

WATER RESOURCE BALANCE AND PROPOSED MEASURES FOR SUSTAINABLE MANAGEMENT IN THE FOUR SECTIONS OF CHAPULTEPEC FOREST

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ABSTRACT

This study examined the water resources in four sections of Chapultepec Forest (CF) to assess their current state and propose strategies for proper management. The forest is significant for Mexico City due to its historical and cultural value, ecological relevance, and contribution to the quality of life of its residents. For diagnosis, a water balance was carried out under current conditions, and water supply and demand were projected to the year 2050. The results show that there is currently a water deficit in sections 1, 2, and 3, mainly due to the demand for irrigation water. Towards 2050, and considering the trend of climatological variables, an increase in the deficit is expected for the entire CF due to increased evaporation and water demand in its various uses.

Key words: supply, demand, water use, deficit, consumption, rainwater harvesting.

INTRODUCTION

Since pre-colonial times, Chapultepec was regarded as a sacred garden, as well as a place of leisure and recreation for its rulers. After 1930, with the expansion of the population, the surrounding areas of the forest began to be settled in a disorderly fashion. Today, the forest continues to serve as a recreational space; however, with the increase in visitors and the reduction in water availability, water resources are beginning to be compromised.

The administration of the Federal Government and Mexico City carried out the Chapultepec Forest (CF) Cultural Complex Project with the purpose of increasing the services that the forest offers from a cultural, environmental, and social perspective. However, several problems affect water resources, starting with the lack of knowledge of water supply and demand for planning under current and future conditions to

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manage its balanced use. Therefore, it is important to carry out a diagnosis of the site in order to implement actions and achieve sustainable management of the water resources.

The CF is located in the Miguel Hidalgo mayorality of Mexico City (Figure 1). It has an area of 686.01 ha, divided into three sections: the First Section, with 274.08 ha; the Second Section, with 168.03 ha; and the Third Section, with 243.90 ha (Gobierno del Distrito Federal, 2003). In addition, there is a proposal for its expansion, including a fourth section.

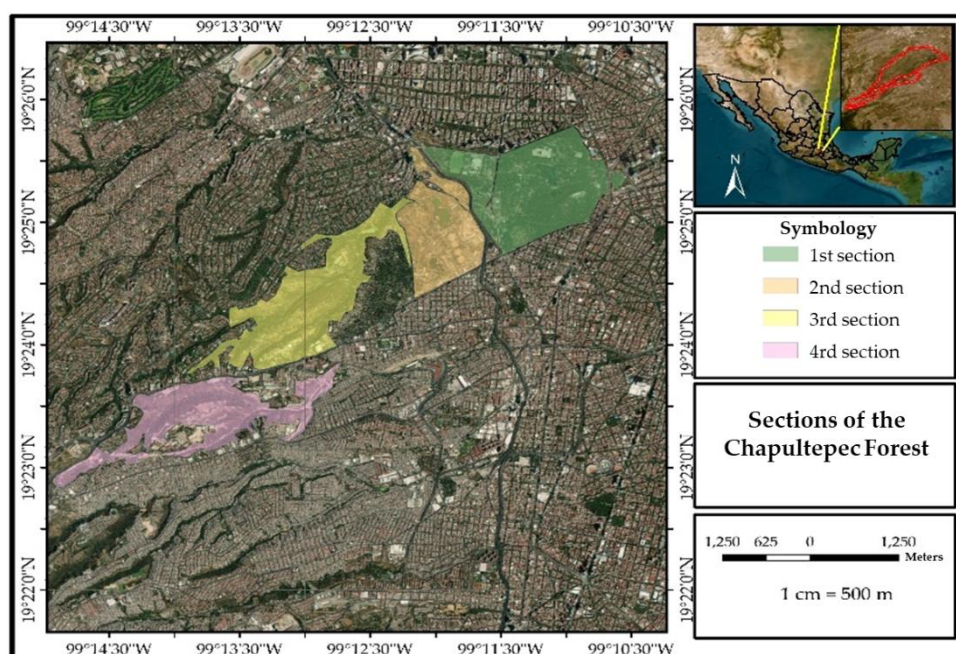


Figure 1. Sections of Chapultepec Forest in Mexico City, Mexico.

The First Section, under the custody of the National Institute of Anthropology and History (INAH), belongs to the historic sector of the park, with 182 ha of green areas. It has two lakes and five museums, including the Chapultepec Castle. There are approximately 55 thousand trees, among which the cedar (*Cupressus lusitanica* Mill.), the thunder tree (*Ligustrum lucidum* W.T. Aiton), and the ahuehuete (*Taxodium mucronatum* Ten.) predominate (SEDEMA, 2011). The Second Section was inaugurated in 1964 for recreational purposes. It is an open space with two lakes, four museums, and approximately 17 500 trees. The Presidential House of Los Pinos and the Papalote Children's Museum are located in this area (SEDEMA, 2011).

The Third Section, inaugurated in 1974 with an environmental vocation, was decreed a Natural Protected Area in 1992. It has extensive green areas and 137.71 ha corresponding to ravines, making it the least known area of the forest. It has an

estimated 85 550 trees (SEDEMA, 2011). The project of the Fourth Section of the CF takes place in what used to be the former Army Weapons Factory, an area that will become an artistic and cultural space, with almost 100 ha destined to the care and conservation of the environment.

In order to understand the current and future state of CF's water resources, a water balance of the area was carried out, for which available information was collected to characterize the region and quantify the current water supply and demand. Subsequently, the predicted water volume for the year 2050 was estimated. The supply is the sum of the annual water volume provided by the various supply sources, whether surface or groundwater, and the demand is the ideal (annual) water consumption resulting from the occupation by visitors and the various services provided.

The CF is located within basin 2670 Mexico City (SINA, 2020a) and aquifer 901 Mexico City Metropolitan Zone (SINA, 2020b). The basin has an available volume of surface water of 1.26 Mm³ (DOF, 2020a), while the aquifer is unavailable, with a deficit of 507.23 Mm³ (DOF, 2020b). Although the basin has surface water availability, Breña-Puyol and Breña-Naranjo (2017) showed that in the Hydrological Administrative Region XIII, where CF is located, the degree of water availability is of extreme scarcity. In both cases, the estimation of these volumes is based on NOM-011-CONAGUA-2015 (DOF, 2015), which establishes the specifications and method for determining the average annual availability of national waters in Mexico. Silva-Hidalgo *et al.* (2013) state that there are several manuals for determining the availability of water in a basin, but they refer to the natural availability of the resource or the natural runoff generated in it, which is different from the legal-administrative or regulatory context contained in the standard.

Many works directed towards the calculation of natural availability can be found in scientific publications. For example, López-García *et al.* (2017), in their work, show a water balance to obtain the natural availability under climate change scenarios of the aquifer in the Galeana Valley in the State of Nuevo León, Mexico. Other studies, such as the one conducted by Ordóñez-Gálvez (2011), show a methodology for estimating the natural surface water balance in Peru.

Very similar methodologies were applied by Gómez-Reyes (2013) and UNESCO (2006) to obtain the surface water balance of the Valley of Mexico basin. These works include the incorporation of the variable of uses of consumption (Uc) and the calculation of the variability and uncertainty of the components of the water balance. On the other hand, according to Silva-Hidalgo *et al.* (2013), scientific publications on the subject of water availability in legal-administrative or regulatory terms are scarce. However, countries such as Chile, Spain, Mexico, and the United States have regulatory documents for water resource management, with some variations, but all focused on the regulatory framework.

In general, the methodologies for obtaining the natural water balance or for regulatory purposes are very similar in their formulation, i.e., they are all based on the basic equation $dV/dt = E - S$, which expresses that the variation in volume (V) is equal to the

inputs (E) minus the outputs (S) of water for a specific time interval (t) (UNESCO, 2006). The only thing that changes in each methodology are the methods for processing the data that feed the water balance equation.

With the implementation of NOM-011-CONAGUA-2015, it is possible to know the availability of water resources in the four sections of CF for its current state and for the year 2050. It is taken into account that, in the variable of consumptive use from urban public use, an increase in the number of inhabitants of the CF is not expected, except in the Fourth Section, where there is a residential land use that is fully occupied. However, the main increase in water use in the four sections will be due to the increase in visitors to the CF. In addition, due to the increase in temperature, an increase in evapotranspiration is expected, causing a water deficit in the projected period.

The objective of this work is to conduct a water balance to determine the current status of the resource as well as its status in 2050, in order to determine its availability and, if necessary, propose a specific action to help minimize any potential water deficits.

MATERIALS AND METHODS

The balance for each of the CF sections was performed by applying the general storage change equation:

$$\frac{\partial V}{\partial t} = E - S$$

where $\partial v / \partial t$ is the change in storage over time, E are the inputs, and S are the outputs. From the equation, the general elements for the water balance are broken down:

$$\Delta V = (Vp + Ear + Im + Re + B + Vm) - (Ev + ET + Eaa + Ex + Uc + f + In + Int)$$

where ΔV is the change in storage, Vp the precipitated volume, Ear the upstream runoff, Im the imports from external basins, Re the returns, B the pumped withdrawals within the polygon, Vm the volume contributed by springs, EV the evaporation from water bodies, ET the evapotranspiration, Eaa the downstream runoff, Ex the exports, Uc the consumptive uses, f the leaks in the drinking water distribution network, In the infiltration, and Int the interception.

However, if we express the volume of runoff per proper basin (Cp), the equation is expressed as:

$$Cp = Vp - ET - In - Int$$

which is reduced to:

$$\Delta V = (Cp + Ear + Im + Re + B + Vm) - (Ev + Eaa + Ex + Uc + f)$$

The origin of the information for the variables considered in the latter equation is explained below.

Runoff per own basin (*Cp*)

The drainage polygons to the four sections of the CF were estimated and subdivided into micro-watersheds. Rainfall-runoff modeling was performed for the whole set with the SWMM application (James *et al.*, 2010).

Land use was classified as residential, built urban, and streets, among others, to delimit the impervious and permeable zones within each micro-watershed. In addition, it was combined with the soil type from the soil cartography of the National Institute of Statistics and Geography (INEGI) Series I of 2005 and Series II of 2013 for the calculation of infiltration losses (variable *Im*). Edaphology and land use were also used to calculate infiltration losses in the microbasins using the Soil Conservation Service method, Curve Number (CN) (NRCS, 1986; SCS, 1991). Likewise, Manning's *n* coefficient was defined for conduits, impermeable surfaces, permeable surfaces, depression storage height above the impermeable area, and depression storage height above the permeable area.

An analysis of stations of the National Meteorological Service (SMN) with daily precipitation record (variable *Vp*) was performed, where the area of influence of the stations was verified from the Thiessen polygons. A greater influence of the Colonia America station (code 9010) was identified, with information from 1980 to 2017. During this time period, the years with the highest and lowest annual precipitation were obtained, and it was determined that the year 2017 represents an average year of precipitation, on which hydrological modeling was performed. Since the linear correlation is greater than or equal to 0.8, the missing precipitation and evaporation data were supplemented with data from the Tacubaya station (code 9048). Evaporation was included because it is a necessary component for the SWMM model to calculate the variable *Int*. The *ET* variable is estimated by the *Uc* component.

The model calibration considered the operation of the intake works at Dolores Dam. Because there is no information on dam levels or hydrometric stations recording runoff at any site in CF and its contributing watersheds, the outflow of $6.9 \text{ m}^3 \text{ s}^{-1}$ was matched to the simulation using 2017 precipitation. Furthermore, the purpose of this dam is to regulate floods during storms, not to store water. The reference expenditure was taken from Trujillo (2016).

Upstream runoff (*Ear*)

To estimate upstream runoff, it was necessary to identify the streams that interconnect the microbasins. This value was obtained using the SWMM hydrologic model.

Imports from external basins (Im_e)

For the First Section, the only import considered is the discharge from the Chapultepec treatment plant (PTAR), which is sent to the minor lake and then to the major lake with a flow rate of 60 L s^{-1} . Then, 40 L s^{-1} are sent to the Acequia canal, where a portion is divided to the pumping sump for the irrigation network of the First Section, and the 15 L s^{-1} surplus is sent to the Reforma Avenue collector.

In the second section, the outflow from the PTAR is considered, with an outflow of 60 L s^{-1} to the minor lake, and then 55 L s^{-1} are sent to the major lake. A portion of this discharge is sent to the pumping sump for the irrigation network, and 20 L s^{-1} are sent to the Avenida Reforma collector.

In the Third Section, the discharges coming from an industrial use register were quantified, which is reported in supply sources as discharges. For the Fourth Section, the discharges presented in the Public Registry of Water Rights (REPDA), corresponding to domestic and service use, are considered.

Imports by potable water network (Im_p)

Information was compiled from plans of the drinking water network for the CF area from the Mexico City Water System (SACMEX). The water volume in each section was estimated based on the pipe diameters, using the Bresse equation (Bresse, 1860), which starts from a very elementary and conservative criterion by using a constant velocity of 0.57 m s^{-1} , which turns out to be a velocity widely surpassed nowadays. This equation is expressed as:

$$D = 1.2\sqrt{Q}$$

Clearing the expense, it remains:

$$\left(\frac{D}{1.2}\right)^2 = Q$$

where Q is the flow rate ($\text{m}^3 \text{ s}^{-1}$), and D is the diameter (in meters).

For water distribution, it was assumed that the supply is made every day of the week in a range of 2 h per day, and that the overall efficiency in the water network in the four sections is 100 %.

Returns (Re)

A percentage was considered for each use (DOF, 2015): 75 % for urban public, 55 % for industrial, and 20 % for irrigation, based on the estimated volume of the drinking water network by SACMEX, pumping reported by REPDA (CONAGUA, 2020), and volume going to the pumping sump intended for irrigation, respectively.

Extractions by pumping within the polygon (*B*)

From the extractions reported by REPDA, only the total volume destined for industrial use was considered, since pumping wells were identified within the CF polygons. This volume of water is included in the initial analysis, but because the flow distribution within the CF is unknown due to a lack of micro-metering and because it is not an industrial zone, it is excluded from the final balance.

Volume supplied by springs (*Vm*)

Based on field surveys, a spring was discovered in the Tacubaya River ravine, just a few meters upstream from the Fourth Section. This spring is pumped by SACMEX and distributed to the drinking water network, but the flow to the CF is unknown. As a result, the drinking water network considers it a component of the variable (*Im*) because the estimated flow includes extractions from supply sources.

Evaporation of water bodies (*Ev*)

Evaporation was taken from climatological station 9048 (Tacubaya), located 1.18 km from the First Section of the CF. This station was considered because it has the longest record. The average monthly evaporation (in millimeters) was applied to the surface of the water bodies as a function of height to obtain the average evaporated water volume per month. In the First Section, the maximum evaporation surface of Chapultepec Lake was considered, which was 68 036.23 m². The Second Section has a maximum evaporation surface of 92 656.56 m². The Dolores Dam is located in the Third Section, but it does not store water, so it was not included in the analysis. The Tacubaya Dam is located in the Fourth Section and has a maximum evaporation surface of 20 278.64 m². In all scenarios, May has the highest evaporation, with 182 mm.

Downstream runoff (*Eaa*)

Downstream runoff was obtained using the SWMM hydrologic model to obtain the runoff described in basin proper (*Cp*).

Exports (*Ex*)

As stated in the demand of water bodies, of the 60 L s⁻¹ that arrive from the PTAR, 15 L s⁻¹ leave the basin as part of what was considered in the First Section. The discharge that is sent to the Reforma Avenue collector, with a flow rate of 20 L s⁻¹, was considered for the Second Section as part of the flow that exits the polygon. There were no sub-basin exports considered in the third and fourth sections.

Uses of consumption (*Uc*)

This index represents the total estimated consumption by type of water use for each section. To determine the type of water use based on land use and vegetation, a land use map was created using a vector map of blocks (INEGI, 2020c) and satellite imagery. The Cropwat application was used to estimate irrigation water use for different soils

(Swennenhuis, 2009), and it calculates the annual lamina required for irrigation. The First and Second Sections are irrigated primarily through a water network fed by pumping sumps, with a flow rate of 35 L s^{-1} applied via sprinkler irrigation at a 70 % efficiency.

The irrigation requirement data was generated using 10-year irrigation schedules, and the irrigation requirement method was based on crop evapotranspiration estimation. The consumption volume for the water bodies was calculated using the volume assigned to each, with flows from the PTAR. The volume of water for urban public use was estimated using records of visitors and employees from the First, Second, and Third Sections, as provided by CF authorities. The demographic data for the fourth section came from the population and housing census (INEGI 2020a).

Leaks in the potable water distribution network by SACMEX (f)

The system is considered to be 70 % efficient. This value is similar to the data provided by Bourguett-Ortiz and Ochoa-Alejo (1996), which found that in various cities across the country, leaks in intakes account for 24.5 % of losses on average.

Projection to 2050

The CF polygons are areas where no urban sprawl or land use change is expected, as they are protected areas by INAH, the Secretariat of the Interior and Ministry of National Defense (SEDENA) in the First, Second, and Fourth Sections, respectively, with the Third Section being a natural protected area. The water balance to 2050 was projected using climate change models and linear trends in climate variables such as temperature, precipitation, and evaporation. Similarly, visitor projections were made for the four sections using the population growth model. The Fourth Section projected only the population of the currently urbanized area. Based on the findings, each parameter in the forward water balance equation was calculated.

RESULTS AND DISCUSSION

The CF and its hydrographic system are located in the Lake Texcoco and Zumpango sub-basin of the Moctezuma River basin, which is one of three basins that comprise Hydrological Region No. 26 of the Pánuco River. Within the CF area, a series of ravines can be identified where rivers run off in a flowing manner during the rainy season. According to the Watershed Water Flow Simulator (SIATL) (INEGI, 2020b), these rivers are classified as intermittent streams because they do not present runoff during the dry season. The Third Section of the CF is formed by the Dolores River; the First and Second Sections do not have watercourses due to their flat topography, and the Fourth Section is crossed by the Tacubaya River, with runoff from wastewater discharges to the dam of the same name.

The study area belongs to the Anahuac Lakes and Volcanoes physiographic subprovince, which is part of the Neovolcanic Axis. The highest point in the basin has an altitude of 2850 m, while the lowest part of the basin reaches approximately

2200 m (INEGI, 2010). The maximum daily rainfall found is between 25 and 95 mm. In this study, 2017 was used as a reference because it was an average year with 943.1 mm of precipitation. The data for evaporation in the microbasins showed an average maximum rate of 6.4 mm d⁻¹ and an average minimum rate of 3.8 mm d⁻¹.

The dominant soil in the CF area and catchment basin is Feozem, which has a medium texture. Their impervious areas of each micro-watershed range from 1.39 to 100 %. The curve numbers obtained range from 76 to 91. This is because each micro-watershed has a weighted value (based on different land uses). The calibration of the simulated model with the average rainfall represented by the 2017 precipitation revealed that by matching the outflow through the intake work of 6.9 m³ s⁻¹, a flow of 0.37 m within the dam was generated.

Current water balance in the CF sections

The water balance was performed using the general equation of storage change, which included input variables (supply) such as runoff from the hydrological model, imports, and the drinking water network, as well as outputs such as evaporation, leaks, transfers, and consumptive uses in the area (demand). As a result, the First, Second, and Fourth Sections experience an annual water surplus. The Third Section has a deficit of almost 400 thousand m³ per year (Table 1).

Table 1. Current potential water balance of the Chapultepec Forest sections in Mexico City, Mexico.

Variable	First Section (m ³ year ⁻¹)	Second Section (m ³ year ⁻¹)	Third Section (m ³ year ⁻¹)	Fourth Section (m ³ year ⁻¹)
(+)E <i>Cp</i>	1 258 456	1 075 281	2 625 404	5 357 618
<i>Ear</i>	125 129	2 427 445	0	2 518 747
<i>Im</i>	2 539 614	2 199 589	66 200	1 136 982
<i>Re</i>	752 406	451 669	46 045	570 250
<i>B</i>	200 000	0	0	0
<i>Vm</i>	0	0	0	0
<i>Ev</i>	111 115	151 324	0	33 119
<i>Eaa</i>	1 548 275	87 223	2 359 257	675 165
(-)S <i>Ex</i>	474 336	632 448	0	0
<i>Uc</i>	1 847 416	389 975	759 886	473 003
<i>f</i>	252 681	90 673	18 418	228 100
(+)E Total	4 875 605	6 153 984	2 737 649	9 583 597
(-)S Total	4 233 823	1 351 643	3 137 561	1 409 387
ΔV Total (m ³)	641 782	4 802 341	-399 912	8 174 210

(+)E: inflow volume; (-)S: outflow volume; ΔV: change in storage volume; *Cp*: volume of runoff by own basin; *Ear*: volume of runoff from upstream; *Im*: import volume; *Re*: return volume; *B*: volume of extraction by pumping; *Vm*: volume contributed by springs; *EV*: volume loss due to evaporation from water bodies; *Eaa*: downstream runoff volume; *Ex*: export volume; *Uc*: volume of consumption use; *f*: losses due to leaks in the distribution network.

However, it is important to consider that pumping (*B*) represents the volume supplied by REPDA supply sources, the amount of water and proportion that it contributes to each section being unknown, as they also supply other neighboring areas outside the CF polygons. Therefore, only the volume estimated using the pipe diameters of the potable water network, which supplies the four sections in total, is considered. Water from runoff and returns was also eliminated due to poor quality (IMTA, 2022), resulting in a water balance of -146, 935, -712, and 402 thousand m³ in the First, Second, Third, and Fourth Sections, respectively.

With this consideration, the First Section also suffers from water deficit. However, if the balance is separated by use, that is, what comes from the PTAR that is used for irrigation and water bodies, and what comes from the potable water network for urban public use minus what is lost in leaks, the available water for irrigation in the First, Second, and Fourth Sections is obtained. Nonetheless, for urban public use, there is a deficit in the First, Second, and Third Sections (Table 2).

Table 2. Current effective water balance of the Chapultepec Forest sections in Mexico City, Mexico.

Variable	First Section (m ³ year ⁻¹)	Second Section (m ³ year ⁻¹)	Third Section (m ³ year ⁻¹)	Fourth Section (m ³ year ⁻¹)
+ PTAR supply	1 897 344	1 897 344	4 807	376 648
+ Drinking water supply network	642 270	302 245	61 393	760 334
- Irrigation demand	1 223 984	92 794	668 207	268 210
- Lake demand	632 448	632 448	0	0
- Urban public demand	623 432	297 181	91 679	204 793
- Leaks	252 681	90 673	18 418	228 100
Irrigation availability	40 912	1 172 102	-663 400	108 438
Urban public availability	-233 843	-85 609	-48 704	327 441

PTAR: Chapultepec wastewater treatment plant.

Projections to 2050

By 2050, the average temperature will oscillate between 12 and 14 °C. For precipitation, based on a linear trend, rainfall of up to 300 mm is expected in August, while climate change projections show a reduction to around 200 mm.

In 2019, there were approximately 19 million visitors per year in the first three sections of the CP, with a projected 28.7 million in 2050. The Fourth Section is expected to receive 3.2 million visitors, as its doors have been opened as a tourist destination until 2022. Finally, by 2050, the four sections are expected to receive 31.9 million visitors per year. In terms of population, no significant growth is expected by 2050, with a projected increase from 3879 (2020) to 5333 people, with the Fourth Section accounting for 80 % of the total.

Water supply to 2050

For the four sections, the WWTP and supply network are expected to remain constant, while surface water runoff volume per basin will decrease due to increased evaporation, resulting in a reduction in total supply volume. Given that it is not feasible to use surface water, including returns, due to the difficulties associated with treating wastewater in the area (IMTA, 2022), it is assumed that the supply in 2050 will remain constant as in the current situation.

Water demand to 2050

Irrigation for pasture and eucalyptus was calculated using climate variables projected to 2050, while land use areas remained unchanged. Finally, for the human consumption demand variable, the projected numbers of visitors and residents in each section were used. The demand or consumption use (U_c) increased from 1.8 to 3.2 million m^3 in the first section, 0.4 to 0.6 million m^3 in the second section, 0.76 to 2 million m^3 in the third section, and 0.47 to 1 million m^3 in the fourth section.

Water balance to 2050

Considering the constant supply, the increase in demand due to population, visitors, and irrigation volume, the separation by balance by use, the volume coming from the PTAR for irrigation and water bodies, and the volume of the potable water network for urban public use deducting what is lost in leaks, we have that the Second Section maintains a volume of water available for irrigation but not for urban public use. The Fourth Section would not be able to meet its irrigation needs, but would maintain a slight volume available for human consumption (Table 3). The First and Third Sections will be in deficit of water for irrigation, lakes, and urban public.

Table 3. Projected effective water balance for the year 2050 in the Chapultepec Forest sections of Mexico City, Mexico.

Variable	First Section ($m^3 \text{ year}^{-1}$)	Second Section ($m^3 \text{ year}^{-1}$)	Third Section ($m^3 \text{ year}^{-1}$)	Fourth Section ($m^3 \text{ year}^{-1}$)
+ PTAR supply	1 897 344	1 897 344	4807	376 648
+ Drinking water network supply	642 270	302 245	61 393	760 334
- Irrigation demand	2 265 917	171 385	1 901 854	500 449
- Lake demand	474 336	632 448	0	0
- Urban public demand	951 533	442 426	117 624	513 327
- Leaks	252 681	90 673	18 418	228 100
Irrigation and lake availability	-842 909	1 093 511	-1 897 047	-123 801
Urban public availability	-561 944	-230 854	-74 649	18 907

PTAR: Chapultepec wastewater treatment plant.

Sustainable management measures within the CF

The measures analyzed to reduce the existing water gap and to 2050 addressed four issues (available water, flood reduction, groundwater recharge, and water quality improvement). In principle, the limited treatment that wastewater can receive (IMTA, 2022) influenced the selection of these measures, as the rugged topography prevents the use of natural wastewater treatment systems, which require significant surface area extensions. It is possible to treat wastewater in a specific way in each discharge using mechanical means; however, this requires significant economic investment (IMTA, 2022).

With the proposed aquifer recharge and flood reduction measures, it is not possible to include the contribution to the volume of water consumed. As a result, rainwater harvesting was chosen to take advantage of the existing and planned building extensions. Rainwater harvesting systems (SCALL) are made up of five basic components: the catchment area, pipelines for conveying water, treatments, storage tank size, and complements. The volume of rainwater harvested in the current and projected 2050 scenarios is roughly 65 thousand m³ per year (Table 4).

When these volumes are compared to the current and 2050 urban public use demand, it is clear that it is not possible to meet the water needs, but it is possible to significantly reduce the volume of water in the rainy months for specific uses such as sanitary use (Figure 2).

Table 4. Volume of water captured (m³ year⁻¹) in the sections of the Chapultepec Forest in Mexico City, Mexico.

Scenario	First Section	Second Section	Third Section	Fourth Section	Total
Current	28 594	10 014	0	26 858	65 466
2050	23 291	10 751	8105	21 387	63 534

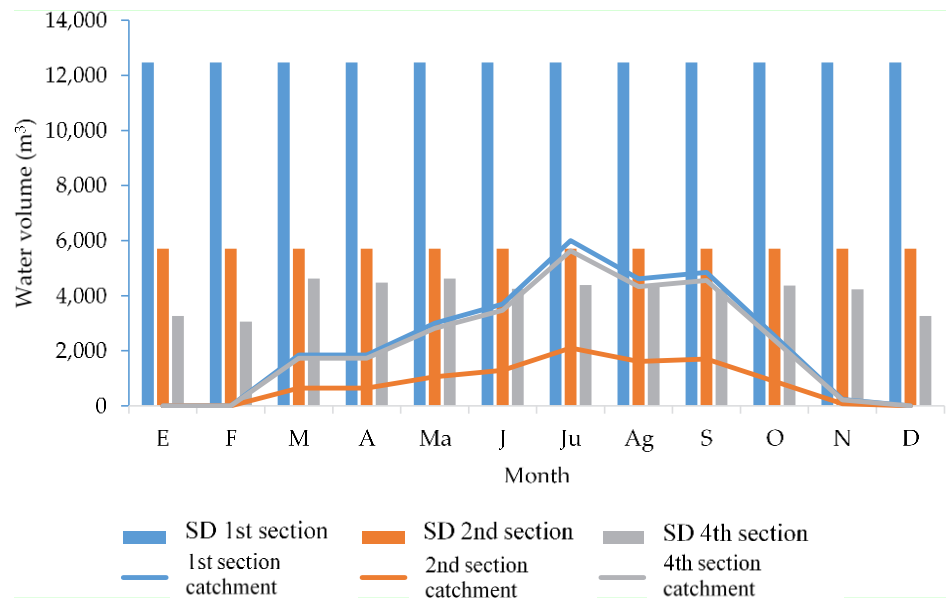


Figure 2. Water catchment volume versus demand volume for monthly sanitary use in the current scenario in three sections of Chapultepec Forest. SD: sanitary demand.

CONCLUSIONS

Currently, the four sections of Chapultepec Forest are in water balance, tending to deficit during dry seasons. However, if the Cultural Complex Project is implemented in the future, it will not be possible to supply water resources to visitors due to the deficit of the aquifer. Towards 2050, an increase in precipitation is observed, but also in temperatures, which leads to an increase in evaporation and a greater demand for consumption. With an increase in the visiting population, a greater demand for urban public use is expected, so the water balance is expected to be negative in the future. Rainwater harvesting is a major contributor to water supply, which could partially pay, in the months of March to October, a percentage of the water demanded for sanitary use of the buildings. More rainwater could be captured; however, there is a restriction due to the division of the administrative management of Chapultepec Forest, resulting in inadequate and suboptimal water management, which is only possible in the Third Section but requires a large investment in infrastructure. To deal with the low availability of water, volumetric meters must be installed to count consumption and detect leaks or losses, so that they can be repaired and drinking water is not wasted.

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