in CDMX.**

Source: INEGI, 2015.

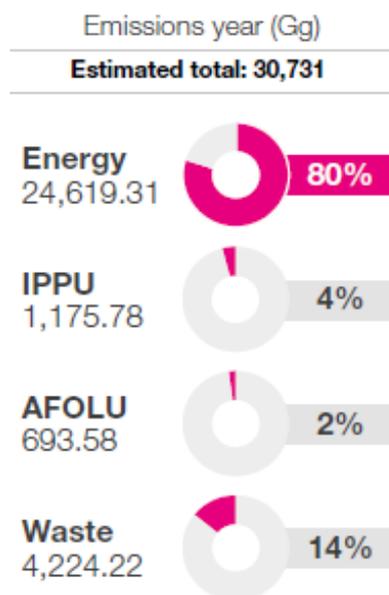


**Graph 2. 11: Rainwater in CDMX, 86 % is lost, mostly due to lack of recharge and retain efforts.**

Source: Author, 2016.

## 2.17 Climate Change

“The CDMX climate policy has been in existence since the 2000s decade, via the Environment Ministry SEDEMA, beginning with the Plan Verde (Green Plan), which considered a medium-term route (15 years). It contains specific strategies and actions in energy matters and climate change to guide the city, along with public policies, Climate Action Strategies and Programs focused on improving the quality of life of the city’s population, and the implementation of actions to face climate change. In 2008, the city was the first entity in the country to develop and orchestrate a State Climate Change Program, amid the need to adopt measures for mitigation, adaptation, communication and environmental education.” (Gobierno, pp: 9-34, 2015).



The GHG and particle emissions determined by INEGI (2013) with the national inventory on GHG emissions, reported 665 MtCO<sub>2</sub>eq of total emissions for Mexico. The transportation, industry and energy generation sectors contributed in around 62 percent of the total domestic emissions. Meanwhile CDMX reported (2012) 30.7 MtCO<sub>2</sub>eq. Being the energy sector the main responsible for 80 percent of the total emissions emitted. Regarding black carbon a total of 1,222 tons were attributed to automobile use in 97 percent on this emissions. The emissions inventory are updated every 2 years. The major risk in the city due to Climate Change is towards Hydro-meteorological phenomena’s like rain, flooding’s and overflow of waste water, calculated economic impact is over 32.4 million dollars other impacts are landslides, earthquakes, forest fires and decrease in health due to contaminants, (Gobierno, 2015).

**Graph 2. 12: CDMX total CO<sub>2</sub>eq emissions by category in 2012.**  
Source: Gobierno, 2015

“The categories included in this hypothetical scenario include: energy, industrial processes and use of products, Agriculture, Forestry and Other Land Uses and waste. The energy category accounted for 80 % of emissions in 2012, and the subcategory of transportation totalled 47 %. Short-Lived Climate Pollutants emissions, such as methane and hydro-fluorocarbons, are included in this projection”, (Gobierno, pp: 14-34, 2015). See figure 2.12

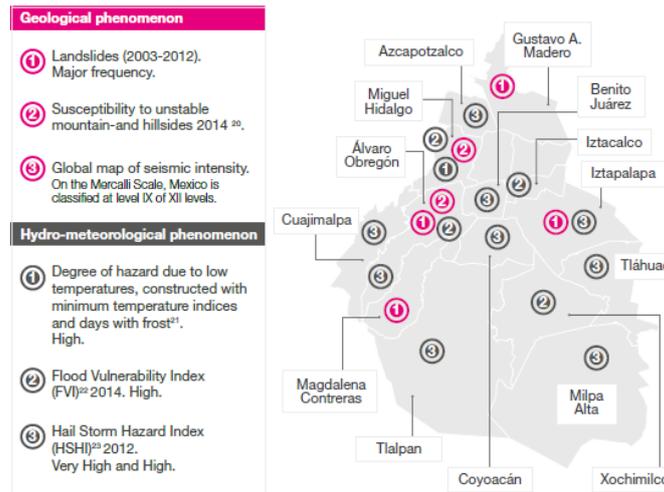
The hypothetical scenarios based on Climate Change projections of an increase of 1°C to 2°C in the average annual temperature of the city would lead to an increase in the presence of diseases, floods, droughts, heatwaves, hailstorms among others, (Gobierno, 2015). The aim of Mexico City Climate Action Programs are to reduce greenhouse gas emissions, reduce vulnerability of the city to the effects of global warming, and heighten the adaptation of the city, (Mexico City Climate Action Program, 2008). The city has identified and stablished different strategic areas to perform line of actions for 2025 vision of the city. From which all affect water basins directly or indirectly being the most important for this research are: environmental improvement with; waste water management and fresh water management. The concerning water availability and natural resources management, preservation of biodiversity and containment of urban sprawl, (see table 2.11). Furthermore, the city has extreme good data and knowledge about their current situation and future risks, for the previous; many actions are taken to Mitigate Climate Change, but recently new action are being taken to also Adapt the city to the phenomena like the recent publication of “Towards Water Sensitive Mexico City” and “CDMX Resilient Strategies”, both documents publish in September 2016.

Type of Natural Disaster	Population/Area affected	Economic impact *
 <b>Hydrometeorologic</b> Rains, floods, winds, hailstorms, sewage overflows	49,970	\$ USD 32.4
 <b>Geologic</b> Landslides and earthquakes	6,338	\$ USD 4,100
 <b>Wildfires</b> 8,657 fires	17,549 He affected	\$ USD 2.7

\* In millions of \$USD (average annual cost for 1980-2014)

**Graph 2. 13: Socioeconomic impacts of natural disasters in CDMX.**

Source: 100 Resilient Cities, 2016



**Figure 2. 28: Potential vulnerability and hazard mapping.**

Source: Gobierno, 2015.

Strategic Area	Line of Action	Transversal Areas
<b>1</b> Energy and rural transition	<ul style="list-style-type: none"> <li>Energy efficiency.</li> <li>Renewable energy.</li> </ul>	<b>6</b> Education and communication <b>7</b> Research and development
<b>2</b> Containment of urban sprawl	<ul style="list-style-type: none"> <li>Urban planning instruments.</li> <li>Intra-urban green spaces.</li> <li>Mobility and transportation infrastructure.</li> </ul>	
<b>3</b> Environmental improvement	<ul style="list-style-type: none"> <li>Reduction of polluting emissions.</li> <li>Comprehensive waste management.</li> <li>Comprehensive water resources management.</li> </ul>	
<b>4</b> Natural resources management and preservation of biodiversity	<ul style="list-style-type: none"> <li>Native species and wildlife.</li> <li>Conservation areas.</li> </ul>	
<b>5</b> Creation/ construction of resilience in the city	<ul style="list-style-type: none"> <li>Risk prevention and mitigation.</li> </ul>	

**Table 2. 12: Strategic priorities and lines of action for 2025 vision of the city.**

Source: Gobierno, 2015

“One of the expected shocks associated with climate change is an increase in extreme rainfall that may result in an increased number of floods. Shocks to sewage systems are projected during intense rainfall seasons, and the frequency and extent of such shocks may increase significantly due to lack of infrastructure maintenance or as a result of future earthquakes, which may result in damaged infrastructure in the city”, (100 Resilient Cities, pp: 20, 2016). In the other hand, water shortage is a common characteristic during dry season, it has showed serious repercussions in the population, with increasing heatwaves and temperature fluctuations that also affect vegetation. Both scenarios according the season reflects the current lack of sufficient water supply or flood protection, answer are to be found with innovative approaches.

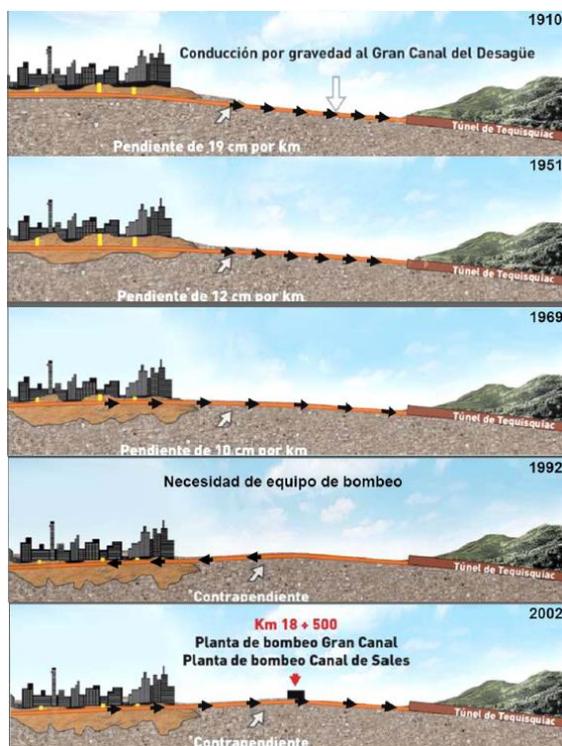
## 2.18 A Water Sensitive Approach



**Figure 2. 29: Current flood risk in CDMX by excess in water.**

Source: De Urbanisten, 2016

The freshly publish document “Towards a Water Sensitive CDMX”, in collaboration with De Urbanisten, Deltares, UNAM and the City Government (2016) shows the current situation of the megacity water management, (see figure 2.31). As mentioned before in this research, the city is surrounded by mountains, in what used to be a lake system, today urbanized in most of the areas where water was to recharge the aquifers. The solution to avoid flooding was to build a deep underground sewage system, capable to take all flood risk from the city. A solution that every day sinks with the city (see figure 2.32). To counter act the new city levels due to the land subsidence, pumps were installed and great energy used to safeguard the city, (UNAM, 2008). Unfortunately the aquifers are not recharging their full capacity and the subsidence will continue, even at greater scales meanwhile underground water levels continue to fall. Flood risk is at its highest point, and could affect millions of habitants.

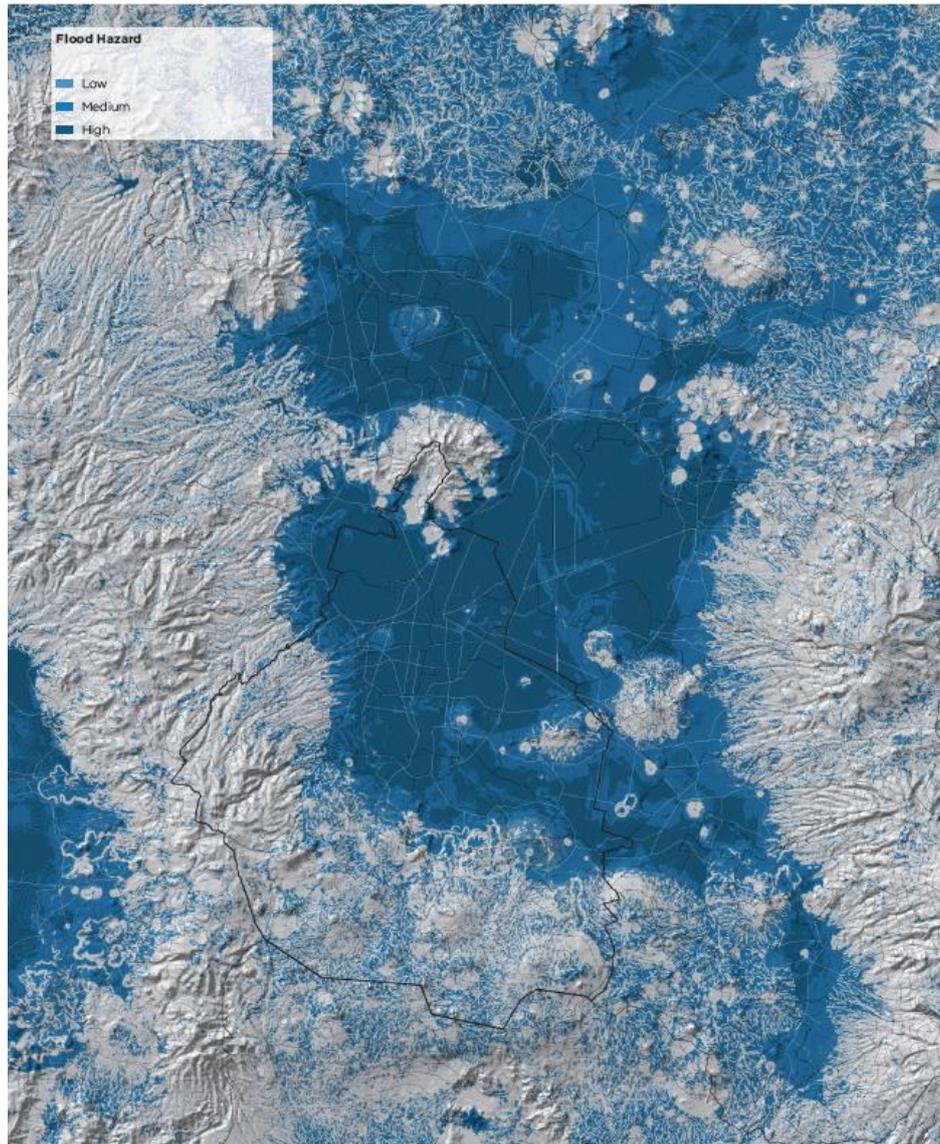


**Figure 2. 30: Sewage system subsidence**

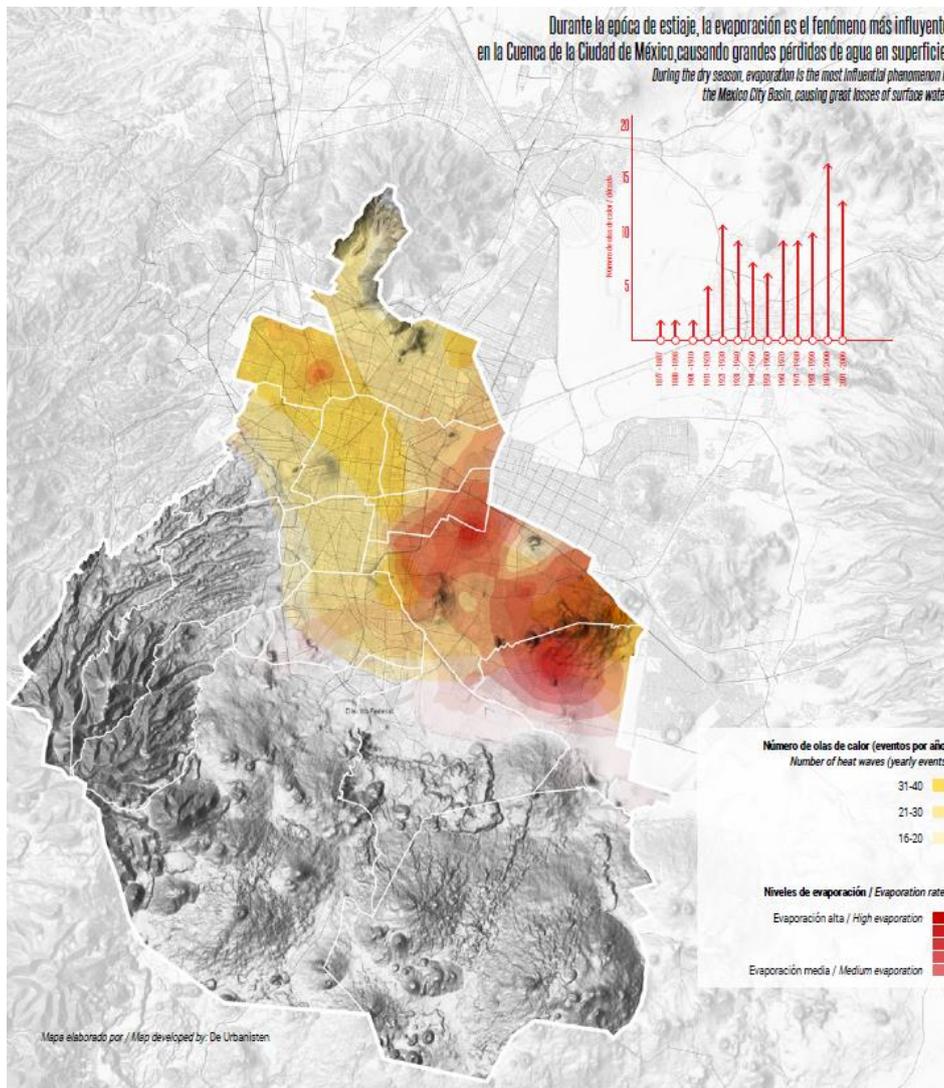
Source: UNAM, (2008)

“Mexico’s City drainage is a large scale complex system of mixed sewage infrastructure that collects rainwater, grey water (household) and black water (sewage). Through a series of collectors, these are discharged into a main underground system that mixes and transports them to the neighbouring state of Hidalgo several kilometres to the north, outside of the urbanized Basin. Originally, the Great Drainage Canal transported the water in the surface; however, with the gradual collapse of subsoil, the capacity of the Canal was dramatically reduced due to a loss of inclination, until eventually at some point its slope was reversed by subsidence therefore supressing its function. Since then, the City has been building and expanding the so-called Deep Drainage System (in Spanish Sistema de Drenaje Profundo), in some cases with some enormous engineering undertakings such as the Oriental Emissive Tunnel (In Spanish Túnel Emisor Oriente; TEO).

*“The main cause for the loss of rainwater in the urbanized Basin bed is the absolute dependence of the City on this drainage system: the streets’ paving and the underground pipes transport the rainwater as quick as possible to the Deep Drainage System. Consequently, the water cannot evaporate, it has no time to infiltrate and ,especially towards the East of the City, the moisture cannot be held by covering trees, because there are hardly any that can survive in this area’s saline and mineral saturated soil” (De Urbanisten, pp: 91, 2016).*



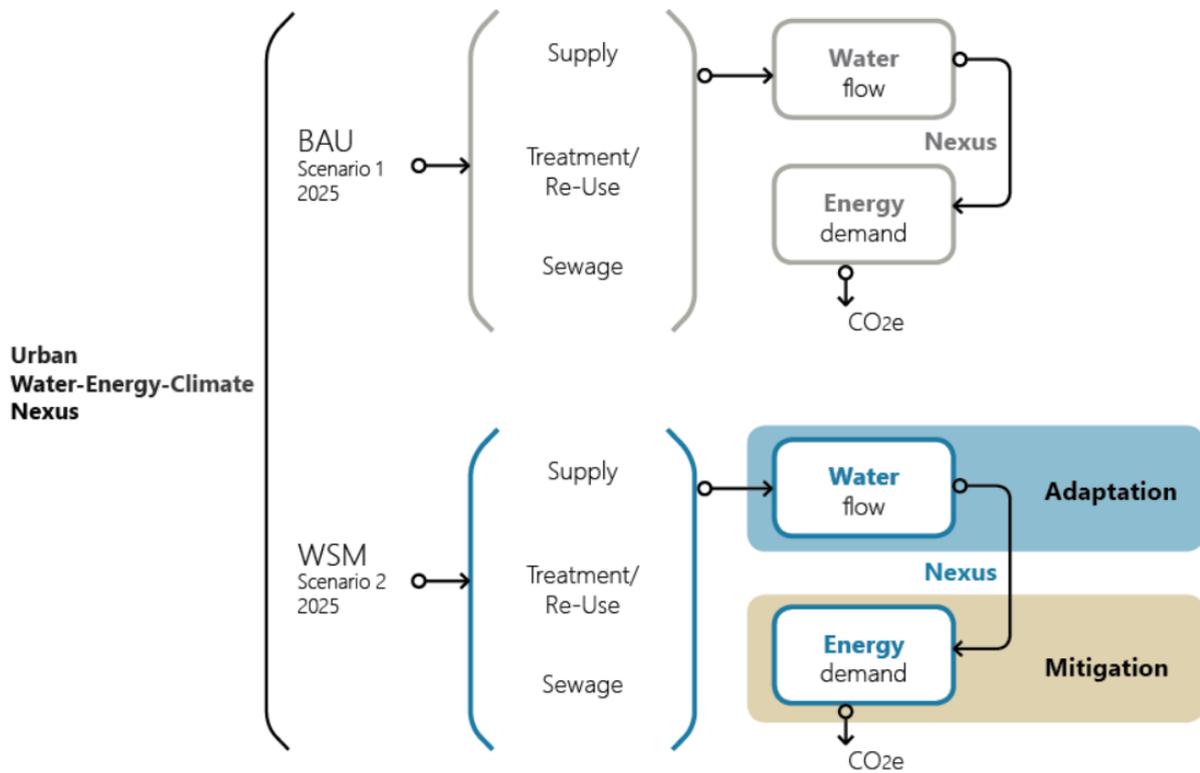
**Figure 2. 31: Flood Hazard in CDMX.**  
Source: 100 Resilient Cities, 2016



**Figure 2. 32: Current heat wave risk, land subsidence due to lack of water in CDMX.**  
 Source: De Urbanisten, 2016

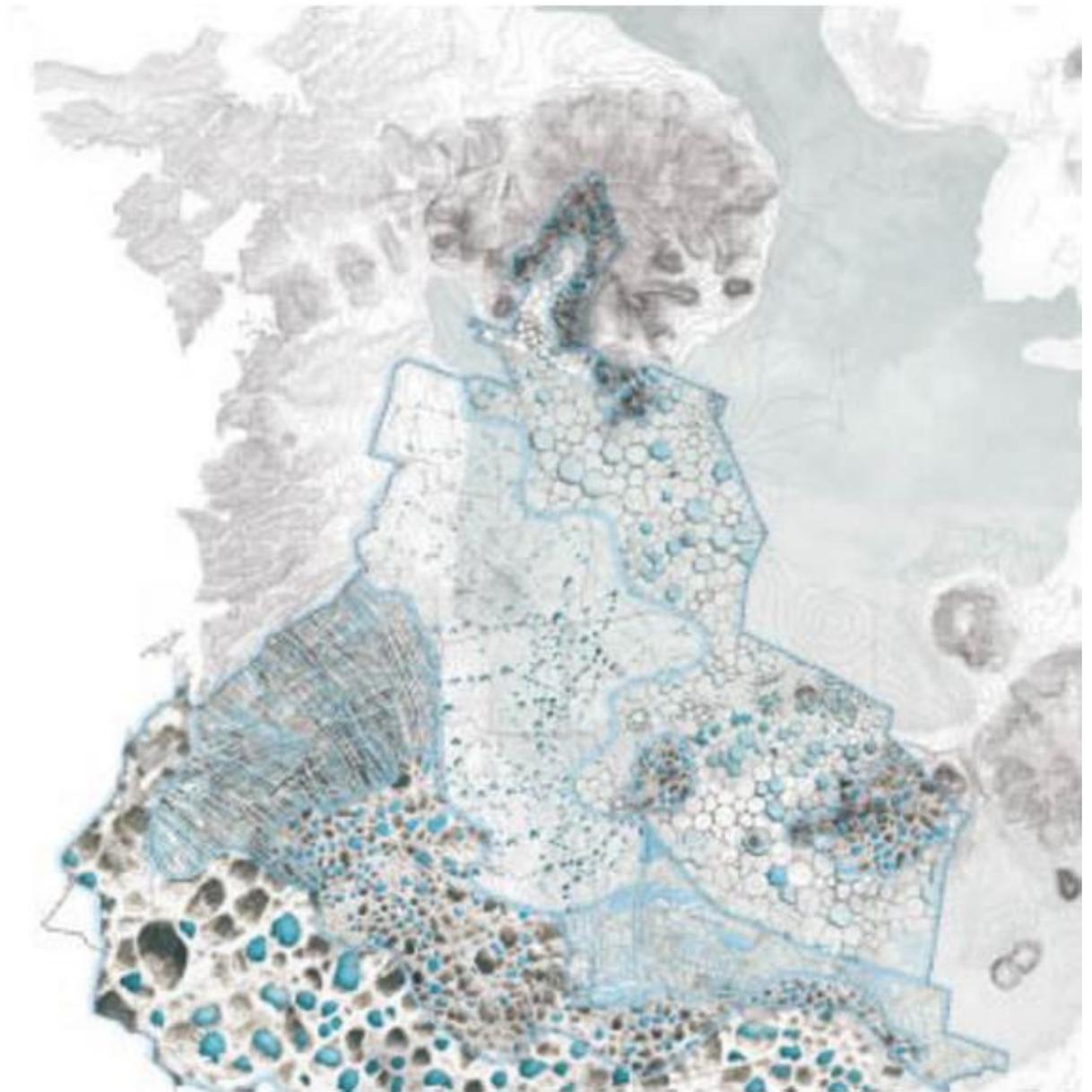
*“Mexico City is facing serious challenges regarding its relation with water in the broadest possible sense. During the rainy season, certain parts of the City suffer flash floods that bring serious damage and represent a great danger. Causes can be found in the landscape’s topography, its vast urbanisation and lack of open green spaces, as well as in its total dependence on an extensive subterranean drainage system. During the dry season there is on the contrary a serious lack of water, that has acute consequences on public health due to heat stress and a drinking water shortage; but this fluctuation also causes the dehydration of vegetation and land subsidence. There is either too much or too little water in the City, and this current system is preventing the establishment of a possible balance which could be brought forth by a circular approach”, (De Urbanisten, pp: 15, 2016). See figure 2.35*

## 2.19 Conceptual Framework



**Figure 2. 33: Conceptual Framework**  
 Author, 2016.

The conceptual framework has been developed from 2 main variables (see figure 2.36) taken from the main research question. The water energy nexus operates as the independent variable underpinning the interlinkages of the resources, focusing over the water cycle thirst for energy. The CO<sub>2</sub>e is the dependent variable. Two scenarios are established BAU (scenario 1) and WSM (scenario 2) over the city urban-water life cycle. The framework establishes the nexus on the energy demanded from the water cycle, consequently producing CO<sub>2</sub>e emissions. The second scenario regards water-energy and carbon savings, meanwhile enhancing the adaptive capacities to the city to climate hazards, as well as carbon emissions abated for mitigation purposes, (see table 3.1).



**Figure 2. 34: Water Sensitive CDMX.**  
Source: De Urbanisten, 2016

## **Chapter 3: Research Design and Methods**

### **3.1 Revised Research Questions**

**To what extent does the water-energy-climate nexus influences CO<sub>2</sub>e emissions at the urban water cycle in CDMX?**

- 1.1 What is the water-energy-climate nexus in the urban water cycle in CDMX?
- 1.2 What are the current flows in the urban water cycle in CDMX, how much energy does it use, and equivalent Co<sub>2</sub> emissions produces, in BAU scenario?
- 1.3 What are the implications of WSM on carbon emissions, and how are they influencing the adaptation mitigation respond of the city to climate change?

### **3.2 Operationalization: Concepts, Variables and Indicators**

In this section, I discuss the main concepts, variables and indicators. The 5 variables in the operationalization are divided over the 2 main concepts.

The first concept has 3 variables: water flow, defined as the 3 main processes (supply, treatment/re-use and sewage) to deliver water services to end-users.

The first process is water supply, divided in 2 sub processes, first; is water withdrawal. In México City occurs mostly from ground water, the aquifer is below the city and has caused the city centre to sink over the years due to unsustainable withdrawals. Second; Water convenience (pumping), and it refers to the water movement in the grid from source and end-user to treatment and disposal. Much of the water loses occur in this instance (40 percent) due to infrastructure and management failure.

Second process is water treatment/re-use. Treatment, refers to all processes to clean the water before and after end-user. Re-use is the processes in which treated water serves any additional purpose in the urban water LCA instead of being discarded.

The third process is sewage, it reference to all water after end-use convened in the grid. After the water is used and discarded to sewage systems, it's typically pumped either to treatment or discarded to other water bodies.

The energy nexus is refer to the amount of electricity used in all the stages of the water cycle. In other words the energy dependency from the water cycle. Both variables have many indicators that validate the total amount of water and energy needed for providing the service to the total amount of the population.

The second concept is divided in 2 variables, adaptation and mitigation that are defined as the respond of the city to climate change. Holding in total 2 indicators for adaptation, regarding water security due to the proposed efficiency measures and technologies. The second indicator is flood capacity enhancement that evaluates the capacity of the WSM, to assist towards flooding in the city by rain or storms. The second variable is mitigation, and it refers to the Co<sub>2</sub> emissions abatement due energy savings performed over the water sector (energy savings by saving water). All the indicators and variables have strong inter-relations among each other, stating the nexus over the water-energy-climate.

### 3.2.1 Operationalization Table

CONCEPT	VARIABLES	INDICATORS
Urban Water-Energy Nexus	Water Flow	Supply Treatment/Re-Use Sewage
	Energy Demand	Supply Treatment/Re-Use Sewage
	CO <sub>2e</sub> Emissions	Supply Treatment/Re-Use Sewage
City Respond to Climate Change	Adaptation	Water Security Flood Capacity Enhancement
	Mitigation	CO <sub>2</sub> Emissions Abatement

**Table 3. 1: Operationalization table.**

Source: Author, 2016.

### 3.3 Research Approach and Techniques

The research has been approached with a quantitative strategy, and purely analytical (Van Thiel, 2007). A survey proved to be helpful to understand and evaluate the opinion of the purposive sample towards local context.

The research study aims to analyse the water service cycle at the city level, and the interlinkages between water energy services and their environmental impact, referred to as the water-energy-climate nexus. The main objective of the research is to analyse the current water flows in the service cycle, the energy involved in the different cycle process, and the CO<sub>2e</sub> emissions related to the energy used. The BAU scenario, consists of collecting data from the previous 3 sectors; water and energy services (energy only used in the urban water LCA) and the CO<sub>2e</sub> emitted from non-renewable sources. Different carbon emission factors are presented and evaluated, regarding Mexico energy mix.

The first approach to acquire the data was desk research, by analysing the secondary data acquired by the water company's reports and academic publications; they are clear and full of information. However, the data corresponding the energy use, does not appear in any of the water company reports, primary data was collected from the periods 2013/15. After a deep analysis, a questionnaire was developed and semi-structured interviews were performed to corroborate the information and acquire new about water flows, and the energy-CO<sub>2e</sub> involvement. In addition, a survey was developed to evaluate expert opinions in the water saving measures and their reliability in the local context.

Consequently, a primer scenario **Business as Usual (BAU)** was developed, including independent analysis of the 3 different sectors; water-energy-CO<sub>2e</sub>. Consecutive forecasting (projections) evaluate the scenarios regarding all 3 sectors of study, towards year 2025. A second scenario, **Water Saving Measures (WSM)** possess analysis over the same previous data, after applying 3 different measures that reduce water use (pricing reforms, reduce water losses and rain harvesting techniques), the WSM scenario consists of the all 3 measures combined to show a best solution. Providing useful information to interested actors to understand CDMX water availability and its energy- energy-CO<sub>2e</sub> emissions towards the coming years.

Meanwhile different the WSM are established, a consequent analysis evaluate the inter-relation between adaptation and mitigation, and their influence towards the respond of the city to climate change.

Both scenarios are forecasted and explained in the following chapter, which intend to build up different scenarios by model design. Contributing with critical analysis to overcome administrative fragmentation and promoting co-collaborative decision-making in the corresponding sectors.

### 3.4 Data Collection Methods

The approach taken to collect the data, is a combination of secondary and primary sources. The main methodology where semi-structured interviews, as partial data was acquired from secondary sources in a desk research approach before the questionnaire was developed, (see [annexe 1](#)). However, the semi-structured interviews where performed, showing to be a strong methodology to gather data. The semi-structured interviews have strengthen the reliability of the study ([Verschuren and Doorewaard, 2010](#)), as a selected sample was interviewed with a breve questionnaire based in 8 open questions (items), successfully acquiring the data needed. Integrated in the same document a breve survey was introduced, the purpose of the previous was to grade and evaluate in a Likert Scale the importance of the previously selected water savings measures (see [table 4.1 & 4.2](#)). In other words, how does experts on the local context understand each of the water saving measures proposed to be more feasible in the Mexican context?

The BAU scenario data has been collected in secondary sources as most of the data is available in national databases, academic publications, international organizations databases and reports, and will compel of quantitative data on the water cycle (supply, treatment/re-use and sewage), as well as quantitative data for the energy sector used in the urban water LCA. It will provide the lecturer the electricity source and burning mix of the centralized power plants, proving reliability to the carbon footprint (CO<sub>2</sub>e emission) assumptions that will be based on the water dependency for energy. The second scenario is based and will use data from the first scenario, with the exception of the implementation of water saving measures for the water service cycle, at this point the efficiency measures and technology implementations are expected to reduce the water used in the urban water LCA, consequently the energy needed in the water cycle and the related emissions. The water savings measures are chosen from other similar studies (literature review) and expert's interviews on the topic, enhancing the internal validity of the process that evaluate similar cases and is expected to provide comparable scenarios to provide water-energy savings and CO<sub>2</sub> abatement at the city level.

The limitations of the study come, with assumptions based on the efficiency measures and technology implementation performance and results. They are based on secondary data and not in first hand experimentation, giving for granted they will have the same performance given in different cities. Both scenarios depend on secondary quantitative data collection, however the indicators for urban water LCA, may need primary data collection in order to acquire present and updated data. The questionnaire, build up from the operationalization process unifies the research completely from problem statement-research questions-literature review-conceptual framework (see [annexe 1 & 2](#)). The questionnaire and survey has been send via e-mail, meanwhile in-deep interviews<sup>4</sup> completed the information needed for modelling both scenarios in the needed time frame, starting from 2004 until 2025.

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<sup>4</sup> All interviews where recorded and are available upon request. Contact: [morediavalek@gmail.com](mailto:morediavalek@gmail.com)

Data has been collected from: See annexe 1& 2 for examples of the questionnaire and survey

1. Primary sources: **In-depth interviews** and a **survey**.
2. Secondary sources from **national databases, academic publications**, international organizations databases and reports.

### 3.5 Validity and Reliability

In terms of congruence between the operational definition and the concept to measure. The reliability and validity of the study is achieved with **interviews to experts in the topic for primary data, triangulated with secondary data collection and a surveys** (Singleton and Straits, 2005). I have evaluated this approach as best for conducting this research, since the necessary data is mostly found in academic publications and governmental reports, the missing data or more updated data is to be recovered from primary sources.

The reliability of the study is strengthened with interviews, combined with secondary data collection and it showed effective results, since the necessary data for the water cycle is mostly found in academic publications and governmental reports, the missing data or more updated data is to be recovered from primary sources. As for the validity it is of most importance to only contemplate the water energy nexus in the water cycle at the city level. Composed from concrete quantitative data collected over the different sectors of the cycle. Also performing interviews to experts on water savings measures in CDMX context enhance the internal validity of the research, the savings inventory has been created from literature review and expert, academic and personal opinions.

The chosen sample (among others) and most important respondents for both survey and semi-structured interviews are as following:

#### CONAGUA (Comisión Nacional del Agua)

- **Dr. Juan Carlos García Salas**  
Director Técnico del Organismo de Cuenca Aguas del Valle de México.  
juancarlos.garcia@conagua.gob.mx
- **Ing. Ramón Alberto López Flores**  
Subgerente de Hidrología e Ingeniería de Ríos Organismos de Cuenca Aguas del Valle de México.  
ramón.lopez@conagua.gob.mx

#### SACMEX (Sistema de Aguas de la Ciudad de México)

- **Ing. Mauricio Hernández García**  
Director Técnico  
wywys06@yahoo.com.mx

#### UNAM (Universidad Autónoma de México)

- **Dr. Manuel Cohen Perló**  
Director del Instituto de Investigaciones Sociales  
perlo@unam.mx

### 3.6 Data Analysis Methods

Data collection started with secondary sources, as the information provided by the different governmental reports and academic publications were compared among each other, founding little variation among the different authors that have asses the topic. Several interviews were done in México City, the most valuables where in the administrative sector; [Water Operator of México City \(SACMEX\)](#), [Water Operator of Valle of México \(OCAVM\)](#) and the academic sector [Universidad Autónoma de México \(UNAM\)](#), the in-depth interviewees showed reliability and willingness as all the respondents showed interest to answered the questionnaires and the survey. The corresponding primary data compels a robust set of information distributed by hard copies, soft copies and recorded audio, that has been analysed and processed over excel sheets<sup>5</sup>. Primary data has been divided over the three different sectors of the urban water LCA and according to the individual process on the cycle (supply, treatment/re-use and sewage), energy related to the specific process and the equivalent CO<sub>2</sub> emitted.

For example, in 2014; the total water supply to the city was 31.076 m<sup>3</sup>/s (979.98 hm<sup>3</sup>/year) this quantity has been divided according to the different sources of the water and broken down in this section for a better understanding: A total of 15.68 m<sup>3</sup>/s is currently being extracted from the underground water sources in the metropolitan area and accounts for 50 percent of the total water supplied to the city. As showed in chapter 4 ([see table 4.1](#)), the water comes from 7 different sources compelling the underground water system of the metropolitan area, and 3.64 m<sup>3</sup>/s or 12 percent are imported from Lerma System, 2.41 m<sup>3</sup>/s from the aquifers in Valle de México and 9.35 m<sup>3</sup>/s are imported from the Cutzamala System, the last 2 compels surface water. The first two figures are managed by SACMEX and the last figures by GAVM, ([UNAM, 2014](#); [SACMEX, 2014](#); [CONAGUA, 2015](#)).

The total energy used for the previous urban water supply was 515,278,288 kWh yr<sup>-1</sup> this data was provided in hard copies from water operational manager SACMEX<sup>6</sup> over one of the interviews performed with the director of technical management. Secondary data was also uploaded to the software and jointly processed for a consequent comparison. CMM determined that the energy used from the water LCA is 1.32 kWh (supply, treatment/re-use and sewage), where 1.23 kWh is the equivalent for supplying the service. In order to understand the energy dependence from the cycle is necessary to break it down as following. Water flows equivalent to 15.68 m<sup>3</sup>/s is currently being extracted from the underground water sources and require around 515 Mw yr<sup>-1</sup> for completing the cycle for underground water source typology ([SACMEX, 2015](#)). Meanwhile the Cutzamala and Lerma Systems have been determined by CMM to jointly perform with 4.54 kWh/m<sup>3</sup> resulting on 1,860 Mw yr<sup>-1</sup>, being the biggest energetic consumer, with an extraordinary 75 percent of energy used overall cycle consumption. Meanwhile, the PAI system has the smallest contributor with 0.253 kWh/m<sup>3</sup> ([Centro Mario Molina, 2013](#)).

The CO<sub>2</sub>e factors given are the result of the energy mix typology of México. Four different factors are analysed according to; low-high results, see section 4.5 ([Itten, 2014](#); [UNAM, 2014](#); [Ramos, 2015](#)). By following up the energy used in the water cycle (provided by primary data and forecasted to future years) I have been able to determine the CO<sub>2</sub>e for both primary and secondary data, using for midterm and basic factor the IPCC (0.065 kg CO<sub>2</sub>e yr<sup>-1</sup>).

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<sup>5</sup> All interviews were recorded and are available upon request. Contact: [morediavalek@gmail.com](mailto:morediavalek@gmail.com)

<sup>6</sup> All hard and soft documents are available upon request. Contact: [morediavalek@gmail.com](mailto:morediavalek@gmail.com)

In order to predict future water-energy-CO<sub>2</sub>e data, independent forecasting's where developed in each of the sectors to analyse. Water forecast is provided as example of formula and methodology, all other forecasting's where developed with the same methods:

Table 3.2, corresponds to water supply and forecast in both BAU and WSM. The table has been developed to explain the methodology and procedures to achieve results, full results are given in chapter 4. The independent and dependent data are operationalized to achieve linear projections of future data, according to previous 11 years. Using the following formula;

=FORECAST(AR200,AS188:AS199,AR188:AR199)

FORECAST(x, known_y's, known_x's)		ACTUAL WATER SUPPLY	WATER SUPPLY FORECAST	WATER SAVINGS OF 8 %	WATER SAVINGS OF 20 %	WATER SAVINGS OF 30 %
I n d e p e n d e n t	(m3/s)					
	2004	32.83	#N/A	#N/A	#N/A	#N/A
	2005	32.79	#N/A	#N/A	#N/A	#N/A
	2006	31.70	#N/A	#N/A	#N/A	#N/A
	2007	32.21	#N/A	#N/A	#N/A	#N/A
	2008	32.34	#N/A	#N/A	#N/A	#N/A
	2009	30.95	#N/A	#N/A	#N/A	#N/A
	2010	31.24	#N/A	#N/A	#N/A	#N/A
	2011	31.91	#N/A	#N/A	#N/A	#N/A
	2012	31.12	#N/A	#N/A	#N/A	#N/A
	2013	29.85	#N/A	#N/A	#N/A	#N/A
2014	31.07	#N/A	#N/A	#N/A	#N/A	
2015	30.33	#N/A	#N/A	#N/A	#N/A	
	2016	#N/A	30.11	27.70	24.09	21.08
	2017	#N/A	29.89	27.50	23.91	20.92
	2018	#N/A	29.67	27.30	23.74	20.77
	2019	#N/A	29.46	27.10	23.56	20.62
	2020	#N/A	29.24	26.90	23.39	20.47
	2021	#N/A	29.02	26.70	23.22	20.31
	2022	#N/A	28.80	26.50	23.04	20.16
	2023	#N/A	28.58	26.30	22.87	20.01
	2024	#N/A	28.36	26.10	22.69	19.86
	2025	#N/A	28.15	25.89	22.52	19.70

Dependent Data

**Table 3. 2: Water Forecast BAU and WSM Scenarios.**  
Source: Author, 2016.

## Chapter 4: Research Findings

In this section, I describe the current findings by category (water, energy and carbon emissions). I present a compendium of the acquired data (primary & secondary) by all the different collection strategies (semi-structured interviews, questionnaire, survey and desk research). A consequent analysis over the data variations are to determine different water-energy and CO<sub>2e</sub> scenarios, and by comparing different studies and primary data collected I forecast the water-energy-climate (CO<sub>2e</sub>) nexus BAU and WSM scenarios.

### 4.1 Survey Results

The following tables (4.2 & 4.3) are the quantification of the respond rate of the selected sample. The survey was developed in adaptation and mitigation of climate change framework, and the respondents had to consider different aspects with an integrated view, to acquire best technique and practices before providing their results, see [annexe 1 & 2](#).

[Table 4.2](#) is measuring the individual importance of the respondents to evaluate off-grid technologies, being useful to understand their view for which technique and technology would be more efficient in the local context. Further analysis is performed in item #2. It has been graded in a 1 – 5 liker scale, showing that number 1 is the most important and number 5 the least. For the previous reason the results had to be inverted in order to obtain the results, technique used in all the survey. [Table 4.3](#) is rated in a scale from 1 – 7 evaluating the most important water saving measures (WSM) in the urban water LCA, consequent energy and CO<sub>2e</sub>.

Survey Results, Q.-8		Respondents						Off-Grid Technologies (eco-technologies)		
	Items	1	2	3	4	5	6	ETotal	Place	%
1	Rainwater harvesting	4	3	5	3	5	5	25	1	28%
2	Water treatment in-sigth	3	1	4	2	3	3	16	3	18%
3	Green roofs and walls	2	2	3	1	2	1	11	5	12%
4	Solar-water heaters	5	4	2	5	4	2	22	2	24%
5	Solar-wind energy production	1	5	1	4	1	4	16	3	18%
	Total	15	15	15	15	15	15	90		100%

**Table 4. 2: Survey results, item #1**

Author, 2016.

Survey Results, Q.-9		Respondents						Water-Energy Saving Options		
	Items	1	2	3	4	5	6	ETotal	Place	%
1	Off-grid technologies implementation	3	5	1	1	6	7	23	3	14%
2	Promote eco-system services	1	4	7	2	4	3	21	5	13%
3	Recycled water use from centralizied treatment plant	5	2	2	3	5	4	21	5	13%
4	Water leakage/loss reduction	7	1	6	7	7	6	34	1	20%
5	Up-date technology	4	7	4	4	1	2	22	4	13%
6	Water pricing reform	6	3	5	6	3	5	28	2	17%
7	Water-Energy savings campaign	2	6	3	5	2	1	19	7	11%
	Total	28	28	28	28	28	28	168		100%

**Table 4. 3: Survey results, item #2**

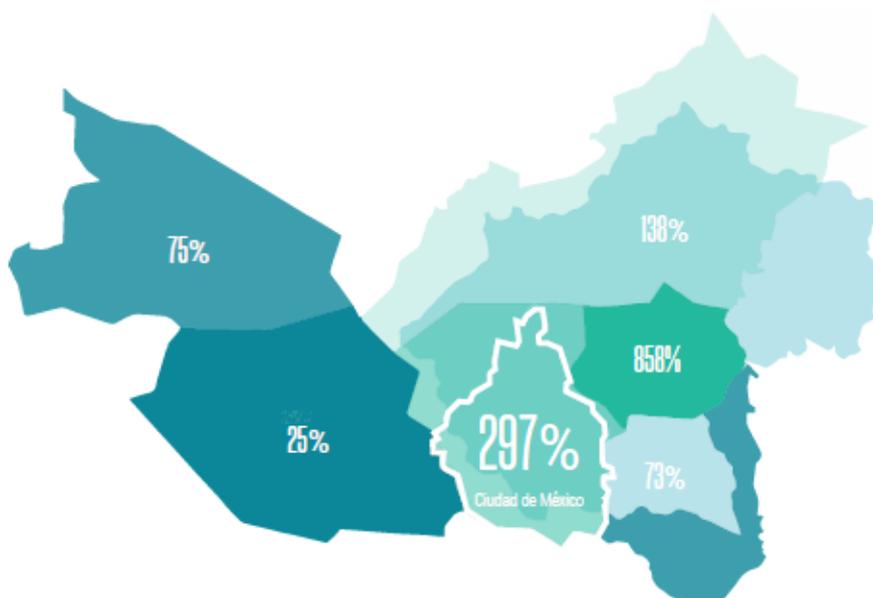
Author, 2016.

## 4.2 Water Sources

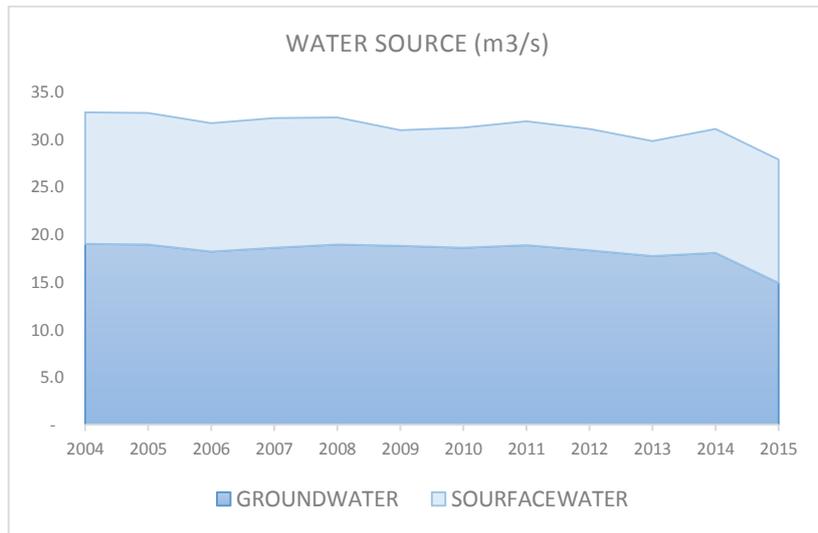
Water sources have been previously described in [section 2.9](#). In the current section, a breakdown is developed by system, showing; who is head administration of the water sources and average water flows by system, the following flows are in the year 2014. The [table 4.1](#) is developed by 2 main sources ([SACMEX, 2014](#); [CONAGUA, 2013, 2014](#)), although other academic sources were considered to acquire a better understanding of the water providence and complexity of the service, ([Haddad, 1991](#); [CONAGUA, 1997](#); [Tortajada, 2003](#); [World Bank, 2013](#)). Over exploitation in the aquifers from the region are clearly explained in [figure 4.3](#)

	Sacmex, 2014. CDMX (hm <sup>3</sup> /y)	Compendio, 2014: Sistema de aguas de la ciudad de México. WATER SOURCES
<b>SACMEX</b> <small>(Sistema de Aguas de la Ciudad de México)</small>	SACAM & PAI UNDERGROUND	Pozos a la Red Norte (2.535): Azcapotzalco, Gustavo A. Madero, Distrito Federal (1.085). Sistema Chiconautla (1.45) Ecatepec, Tecamac, Acolman, Estado de México. (Located outside CDMX. Data united for simplification) Pozos a la Red Centro (1.796): Benito Juárez, Cuauhtémoc, Coyoacan, Distrito Federal. Pozos a la Red Sur (8.198): Milpa Alta, Tláhuac, Xochimilco, Distrito Federal. Pozos a la Red Oriente (2.045): Iztacalco, Iztapalapa, Venustiano Carranza, Distrito Federal. Pozos a la Red Poniente (0.412): Álvaro Obregón, Cuajimalpa, Magdalena Contreras, Miguel Hidalgo, Tlalpan, Distrito Federal. Manantiales (0.691): Álvaro Obregón, Cuajimalpa, Magdalena Contreras, Tlalpan, Distrito Federal.
	LERMA SYSTEM	Sistema (3.832): Ocoyoacac, Otzolotepec, San Lorenzo Oyamel, Temoaya, Xonacatlan, Almoloya de Juárez, Almoloya del Río, Calpuhuac, Ixtlahuaca, Jiquipilco, Joquicingo, San Pedro Techuchulco, Santa Cruz Atizapán y Santiago Tianguistenco, Estado de México.
	VALLE DE MEXICO AQUIFERS	Sistemas de Aguas del Norte Barrientos y Risco (2.239): Tultitlan, Cuautitlán, Tlalnepantla, Estado de México. Sistema de Aguas del Sur (0.382): Milpa Alta, Tláhuac, Valle de Chalco y La Paz, Estado de México .
<b>GAVM</b> <small>(Gerencia de Aguas del Valle de México)</small>	CUTZAMALA SYSTEM	Sistema (9.575): Ixtapan del Oro, Valle de Bravo, Donato Guerra, Villa de Allende, Villa Victoria, Almoloya de Juárez, Toluca, Estado de México.

**Table 4. 4: Water flows by system and administrative dependence.**  
Source: Author, 2016.

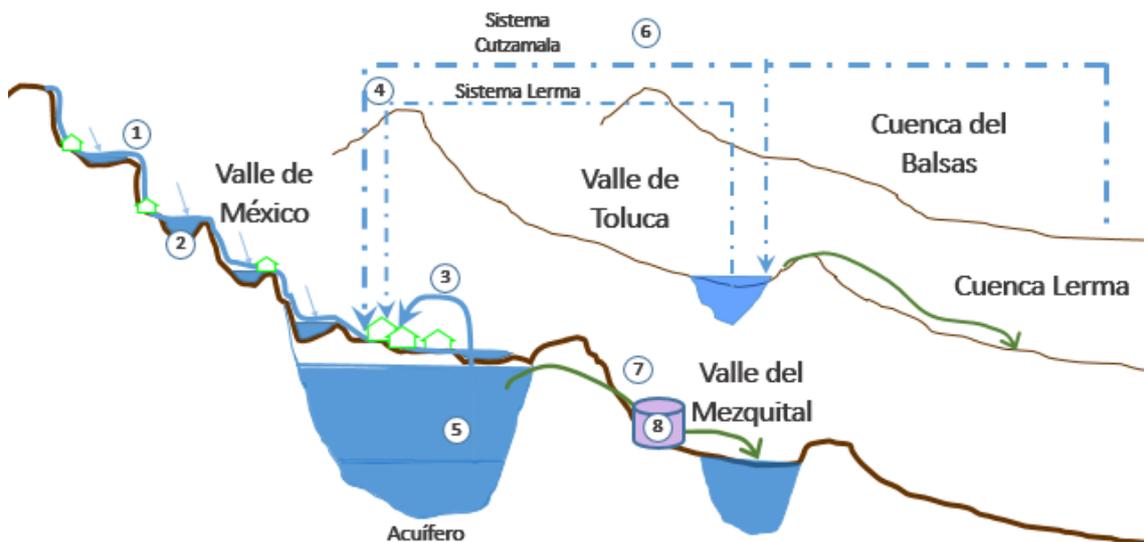


**Figure 4. 1: Mexico City basin and adjacent aquifers exploitation.**  
Source: De Urbanisten, 2016.



**Graph 4. 1: Water supply by source.**  
Source: Author, 2016.

Ground water for year 2014 represents a total of 58 percent or 570 hm<sup>3</sup> and their source is SACAM, PAI & VDM Aquifers, meanwhile surface water represents a total of 42 percent or 410 hm<sup>3</sup>, by Lerma-Cutzamala Systems (see graph 4.1). Exploitation of underground water is causing land subsidence, meanwhile surface water importation causes conflict among livelihoods that crosses and involves 4 states (Michoacán, Estado de Mexico, Jalisco and Hidalgo). Both cause environmental degradation. Figure 4.4 shows current water sources and conveyance in ZMVM, to supply CDMX. In point number 1, 2 & 3 it's possible to appreciate how urban expansion is affecting recharge areas (see section 2.15). Point 4 & 6 are surface water importation systems and it's possible to appreciate long traveling distances and altitudes, for more details see section 4.2.4.



**Figure 4. 2: RHA XIII, Diagram of water supply & disposal.**  
Source: Primary Data<sup>7</sup>

1.-Rainwater (1,688 hm<sup>3</sup>/y), 2.-Aquifers recharge (Valle de Mexico Aquifers), 3.-Water withdrawal from ground water system in CDMX, (SACAM and PAI), 4.-Water importation Lerma System, 5.-Water stress and overexploitation in source, 6.- Water importation Cutzamala System, 7.- Deep sewage system, 8.- Water treatment Plant Atotonilco (not yet operational).

<sup>7</sup> Soft data (PowerPoint presentation) acquired by primary sources: OCAVM, 2016. Available upon request. **Contact:** [morediavalek@gmail.com](mailto:morediavalek@gmail.com)

## 4.3 Water Conveyance

CDMX	2004			2005			2006			2007			2008			2009		
	m3/s	Hm3/y	%															
<b>LCA</b>																		
SACAM & PAI UNDERGROUND	16.32	515	50%	16.23	512	49%	15.53	490	49%	16.04	506	50%	16.31	514	50%	16.24	512	52%
LERMA SYSTEM	3.99	126	12%	3.99	126	12%	3.90	123	12%	3.92	123	12%	3.83	121	12%	4.39	138	14%
<b>SUBTOTAL SACMEX</b>	<b>20.32</b>	<b>641</b>	<b>62%</b>	<b>20.22</b>	<b>638</b>	<b>62%</b>	<b>19.43</b>	<b>613</b>	<b>61%</b>	<b>19.96</b>	<b>629</b>	<b>62%</b>	<b>20.14</b>	<b>635</b>	<b>62%</b>	<b>20.63</b>	<b>651</b>	<b>67%</b>
VALLE DE MEXICO AQUIFERS	2.67	84	8%	2.71	85	8%	2.67	84	8%	2.55	80	8%	2.62	83	8%	2.58	81	8%
CUTZAMALA SYSTEM	9.84	310	30%	9.87	311	30%	9.60	303	30%	9.71	306	30%	9.58	302	30%	7.74	244	25%
<b>SUBTOTAL GAVM</b>	<b>12.52</b>	<b>395</b>	<b>38%</b>	<b>12.58</b>	<b>397</b>	<b>38%</b>	<b>12.27</b>	<b>387</b>	<b>39%</b>	<b>12.26</b>	<b>386</b>	<b>38%</b>	<b>12.19</b>	<b>385</b>	<b>38%</b>	<b>10.32</b>	<b>325</b>	<b>33%</b>
<b>TOTAL WATER SUPPLY</b>	<b>32.83</b>	<b>1,035</b>	<b>100%</b>	<b>32.79</b>	<b>1,034</b>	<b>100%</b>	<b>31.70</b>	<b>1,000</b>	<b>100%</b>	<b>32.21</b>	<b>1,016</b>	<b>100%</b>	<b>32.34</b>	<b>1,020</b>	<b>100%</b>	<b>30.95</b>	<b>976</b>	<b>100%</b>
TOTAL RE-USE	3.79	120	12%	3.53	111	11%	3.53	111	11%	2.81	88	9%	3.12	98	10%	3.33	105	11%
TOTAL SEWAGE	29.04	916	88%	29.27	923	89%	28.18	889	89%	29.41	927	91%	29.21	921	90%	27.62	871	89%
<b>TOTAL RE-USE &amp; TREATMENT</b>	<b>32.83</b>	<b>1,035</b>	<b>100%</b>	<b>32.79</b>	<b>1,034</b>	<b>100%</b>	<b>31.70</b>	<b>1,000</b>	<b>100%</b>	<b>32.21</b>	<b>1,016</b>	<b>100%</b>	<b>32.34</b>	<b>1,020</b>	<b>100%</b>	<b>30.95</b>	<b>976</b>	<b>100%</b>
<b>TOTAL LCA WATER CONVEYED</b>	<b>65.67</b>	<b>2,071</b>	<b>100%</b>	<b>65.58</b>	<b>2,068</b>	<b>100%</b>	<b>63.40</b>	<b>1,999</b>	<b>100%</b>	<b>64.43</b>	<b>2,032</b>	<b>100%</b>	<b>64.67</b>	<b>2,039</b>	<b>100%</b>	<b>61.90</b>	<b>1,952</b>	<b>100%</b>

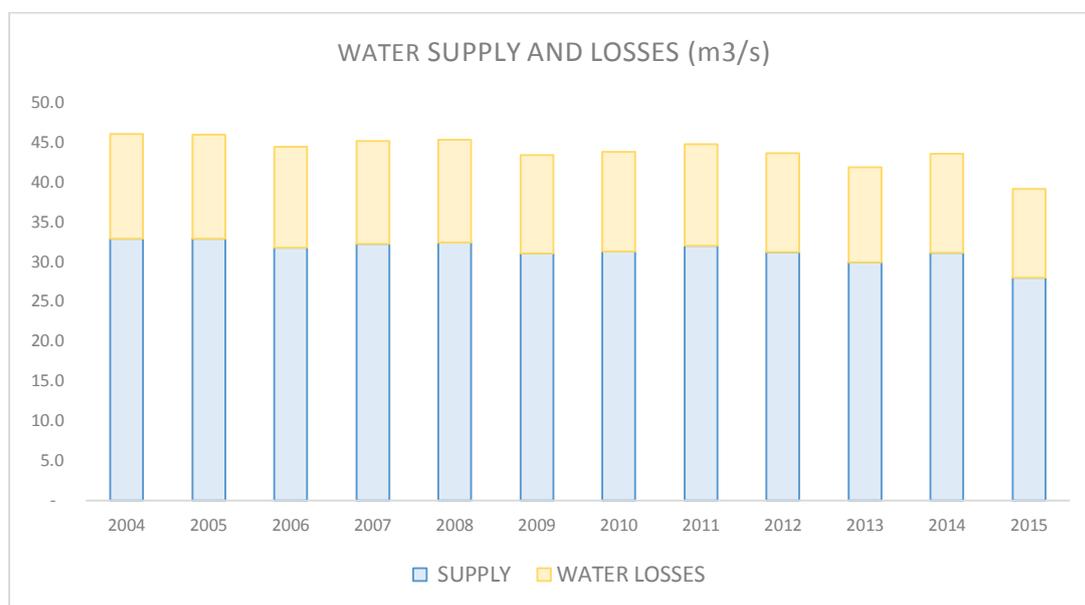
CDMX	2010			2011			2012			2013			2014			2015		
	m3/s	Hm3/y	%	m3/s	Hm3/y	%	m3/s	Hm3/y	%									
<b>LCA</b>																		
SACAM & PAI UNDERGROUND	16.26	513	52%	16.27	513	51%	15.96	503	51%	15.40	486	52%	15.68	494	50%	12.50	394	45%
LERMA SYSTEM	4.20	132	13%	3.95	125	12%	4.14	131	13%	4.03	127	13%	3.64	115	12%	3.64	115	13%
<b>SUBTOTAL SACMEX</b>	<b>20.46</b>	<b>645</b>	<b>65%</b>	<b>20.22</b>	<b>638</b>	<b>63%</b>	<b>20.10</b>	<b>634</b>	<b>65%</b>	<b>19.43</b>	<b>613</b>	<b>65%</b>	<b>19.32</b>	<b>609</b>	<b>62%</b>	<b>16.14</b>	<b>509</b>	<b>58%</b>
VALLE DE MEXICO AQUIFERS	2.33	74	7%	2.60	82	8%	2.40	76	8%	2.34	74	8%	2.40	76	8%	2.40	76	9%
CUTZAMALA SYSTEM	8.45	266	27%	9.09	287	28%	8.62	272	28%	8.09	255	27%	9.35	295	30%	9.35	295	34%
<b>SUBTOTAL GAVM</b>	<b>10.78</b>	<b>340</b>	<b>35%</b>	<b>11.69</b>	<b>369</b>	<b>37%</b>	<b>11.02</b>	<b>348</b>	<b>35%</b>	<b>10.43</b>	<b>329</b>	<b>35%</b>	<b>11.75</b>	<b>371</b>	<b>38%</b>	<b>11.75</b>	<b>371</b>	<b>42%</b>
<b>TOTAL WATER SUPPLY</b>	<b>31.24</b>	<b>985</b>	<b>100%</b>	<b>31.91</b>	<b>1,006</b>	<b>100%</b>	<b>31.12</b>	<b>981</b>	<b>100%</b>	<b>29.85</b>	<b>941</b>	<b>100%</b>	<b>31.072</b>	<b>980</b>	<b>100%</b>	<b>27.90</b>	<b>880</b>	<b>100%</b>
TOTAL RE-USE	3.33	105	11%	3.33	105	10%	3.06	97	10%	3.11	98	10%	3.42	108	11%	3.42	108	12%
TOTAL SEWAGE	27.91	880	89%	28.58	901	90%	28.05	885	90%	26.74	843	90%	27.65	872	89%	24.48	772	88%
<b>TOTAL RE-USE &amp; TREATMENT</b>	<b>31.24</b>	<b>985</b>	<b>100%</b>	<b>31.91</b>	<b>1,006</b>	<b>100%</b>	<b>31.12</b>	<b>981</b>	<b>100%</b>	<b>29.85</b>	<b>941</b>	<b>100%</b>	<b>31.07</b>	<b>980</b>	<b>100%</b>	<b>27.90</b>	<b>880</b>	<b>100%</b>
<b>TOTAL LCA WATER CONVEYED</b>	<b>62.48</b>	<b>1,970</b>	<b>100%</b>	<b>63.82</b>	<b>2,013</b>	<b>100%</b>	<b>62.23</b>	<b>1,963</b>	<b>100%</b>	<b>59.71</b>	<b>1,883</b>	<b>100%</b>	<b>62.14</b>	<b>1,960</b>	<b>100%</b>	<b>55.79</b>	<b>1,759</b>	<b>100%</b>

**Table 4. 5: Water flows by system and administrative dependence.**

Source: Author, 2016.<sup>8</sup>

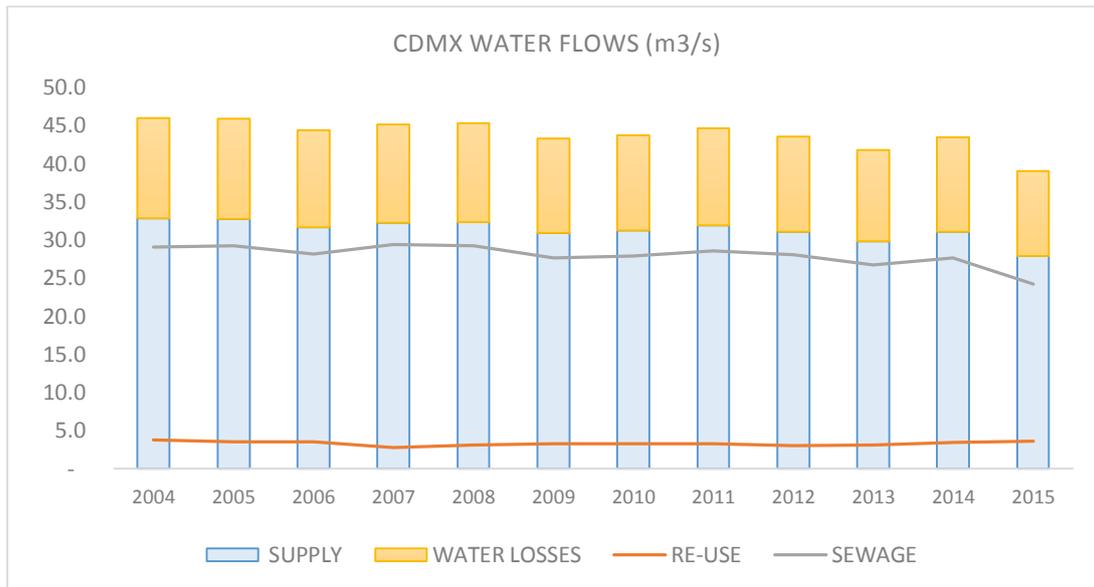
<sup>8</sup> This table ignores all rainwater flows in sewage, it is calculated on supply minus re-use.

Water flows are clearly showed in [table 4.2](#). Represented by year, from 2004/15, both  $m^3/s$  and  $hm^3/y$ . The data shows in the year 2014, that 50 percent of the water supplied belongs to the underground water system SACAM & PAI, a total of  $494 hm^3$ . In comparison to previous 52 percent in 2013 ( $486 hm^3$ ), and 51 percent in 2012 ( $503 hm^3$ ) and so on. The Lerma System has supplied Mexico City with 12 percent (2014) a total of  $115 hm^3$ , in previous years correspondently with 13 percent ( $127$  and  $131 hm^3$ ). Both administrated by SACMEX (2016), provided 62 percent of the water ( $609 hm^3$ ) to the capital city in 2014. GAVAM supplied in 2014 a total amount of  $371 hm^3$  or 38 percent of the total water, conveyed from Valle de Mexico Aquifers with 8 percent ( $76 hm^3$ ) and Cutzamala System with 30 percent ( $295 hm^3$ ). Being 2014/15 the years with biggest dependence on water importation from the Cutzamala. A total of  $980 hm^3$  of water where supplied in 2014, by now we know that leakages in the system are around 40 to 50 percent or additional  $392 (12.42 m^3/s)$  and  $490 hm^3 (15.53 m^3/s)$  (see [table 4.2](#)) correspondently, added to the following tables (or numbers) showing more realistic history of the water conveyed in the supply grid. Solutions are to reduce and control water losses.



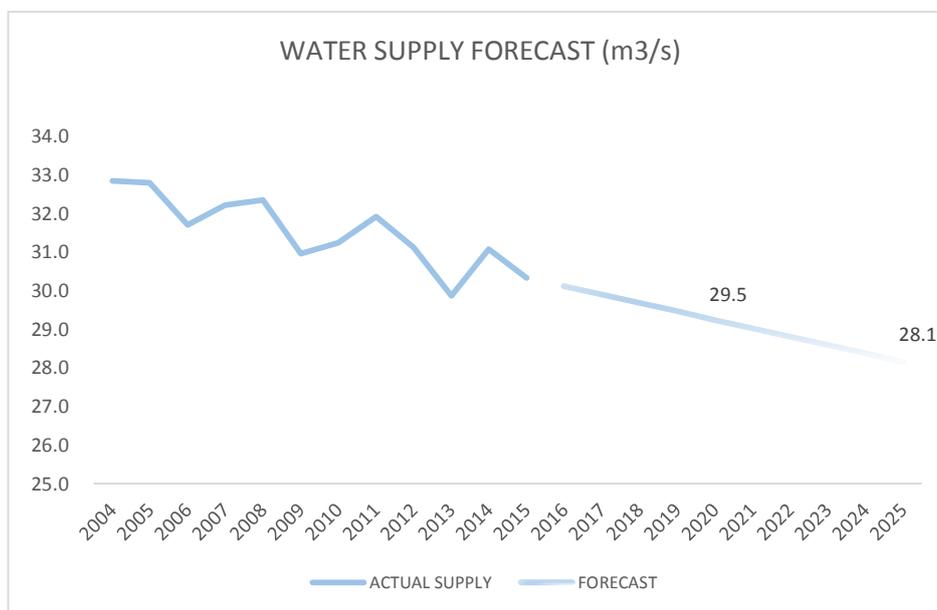
**Graph 4. 2: Water supply and grid losses of 40 percent.**  
Source: Author, 2016.

Both [graph 4.2](#) and [4.3](#), show the total water flows in CDMX. Water treatment and re-use is done only in 12 percent (2015), and mostly for agricultural and industrial purposes, sending the rest 88 percent of water to the sewage, easily flooded by storms (most of the sewage water is not treated and is pumped many km to the Gulf of Mexico, the water quality is never mentioned and highly suspicious whereabouts). Showing a great potential for water savings in future years, (see [section 4.9](#)). Currently the biggest treatment plant in the world is under construction, it will treat up to 60 percent of the total flows of ZMVM and hopefully will reduce water dependence of over-exploited sources.



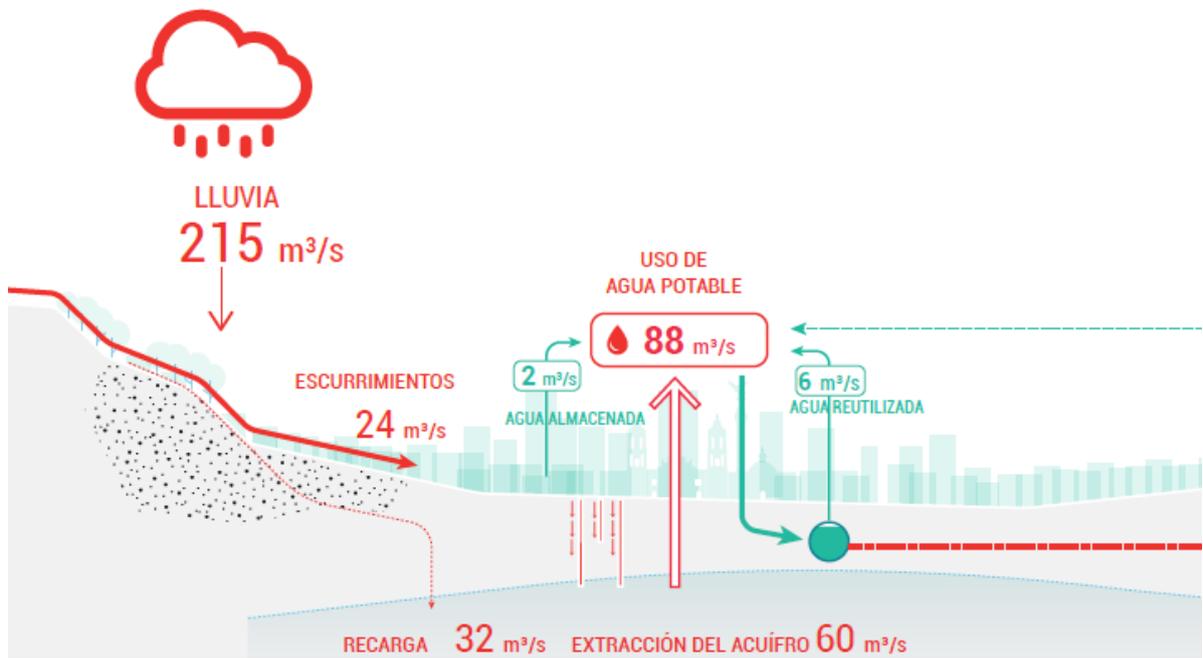
**Graph 4. 3: Water flows by typology.**  
Source: Author, 2016.

Even though CDMX has a population of almost 9 million habitants the growth rate has decreased intensively from 4,8 percent in 1960 to a current 0,3 percent, in contrast with the national average of 1.9 percent according to INEGI (2015). As the population decreases the city’s water consumption has also decreased. From; 1,035 hm<sup>3</sup>/y in 2004 to 980 hm<sup>3</sup>/y in 2014, (see graph 4.3). A water supply forecast is also showed in the previous, made from the 11 years of historic water supply in the city, it predicts a linear decrease. According to the current baseline scenario<sup>9</sup> a linear reduction towards 2020 will be around 29.5 m<sup>3</sup>/s or an equivalent 930 hm<sup>3</sup>/y, and will continue towards 2025 with 28.1 m<sup>3</sup>/s or an equivalent of 886 m<sup>3</sup>/s, by the current decrease rate. See graph 4.4

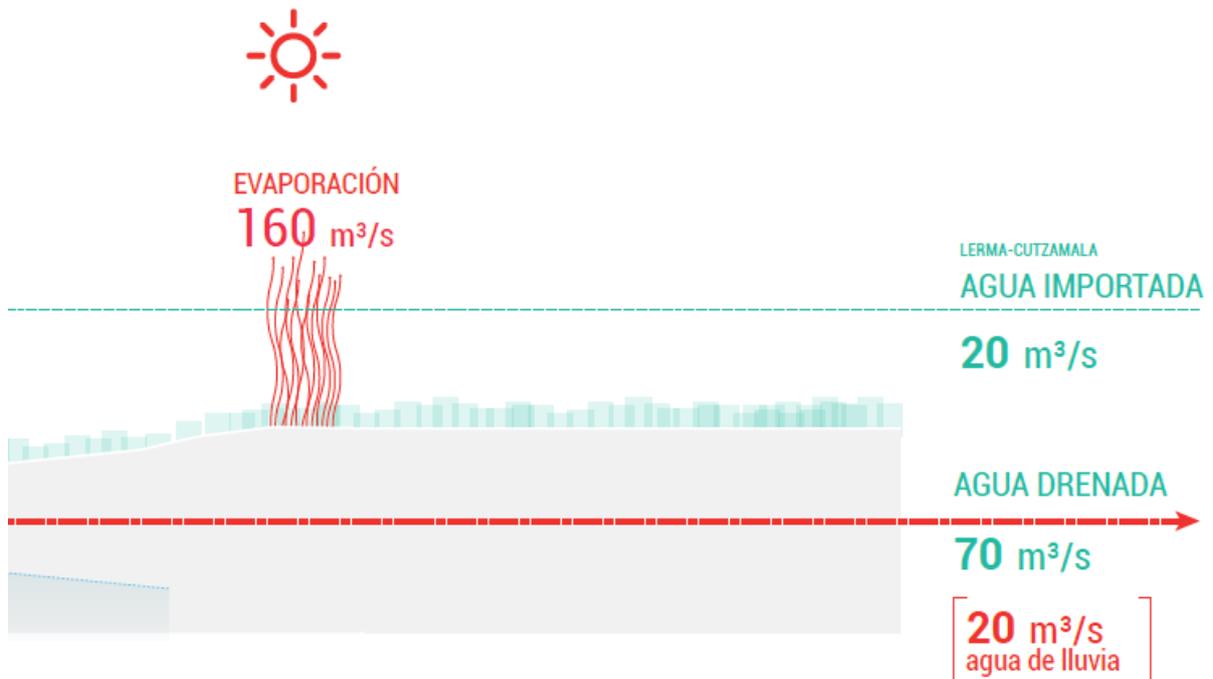


**Graph 4. 4: Water supply forecast.**  
Source: Author, 2016.

<sup>9</sup> The year 2015 has not been taken account of as it drastically changes the forecasting on the water supply, due to its aggressive decrease is not confirmed to be linear in future years.



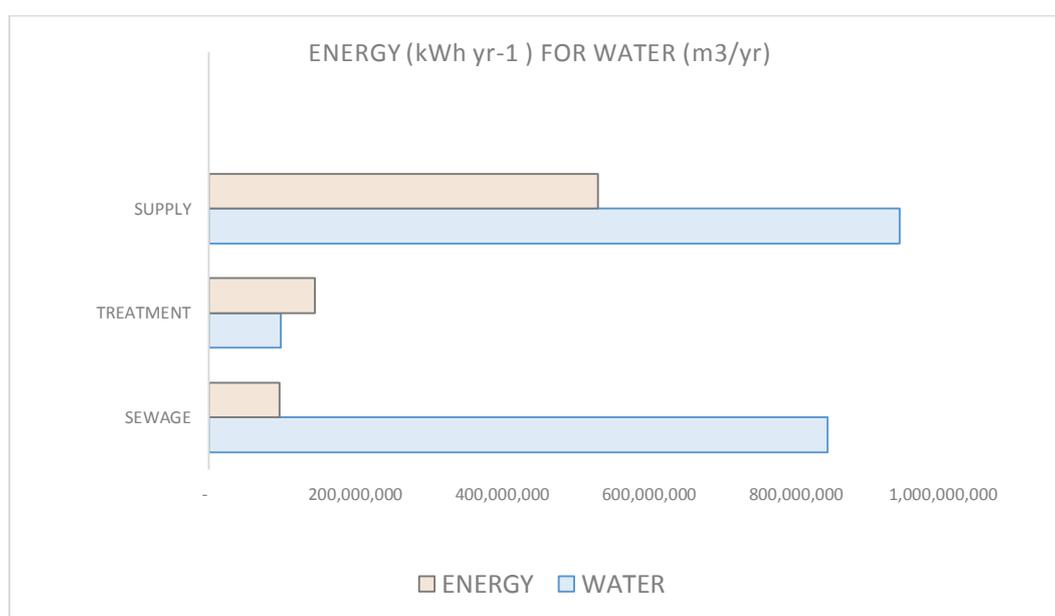
**Figure 4. 3: Mexico City water flows.**  
Source: De Urbanisten, 2016.



**Figure 4. 4: Mexico City water flows.**  
Source: De Urbanisten, 2016.

## 4.4 Energy Demand

Water dependency on energy is showed in the following graph (4.5). It establishes the relation between water and energy and potential savings. The current energy data was collected by primary sources<sup>10</sup>, is based on all the water cycles processes (supply, treatment, and sewage). Rain water is not showed in this table but forms part of the total energy consumption for sewage that represents 21 percent of the total energy used in the water LCA in 2015. It is calculated (Valdez, 2016) that around 30 percent of the water supplied in 2014 enters the sewage systems and it is possible to add this percentage to the total water pumped by the sewage system (9.32 m<sup>3</sup>/s), although the energy will not be affected. The energy used for water supply in 2014 accounted for 71 percent of the total energy paid by the city water company SACMEX, 10 percent for water treatment and re-use, and 13 percent in sewage. By the current table we relate the water to a certain energy use, stating water savings would mean energy savings.



**Graph 4. 5: Energy (kWh yr-1) consumption by process in the urban-water (m3/yr) cycle.**

Source: Author, 2016.

LCA CDMX ENERGY DEMAND	2013			2014			2015		
	m3/s	kWh yr-1	%	m3/s	kWh yr-1	%	m3/s	kWh yr-1	%
TOTAL SUPPLY	29.85	530,009,216	69%	31.072	515,278,288	71%	27.90	392,000,514	68%
TOTAL TREATMENT / RE-USE	3.11	144,397,108	19%	3.42	75,005,410	10%	3.64	60,335,845	11%
TOTAL SEWAGE	26.74	96,409,852	13%	27.65	130,920,469	18%	24.26	121,388,489	21%
<b>TOTAL Urban-Water LCA ENERGY DEMAND</b>	<b>59.71</b>	<b>770,816,176</b>	<b>100%</b>	<b>62.14</b>	<b>721,204,167</b>	<b>100%</b>	<b>55.79</b>	<b>573,724,848</b>	<b>100%</b>

**Table 4. 6: Energy consumption by process in the urban-water cycle.**

Source: Author, 2016.

<sup>10</sup> All hard copy's where recorded and are available upon request. Contact: [morediavalek@gmail.com](mailto:morediavalek@gmail.com)

By studying the urban water-energy nexus, I'm able to forecast the energy use by the urban water cycle in the future years, using CMM energy intensity factor<sup>11</sup>. It is possible to show that the baseline scenario for energy will decrease demand from the water cycle use in the city. By 2020 the energy use from the water cycle forecast is to demand 1,134 million kWh yr-1 and by 2025 will decrease on 1,091 million kWh yr-1

YEAR	WATER FORECAST (m3/s)	ENERGY FORECAST kWh yr-1
2016	30.11	1,167,962,147
2017	29.89	1,159,496,916
2018	29.67	1,151,031,684
2019	29.46	1,142,566,453
2020	29.24	1,134,101,221
<b>SUB-TOTAL DEMAND</b>	<b>148.37</b>	<b>5,755,158,421</b>
2021	29.02	1,125,635,990
2022	28.80	1,117,170,759
2023	28.58	1,108,705,527
2024	28.36	1,100,240,296
2025	28.15	1,091,775,064
<b>TOTAL DEMAND</b>	<b>291.28</b>	<b>11,298,686,057</b>

**Table 4. 7: Water supply forecast and the equivalent energy.**  
Source: Author, 2016.

## 4.5 Equivalent Carbon Emissions

The equivalent CO<sub>2</sub> emissions due the energy use on the urban water cycle are determined by the mix typology of Mexico energy production in this case a selected factor of 0.65 kg per kWh, according to IPCC factor corresponding to the country, other factors are established and compared in the following graphs (4.6 & 4.7). In 2013, water supply was in its lowest points than in the previous 10 years, growth in water re-use stagnated. The total energy consumed by the water urban-cycle has CO<sub>2</sub> implication as stated before. The emissions produced for the supply are 344,505 ton CO<sub>2e</sub> yr-1, in comparison with 2014 that supplied more water with better efficiency up to 2015 that has lower emissions in all 3 p. The re-use and treatment sector has impressively increased its energy efficiency and related emissions, in the last 3 years was cut by half, meanwhile a slight increase on re-use has been denoted. This may be possible due to better and more efficient treatment plants, since 2012 municipalities have developed reforms oriented by international organizations not only to increase efficiency and cut emissions but also to produce energy (ESMAP, 2012). Energy production from wastewater is an important upgrade for the Mexican context. The Atotonilco treatment plant is under construction and will be capable of treating 60 percent of total water from ZMVD, meaning that still best water management plans are oriented to travel 60 km to find treatment, when the solution to several problems are meet by treating and re-using the water as many times and as close possible. In a water stressed city like the mega-polis, stricter, ambitious and innovative management has to endure the population growth, urban sprawl and climate change. Best practices around the

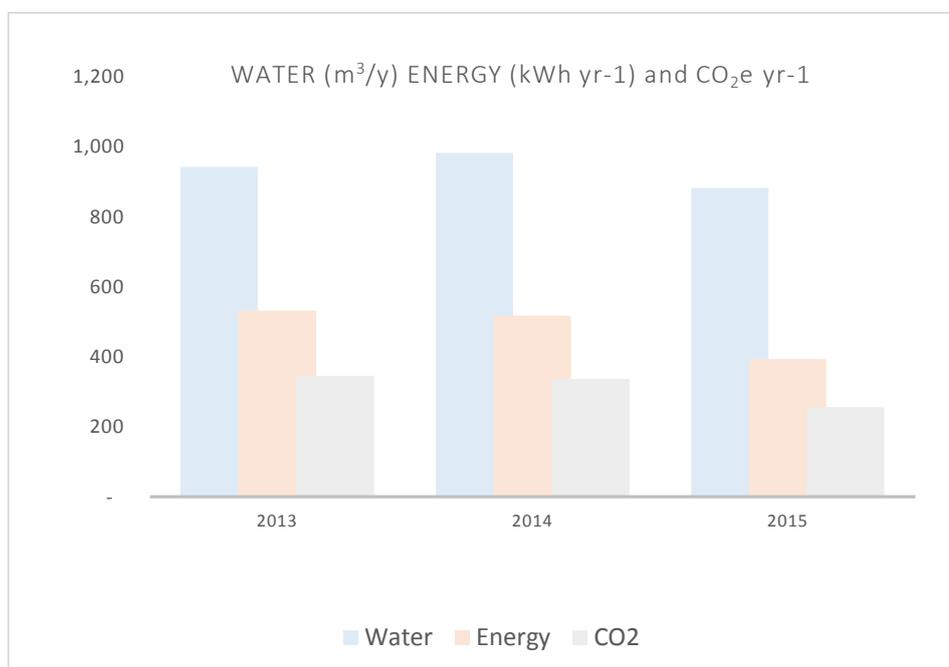
<sup>11</sup> I used CMM energy intensity factor, because primary data has been denied for most of the energy consumed separately in all of the different sources, and insufficient years data to forecast adequately.

world have found synergy's to the water-energy-climate nexus like producing more energy that the treatment plant needs to not only stop consuming massive amounts of energy with high emissions factor but also to supply energy to the grid that may alleviate pick hours, proving itself to be cost and environmental effective, and comes without question a water resilience agenda, as this water may be used not only for re-use for the green and blue services of the cities but also to recharge aquifers levels that in the Mexican context has a millionaire value. The following table may be interpreted as an opportunity to reduce carbon emissions and reduce energy, meanwhile ensuring water security. It is in this table where data co-relates and interlink the 3 main variables of this research, the water-energy-climate nexus is proven, and the identification of possible water-energy savings are of most interest for a city like CDMX, as today is a laboratory of urban innovation with the highest complexity.

LCA CDMX CO <sub>2</sub> e BY ENERGY MIX 0.65	2013				2014				2015			
	m <sup>3</sup> /s	kWh yr-1	kg CO <sub>2</sub> e yr-1	%	m <sup>3</sup> /s	kWh yr-1	kg CO <sub>2</sub> e yr-1	%	m <sup>3</sup> /s	kWh yr-1	kg CO <sub>2</sub> e yr-1	%
TOTAL WATER SUPPLY	29.85	530,009,216	344,505,990	69%	31.072	515,278,288	334,930,887	71%	27.90	392,000,514	254,800,334	68%
TOTAL RE-USE	3.11	144,397,108	93,858,120	19%	3.42	75,005,410	48,753,517	10%	3.64	60,335,845	39,218,299	11%
TOTAL SEWAGE	26.74	96,409,852	62,666,404	13%	27.65	130,920,469	85,098,305	18%	24.26	121,388,489	78,902,518	21%
<b>TOTAL LCA WATER CONVEYED</b>	<b>59.71</b>	<b>770,816,176</b>	<b>501,030,514</b>	<b>100%</b>	<b>62.14</b>	<b>721,204,167</b>	<b>468,782,709</b>	<b>100%</b>	<b>55.79</b>	<b>573,724,848</b>	<b>372,921,151</b>	<b>100%</b>

**Table 4. 8: Urban water-energy-carbon emissions by year and process.**

Source: Author, 2016.



**Graph 4. 6: Urban water-energy-carbon emissions by year and process.**

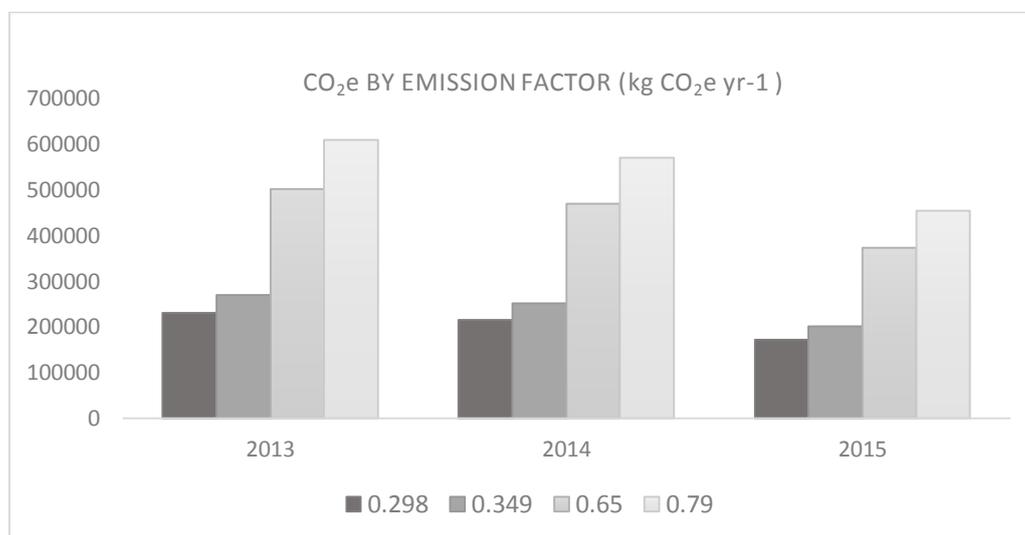
Source: Author, 2016.

Different academic sources have talked of the energy mix factors for the Mexican context, it is imperative that emission factors continue reducing, basically by changing the energy mix and changing the technology to one up to date towards more climate/economic effectiveness. In this research the carbon emissions are calculated by the 0.65 factor (IPCC, 2103), and three other factor established to compare among each other. If the energy mix factor reduces by almost half (0.349) the carbon emissions do consequently, a potential carbon abatement is to be considered by the energy nexus. Being not part of this study as I focus on the urban-water cycle may contribute with strong numbers to the mitigation potential of the city.

ACADEMIC SOURCE ENERGY MIX FACTOR	kg CO <sub>2</sub> e yr-1			
	INNEC, 2012 0.298	UNAM, 2014 0.349	IPCC, 2013 0.650	Itten, 2014 0.790
<b>2013</b>	229,703,220	269,014,845	501,030,514	608,944,779
<b>2014</b>	214,918,842	251,700,254	468,782,709	569,751,292
<b>2015</b>	170,970,005	200,229,972	372,921,151	453,242,630

**Graph 4. 7: Carbon emissions by year compared with different emissions factors.**

Source: Author, 2016.



**Table 4. 9: Carbon emissions by year compared with different emission factors.**

Source: Author, 2016.

By studying the urban water-energy-climate nexus, I'm able to forecast the energy use by the urban water cycle in the future years and its equivalent CO<sub>2</sub> emissions. It is possible to show that baseline scenario for energy will decrease demand from the water cycle use in the city and consequently the emissions. By 2020 the CO<sub>2e</sub> emitted from the water cycle forecast is to decrease to 737 million kg CO<sub>2e</sub> and by 2025 the forecast shows that it will continue decreasing to 709 million kg CO<sub>2e</sub>, showing strong potential from the urban-water cycle to increase efforts to contribute to mitigate climate change effects, (see table 4.7).

YEAR	WATER FORECAST	ENERGY FORECAST	CO2 EMISSIONS
	(m3/s)	kWh yr-1	kg CO2e yr-1
2016	30.11	1,167,962,147	759,175,396
2017	29.89	1,159,496,916	753,672,995
2018	29.67	1,151,031,684	748,170,595
2019	29.46	1,142,566,453	742,668,194
2020	29.24	1,134,101,221	737,165,794
<b>SUB-TOTAL DEMAND</b>	<b>148.37</b>	<b>5,755,158,421</b>	<b>3,740,852,974</b>
2021	29.02	1,125,635,990	731,663,393
2022	28.80	1,117,170,759	726,160,993
2023	28.58	1,108,705,527	720,658,593
2024	28.36	1,100,240,296	715,156,192
2025	28.15	1,091,775,064	709,653,792
<b>TOTAL DEMAND</b>	<b>291.28</b>	<b>11,298,686,057</b>	<b>7,344,145,937</b>

**Table 4. 10: Water supply forecast and its equivalent energy-carbon.**  
Source: Author, 2016.

## 4.6 Data Comparison

Currently the water-energy nexus has been slightly studied, in the course of this research Mario Molina Institute and UNAM have been the only to explore this sector. Interesting as it sounds the rest of the publications are based on their research. For reasons unknown to me the institute shows high jealousy on their study as small publication are revealed, meetings with their research staff was impossible in my visit to the capital city and their methodology unclear. However, they do reveal some numbers and by the primary data I collected I've been able to develop the following table (4.8).

LCA CDMX 2014	SACMEX PRIMARY					CMM SECONDARY				
	m3/s	%	kWh yr-1	kg CO2e yr-1	%	m3/s	%	kWh yr-1	kg CO2e yr-1	%
			<b>0.65</b>					<b>0.65</b>		
SACAM & PAI UNDERGROUND	15.68	50%	515,278,288	334,930,887	71%					
SACAM UNDERGROUND						23.93	77%	403,664,282	262,381,783.02	26%
PAI UNDERGROUND						1.55	5%	12,395,565	8,057,117.50	1%
LERMA SYSTEM	3.64	12%								
<b>SUBTOTAL SACMEX</b>	<b>19.32</b>	<b>62%</b>	<b>515,278,288</b>	<b>334,930,887</b>	<b>71%</b>	<b>82%</b>	<b>416,059,847</b>	<b>270,438,901</b>	<b>27%</b>	
VALLE DE MEXICO AQUIFERS	2.40	8%								
LERMA - CUTZAMALA SYSTEM						5.59	18%	801,116,082	520,725,453.40	52%
CUTZAMALA SYSTEM	9.35	30%								
<b>SUBTOTAL GAVM</b>	<b>11.75</b>	<b>38%</b>				<b>18%</b>	<b>801,116,082</b>	<b>520,725,453</b>	<b>52%</b>	
<b>TOTAL WATER SUPPLY</b>	<b>31.07</b>	<b>100%</b>	<b>515,278,288</b>	<b>334,930,887</b>	<b>71%</b>	<b>31.07</b>	<b>100%</b>	<b>1,217,175,929</b>	<b>791,164,354</b>	<b>80%</b>
TOTAL RE-USE	3.42	11%	75,005,410	48,753,517	10%	3.42	11%	265,318,675	172,457,138.88	17%
TOTAL SEWAGE	27.65	89%	130,920,469	85,098,305	18%	27.65	89%	43,601,674	28,341,087.84	3%
<b>TOTAL RE-USE &amp; TREATMENT</b>	<b>31.07</b>	<b>100%</b>	<b>205,925,879</b>	<b>133,851,821</b>	<b>29%</b>	<b>31.07</b>	<b>100%</b>	<b>308,920,349</b>	<b>200,798,227</b>	<b>20%</b>
<b>TOTAL LCA WATER CONVEYED</b>	<b>62.14</b>	<b>100%</b>	<b>721,204,167</b>	<b>468,782,709</b>	<b>100%</b>	<b>62.14</b>	<b>100%</b>	<b>1,526,096,278</b>	<b>991,962,581</b>	<b>100%</b>

**Table 4. 11: Data comparison on primary-secondary collection for the urban water-energy-carbon emissions.**  
Source: Author, 2016.

In the previous table, the baseline scenario for water is kept by the operator SACMEX but the percentages over source are shifted from their study. The Mexican operator reports a total water supplied of 31.07 m<sup>3</sup>/s in the year 2014, same year of the Institute publication (CMM). In contrast from the baseline reported of 50 percent from underground water from SACAM and PAI, Centro Mario Molina notifies 77 percent of total water extraction from underground sources, meaning that not even all underground sources even outside CDMX will total their numbers, and only 58 percent of the water has been supply from this sources in the current year, consequently altering the percentages of all other sources. However, they have established the baseline energy consumption of the LCA in 1.32 kWh per m<sup>3</sup>. The previous contemplates the energy demand of the service for water supply, treatment and sewage. They have even break it down in deeper levels as following; tap water has an [energy consume index \(ICE\)](#) of 1.23 kWh/m<sup>3</sup> and sewage of 0.05 kWh/m<sup>3</sup>. Meanwhile water treatment has a total ICE of 2.46 kWh/m<sup>3</sup>. Further statements assure ICE increase within time and equivalent emissions. The numbers for supply from the operator SACMEX have been close to the given numbers.

Of great value to my study, the ICE per system was also given by the institute. Previous interview with head staff of technical department of GAVM was not able to proportionate the energy consume of their process, but it is well known by all the international organizations academic, governmental institutions and overall stakeholders, that their energy consumption is unprecedented, and some may even say that represents up to 80 percent of their total cost. For the previous CMM holds up to date the only ICE by system and it is as following; 0.535

kWh/m<sup>3</sup> from underground water SACAM; 4.541 kWh/m<sup>3</sup> Lerma-Cutzamala System and 0.253 kWh/m<sup>3</sup> from PAI. Note that this energetic average of the cycles are analysed and compared by their water percentages but maintaining the water baseline given by the official water operators. In contrast with a 42 percent of water supplied by the Lerma-Cutzamala Systems (SACMEX, 2014), CMM (2014) have established that the previous had supplied in that year with only 18 percent of the total water to CDMX, with a total 801,116 MWh/m<sup>3</sup> and by the emissions factor (0.65) estimates that the total emissions from the Lerma-Cutzamala are of 520,725,453 kgCO<sub>2</sub>eyr<sup>-1</sup>. The previous numbers are of very interesting as water importation establishes enormous GHG emissions and by stopping reducing gradually their supply, huge abatement is related. And related problematic to water conflicts are also bounded.

## 4.7 Water Savings Measures

In this section the identification of water savings measures, for the city context are establish. It is a combination between the previous chapter 2 and data collection from the survey, answered by the experts in Mexico City, the savings are bravely explain as followed, (see table 2.2). First, the selection of the saving measures are according to their results ranking, and only the 3 best will be selected (see section 4.1).

Adaptation-Mitigation Interrelations				
Urban Water-Energy-Climate Nexus	City Respond to Climate Change			
Water Saving Measures	Water Security	Flood Capacity Enhancement	CO <sub>2</sub> Emissions Abatement	
3	Rainwater harvest on buildings by off-grid technologies	Water source relief	Delay and capture rainwater	Lowens systems energy consumption
	Rainwater harvest and reteinment on public space by promoting eco-system services and water sensible infrastructure	Water source relief	Delay and capture rainwater	Lowens systems energy consumption
	Recycle water use	Water source relief		Technology implementation to produce clean energy
1	Water leakage/loss reduction in grids	Water source relief		
	Up-date technology in the urban water cycle service			Lowens systems energy consumption
2	Reform on water pricing, according to water consumption and based tariffs	Water source relief		
	Water savings campaign	Water source relief		

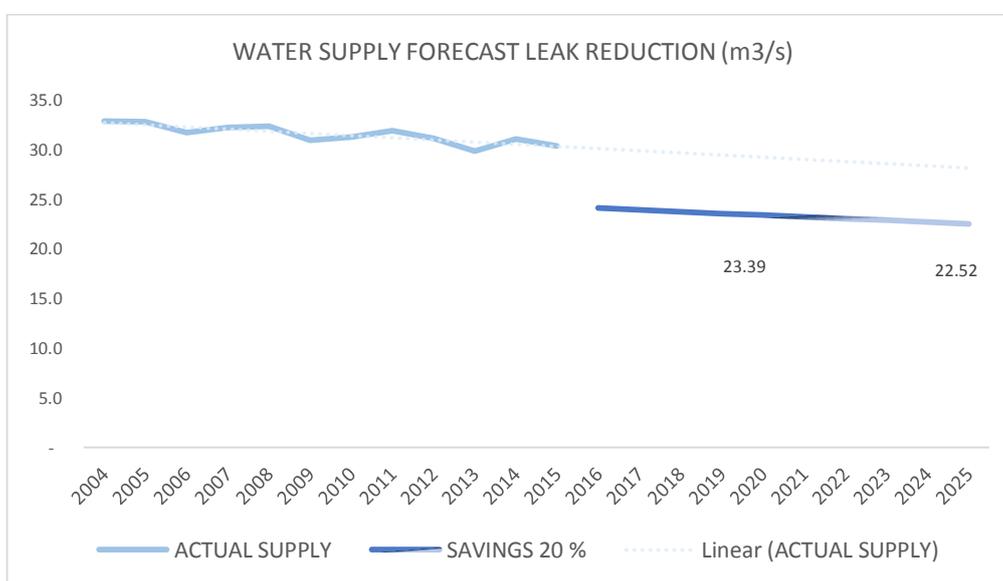
**Table 4. 12: Selected WSM for the local context (CDMX) and interrelation with the city respond to climate change.**

Source: Author, 2016.

### 4.7.1 Leakage reduction

Proven by both the survey and literature, this measure proved to be the most important water saving measure. In CDMX context it comes to 40-50 percent of water lost in primary and secondary grids. For years, governmental strategy has been developed and financed to cover as much as **20 percent** of the current leakage and to avoid water losses before year 2030, (CONAGUA, 2013, 2014, and 2015; 100 Resilient Cities, 2016). Such repairs could currently be of a total **6 m<sup>3</sup>/s**, double amount of the current water delivered from the Lerma System, or 60 percent of the current Cutzamala System and equivalent energy-CO<sub>2</sub>. Future projects to import water are also estimated in 6 m<sup>3</sup>/s like Temascaltepec or Tula-Hidalgo with a future supply estimated in 7 m<sup>3</sup>/s (CONAGUA, 2016). One of the survey respondents said:

*“Potential water savings and energy use reduction in the cycle, relies on the efficient distribution of the water systems. It currently losses around 40 to 45 percent, being such option the most viable.”*



**Graph 4. 8: Water supply forecast with 20 percent savings, 2016/25.**

Source: Author, 2016.

This measure show strong potential to reduce water-energy use, meanwhile mitigating substantial Co<sub>2e</sub> emissions. Water availability will increase as less leakage will allow delegations with low supply to enjoy this resource, it’s forecasted that; 20 percent savings are achievable by implementing this option (SACMEX, 2016) and it may bring water consumption by 2020 to 23.4 m<sup>3</sup>/s or an equivalent of 738 hm<sup>3</sup>/y. A consequent decrease on the energy, assumes that by 2020 a total demand of 1,134 million kWh yr-1 and by 2025 will further decrease on 1,091 million kWh yr-1. The equivalent Co<sub>2</sub> is forecast to decrease to 737 million kg CO<sub>2</sub> and by 2025 the forecast shows that it will continue decreasing to 709 million kg CO<sub>2</sub>, showing strong potential to mitigate climate change effects, (see graph 4.8 and table 4.10).

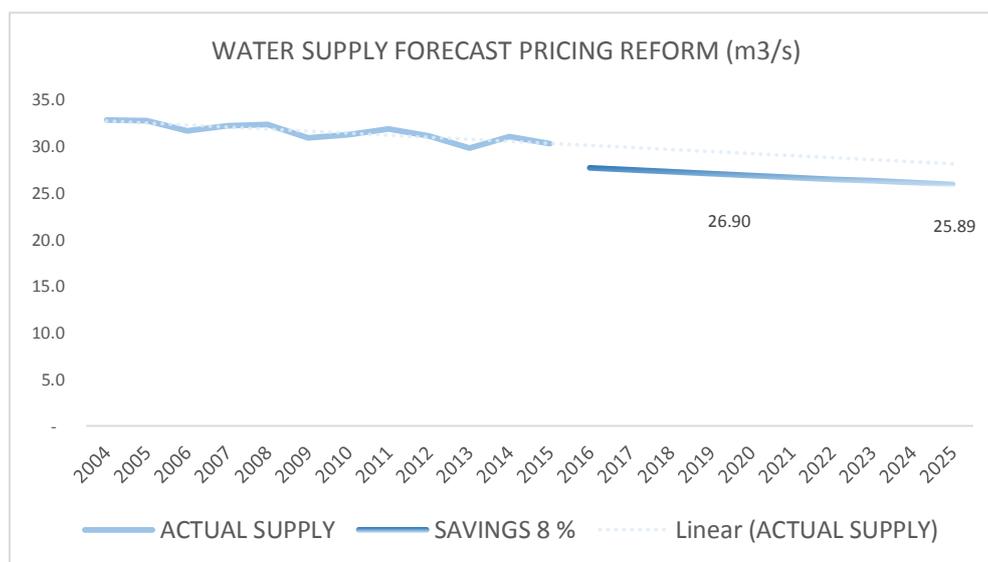
YEAR	SAVINGS 20 % m3/s	kWh yr-1	kg CO2e yr-1
2016	24.09	934,369,718	607,340,316
2017	23.91	927,597,532	602,938,396
2018	23.74	920,825,347	598,536,476
2019	23.56	914,053,162	594,134,555
2020	23.39	907,280,977	589,732,635
2021	23.22	900,508,792	585,330,715
2022	23.04	893,736,607	580,928,794
2023	22.87	886,964,422	576,526,874
2024	22.69	880,192,237	572,124,954
2025	22.52	873,420,051	567,723,033

**Table 4. 13: Water supply forecast with 20 percent savings, 2016/25.**

Source: Author, 2016.

### 4.7.2 Water Pricing Reform

To my surprise the survey has ranked as second best option, a reform over the water prices. The first objective to design efficient water rates is to generate revenues that covers costs. Pricing rates must allocate costs between users, meanwhile provide incentives for efficient use and water conservation. This criteria has to be applied to determine a successful pricing scheme. In CDMX there is little understanding of the role played by water prices and the market is not valuating resource scarcity. It has evaluated by CMM (2014) that water pricing reforms could create water savings of minimum **8 percent**, taking in consideration such number a total of **2.48 m3/s** yearly by the 2014 supply, a consequent reduction on energy and CO<sub>2e</sub> is evident in [graph 4.9](#) and [table 4.12](#).



**Graph 4. 9: Water forecast with 8 percent savings, 2016/25**

Source: Author, 2016.

YEAR	SAVINGS 8 %		
	m3/s	kWh yr-1	kg CO2e yr-1
2016	27.70	1,074,525,175	698,441,364
2017	27.50	1,066,737,162	693,379,156
2018	27.30	1,058,949,149	688,316,947
2019	27.10	1,051,161,137	683,254,739
2020	26.90	1,043,373,124	678,192,530
2021	26.70	1,035,585,111	673,130,322
2022	26.50	1,027,797,098	668,068,114
2023	26.30	1,020,009,085	663,005,905
2024	26.10	1,012,221,072	657,943,697
2025	25.89	1,004,433,059	652,881,488

**Table 4. 14: Water-energy and CO2 forecast with 8 percent savings, 2016/25**

Source: Author, 2016.

### 4.7.3 Rainwater Harvest

Ranked number 1 for best off-grid technology, and number 3 in savings potential, identified as the most efficient method to save water-energy in buildings, meanwhile abate CO<sub>2</sub> emissions and enhance the adaptation-mitigation respond to climate change in the Mexican mega city. In a research developed by Valdez (2016), a model was created to analyse different types of buildings in Mexico City.

In the methodology, part of the assumptions of this study towards the rainwater harvesting was; that buildings where supplied by municipal water, and total water use would be influenced by total rainwater harvested in the year, not discounting factors like water losses by evaporation or leakage. Rainwater was calculated in 700 mm/m<sup>2</sup> annually, data taken from CONAGUA (2009), in a representative area of the city that was measured from 1980-2010 by a meteorological station. An important factor not measured in this study is the energy (Co<sub>2</sub>) implication of additional-individually pumping systems in every household that may produce more “damage” as individual systems may consume more energy than centralized systems (Olson, 2012). Consequently, the implementation of the rainwater harvest systems should go hand to hand with clean-energy production (wind-solar), for the nexus to work and deliver co-benefits. However, the results proved that rainwater harvesting can reduce CO<sub>2eq</sub> emissions in the city (mitigation), by saving municipal water (water-energy security) and reduce hydraulic stress of the system. Meanwhile enhancing the capacity of the city (adaptation) towards flood risk, (Gwenzi and Nyamadzawo, 2014), assuming all rainwater on rooftops was harvested, and not sent to the sewage. The electricity consumption was calculated to deliver 0.79 kgCO<sub>eq</sub>/kWh an average of Mexico electricity mix, according to Paul Scherrer Institute (Itten et al., 2014), and used for calculating the emissions from the electricity consumption on the urban-water LCA. However the electricity consumption of the LCA was taken from the study of Centro Mario Molina (2012), determined that 82 percent of freshwater was taken from overexploited aquifer below the city, and 18 percent from neighbourhood water importation from the basins Lerma-Cutzamala .The correspondent energy was 0.25, 0.53 kWh/m<sup>3</sup> min/max and the latter 4.54kWh/m<sup>3</sup>, assuming a total energy consumption of both systems to be over 65 percent of the total energy used by the urban-water LCA, but only supplying 18 percent of the water to the city, resulting on an average consumption of 1.32 kWh/m<sup>3</sup> (Centro Mario Molina, 2012; Valdez, 2016). Additionally the different scenarios calculated in this study will not be

discussed, only the most significant for this research will be compared as a best solution for the WSM in the locality context. Scenario base corresponds to the regular water management in most buildings in the city. The municipality supplies water to all uses in the building, normally stored in an underground potable water deposit (cisterna). Most likely to be pumped to header tanks (tinacos) on the building rooftops, pumps owned by the building and electricity paid by the owners<sup>12</sup>, to be later distributed by gravity to the different points of the building, see figure 4.5. It is important to remember that CDMX supplies water from ground water (land subsidence) or surface water (water importation), so every m<sup>3</sup> supplied, has an enormous baggage behind (water footprint). In this first scenario the rainwater is directly send to the sewage system, and like stated before, stresses the capacity of the sewage system in rainy-storm seasons, producing flooding in the city.

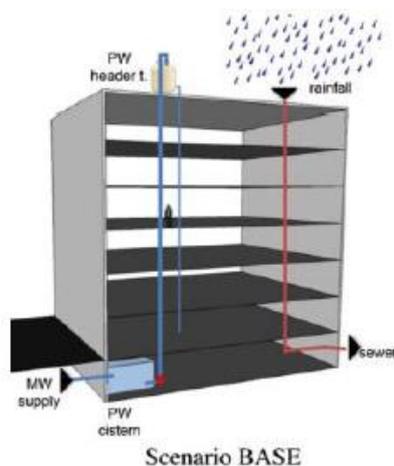


Figure 4. 5: No rainwater harvest, scenario base. Standard buildings in Mexico  
Source: Valdez, 2016

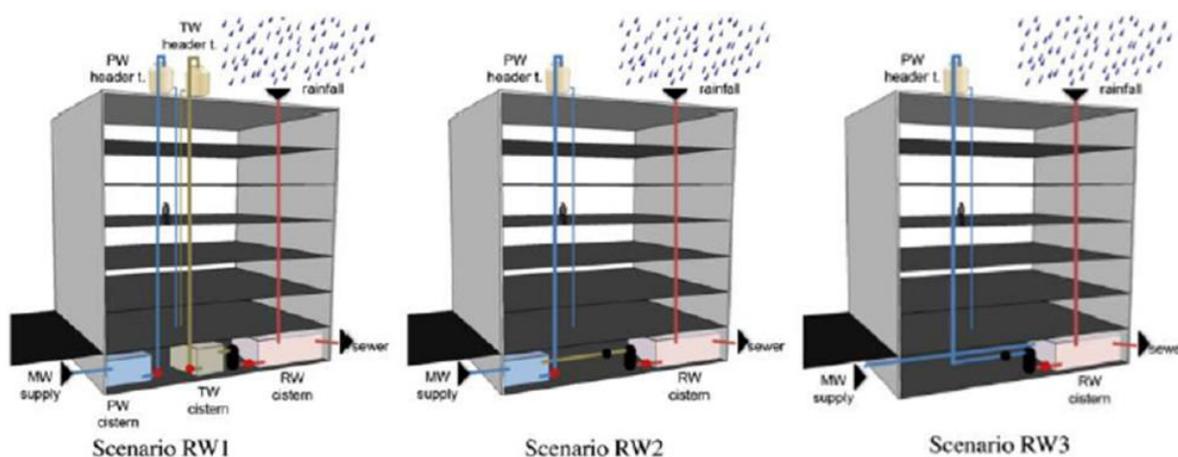


Figure 4. 6: Rainwater harvest, scenario RW 1, 2 & 3. Scenario 1 non-potable, scenarios 2 and 3 potable water. All have different storage capacities.  
Source: Valdez, 2016.

Scenario RW1 (see figure 4.6), has implemented rainwater harvesting for non-potable uses. The scenario is built with 3 underground water storages consisting of **Municipal Water Storage (MW)**, **Rainwater Storage (RW)** and **Treated Rainwater Storage (TW)**. The water is conveyed by equivalent equipment on the build system to pump, treat and store in both underground and rooftop headers and independent piping system, for each of the 3 water qualities. (Municipal, rainwater and rain treated water). In my opinion, it's a costly methodology, and not viable for

<sup>12</sup> Interesting study to be performed on electricity costs of in-sight water conveyance, and average percentage of household salary spend towards this necessity. Suggested by Dr. **Manuel Cohen Perló**, during semi-structure interview at UNAM, (see section 3.1.7 for contact information).

the average household to cover costs, as to many “extras” need to be added, enhancing the costs of the system. Next scenario for comparing is RW2 (see figure 4.6), it harvests rainwater and treats it to potable standards. The water collected it is stored in RW underground storage, then treated and purified, to be transferred to the same storage of the municipal water. The municipal water standards are not consumable as it is disinfected by chlorine and the same amounts of chlorine is not present at all the city locations. The disinfection methodology for this study is sand filtration with backwashing and silver ion. However, supposing the combined water in the MW storage was potable, still the cost (economic-energetic and environmental) of drinking water for all the building uses is not viable in the Mexican context, or I would say in any context. I argue individual technologies, to purify tap water to drinking standards in the selected indoor taps, (Decentralization for green economy, author hypothesis). Last scenario to compare is RW3 (see figure 4.6), ranked best average in all buildings typology as **Global Warming Potential (GWP)**<sup>13</sup> reductions are evident, ex; low-rise building, between 7.1 and 18.4 percent reductions. Only bettered by scenario RWg that will not be discussed as it is unlikely implementable in the Mexican context, for the construction typology and low adaptive capability. Scenario RW3 also ranked best. Because the new materials for building the combined underground RW+MW storage are counted for one individual cistern (concrete, iron, etc), and using the same piping infrastructure, lowering the total GWP of the system (see graph 4.10). However, this scenario losses validity as only would be applicable for new buildings, for the construction of underground storage for both RW & MW will not be contemplated by current buildings, also the size of the storage could produce problematic in many buildings that lack space. “*The storage capacity was determined by the volume required to retain peak rain events*”, (Valdez, pp 11, 2016). Graph 4.11 shows a positive relation between GWP and rain water availability, the higher available rain water the best GWP reductions are acquired. Other innovative options for storing rainwater may reduce the scenario GWP, like recycled plastic storage tanks that could be both cost effective and friendly to the environment. The combination of scenario RW 1&2 would be the best suited solution towards the local context. I argue rainwater harvest, stored in RW storage, treated to non-potable standard and:

1.- Used for non-essential uses. In Mexico the per capita water use is 110 lt (Pigoo, 2013), ONU (2014) determined essential water use to be 50 lt, meaning that around half of the water is used in non-essential uses, like watering the garden, cleaning outdoor areas and automobiles, among other uses. The water used inside building-household, can be drastically reduced by technologies that got more efficient in the latest years and will continue to do so. Bringing better efficiencies for most of the heavy water consumers inside, ex: low water wc, airhead shower caps and efficient clothes & dish washers.

2.- Reinserted to the underground aquifer. To “re-establish”<sup>14</sup> the aquifer water levels to prevent further land subsidence in the city. This could be established by policy making, for new buildings immediately and for present buildings to do so in a time period (5 years). This methodology to acquire mandatory climatic infrastructure was implemented before, in the green-roof policy by the municipality in 2010. France, Netherlands, Denmark, among others; have also acquire laws to deploy climatic infrastructure around the city, in all cases hand to hand with incentives, mostly fiscal.

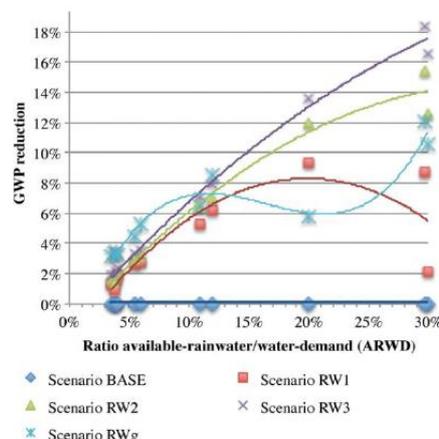
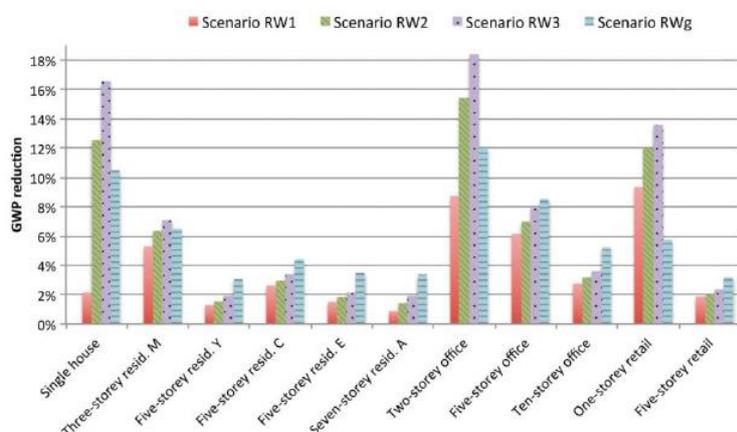
The results of the previous study by Valdez (2016), shows that buildings in CDMX use between 5 to 13 percent of total energy in the LCA for pumping water to header tanks. GHG emissions from municipal pumping and treatment could be reduce by rainwater use, equivalent to total amount of rainwater harvest, annual volume that was able to cover around **30 percent or 9.33 m<sup>3</sup>/s** (2014) of total demand. Potabilization was not very cost effective, further study is to

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<sup>13</sup> Key indicator in Valdez study (2016) to quantify the GHG emissions by functional unit expressed in kgCO<sub>2</sub>eq/m<sup>3</sup>. Other indicators like Cumulative Energy Demand (CDE) refer the energy consumed trough the system’s life cycle per m<sup>3</sup> of water consumed by the building, and expressed in kWh/m<sup>3</sup>.

<sup>14</sup> Contribute to re-establish underground water levels.

indicate that water re-insertion to the aquifer would slow down land subsidence as well as be economically and environmentally sustainable as the urban-water cycle could be closed by this method. This study shows that decreasing buildings water consumption in CDMX, by harvesting rainwater is able to bring double benefit; GHG emissions and water security, (UNAM, 2014a and 2014b).



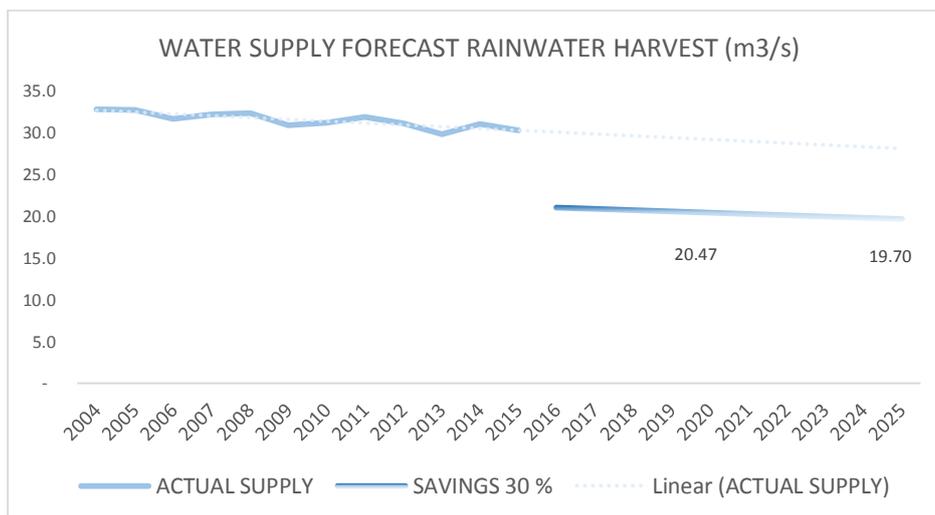
**Graph 4. 10: Global Warming Potential (GDP) reduction by scenario.**

Source: Valdez, 2016.

**Graph 4. 11: Relation between Global Warming Potential (GDP) reduction and rainwater availability, by scenarios.**

Source: Valdez, 2016.

Equally to the previous savings options, I have developed a forecast that is able to show the total water supplied to the city. Assuming that is implemented effectively and reduces 30 percent of the total water supplied in the urban cycle by harvesting rain from all year round. This measure show strong potential to reduce water-energy use, meanwhile mitigating substantially CO<sub>2</sub>e emissions. Water availability will increase as rain harvesting has proved to be a suitable solution to achieve water security, especially over the sectors in the city that is in greater disadvantage where less water is supplied from the municipality. Being a strong solution towards water security and equity in ZMVM, (Isla Urbana, 2009). It's forecasted that; if 30 percent savings are achievable by implementing this option (Valdez, 2016) and it may bring water consumption by 2020 down to 23.4 m<sup>3</sup>/s or an equivalent of 738 hm<sup>3</sup>/y. A consequent decrease on the energy, assumes that by 2020 a total demand of 1,134 million kWh yr-1 and by 2025 will further decrease on 1,091 million kWh yr-1. The equivalent CO<sub>2</sub> is forecast to decrease to 737 million kg CO<sub>2</sub> and by 2025 the forecast shows that it will continue decreasing to 709 million kg CO<sub>2</sub>, showing strong potential to mitigate climate change effects, (see graph 4.12).



**Graph 4. 12: Water forecast with 30 percent savings, 2016/25.**

Source: Author, 2016.

YEAR	SAVINGS 30 %		
	m3/s	kWh yr-1	kg CO2e yr-1
2016	21.08	817,573,503	531,422,777
2017	20.92	811,647,841	527,571,097
2018	20.77	805,722,179	523,719,416
2019	20.62	799,796,517	519,867,736
2020	20.47	793,870,855	516,016,056
2021	20.31	787,945,193	512,164,375
2022	20.16	782,019,531	508,312,695
2023	20.01	776,093,869	504,461,015
2024	19.86	770,168,207	500,609,335
2025	19.70	764,242,545	496,757,654

**Table 4. 15: Water-energy-CO2 forecast with 30 percent savings, 2016/25.**

Source: Author, 2016.

#### 4.7.4 Combined Solutions

The previous savings potential have been evaluated to be feasible (Tortajada, 2006; Isla Urbana, 2009; CONAGUA, 2015; SACMEX, 2015; Valdez, 2016) , and all together (leakage reduction, pricing reform and rain harvesting) could stablish water-energy-carbon savings of 58 percent, meaning that for 2020/25 respectively; water supply could go down to around 12.28 and 11.82 m3/s, the energy demand of the system shows reductions down to 476,322 and 458,545 million kWhyr-1 and equivalent Co2 emission reduction of 309,609 and 298,054 kg CO2e yr-1.

YEAR	58% SAVINGS	ENERGY FORECAST	CO2 EMISSIONS FORECAST
	m3/s	kWh yr-1	kg CO2e yr-1
2016	12.65	490,544,102	318,853,666
2017	12.55	486,988,705	316,542,658
2018	12.46	483,433,307	314,231,650
2019	12.37	479,877,910	311,920,642
2020	12.28	476,322,513	309,609,633
<b>SUB-TOTAL DEMAND</b>	<b>62.32</b>	<b>2,417,166,537</b>	<b>1,571,158,249</b>
2021	12.19	472,767,116	307,298,625
2022	12.10	469,211,719	304,987,617
2023	12.00	465,656,321	302,676,609
2024	11.91	462,100,924	300,365,601
2025	11.82	458,545,527	298,054,593
<b>TOTAL DEMAND</b>	<b>122.34</b>	<b>4,745,448,144</b>	<b>3,084,541,293</b>

**Table 4. 16: Water-energy-CO2 forecast with 58 percent savings, 2016/25.**

Source: Author, 2016.

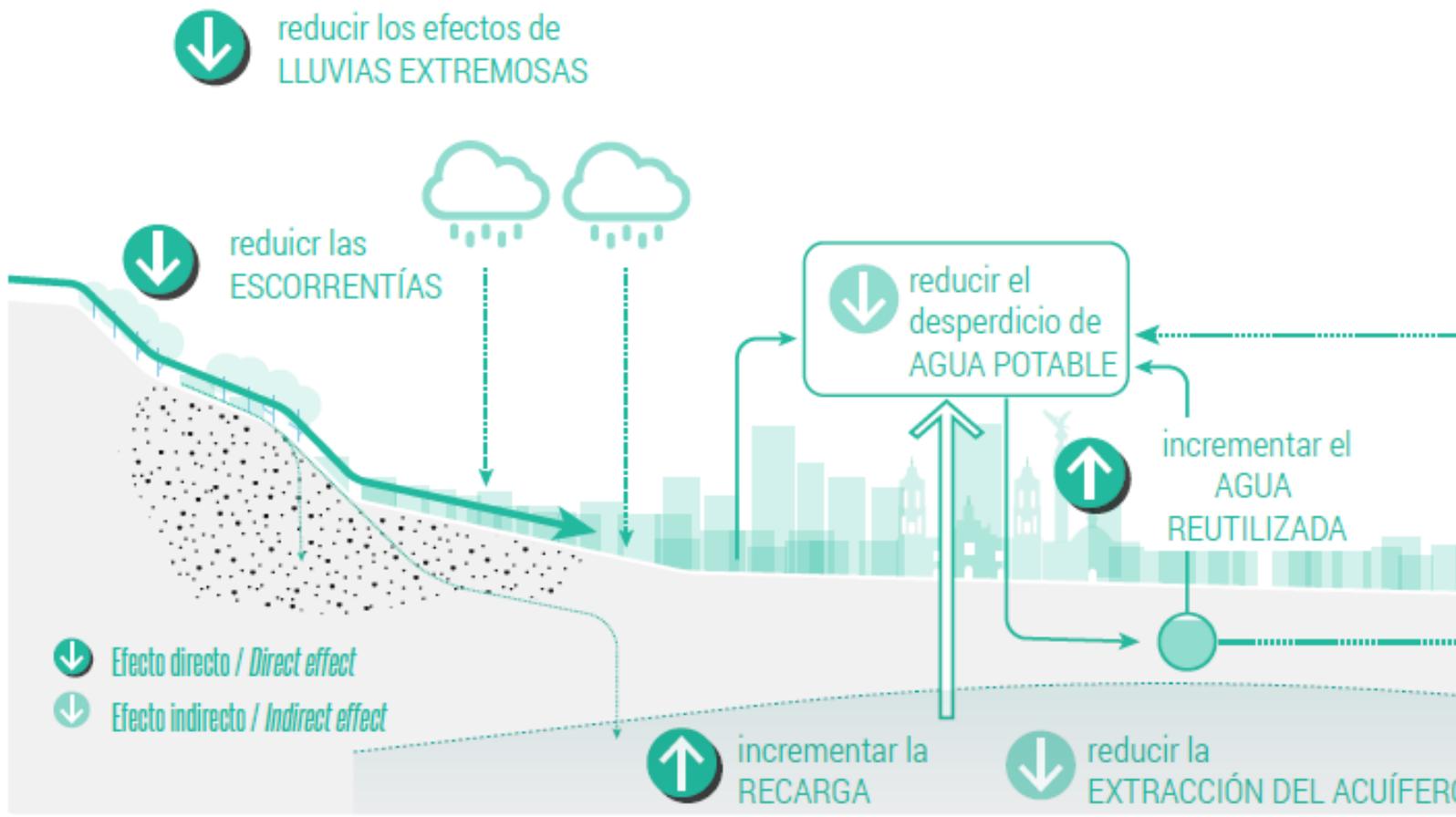
A consequent comparison for the two final scenarios has been develop, it is possible to show in the following table (4.17) the overall forecast with business as usual and the water savings measures scenario. The BAU represents the forecast of current water supply and the related energy-Co<sub>2</sub>. The year savings of column, represents total amounts of the BAU minus WSM of all combined measures (58%) reviewed previously. It is highly unlikely that implementing all measures are feasible in the same year, for that reason this research remains only informative for creating awareness of the potentiality of assessing the nexus in a combined, tailor made strategy.

	m3/y			kWh yr-1			kg CO2e yr-1		
	BAU	WSM	YEAR SAVINGS OF	BAU	WSM	YEAR SAVINGS OF	BAU	WSM	YEAR SAVINGS OF
2016	949,562,721	398,816,343	550,746,378	1,167,962,147	490,544,102	677,418,045	759,175,396	318,853,666	440,321,729
2017	942,680,419	395,925,776	546,754,643	1,159,496,916	486,988,705	672,508,211	753,672,995	316,542,658	437,130,337
2018	935,798,117	393,035,209	542,762,908	1,151,031,684	483,433,307	667,598,377	748,170,595	314,231,650	433,938,945
2019	928,915,815	390,144,642	538,771,173	1,142,566,453	479,877,910	662,688,543	742,668,194	311,920,642	430,747,553
2020	922,033,513	387,254,076	534,779,438	1,134,101,221	476,322,513	657,778,708	737,165,794	309,609,633	427,556,160
<b>SUB-TOTAL</b>	<b>4,678,990,586</b>	<b>1,965,176,046</b>	<b>2,713,814,540</b>	<b>5,755,158,421</b>	<b>2,417,166,537</b>	<b>3,337,991,884</b>	<b>3,740,852,974</b>	<b>1,571,158,249</b>	<b>2,169,694,725</b>
2021	915,151,211	384,363,509	530,787,703	1,125,635,990	472,767,116	652,868,874	731,663,393	307,298,625	424,364,768
2022	908,268,909	381,472,942	526,795,967	1,117,170,759	469,211,719	647,959,040	726,160,993	304,987,617	421,173,376
2023	901,386,607	378,582,375	522,804,232	1,108,705,527	465,656,321	643,049,206	720,658,593	302,676,609	417,981,984
2024	894,504,305	375,691,808	518,812,497	1,100,240,296	462,100,924	638,139,372	715,156,192	300,365,601	414,790,591
2025	887,622,003	372,801,241	514,820,762	1,091,775,064	458,545,527	633,229,537	709,653,792	298,054,593	411,599,199
<b>TOTAL</b>	<b>9,185,923,623</b>	<b>3,858,087,922</b>	<b>5,327,835,701</b>	<b>11,298,686,057</b>	<b>4,745,448,144</b>	<b>6,553,237,913</b>	<b>7,344,145,937</b>	<b>3,084,541,293</b>	<b>4,259,604,643</b>

**Table 4. 17: Water-energy-CO<sub>2</sub>e forecast with 58 percent savings, 2016/25.**

Source: Author, 2016.

Figure 4. 7: Water Sensitive CDMX.  
Source: De Urbanisten, 2016



## Chapter 5: Conclusions and Recommendations

Research questions

To what extent does the water-energy-climate nexus influences CO<sub>2</sub>e emissions at the urban water cycle in CDMX?

1.1 What is the water-energy-climate nexus in the urban water cycle in CDMX?

**It's the interrelation between water, energy and CO<sub>2</sub> emissions due to water flows in the city LCA. The water sector has a strong dependence on the energy sector and due to the energy production typology carbon emissions are involved, which have environmental impacts.**

1.2 What are the current flows in the urban water cycle in CDMX, how much energy does it use, and equivalent CO<sub>2</sub> emissions produces, in BAU scenario?

**In 2016, water supply in the city was determined in 30.11 m<sup>3</sup>/s (949.6 Hm<sup>3</sup>/y) demanding a total energy consumption of 1,167,962,147 kWh yr<sup>-1</sup>, consequently 759,175,396 kg CO<sub>2</sub>e yr<sup>-1</sup> will be emitted by the end of this year.**

1.3 What are the implications of WSM on carbon emissions, and how are they influencing the adaptation mitigation respond of the city to climate change?

**Estimations (2016) are that 1 Hm<sup>3</sup>/y in the LCA demands an overall energy use of 1,230,000 kWh yr<sup>-1</sup>, and produces equivalent carbon emissions, estimated (0.65 factor, IPCC) to be 799,500 kgCO<sub>2</sub>e yr<sup>-1</sup>. Significant reductions on energy and carbon emissions may be achieved by water savings. In addition, 3 WSM are selected (leakage reduction, pricing reforms and rainwater harvesting), they are determined to enhance the city respond to climate change in 3 different sectors. Water security, flood capacity enhancement and CO<sub>2</sub> emissions abatement in the following amounts, see table 5.1**

Adaptation-Mitigation Interrelations				
Urban Water-Energy-Climate Nexus		City Respond to Climate Change		
Water Saving Measures 2016		Water Security	Flood Capacity Enhancement	CO <sub>2</sub> Emissions Abatement
2016 water use = 949.5 hm <sup>3</sup> y				
1	Water leakage/loss reduction in grids	Water source relief		Lowers systems energy consumption
	20%	6.02 m <sup>3</sup> /s 189.91 Hm <sup>3</sup> /y	N/A	151,832,879 kgCO <sub>2</sub> e yr <sup>-1</sup>
2	Reform on water pricing, according to water consumption and based tariffs	Water source relief		Lowers systems energy consumption
	8%	2.41 m <sup>3</sup> /s 75.96 Hm <sup>3</sup> /y	N/A	60,733,151 kgCO <sub>2</sub> e yr <sup>-1</sup>
3	Rainwater harvest on buildings by off-grid technologies	Water source relief	Delay and capture rainwater	Lowers systems energy consumption
	30%	9.03 m <sup>3</sup> /s 284.86 Hm <sup>3</sup> /y	284.86 Hm <sup>3</sup> /y	227,749,318 kgCO <sub>2</sub> e yr <sup>-1</sup>

**Table 5. 1: Selected WSM for the local context (CDMX) and interrelation with the city respond to climate change.**

Source: Author, 2016.

In the previous chapters, the water-energy-climate nexus has been analysed in the urban-water cycle of CDMX. The megacity holds over 9 million habitants with a density of 5,987 hab/km<sup>2</sup>. Located in an endorheic basin, surrounded by mountains. CDMX water life-cycle currently depends over multiple sources on both ground and surface water withdrawals. The surface water is imported from basins through Lerma-Cutzamala system. The ZMCM (Zona metropolitana de la Ciudad de México) aquifer water withdrawals are up to 1103.46 hm<sup>3</sup>/year meanwhile the recharge rate accounts for 512.80 hm<sup>3</sup>/year, creating an approximate deficit of the freshwater levels of 590.66 hm<sup>3</sup>/year (Conagua, 2016). The unsustainable freshwater withdrawals and soil typology has caused land subsidence in multiple locations with annual variations from 15 to 36 cm, causing damage to the city's infrastructure, including the water network and drainage system. In addition, to leaky piping systems lack of measurement and clandestine water connections, the system presently loses around 40 to 50 percent of the water in the grid, according to both CONAGUA and SACMEX (administrative and operational dependencies). The energy produced from burning fossil fuels accounts for 45 percent of generated Co<sub>2</sub> emissions (World Bank, 2011) and at national level around 15 percent of the energy produced is lost in energy transmission (CFE, 2014) in order to provide electricity. As for the city's water life-cycle; it has been determined to use 2,113 GWh/year 16 percent of the electricity totally consumed for all purposes (Centro Mario Molina, 2011). In total, the LCA is equivalent to 1.23 kWh/m<sup>3</sup> (Centro Mario Molina, 2013), used to deliver the service from extraction to the end user; for which up to 40 percent of the most vital resource to humanity is wasted due to extensive, costly, obsolete, leaky piping systems. Meaning that almost half of the water and energy used in the urban water LCA is not being properly used nor evaluated as it is related to high environmental damage that could be tackled by the evolution of the service delivery.

Building up on the previous statements and by analysing the data recovered from primary sources such as in-deep interviews and surveys to the experts both from the academic institution UNAM (Universidad Autónoma de México) and the governmental water institutions CONAGUA and SACMEX, has been determined that leakage control would bring effective water savings to the system. They have evaluated that as much as 20 percent in leaks reduction over the grid would equal future plans to import water from neighbour basins over 6.22 m<sup>3</sup>/s. However, the challenges to fulfil this WSM is determined over high capital investment to upgrade the life-span of the infrastructure, and planned to finish not before 2030. Other measures are being evaluated in this paper such as water harvesting, recently proven not only by academics. They've stated that such implementation could lower the warming potential up to 18.4 percent while using 30 percent less water every year or around 9.3 m<sup>3</sup>/s (Valdez, C., 2016), but also being tested on the field by Isla Urbana a civil society, partnered with IRRI-Mexico (Instituto Internacional de Recursos Renovables AC) that have installed over 2500 rainwater harvesting systems to the most needed, being a real and tangible solution to alleviate water scarcity and flood risk. In addition, municipal wastewater treatment uses for pumping 0.48 kWh/m<sup>3</sup> and treatment around 2.45 kWh/m<sup>3</sup> (Centro Mario Molina, 2011), and less than 11 percent being re-used, mostly for industrial or agricultural purposes. Meanwhile treating and using wastewater could bring more than 7 m<sup>3</sup>/s to the LCA or as recharge water for the aquifer in order to slow the land subsidence. In the case of using in-site technologies, further economic benefits from a green-economy may be induced in the market (eco-technology offer-demand, job creation, technology development, etc). Producing clean energy in-site is essential to achieve a good performance towards the previous proposals as the nexus co-benefits are linked in this partially decentralized scenario that will also enhance the mitigation and adaptation capacities of the city towards climate change, (Venema & Rehman, 2007; Molyneaux, L., Wagner, L., Foster, J., 2015) alleviating and diminishing stress on overwhelmed capacity flows of the highly centralized sources on power, water and sewage systems, but also to reduce the huge maintenance costs, environmental damage and resource depletion while ensuring better water/energy management and CO<sub>2</sub>e abatement.

This research is able to confirm that the nexus has a strong relationship between the variables (water, energy and CO<sub>2</sub>), and the research findings have been completely fulfilled, although further analysis may be performed to establish the water-energy-climate nexus in the urban cycles and services. As greater potentiality to abate CO<sub>2</sub> emission can be easily reached by exploring synergies that emphasize more on the energy sector, this research is concerned more on water cycle, water security and adaptation capacities of the city, meanwhile exploring the potential synergies among each other. Consequently further research is to evaluate economic-environmental-social costs of the current performing water-energy services and determine what solutions could be better approached with the current resources to achieve better results. By conceptualizing the water-energy-climate nexus in Mexico City, I analysed the water service cycle and the interlinked relationships with the energy sector, and the equivalent CO<sub>2</sub> emitted due to the energy demand on each of the processes. I have divided the water cycle in 3 main concepts; supply, treatment/re-use and sewage, and created a business as usual (BAU) scenario by each of the processes, detailing the water conveyed, the energy demand, the equivalent carbon emissions and future projections on to 2025 (forecast). The BAU scenario has been extremely useful for developing a detailed description of the findings for the Mexico City context. And the savings scenario determined potential water savings in the urban context that may reduce up to 58 percent of the water supply and the energy-CO<sub>2</sub> e. All this savings are strategic not only towards resource and service efficiency but to enhance the adaptive and mitigation capacities of the city to climate change. The research conclusions are:

**First;** water availability is seriously endangered and extreme measures towards water security needs to be performed immediately to ensure prosperity of the inhabitants. The deficit has been estimated in approx. 3000 l/s (94,608,000 m<sup>3</sup>/y) affecting more than 1 million people that have unreliable supply, (Tortajada, 2006).

**Second;** by implementing significant water savings measures, different sectors and disciplines are affected, referred as the nexus synergies and trade-offs. They can all be translated in economic costs.

Water importation has resulted extremely expensive as incredible infrastructure has been developed to convey water to supply the region from neighbour basins, resulting in costly mega-structures. Same typology is developed for sewage.

The robust infrastructure needs high maintenance and has resulted in elevated prices, such are not contemplated in the water prices and are mostly paid by federal, state aid and subsidies.

Lack of proper maintenance poor management and land subsidence have created great losses-leakages in the system that are evaluated from 40 to 50 percent of the total water supplied to the city. Every m<sup>3</sup> loosed in the grid has economic, social and environmental implications.

Land subsidence differs in the city locations, mostly created by the extraction of underground water or over-exploited aquifers. The city infrastructure, (roads, buildings, monuments, water-sewage grids, etc) have developed a system to level certain areas of the city to stop them from “sinking”, resulting of great expenditure and problematic in the capital city.

The energy involved in water importation has elevated costs, in the Cutzamala System is up to 80 percent of total costs.

Water-energy security is far from being achieved, meanwhile the environment progressively endangered.

The adaptation-mitigation capacities of the city may be enhanced greatly by implementing the water saving measures proposed in this research.

**Third;** water supply is the process that demands more energy in all the water cycle, with a total 71 percent (2014), followed by sewage with 18 percent and treatment (re-use) with 10 percent. It is extremely important to understand that surface water importation from the Lerma-Cutzamala Systems uses a total of 52 percent of the total energy demanded by the water cycle, contributing to more than 520,725 million kg CO<sub>2e</sub> yr<sup>-1</sup>. Consequently stopping present and future water importation projects is achievable by innovative solutions, like decentralization of services and multi-sectorial management approach.

**Forth;** water savings potential, has been evaluated in this paper and 3 strong measures are selected on the local context:

**Leakage control;** by arriving to a **20 percent** goal reduction significant implications are deduced. Such repairs could currently be of a total **189 million m<sup>3</sup>/y** (6 m<sup>3</sup>/s), double amount of the current water delivered from the Lerma System, or 60 percent of the current Cutzamala System, and around equivalent energy of **233 million kWh yr<sup>-1</sup> and 151 million kg CO<sub>2e</sub> yr<sup>-1</sup>** emissions yearly. Future projects to import water (energy and CO<sub>2e</sub>) from “neighbour” basins are also estimated in 6 m<sup>3</sup>/s like Temascaltepec or Tula-Hidalgo with a future supply estimated in 7 m<sup>3</sup>/s. Further percentages are considered to be reduced from better maintenance practices, this option has been chosen as most popular among the survey respondents.

**Pricing reform;** showed potential to reduce water use and fair tariffs among users regarding volumetric and not fixed tariffs. The implementation of full measurement to water users is one of the difficulties on this option as 36 percent of the existing connection are illegal and not registered, being one of the main problems for the local government in terms of cost-recovery. It has been determined that this option could bring savings of **8 percent** of the total water demand; or water savings around **75 million m<sup>3</sup>/y** (2.41 m<sup>3</sup>/s), consequent **93 million kWh yr<sup>-1</sup> and 60 million kg CO<sub>2e</sub> yr<sup>-1</sup>**.

The previous potential savings have been evaluated to be feasible, and **all together** could stablish water-energy-carbon savings of **58 percent**. Meaning that, IF IMPLEMENTED FROM CURRENT YEAR<sup>15</sup> by **2020/24** water savings respectively would be up to; **2,713 and 5,327 million m<sup>3</sup>/y** (86.05 and 168.94 m<sup>3</sup>/s), the energy savings would be around **3,337 and 6, 553 million kWh yr<sup>-1</sup>**, and the Co<sub>2</sub> emissions abated would be around **2,169 and 4,259 million kg Co<sub>2e</sub> yr<sup>-1</sup>**. The previous water savings have the capacity to reduce 28 times the amount of reported deficit and may contribute towards the solution of other problematic surrounding the CDMX water conflict, like; social, economic, urban and environment, that may potentially benefit millions not only in the city but also in the hydrological region XIII and surrounding states, like Michoacán and Jalisco. That may use water from the Lerma Rivers that propitiates quality of life in Michoacán, and feeds the biggest lake in the country, Chapala Lake. The previous is an important water supply for Guadalajara City the head municipality of the state, and the 3th most populated metropolitan area in the country with 7,965,828 million people, and a contribution of 6.5 percent to the national GDP.

Water treatment and re-use; Atotonilco treatment plant has been discussed previously in chapter 2. Designed for treating 60 percent of sewage water when operational, and promises great water re-use potential. A very interesting characteristic for the nexus is, if equipped with up to date technology to produce energy from the biological reactions. This facility promises important reductions in the water importation from neighbour basins, and it has the potential to produce clean energy for the entire water system, meanwhile reducing CO<sub>2</sub> emissions

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<sup>15</sup> Speculations for academic purposes, 2016.

(Danish example on treatment plants). The environmental impacts of the treatment plant have to be flawless.

## Recommendations

1. Full implementation of the current governmental strategy towards legal and institutional reforms, such as 100 percent billing and meter-reading, leakage repair and modification of pricing mechanisms may be effective towards better management and self-sufficient service provider. Around 40 to 50 percent of the current water supply is lost in leaks, illegal or not registered connection to the grid and it represents one of the main problems for the local government in terms of cost-recovery, (Tortajada, 2006, SACMEX, 2016). In 1992 an effort to promote changes was not to consider water as a public good and was translated in to heavy state subsidizes, consequently the institution faced severe crisis due to deterioration of infrastructure and economic conditions based in a deficient pricing methodology on fixed tariffs, meanwhile improving overall efficiency of the water tariffs strictly to **volumetric pricing to all users and stablish difference between users**, may have better results. In order to promote water conservation, **subsidies need to be gradually taken out** and prices should regulate the market, this way you ensure water-energy preservation and egalitarian costs.
2. The survey developed to environment, water and energy experts showed institutional fragmentation. A **multi-disciplinary agenda is to ensure the different synergies and trade-offs of delivering services**. Resource efficiency, environmental conservation, social equity and cost effectiveness is to evaluate inter-linked solutions from the different angles. A special and new developed governmental department is to ensure that the four angles are present in the future development proposals, basing their strategies in those principals of a circular economy and the city's resilience.
3. **Water importation should be avoided at all cost**. Innovative, bold and dominant urban solutions are to implement and continuously increase; re-use of water, rainwater harvesting, sewage-storm water separation (by implementing blue ecosystems, water squares) and aquifer levels restoration. Meanwhile exponentially decreasing water losses in the grid.
4. Current and future water treatment plants need to ensure high index of treatment and re-use, and the implementation of the best technologies to reduce energy consumption and **surplus production of clean energy from water treatment processes**. In addition, inserting treated water to the city aquifer may reduce land subsidence closing the water extraction-use-insertion circle. Circular economy approach
5. **Off-grid technologies may be essential in the CDMX** context, which holds almost 100 percent of urban population. If implementing public and private strategies by the development of partnerships the technology could be produced and sold at affordable costs, and even in monthly payments to the users by the municipality or company.
6. **Land preservation** is to be acquired in order to achieve natural aquifers level regeneration and ecosystem services. Most of the **natural recharge zones** have been urbanized, if only strategic portions of land should be determined towards ecosystems quality of life of all surroundings would be greatly increased, meanwhile **aquifers regeneration**.

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## Annex 1: Questionnaire Example

### A study of the urban water cycle and potential savings, towards a resilient and low carbon city.

#### Ciclo del agua en la Ciudad de México

En el presente cuestionario se evalúa el ciclo del agua en la Ciudad de México (retiros, potabilización, suministro y tratamiento de aguas residuales), y sus cifras en materia hídrica, eléctrica y ambiental.

1. Cuál es la cantidad anual de agua "en movimiento" en los diversos procesos del ciclo del agua (retiros, potabilización, suministro y tratamiento de aguas residuales) en la Ciudad de México (hm<sup>3</sup>/año)?

2. Cuál es la demanda anual de energía eléctrica utilizada en los diversos procesos en el ciclo del agua (retiros, potabilización, suministro y tratamiento de aguas residuales) la Ciudad de México (MW/hm<sup>3</sup>), y las emisiones de Co<sub>2</sub> relacionadas a cada proceso (ton/MW)?

3. Cuál son los distintos orígenes del suministro de agua para la Ciudad de México, de cuánta agua dispone, cuánta agua es extraída y cuál es su índice de recarga anual?

4. Cuál es la cantidad estimada anual de agua perdida debido a fugas en la red hidráulica de la ciudad (hm<sup>3</sup>/año), cuáles son las estrategias implementadas para reducir dichas pérdidas y cuál es el costo monetario anual por reparación de dichas fugas?

5. Cuál es la capacidad actual de tratamiento de aguas residuales, qué cantidad de agua reciclada es reutilizada/reinsertada en la red de suministro, qué usos se le otorga y aproximadamente qué cantidad de agua de lluvia es procesada anualmente en la Ciudad de México (hm<sup>3</sup>/año)?

6. Actualmente qué estrategias se implementan para lograr ahorros simultáneos de agua y energía, dentro del ciclo del agua de la Ciudad de México. Cuáles son las acciones de cooperación entre la comisión del agua, la secretaria de energía y la secretaria del medio ambiente, para eficientar procesos y reducir el consumo de recursos hídricos y energéticos. Y qué mecanismos se están utilizando para superar la fragmentación departamental y diferentes regiones hidrológicas?

Active link: <https://es.surveymonkey.com/r/9PPNZHQ>

## Annex 2: Survey Example

### A study of the urban water cycle and potential savings, towards a resilient and low carbon city.

#### Ciclo del agua en la Ciudad de México

7. En su opinión; cuál de las siguientes tecnologías "off-grid" implementadas en edificaciones podrían ser más efectivas para lograr:

- a.- Ahorro de agua y energía, suministrado por la red urbana?
- b.- Reducción de emisiones Co2 (relacionadas a el ahorro de energía eléctrica)
- c.- Incrementar la respuesta de la ciudad al cambio climático, en materia de mitigación/adaptación a las amenazas climatológicas?

(1 para la tecnología más efectiva, 5 para la menos efectiva)

⋮	<input type="text"/>	Recolección de aguas pluviales para uso en edificaciones. Capaz de reducir la dependencia institucional, creando ahorros hídricos, energéticos y reducción de Co2eq.
⋮	<input type="text"/>	Re-use de agua reciclada con tecnologías "In-sight" en edificaciones. Tecnología capaz de reducir la dependencia institucional, promover uso de agua reciclada, creando ahorros hídricos, energéticos y reducción de Co2eq.
⋮	<input type="text"/>	Implementación de azoteas y muros verdes, método capaz de reducir la precipitación pluvial y sosegar inundaciones entre otros beneficios ecosistémicos.
⋮	<input type="text"/>	Calentadores solares de agua, capaces de disminuir el consumo de energía eléctrica y de combustión como el gas LP, natural, etc. creando ahorros energéticos y de Co2eq.
⋮	<input type="text"/>	Producción de energía eléctrica por sol / viento. Capaz de reducir la dependencia institucional, creando ahorros energéticos y de Co2eq.

8. En su opinión; cuál de las siguientes opciones podrían ser más efectivas, en el ciclo del agua de la Ciudad de México, para lograr:

- a.- Ahorro de agua y energía, suministrado por la red urbana?
- b.- Reducción de emisiones Co2 relacionadas a el ahorro de energía eléctrica en ambos servicios?
- c.- Incrementar la respuesta de la ciudad al cambio climático, es decir respuesta a mitigación/adaptación en las amenazas climatológicas?

(1 para la opción más efectiva, 7 para la menos efectiva)

⋮	<input type="text"/>	Implementación en gran escala de tecnologías "off-grid" en edificaciones. Método capaz de reducir la dependencia institucional, creando ahorros energéticos y de Co2eq.
⋮	<input type="text"/>	Promover servicios ecosistémicos, donde se incluyan almacenamiento de agua pluvial para reducir inundaciones, entre otros servicios ambientales.
⋮	<input type="text"/>	Re-use de agua reciclada proveniente de las plantas de tratamiento. Capaz de reducir la demanda e importación de agua de las cuencas, creando ahorros hídricos, energéticos y reducción de Co2eq.
⋮	<input type="text"/>	Reparación de tuberías en la red de suministro de agua para evitar fugas excesivas. Costoso y eterno pero efectivo método para reducir la demanda de agua, creando ahorros hídricos, energéticos y reducción de Co2eq.
⋮	<input type="text"/>	Implementación de tecnología de vanguardia para optimizar el funcionamiento y mejorar la eficiencia de cada proceso en el ciclo del agua, creando ahorros energéticos y de Co2eq.
⋮	<input type="text"/>	Reforma en los costos del agua y energía, de acuerdo a la tipología del consumidor y sus características. Buscando reducir al máximo el uso de agua no-esencial utilizada en la ciudad y desincentivar grandes subsidios.
⋮	<input type="text"/>	Campaña de educación para promover ahorros de agua y energía. La educación en los usuarios puede ser una herramienta poderosa para la reducción de recursos naturales.

9. Favor de explicar detalladamente su elección en las últimas dos preguntas

\* 10. Contacto

Nombre	<input type="text"/>
Organismo / Dependencia o Departamento.	<input type="text"/>
Dirección	<input type="text"/>
Ciudad	<input type="text"/>
Código Postal	<input type="text"/>
País	<input type="text"/>
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