Water management analysis of the city of Tijuana, Baja California: Critical factors and challenges

Análisis del manejo de agua en la ciudad de Tijuana, Baja California: Factores críticos y retos

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Abstract

This article analyzes water management issues in the urban area of Tijuana for the period from 1991 to 2009. A comprehensive systematic management system was used as a theoretical framework. For the methodological framework, robust databases were compiled through documentary research, semi-structured interviews were conducted, and Geographical Information Systems (GIS) were used to visualize the spatial distribution of water use. The results reveal that water resource management is conducted under a linear process that does not consider a broad assessment of social elements in water anagement. The research results show also inequality in the spatial distribution of water services, and little reuse of treated wastewater and the need for long-term planning to secure water supply and consumption after 2020.

Keywords: water, comprehensive and systematic water management, unsustainability, water balance.

Resumen

Este artículo tiene por objetivo analizar la problemática de la gestión del agua en el contexto urbano de la ciudad de Tijuana en el periodo de 1991 a 2009. Se utilizó como marco teórico la gestión integral y sistémica; y en el marco metodológico se construyeron bases de datos robustas a través de la investigación documental, se efectuaron entrevistas semiestructuradas y se construyó un SIG para la distribución espacial del consumo de agua. Los resultados ponen de manifiesto que la gestión de los recursos hídricos se realiza bajo un proceso lineal, que no considera un diagnóstico amplio de elementos sociales del manejo del agua. Los resultados de la investigación muestran inequidad en la distribución espacial de los servicios hídricos, así como el casi nulo proceso de reciclaje del alcantarillado sanitario tratado y la necesidad de una planeación de largo plazo para asegurar el abasto y consumo de agua después del 2020.

Palabras clave: agua, gestión integral y sistémica del agua, insustentabilidad, balance hídrico.

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Introduction

Since the early twentieth century, a supply-oriented water delivery approach has prevailed at the global level, which is largely due to the approach's results of social well-being.[1] Although steady progress on coverage and sanitation has been made, the water management model has failed to reduce the unequal distribution of water resources (World Health Organization [WHO], 2010; United Nations Fund for Children [UNICEF], 2006, 2008).

At the global level, shortages of water resources are increasingly becoming a threat to countries that have reached the limits of their own water sources. Approximately 2.8 billion people face some form of water scarcity (United Nations Development Programme [UNDP], 2006), and scenarios indicate that by 2030, more than half of the world's population will be located in areas of water stress (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2009). Moreover, the exploitation and pollution of ground and surface water sources have increased in the last 50 years.[2]

Tijuana[3] is a particularly interesting case because it faces two major challenges that affect the sustainable management of its water resources. First, Tijuana is has one of the most dynamic populations and economic growths in the State of Baja California, which has created high demand for urban water utilities (Consejo Nacional de Población [CONAPO], 2009 and Instituto Nacional de Estadística y Geografía [INEGI], 2005 and 2006) and has increased the use of drinking water and the generation of wastewater. Second, the city has limited naturally available water sources due the scarcity of surface and groundwater resources.[4] This has led to a reliance on water from the Colorado River (Bernal, 2005; Marcus, 2000).

To address these issues, a comprehensive and systemic approach was used as a theoretical framework. The framework uses a multidimensional perspective in which the social, economic and environmental aspects[5] that are involved in the management of water resources are interrelated in addition to their relationship with the present and future social and environmental well-being.

[1] For further information about the growth of the world population and the advancement of water sanitation and coverage, see the report by the WHO and UNICEF (2006), which states that the world population's access to improved water sources increased from 78% in 1990 to 87% in 2006, which represents a reduction in shortages for 600 million people. Sanitation coverage increased from 54% to 62% by 2006 (WHO and UNICEF, 2006).

[2] Groundwater use has increased substantially and now supplies 70% of the demand in the agricultural sector (UNESCO, 2009). Approximately 75% of rivers have been diverted from their natural routes to supply various demands (UN, 2009).

[3] The city of Tijuana is located in the northwestern region of the State of Baja California and is bordered by the United States and the municipality of Tecate to the north, by the town of Ensenada and Playas de Rosarito to the south, by the municipalities of Tecate and Ensenada to the east, and by the municipality of Playas de Rosarito, the Pacific Ocean and the United States to the west. The region represents 1.57% of the total area of the state (INEGI, 2005). Hydrologically, the city is located at the lowest point of the Tijuana River Basin, which is a morphological unit that is located to the west of the US-Mexico border, which allows rainwater and wastewater runoff from the urban areas of Tijuana and Tecate by the Tijuana River. Its natural drainage flows across the US border to the southwest part of San Diego County into the Tijuana River Estuary, which eventually empties into the Pacific Ocean.

[4] The city contains several groundwater sources, such as the Tijuana River aquifer and the La Misión wells. However, their levels of pollution and the reduction of their supply capacity have made them practically unproductive.

[5] Although environmental issues could theoretically include social aspects, this study separates economic, social and environmental or ecosystem issues to integrate the three pillars of sustainability into the analysis.

Along these lines, Girardet (1999) suggests studying water issues within cities as an organism with a particular metabolism. He provides a socio-spatial dimension to research this subject that has not yet been clearly addressed in other studies. This approach considers the management of water resources within a city to be essentially linear in contrast with a cyclical environmental system.

Concurrent with the development of this systemic approach, Brooks (2005), and Wolff and Gleick (2002) suggest the need for a new paradigm of comprehensive management through the efficient use of resources and the provision of water services according to the end users' requirements.

Based on this theoretical approach, sustainable water management is defined in this study as a process that relates demand management,[6] efficient water use, and co-responsibility and leads to the conservation and protection of water sources with the aim of not only meeting the current needs of the population but also anticipating future social and environmental requirements.

The results of this research are presented in five sections. The first section provides the methodological framework. The second section presents the major findings about the provision of water services in Tijuana, including the water supply, distribution and consumption, sewerage, sanitation and the reuse of treated wastewater. The third section presents the planning and financial structure of the Comisión Estatal de Servicios Públicos de Tijuana (CESPT). The fourth section discusses and analyzes the critical factors and axes of unsustainability in water management in Tijuana. The final section presents the findings, proposals and challenges for sustainable management.

Methodological clarifications for this analysis

In methodological terms, this study consists of four stages. In the first stage, information from secondary sources about the case study and theoretical approaches was reviewed. In the second stage, the CESPT was defined as the central analysis unit with the following areas of analysis: drinking water supply, sewerage, reuse and the financial structure of this water utility. These aspects provide a solid documentary basis for analyzing water service in Tijuana over the last two decades (1991-2009). The field research was performed in the third stage. It included a three-month stay in the CESPT, tours of the water purification and wastewater treatment systems, and the application of 34 semi-structured interviews.[7] Twenty of the interviews were conducted with key officials that operate and manage water resources with local advocacy groups, and 14 interviews were conducted with providers and users in the shanty town of Valle Redondo,[8] which is located at the eastern end of the city of Tijuana, to determine the supply and demand characteristics of water service as well as the water costs and quality. In the fourth stage, the collected data were processed and analyzed in Geographic Information Systems (GIS).

[6] When this issue is reviewed theoretically, demand management is an important element in the discussion. However, this water management perspective is not feasible for the city of Tijuana because the population's water consumption is very low; therefore, proposals under this approach could be contrary to the well-being of the population.
[7] The interviewee list and interview script are available in Navarro (2010).
[8] The municipality of Valle Redondo, which is located at the eastern end of the city of Tijuana, was used as the study site because officials of the water facility stressed its significance due to its size, rapid population growth and limited progress on water coverage. The neighborhoods of El Niño, Ojo de Agua and Maclovio Rojas were covered. Interviews were conducted with a population that had access to water through a waterpipe service due to the irregular situation in that neighborhood.

During the information processing and analysis, the residential users' water consumption was classified using the 495 684 active residential accounts for 2009 (based on the user registry of the CESPT), which is equivalent to 93.9% of the users. Based on these data, a parameter called the Residential Consumption Range (RCR) was created, in which 17 ranges were established that progressively increase by 5 m^3/user-month. Per capita consumption was calculated based on the housing index of the city of 3.8 inhabitants per household as established by INEGI (2005). The parameters that were established by the WHO (2003) about the impact of the level of supply on health were used to categorize the water consumption. This method showed that the largest number of users is concentrated in RCRs 1 to 5, which represent 92% of the accounts of drinking water services with consumptions of 0 to 25 m^3/user-month, followed by RCRs 6 to 10, which represent 7% of the accounts with consumptions of 26 to 50 m^3/user-month. Moreover, the study "Domestic Water Quantity, Service Level and Health" (WHO, 2003) was used to establish a reference framework to categorize the level of consumption. The study sets the degrees to which the per capita water supply has an impact on social well-being. Based on these parameters, the consumption ranges were grouped to exclude the populations below and above the consumption that was suggested by the WHO. Compliance with the guidelines of wastewater decontamination was analyzed using data about the influent and effluent characteristics that were provided by the monthly lab tests from the Planta de Tratamiento de Aguas Residuales San Antonio de los Buenos (PSAB) for the period 1996 to 2008. The data were compared with the Límites Máximos Permisibles (LMP) that were established by the *Norma Oficial Mexicana NOM-001-ECOL-1996,* which defines the maximum permissible limits of pollutants in wastewater discharges into national waters and goods (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT], 1996), and with the LMPs of pollutants for the reuse of treated wastewater in services to the public that were established by the *Norma Oficial Mexicana NOM-003-ECOL-1997* (SEMARNAT, 1998).

Findings about the provision of water services in Tijuana

Water supply

The period from 1950 to 1980 represented a critical period of water shortage in the city of Tijuana. Many factors, mainly including migration and industrial growth factors, caused an increase in the population of eight times (from 65 364 to 514 583 inhabitants), which prompted the rapid build-up of the water infrastructure. By 1987, only five years after the opening of the Colorado River-Tijuana Aqueduct (CRTA),[9] its capacity had to be expanded from 1 500 to 2 660 l/sec, and it was expanded to 4 000 l/sec in 1993. In 1999, its capacity was again expanded to 5 300 l/sec, which is expected to meet the requirements until 2017. These data show that Tijuana has followed a traditional supply and demand-oriented linear model.

Under this "expansion model", the drinking water supply and distribution system has been expanded four times in the past three decades, similar to the volumes of water extraction. The most recent expansion uses the maximum water volume of the Colorado River quota for the city.[10] These data suggest that to address the demands

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[9] The Colorado River-Tijuana Aqueduct starts at the bi-national Morelos Dam, passes through the Mexicali Valley and the Rumorosa area to the El Carrizo Dam, and ends at the El Florido water treatment plant. It covers a distance of 135.3 km and reaches a height of approximately 1 061 meters in the Rumorosa area. This water transmission line to the city of Tijuana includes several pumping systems, which generate high costs for energy use, maintenance and system operation.

[10] The Colorado River water that supplies the CRTA is legalized by the Boundary Waters Treaty, which was signed in 1944. The agreement states that the United States will transfer an annual quota of 1 850 hm^3 of

beyond 2017, the city will have to negotiate and buy additional water blocks[11] or analyze economic alternatives of seawater desalination. These projections lead us to reflect on the urgency of long-term planning and thereby on the incorporation of intergenerational equity in water management. If the current trend continues, the negotiation and purchase of water will cause greater pressure and deterioration of the supply, increases in the water price, and marked competition for the resource, whose distribution possibilities are equally finite.

Against this backdrop, both local and international consumers with equal or similar issues of rapidly growing demands and inefficient water resource management will be negotiating for an increasingly scarce and expensive resource. This situation may represent disadvantages for Mexico considering the historical economic and political inequalities with its northern neighbor.

Currently, Tijuana is significantly dependent on the Colorado River. This dependence has been raised by Clausen and Hafkesbrink (2005), Gleick et al. (2009), Larsen and Gujer (1997), and Sharma and Vairavamoorthy (2008) as one of the greatest challenges of sustainable water management.[12] The Colorado River supplies 96.2% of the city's water; however, this amount corresponds to 5.3% of the total volume that is allocated to Mexico because the major part (approximately 87%) is used in the Mexicali Valley (CESPT, 2006).[13] These data are significant for understanding that water management has regional and even cross-border dimensions when assuming co-responsibility for its efficient use.

The CESPT, which is a decentralized body that is responsible for operating local water services, steadily increased the production of drinking water by an annual average of 3% from 1991 to 2009. For residential users, this represented an increase in coverage from 82.6% in 1991 to 98.4% in 2009, which is higher than the national average (90.3%) that was estimated by the Comisión Nacional del Agua (CONAGUA, 2010) for 2008, and service is available twenty-four hours a day. However, this increase in coverage is completely related to management that focused on the building of new infrastructure. Authors such as Brooks (2005) and Wolff and Gleick (2002) suggest changing this management approach and point to efficient use under the *"soft path"* concept, which recognizes that the delivery of water-related services must match users' needs and intends to lower costs of treatment and the increased use of treated wastewater.

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water to Mexico (CESPT, 2006). A significant competition for this resource occurs at the national and international levels. In Mexico, this is the largest source of surface water for Baja California and part of Sonora. Moreover, both the quantity and quality of the resource largely depend on the demand and the types of use in Utah, Arizona, Nevada and California in the United States.

[11] Although the proposed system of water reuse is a more positive and self-sufficient system with clear environmental benefits, an economic analysis would have to be conducted to compare the economic feasibility of the acquisition of water blocks, the high costs caused by the development of the water reuse infrastructure, and possible desalination alternatives.

[12] In addition to encouraging minimizing the reliance on external water resources, these authors draw special attention to the conservation of water sources and to the reduction of pollution levels; according to them, these three elements are essential to the sustainable management of urban water.

[13] The most important needs that must be addressed are agricultural production and the environmental preservation of the mouth of the Colorado River. Therefore, it is important to consider the discussion of Wolff and Gleick (2002), in which they argue that farmers do not demand drinking water but rather a supply of water to grow their crops. From this standpoint, the water supply may have different qualities and forms of separate payment that vary according to its use (Jiménez and Martínez, 2003).

Although it is clear that coverage levels as high as those that have been obtained by the CESPT have social benefits, the measurement of water supply efficiency due to increased production volumes encourages practices such as excess demand for water and ignores the problems of the 8 100 homes that still have no access to water service. The need to design and implement national indicators that are aimed at measuring efficient water use, practices to manage demand, and the specific context of each town become evident. It is no longer possible to continue evaluating the efficiency of water use through general indicators when the country has large disparities in the availability and demand for water resources. The same is true for the quality of the water resources. The salinity levels of the Colorado River are increasing, and the levels of pollutants in treated wastewater fail to comply with the official standards (Navarro, 2010).

Water supply and consumption

An analysis of the measurement and billing indicators for the last twenty years showed that despite the increase in supply from 2% to 4% of the annual average, water losses decreased by 1%. In 2009, approximately 20% of the total production of drinking water in Tijuana was lost in the transmission and distribution system.[14]

Even though this loss is lower than the national average of 10% that was found by the Instituto Mexicano de Tecnología del Agua (IMTA, 2003), its efficiency for the specific case of Tijuana is questionable. From an economic viewpoint, losses contribute to an increase in production costs and directly affect retail price. Tijuana is located in a hydrological-administrative region with very low natural availability and strong pressure on water resources (SEMARNAT, 2008), which, along with the city's reliance on external resources, makes water losses more significant.

Moreover, according to data from 2008, 2009 and 2010, losses directly reduce revenues to the water utility by an average of 54.4 million pesos per year. In other words, the inclusion of economic aspects such as higher production costs, the loss of the water utility's revenue, and the increase in the sales price is directly related to the dependency on the resource. It is thus crucial to include long-term projections that analyze the costs, benefits, effectiveness and user expectations.

From a social perspective, based on data from the relationship between losses and the annual average consumption, lost volumes and the lack of infrastructure limit the ability to supply the needs of users that do not have water services. Inefficiencies in the water distribution system also affect environmental stability because water resources are extracted from the natural ecosystem; thus, important reserves are no longer available for future generations.

These data on the relationship between users that lack water service and water losses support the argument that it is not possible to exclusively utilize conservation and sustainability policies in water resource management if minorities that are in need and future generations are not included in the plans (Jiménez and Martínez, 2003).

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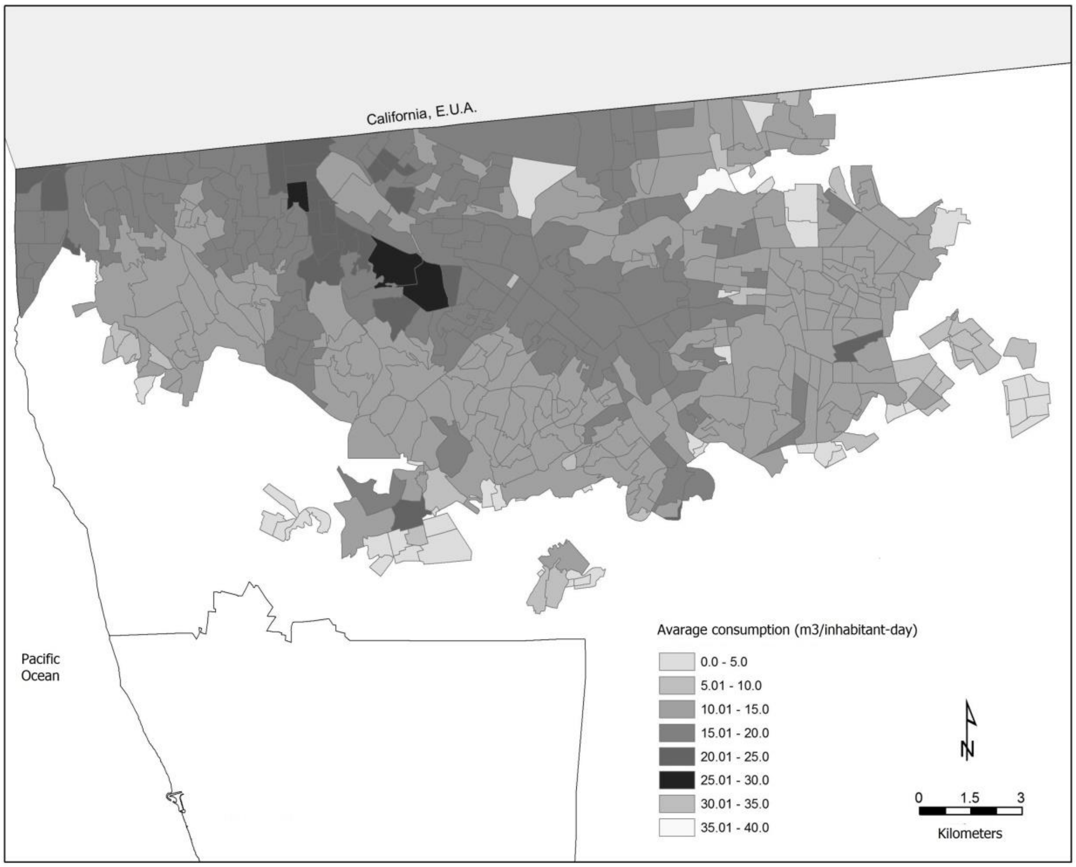
[14] According to Larsen and Gujer (1997), reducing leakage losses is an enormous task for the regions; therefore, before implementing new measures, the efficiency of existing ones should be ensured, and greater use of wastewater should be encouraged (Girardet, 2006; Sharma and Vairavamoorthy, 2008).

However, the spatial distribution of the drinking water supply in Tijuana (Figure 1) shows that the highest levels of consumption per capita are located in the downtown area and that the levels decrease toward the outskirts, which have extremely low levels of consumption.

Figure 1. Spatial distribution of drinking water consumption in Tijuana in 2009. Data are in m^3 per day per inhabitant



Source: The authors.

Bustillos (2009), Sánchez (1988, 1993), and Sánchez, Ganster and Bachelor (1999) considered the connection between the social and spatial aspects of water supply in their research. This relationship between the location and trend is associated with the centralized development of water infrastructure and its slow growth from 2000 to 2010 to the south and east of the city as well as the economic conditions of the population. That is, in Tijuana, the community with fewer economic resources has more limited access to the water supply, and those who are provided with this service have low levels of consumption.

Another factor that is associated with the uneven spatial distribution of the water supply is its impact on communities in irregular settlements (Pombo, 2004). These areas do not have legalized land ownership, which limits the direct provision of water services by the CESPT. The water service system for this population consists of a chain of intermediaries that is composed of authorized resellers, who purchase water from the CESPT (this point of delivery is known as "garza" [heron]) and transporters and sellers, who supply water in tank trucks (called "pipa").

Even though the Revenue Law (ley de ingresos) of Baja California annually stipulates the fees that are charged by the CESPT to authorized water resellers, which implies that the price is regulated annually with a reasonable variation in its increase, this does not apply to the final sales price to irregular users. According to the data that were obtained in this study, the purchase price by users from these areas increased from MXN 30 to MXN 100 per m^3 (a 233% increase) over only five years (2005-2010). Based on information that was provided during interviews, "pipas" users pay up to eight times more than CESPT users for a cubic meter of water. The "pipas" users pay MXN 100 for each cubic meter, whereas the CESPT users are charged MXN 12.19 with a minimum consumption of 0 to 5 m^3 per month. Price pressure on the population's economy is reflected in the reduction in water consumption to very low levels. Households in these communities buy only 1 m^3 of water per month, which represents 8 l/inhabitant-day. This level of consumption may have health risks (WHO, 2003), especially considering that this settlement also lacks a drainage system. As noted by Ávila (2009, p. 156), "within cities, water scarcity is explained by socio-spatial segregation; a process of differentiation of urban space occurs as a result of social inequalities".

In summary, social inequality factors clearly occur in the population that is located in the unauthorized settlements, such as irregular access to water, cost overruns and low consumption. To be sustainable, the management of drinking water services must be designed to address these social problems because high water supply ratios are insufficient when they hide high levels of marginalization.

In turn, consumption highlights key elements of user behavior regarding water services management, which provides a reference point to develop demand management strategies. Contrary to expectations, the per capita consumption for the study period decreased by an annual average of 7 l/inhabitant-day (see Table 1).

Table 1. Categorization of residential users' consumption

Residential Consumption Range (RCR)	Percentage of the population (%)	Average consumption per household (m^3/user-month)	Per capita consumption (l/inhabitant-day)	Consumption categorization
RCR1 to RCR2	51%	5	47	Low
RCR3 to RCR5	41%	18	155	Normal
RCR6 to RCR10	7%	34	299	Average
RCR11 to RCR14	1%	128	1122	High

Source: The authors.

The consumption data (Table 1) show that 51% of the population has a per capita consumption of 47 l/inhabitant-day, which, according to guidelines established by the WHO (2003), is a low level that can compromise health and has potential negative implications for public health. This level of consumption may pose even greater risks considering that in the irregular settlements, the number of inhabitants per household is greater than the population index that was established by the INEGI.

The analysis indicates that this reduction in the consumption of drinking water could be justified because users self-regulate as they face high water service costs. This is based on the documented inverse relationship between price[15] and per capita consumption. Indeed, the former increased at a rate of 9% from 2000 to 2010, whereas consumption decreased by an annual average of 7%.

These results suggest that the level of consumption is directly influenced by the price. However, they also indicate that by implementing policies of price increases, users with low consumption, which represent more than half of the population, are pressured into further reducing their use, which causes considerable damage to social well-being. Therefore, the issue of social inequality as a factor in the analysis of the variability of the spatial distribution of drinking water use must be addressed. Moreover, Resolution 64/292 (UN, 2010) recognized that access to safe drinking water and sanitation as a human right and stated that administrative management must ensure an essential volume to population at risks, whose cost must be borne by society as a whole.

Sewerage, sanitation and the reuse of treated wastewater

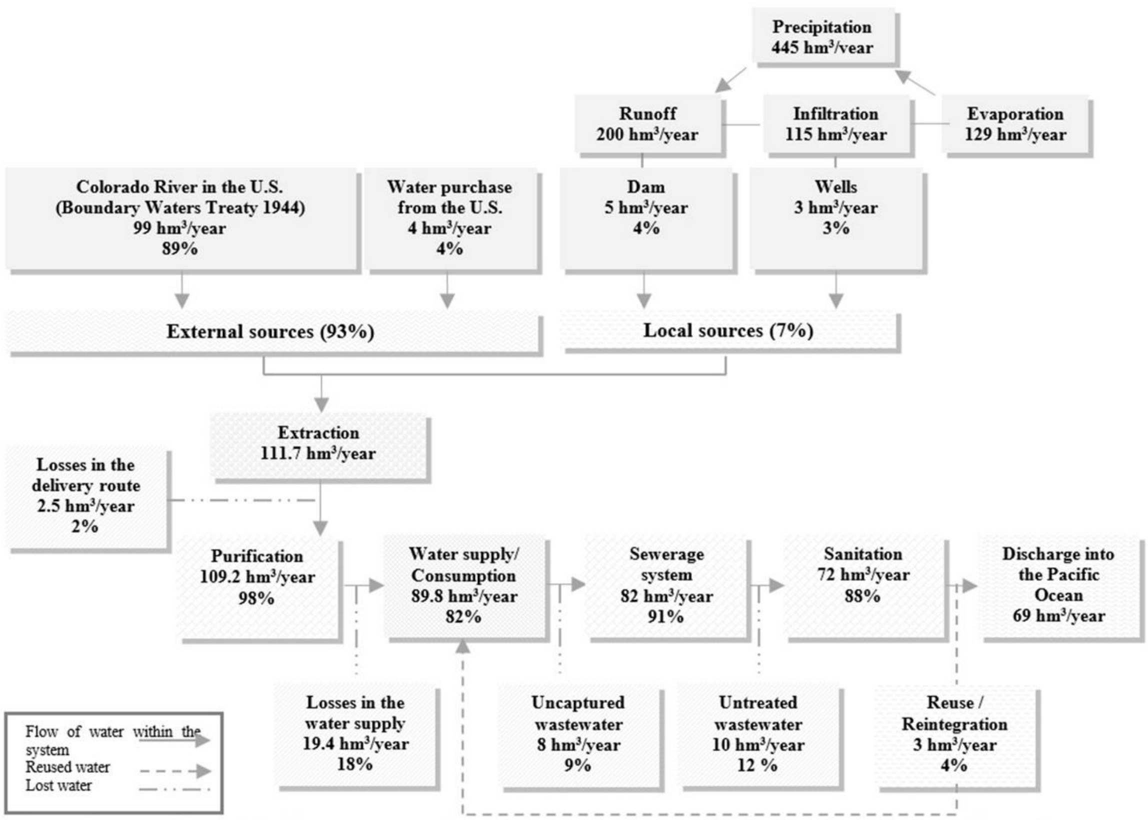
Over half a century after the construction of the first sewerage system, several binational treaties were signed, and a variety of infrastructure was built to address wastewater spills in the cross-border zone. The reactive logic on which most of this history has been structured has emphasized water collection and removal and has delayed the need for efficient sanitation and the reuse of treated water. Girardet (2006) and Sharma and Vairavamoorthy (2008) suggest a review and focus on the efficiency of existing processes before implementing new constructive measures, including the reuse of drainage water (Larsen and Gujer, 1997) .

Despite the increase of sewerage services (by an average of 1.7% annually), this development has not been successful in addressing social and environmental needs. Two factors support this statement. The first factor is the backwardness of the service delivery for 12% of the users. The concentration of the infrastructure in the center and north of the city has caused the population that is located in the far southern and eastern outskirts to be the affected by the backward coverage. In addition, the irregular settlements, which are mostly located in this area, lack access to this service. Moreover, wastewater discharge from this population pollutes the environment, which also has a negative impact on health and social well-being. These deficiencies in the distribution of sewerage services demonstrate the problems of these services due to the disordered population growth and social inequality.

The second factor is the inefficiency in the operation of the system because it maintains the discharge of wastewater into natural canyons and channels in the city. Approximately 46% of the drainage network is obsolete and has reached its useful life, which has resulted in an increased risk of land pollution and destabilization because of leaks and spills. Furthermore, an analysis of the data shows that only 79% of the system is efficient due to the lack of maintenance and replacement of the pipelines. Therefore, 21% of the wastewater, which is equivalent to an average of 18 hm^3 per year, will continue to be discharged directly into the environment (Figure 2). These issues with the sewerage system are mainly related to the fact that the CESPT has failed to respond to the rapid population growth, largely because of the financial deficit of the water utility since 2004.

[15] For further information on the tariff aspects of the water supply operator in Tijuana, please refer to the work of Navarro (2010) on the impact of price on the level of consumption by domestic users as well as the work of Quiroz (2004) and Flores (2008) on the tariff structure of Tijuana and its impact on environmental issues, such as water conservation.

Figure 2. Tijuana water balance, 2007-2009



Notes: Percentages of precipitation, evaporation and runoff were estimated based on data from CONAGUA (2010). The annual precipitation in Tijuana was estimated at 250 mm (Winckell, Le Page and González, 2005). A ratio of 1 mm = 1.78 hm^3/year was used to convert this value into cubic meters; moreover, 1 hm^3 (cubic hectometer) equals 1 million m^3. The percentages of extraction, purification, sanitation and discharge were estimated in this study.

Source: The authors.

Even though the sanitation system is modern (the first plant began operation in 1987), it has grown rapidly and is expected to have an installed capacity of 96% in this decade.[16]

However, the estimates and fieldwork that were conducted in this research indicate that effective sanitation is available for only 70.85% of the wastewater that is generated in the city. This is mainly due to the lack of coverage of the sewerage

[16] The total capacity of Tijuana's sanitation system is approximately 3.060 l/sec; 90% of this volume is treated by the CESPT. When the currently planned plants become operational, 96% of wastewater generated in Tijuana will be treated.

system and to the fact that water treatment plants do not work at full capacity and have maintenance and operational failures.

Moreover, the Planta San Antonio de los Buenos (PSAB) and the International Wastewater Treatment Plant (IWTP), which process most of the wastewater that is generated in the city (63%), do not meet the decontamination guidelines that allow for discharges into the environment.[17]

Despite the social and environmental benefits that are associated with the increase in sanitation capacity, both the treated volumes and the quality of their decontamination will determine the potential reuse of this resource.

Tijuana does not reuse treated water, which would make reuse into a sustainable practice. The "Project Purple" initiative (Proyecto Morado), which planned to use 20% of the treated wastewater by 2010, has only managed to reuse 4% (Figure 2), and the remaining volume is discharged into the Pacific Ocean. This leads to the over-exploitation of natural water resources and to a complete waste of treated wastewater, which contributes to the loss of important economic resources due to water wastage and sanitation investment costs.

Reuse in the city is limited because it has not been a priority in water planning and consequently has not been effectively or continuously included in the operation of the institutions that are responsible for water management at the local level. However, this issue has major opportunities, the ongoing support of the CESPT, and the potential interest of the private sector.[18]

Several factors make wastewater reuse economically and technically feasible in the future provided that reintegration is included in the provision of water services.

Planning and financial structure of the CESPT

In Tijuana, water resource planning is directly structured with development policy at the state and municipal levels. In recent years, this has led the CESPT to operate under the short period of a government's tenure and to constantly focus on increasing the water infrastructure. Although the service operator has a master plan "Plan Maestro de Acueducto y Alcantarillado" in which long-term strategies are planned, it is more often used to analyze issues rather than as a management guide to meet future needs.

The inter-institutional relationship between the CESPT and management bodies (Comisión Estatal del Agua [CEA] and CONAGUA) has focused on the planning and development of water infrastructure. Conversely, issues such as the common development of diagnostics, the implementation of hydraulic plans, and future planning are handled in a disjointed manner within each institution. Therefore, the

[17] These approaches are based on an evaluation of the influent and effluent characteristics, which were provided by the monthly laboratory analysis of the PSAB for 1996 to 2008.

[18] In the city, there is a demand for raw water, which is defined as water without pre-treatment, by "... builders, for earthmoving activities, slope stabilization, emission control, compaction of embankments. The Club Campestre country club, the Airport, the Golf Resort Real del Mar and Morelos Park also make use of this service, by purchasing raw water and reinjecting it into their private Waste Water Treatment Plant (WWTP) for irrigation of green areas. Thus an opportunity is emerging to encourage new groups of users of different water qualities" (Navarro, 2010, p.133). These alternative potential wastewater markets in Tijuana are already being considered; see González (2012).

environmental management of water resources still does not have a common inter-institutional commitment.

The user is currently not identified as a co-responsible agent through whom the water management style can be innovated. The culturalization of society to directly involve it in efficient water management is a priority in models of sustainable management, such as the "New Water Culture" that was proposed by Arrojo (2005) and Jiménez and Martínez (2003). However, this requires a political and social configuration to restrict its application. Barkin (2006) notes that in cases such as Mexico, these management issues are unattainable because efficient social and ecological management has not yet been achieved.

The CESPT has a Departamento de Cultura del Agua, an operational program under the same name, and several advertising campaigns. However, these have thus far been limited to information processes. Although they are an important step in raising awareness, they need to move in the direction of user culturalization and the active participation of users in conservation and the acceptance of future water reuse programs.

Moreover, based on the analysis of information that was provided by the CESPT, revenues decreased significantly from 2004 to 2009.[19] This decrease was due to declining water sales because although the number of accounts increased during these years, the volume of consumed water per user decreased. Similarly, accounts receivable increased by up to 16% annually,[20] and the fare collection efficiency decreased to only 55% of what was charged. The progressive decapitalization of this water utility in the last four years represents a loss of more than two billion pesos. This financial deficit may adversely affect efficient water management and attention to future demands.

In 2005-2009, the cost of the CESPT to supply a cubic meter of drinking water was MXN 27.52.[21] However, the CESPT recovered only MXN 16.24. Thus, the revenue of drinking water represents only 60% of its production cost. Water sales that are below the costs lead to a long-term lack of funds that has a direct impact on system expansion and maintenance (Sterner, 2008). As demonstrated by the case of Tijuana, individuals with fewer economic resources end up paying more for water. Moreover, the tariff structure[22] does not include the total costs for sanitation services; it does not

[19] A detailed analysis of the trends of revenues and expenditures of the CESPT system for 1991-2009 was performed by Navarro (2010, pp. 154-166).

[20] The accounts receivable for 1991-2009 increased despite the effort by the service operator to increase the installation of water meters (their number increased by 2% annually to 90% coverage). This illustrates the low capacity of the service operator to improve the efficiency of the collection process, which could also be associated with the *Ley de Salud Pública para el Estado de California* of 2001, which prohibited the interruption of water supplies (Navarro, 2010, pp. 162-163).

[21] The costs of water extraction (including payments for the rights to water), transportation and purification are covered in the production costs of the CESPT. These costs are calculated by the service operator as the total production expenditures divided by the total volume of water produced. Likewise, sewerage and purification services are included in the drinking water service (wastewater collection, removal, treatment and final disposal) because the CESPT charges a flat rate. Therefore, the service operator does not distinguish between the costs of each of these services in the billing invoice that is delivered to users, but it estimates in the tariff framework that 40% of the invoice corresponds to the operating costs of the sanitation services (Navarro, 2010, pp. 167-173).

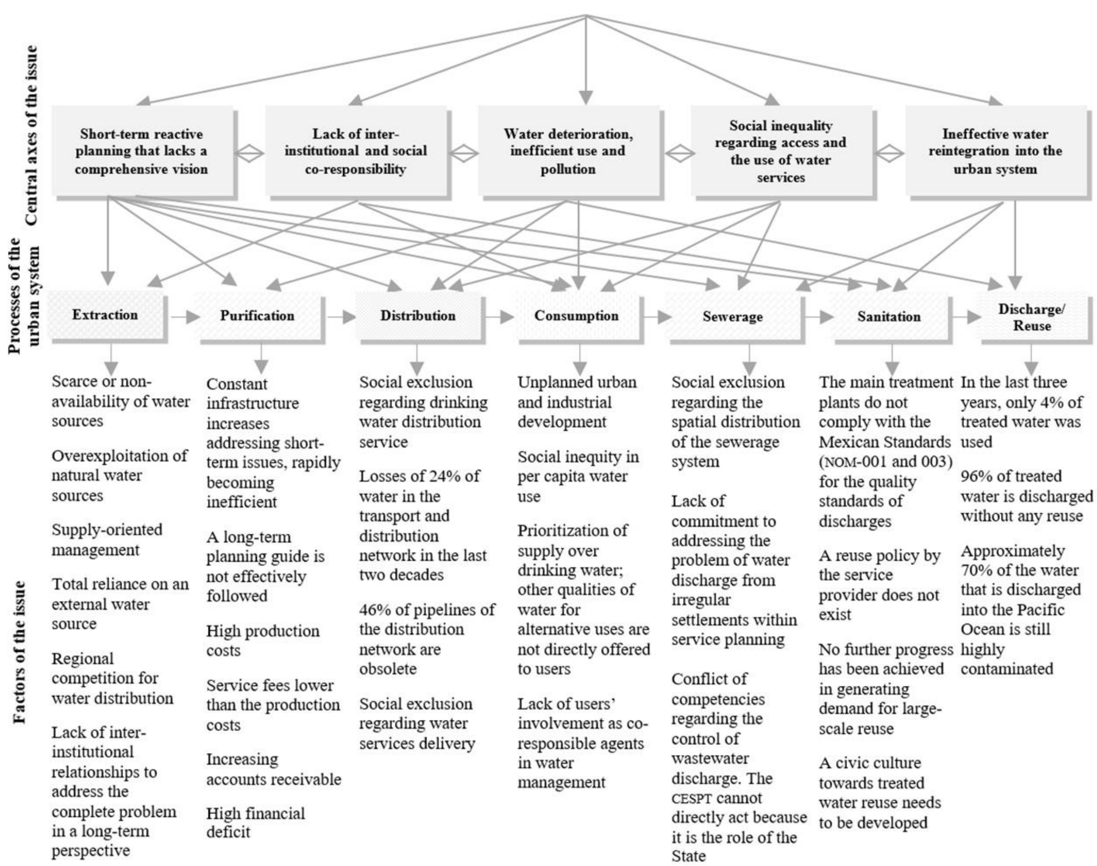
[22] The design of the tariff structure of the CESPT is based on the ranges of consumption, determining the limits of the volumes of water to be consumed, and the base and incremental prices for each range. This type of fee is known as increasing block rates or tiered pricing because of the incremental increase in the amount of the invoice with the increase in consumption. Users are classified into domestic and non-domestic

provide criteria for the conservation of water resources or socio-economic differences in the population. Therefore, the CESPT charges a fee that is not representative of the real price of water services and does not reflect the level of water scarcity and its users' characteristics.

Discussion of research outcomes: Analysis of axes and critical factors of the unsustainability of water management in Tijuana

Water services management in Tijuana appears to be an unsustainable system. As shown in the water balance (Figure 2), the city depends on a limited supply from an external source, which is further complicated by losses and the lack of reuse of "outflows" or treated wastewater. This situation allows a critical analysis of the water management, which has been developed using a linear process; despite its cyclical nature and although it is renewable, the system has reached its limits, and its regeneration capacity is exceeded by the demand. This issue is one of five central axes (Figure 3):

Figure 3. Axes and critical factors in the unsustainability of Tijuana's water supply



Source: The authors.

services; industrial, commercial and government users are included within the latter classification for the provision of drinking water and sewerage.

The first axis is related to short-term planning and the lack of a comprehensive vision of social and environmental objectives related to water management. Since its beginnings, water service management in Tijuana has been based on supply management, which has led to the development of an inefficient water infrastructure in which the available capacity is quickly exceeded by the demand. Although social benefits were generated by the increased area of water service delivery, it has also led to the greatest water stress in the region by increasing the volumes of extracted water to the available capacity. Under the current management model, this situation implies large construction projects and therefore the need to find additional water sources.

The second axis is the inefficient use of water. Although measurement and billing indicators have increased annually in the city, water losses have remained at an average of 24% for the last twenty years.[23] Given the rapidly growing demands from urban sprawl, the loss of these water resources represents major social, economic and environmental expenses.

The third axis is the lack of coordinated and strategic inter-institutional work at the local level as well as the limited co-responsibility of users in water management. The common scheme between the service operator and the various local agents that are involved in resource management that is used to address issues is very weak, and there is no collaboration in future water management projects.

The fourth axis is inequity in the spatial distribution of urban water services due to the poor coverage for the population that is located in irregular settlements and the lack of planning to correct these problems.

The fifth axis is the lack of effective reintegration of wastewater into the city. The dynamics of the water flow demonstrate that the sanitary sewerage system directly interacts with the drinking water system. However, its development in the city has not been planned or developed in this way. The treated water does not meet the regulatory standards of decontamination, and reuse projects do not have the capacity to incorporate significant volumes of treated water into the city's system.

The relationships of each of these axes to the different processes of water supply into the urban system (extraction, purification, distribution, consumption, sewerage, sanitation and reuse) highlight many critical factors that contribute to the unsustainability of water management in the city of Tijuana.

Conclusions, proposals and challenges for sustainable management

The flow of water in an urban system (Figure 3) reflects a wide variety of ecological, social, administrative and economic connections, which in turn play a determinant role in its sustainable management. In short-term models that lack comprehensive management. This situation is a limiting factor for the socioeconomic development of the city. It may also be a central element of future binational political conflicts and of competition between users at the regional level.

[23] The data on water losses from 1991 to 2009 that were analyzed in this study are available in detail in Navarro (2010, pp. 63-65), who specified that 92% of losses occur in the distribution system (water transport and distribution to users), and 8% occurs in the delivery route (from water collection to its delivery to water purification facilities). The water loss from the system has decreased by 1% annually, whereas the number of working water meters has increased by 2%.

The spatial distribution of drinking water and sewerage reflects social inequality towards the southern and southeastern suburbs of Tijuana, where users with fewer economic resources pay more for a lower service coverage and quality. This results in a social segregation "belt" for the access to water in this sector.

This study reveals the existence of social inequality factors in water access and supply and highlights that the high indicators of the coverage and efficiency of the service operator are overemphasized. Therefore, it is necessary to develop effective and appropriate indicators to measure the service backwardness in marginalized populations, shortage variables, and the reliance on external sources that can serve as tools for water resource management to be more in line with the social and environmental conditions of the region. Moreover, the water balance shows losses that must be considered as unacceptable in cities with arid ecosystems, where water is precious. Likewise, the lack of recirculation "outflows" (treated wastewater) results in a linear management model in which the city's water stability is compromised.

Therefore, the sustainable use of water must include a reduction of the physical and commercial losses by the service operator, social equity in water delivery, co-responsible management among management institutions, operators and users of the service and, most importantly, the effective increase of water reuse.

It is important to note that the reduction in water use is not included as a critical factor to guide the management model towards sustainability because the analysis of the spatial distribution showed a decrease in the per capita water use by Tijuana's population, and approximately 90% of the population consumes medium to low amounts of water. Therefore, instead of attempting to reduce the supply of water, a new culture of water use must be developed in which factors such as a social awareness of water scarcity, its high value, and the future implications of pollution and resource deterioration play important roles.

The management paradigm for Tijuana must transition from a perspective that is based on the scarcity of water resources to one that focuses on the efficient use of existing sources. This study suggests considering treated water as the city's main water resource. This may have multiple social challenges. First, a process must be developed to gain acceptance for treated water; its implications in public health and in the economy must be controlled. Planning effective reuse systems may also be necessary. The efficient operation of wastewater treatment plants to comply with decontamination standards entails several technical challenges. Finally, political commitments must be aimed at developing public policies that encourage the use of treated wastewater, promoting and generating "clients", and increasing demand for this resource. Very little progress has been made on these topics at the local level, which represents a challenge whose ultimate goal is to reduce the need to extract greater volumes of natural sources of water and thereby mitigate water stress in the region.

In the city, the actual price of water is not charged. Less than half of what is charged is collected, water losses still occur, and progress towards co-responsibility and comprehensive planning is limited. Therefore, the service operator must integrate environmental aspects into the infrastructure planning of water services, such as the reduction of water sources based on climate change scenarios, critical periods of water scarcity, conservation of water resources and studies of alternative sources. The social aspects of demand behavior and the citizens' perceptions of the efficient use of water must also be integrated. There must be an overview of the current status of water management and a projection toward future scenarios.

To this end, we propose building a tariff structure by relating the economic stratification of the population to the staggered consumption by different types of users. To economically characterize the users, we suggest that the CESPT use the classification of properties that is established by the City Council to levy property taxes. Assuming that this classification is consistent with the population's economic conditions, the rate stratification would be more likely to achieve social equity by considering the conditions of domestic users in suburbs with low consumption as well as major consumers that are located throughout the city and thus reach sustainability in the provision of water services.

We also suggest that charging for water based on strata or ranges of economic or social conditions may contribute to the recovery of the real costs of producing water. At the same time, it would encourage the efficient use of services by users and allow the operator to reach financial stability. However, tariff restructuring may require a prospective study on its impact on domestic consumption and the water utility's finances.

As a result, we suggest the establishment of a liaison office between the Departamento de Planeación of CESPT and the Instituto Municipal de Planeación (IMPLAN) for constant real-time communication on relevant changes in authorizations that are granted to new urban developments. This collaboration may help to improve efficiency and prioritize investments in home construction, aqueducts, and water and sewerage networks.

In addition to providing the necessary information to make users aware of the importance of protecting water, it would also be desirable for the CESPT and CEA to go beyond education, which is what the program of water culture of the CESPT is based on, to reach co-responsibility with the objective that the users become aware of the issue and actively participate in its solution. This could have an impact on developing viable projects of treated wastewater reuse and on increasing the culture of service payment.

As a complementary strategy to this proposal, we suggest that the CESPT modify the appearance of the receipt of user fees. The bill must no longer be a payment document collection but must be used as an important means of communication and rapprochement between the water utility and its users. To this end, we propose that the bill integrate: *1)* economic aspects, such as the structure, payments to be made, subsidies that are provided or granted, discounts and the prices of different types of water (drinking water, wastewater, treated water); *2*) natural aspects, such as the quality and quantity of the water sources that are used for purification, and *3)* socio-cultural aspects, which tend to raise awareness of water saving and efficient use.

In terms of the social equality of water distribution, the needs of informal settlements, their growth and the trends in their demand for drinking water and sewerage are also considered to be priorities. Although it is clear that legal constraints regulate the service delivery most of the city, ignoring the needs of informal settlement may have negative impacts on their health and quality of life and may cause environmental pollution and economic losses for the service operator. The same social policy of the public administration requires a paradigm shift that recognizes that bearing the costs (for vulnerable social groups) is not an economic inefficiency but a long-term investment that will benefit the community.

Finally, it is important to emphasize that the CESPT needs to include in its planning the potential demand that would occur with regularization and hence the normal service delivery to the informal settlements. Therefore, an analysis of future scenarios that consider this population's future demand may allow the service operator to develop a long-term plan for the production and efficient use of water and for the necessary infrastructure in areas of increased urban development to avoid critical scenarios of the lack of coverage.

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