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# Current and Future Scenarios of Water Availability and Demand in an Aquifer: Case Study of Libres-Oriental, Puebla, Mexico Aquifer

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**Abstract:** This study aimed to perform a general balance between the availability and the demand of the Libres-Oriental aquifer, which allowed the construction of current and future scenarios and the temporary projection of their availability or potential deficiency. All the consumptive uses of the water were considered, emphasizing the agricultural use, which occupies around 80% of the total volume concessioned in a year. Water needs and irrigation requirements of the established crop pattern (cyclic and perennial) were estimated using the FAO-56 method modified by Penman-Monteith. The results obtained regarding the availability and demand of groundwater, according to a projected scenario, for the period 2015-2070, show an availability of around 18.49% for 2015, gradually decreasing this in the following years until reaching at 5.58% availability around the 2030 year. Starting this year, a deficit period will begin first of 3.32% increasing this in subsequent years until reaching an underground water deficit of 12.86% for the 2070 year. Limitations of the study could lie in having taken as a basis only a year in agricultural statistics (2015), and in the realization of linear projections and by least squares in terms of population growth (2050-2070) based on data from the National Institute of Statistics, Geography and Informatic (INEGI) (2010) and from the National Population Council (CONAPO) (2015-2030). Implications of the same suggest that urgent measures must be implemented tending to the sustainable use and above all to the conservation of the groundwater still available.

**Key words:** underground water, consumptive use, water deficit, conservation

## 1. Introduction

Satisfaction of water demand in its main consumptive uses — domestic and urban, agricultural and livestock and industrial and other uses — is based on a large part (39%) of access to sources of groundwater supply. There are 653 aquifers in the country, of which 205 (31%) are currently unavailable, in the Puebla State, the Tecamachalco and Libres_Oriental Valleys aquifers are in this condition.

Water is an essential resource for life. 70% of the land surface is covered by water, of which only 2.5% of it is fresh water. Of this small percentage, scarcely 1% of the total water of the planet can be used by living beings [1].

Groundwater, in particular, is one of the most valuable natural resources since many of the urban and rural areas of developed countries depend on this resource. Of the 37 million $km^3$ of fresh water estimated on Earth, about 22% exists as groundwater, which constitutes approximately 97% of the freshwater in liquid state available for human use.

Availability of groundwater depends, to a large extent, on the recharge of aquifers. This recharging takes place, mainly, by rainwater.

The importance of groundwater is manifested in the magnitude of the volume used by the main users. 38.9% of the total volume granted for consumptive uses (i.e.,

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33,311 million cubic meters per year as of 2015), belongs to this origin. For purposes of groundwater management, the country has been divided into 653 aquifers. From that moment, a process of delimitation, study and determination of the average annual availability of the aquifers was initiated. As of December 31, 2015, the availabilities of the 653 aquifers of the Mexican Republic had been published, identifying the 205 aquifers without availability, a situation also known as water deficit (CONAGUA, 2016, p. 48).

According to results of recent studies, it is defined if the aquifers are considered overexploited or not, depending on the extraction/recharge ratio. From 2001 to date, the number of overexploited aquifers has oscillated between 100 and 106. As of December 31, 2015 there were 105 aquifers in this condition and in the case of Puebla, the Tecamachalco Valley and the Libres-Oriental aquifers, respectively.

In order to reverse Mexico's aquifers and watersheds, restore the hydrological balance and safeguard the public supply and socioeconomic development, the Federal Government has various regulations: closures, regulations, reserves and rescues. These ordinances restrict the extraction of groundwater in various areas of the country.

With respect to the country climatic vulnerability, specifically that caused by the rainfall and temperature conditions, CONAGUA categorizes the drought according to its characteristics; highlighting the meteorological drought (periods of time without rainfall), agricultural (drying in areas of the rhizosphere or immediate area to the living roots of the plants), hydrological (affecting the water supply of the subsoil and the levels of the bodies of water ) and socioeconomic (effects on society and its economic activities) (CONAGUA, 2015, p.40).

Evaluation of the drought considers that since this is a phenomenon in which rainfall decreases below its regional average, its characteristics are specific to each place where it occurs (CONAGUA, 2016, p.40).

In view of the growing concern of the population in general, the different government bodies, the agricultural and industrial producers and the service providers, all users of the aquifers groundwater that are part of the basins and sub-basins of the administrative hydrological regions of the Mexican Republic, with respect to the current availability and demand of groundwater and the prospects of future availability, is framed the present study, in which, based on an analysis of statistical information, the projection of future scenarios is carried out -a little more of 50 years, of the current date- on the demand and availability of groundwater of the Libres-Oriental aquifer, this according to its different consumptive uses; agricultural, urban and industrial and other uses.

In addition to the above, and based on the premise that in agricultural activities a greater consumptive use is made of this vital resource - sometimes in more than 80% of the volumes available and officially licensed - the irrigation requirements and volumes were estimated of each of the crops that were part of the established crops pattern, under irrigation conditions, in 2015, in the area of influence of the Libres-Oriental aquifer.

The importance of the study lies in the need to have objective and accurate information through the analysis of cunatitative data on the volumes of water available and the demand for it, for each of the consumptive uses made in the area of influence of an aquifer, in this case, the Libres-Oriental aquifer in the state of Puebla to carry out a projection, constructing current and future scenarios that allow for strategic planning and decision-making aimed at management, protection, conservation, management and sustainable use of water.

### *1.1 Water Balances Studies*

Sahuquillo (2009) [2] mentions that groundwater is cheap, easily accessible and vital for a third of the risks and the supply of the world's population. Despite the possibilities that groundwater allows, these are not considered adequately in the water administrations of many countries. In addition, many do not have enough hydrogeologists, and they have serious shortcomings in protection against pollution.

He establishes that groundwater has been used since ancient times to supply populations and for irrigation. The improvement of well drilling techniques and the introduction of the submersible pump have led to greater use of groundwater. In recent decades, the increase has been spectacular, especially for irrigation in arid and semi-arid regions. In some cases, the intense exploitation of aquifers has led to significant declines in water levels, decreases in river and spring flows, affecting wetlands and ecosystems and causing degradation of water quality or the phenomenon of marine intrusion. in coastal aquifers.

Cruz, Ramírez, Vázquez, Nava, Troyo, and Fraga (2013) [3] made a hydrological balance of the La Paz aquifer, B.C.S., Mexico, which would serve as an instrument to regulate the extraction of water from the aquifer. The same authors found that the extraction is greater than the recharge and therefore, the aquifer was overexploited, so they recommended the need to implement measures for its conservation.

Lesser, Lesser, Arellano and González (2011) [4] conducted a study on water balance and groundwater quality in the Mezquital Valley aquifer, Hgo., Mexico, carrying out, among other things, a geohydrological update study in the aquifer through which they differentiated two aquifer horizons that had not been detected in previous studies, one superficial and one deep. As a result of the groundwater balance, they found that the main water input to the aquifer corresponded to the infiltration of untreated wastewater from Mexico City, through irrigation channels and returns.

Valis (2017) [5], mentioned in relation to the document "Law of groundwater: a proposal" citing Dr. Gonzalo Hatch Kuir, that currently the regulation of groundwater is made from an inadequate scientific base, calculating the water balance, even that takes into account estimations with parameters such as evapotranspiration, precipitation and soil type, a system that is considered to be prone to failures, since they take into account old cartographic descriptions, due to the fact that there are no meteorological stations necessary to carry out these estimations. Groundwater management is carried out based on conventional estimates and delimitations of an administrative nature, without taking into account the actual size of the aquifer, which translates into inefficient exploitation and collateral environmental damage. For what it proposes that to determine the geological units (aquifers) it is necessary to make exploratory drilling, to know the temperature and quality of the water, in addition to performing isotopic tests. By knowing the aquifer's own information, it will be possible to determine the size and the recharge and discharge points [5].

According to the CONAGUA in provisions published in the Official Gazette of the Federation (DOF) in the Agreement that gives information about the results of the technical studies of the waters of the Libres-Oriental aquifer dated 28 January 2016, it is concluded that in the aquifer under study, there is no average annual availability of groundwater to grant new concessions or assignments; Therefore, the underground water resource must be subject to controlled extraction, exploitation, use and exploitation to achieve environmental sustainability and avoid aggravating over-exploitation of the aquifer [6].

In the Libres Oriental aquifer, there is still the risk of aggravating its problems, to the detriment of the environment and the groundwater users. Therefore, the General Agreement for the suspension of free birth establishes that it will be in force in the aquifer, until the legal instrument that the National Water Commission, through the Secretariat of Environment and Natural Resources, proposes to the Owner of the Federal Executive, which will allow the administration and sustainable use of subsoil national waters in the aquifer in reference.

The present study had the purpose of making a general balance between the availability and demand of the Libres-Oriental aquifer, Puebla, which would allow the construction of current and future scenarios and the temporal projection of its availability or potential deficiency.

## 2. Materials and Methods

The Libres-Oriental aquifer, is located in the center-northeast corner of the state of Puebla, covers an area of 3,973.80 square kilometers, representing 11.58% of the total state area (Fig. 1). It includes the municipalities of Aljojuca, Chichiquila, Chilchotla, Guadalupe Victoria, Lafragua, Mazapiltepec de Juárez, Oriental, Quimixtlán, Rafael Lara Grajales, San José Chiapa, San Nicolás Buenos Aires, Tlachichuca, Tepeyahualco and San Salvador El Seco. partially to the municipalities of Ocotepec, Libres, Cuyoaco, Nopalucan, San Juan Atenco, Chalchicomula de Sesma, Soltepec, Chignautla, Ixtacamaxtitlan, Tlatlauquitepec, Atzitzintla, Zautla, Aquixtla, Esperanza, Tetela de Ocampo, Zacapoaxtla and Zaragoza, all of them belonging to the state of Puebla [6].

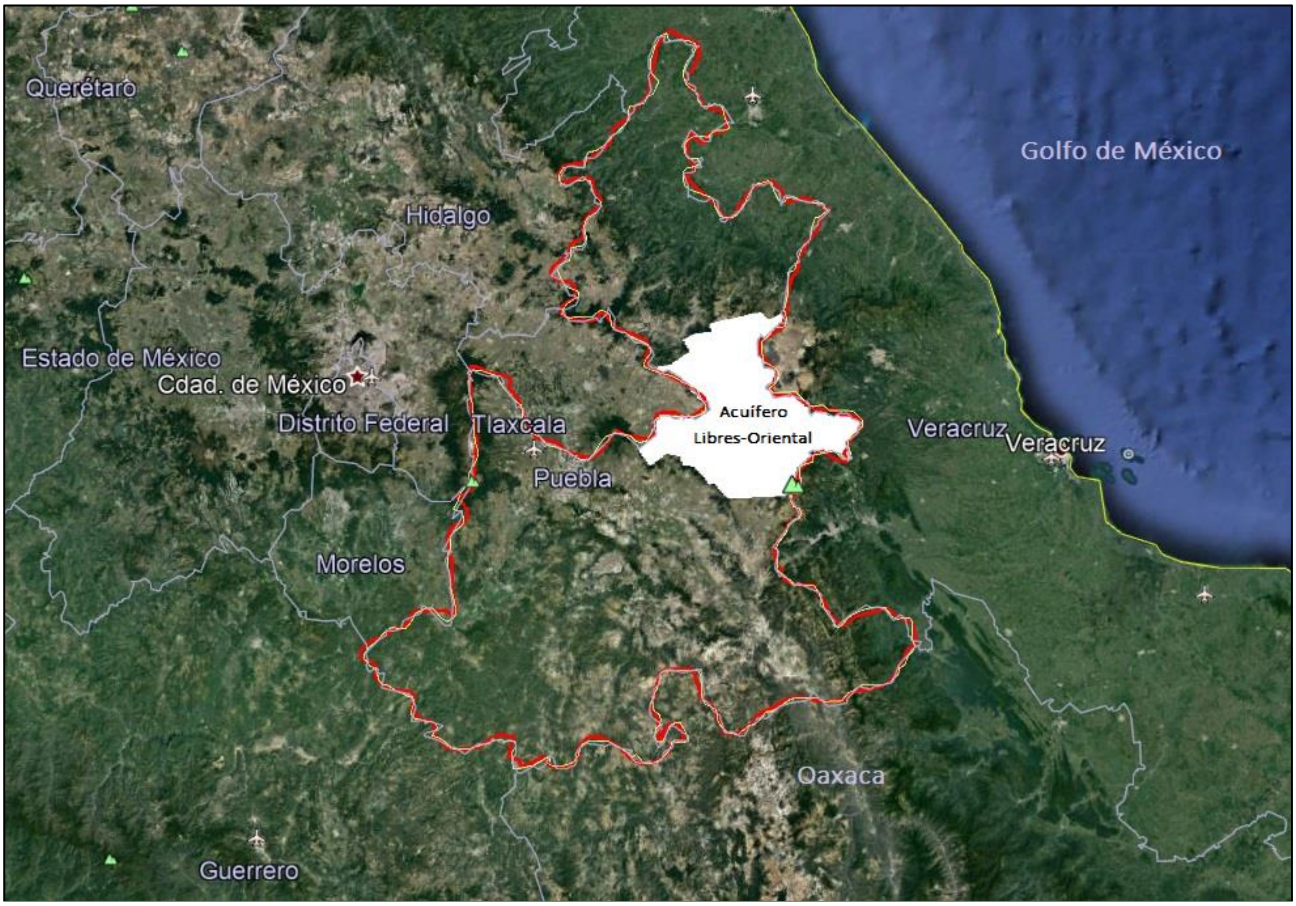


**Fig. 1 Location of the Libres-Oriental aquifer, Puebla [7].**

The update of the average annual availability of groundwater published in the DOF on April 20, 2015, corresponding in turn to a cutoff date in the Public Registry of Water Rights (REPDA) as of June 30, 2014, is shown in Table 1; it highlights in the same, the data of ground water deficit in the aquifer of the order of 351,629 $m^3$.

In geohydrological studies carried out in the 60s, it was mentioned that the Libres-Oriental aquifer had hydrogeological conditions very similar to the original ones, since what entered the subsoil was naturally released — by evaporation and underground south and northeast of Soltepec, heading to the state of Veracruz. Years later, with the location of a large number of groundwater deep wells, levels began to fall, intercepting the natural outputs of the aquifer and, as a consequence, lakes Totoloapan and El Salado, practically disappeared, as the water depth went down between 2 and more than 5 m. Also at that time it was planned to derive water from the Libres-Oriental aquifer to the Federal District, since it was estimated a significant availability. Major regional geological faults are natural water conductors, which drain through the mountain ranges, and flow at depth, such as occurs in the Sierras de Soltepec and Citlaltepetl, to the south and west of the valley, respectively. At present, the aquifer receives less contributions from the Huamantla area and its outputs have decreased, due to the increase in the pumping of the deep wells located in the region (CONAGUA, 2015, p. 3).

**Table 1 Update of the average annual groundwater availability of the Libres-Oriental aquifer [6].**

| CODE | AQUIFER | R | DNCOM | VCAS | VEXTET | DAS | DEFICIT |
|---|---|---|---|---|---|---|---|
| | | FIGURES IN MILLIONS OF CUBIC METERS PER YEAR | | | | | |
| 2102 | LIBRES-ORIENTAL | 179.3 | 20.0 | 159.651629 | 103.0 | 0.000000 | -0.351629 |

R: Annual average recharge; DNCOM: natural discharge committed; VCAS: groundwater concessioned volume; VEXTET: groundwater extraction volume consigned in technical studies; DAS: groundwater average annual availability. The definitions of these terms are those contained in the numerals "3" and "4" of the Official Mexican Standard NOM-011-CONAGUA-2015.

In the area of influence of the aquifer, the temperate, subhumid climate predominates, with rainfall in summer, except for the central part, which is semi-dry, with an average annual temperature of 14°C and average annual rainfall of 590 mm; rainy season covers the months of April to October, being August and September the rainiest, with water depths of 50 to 140 mm. Likewise, the average annual potential evaporation is 1,460 mm and similar variations to temperature, while the actual evaporation is 472 mm/year (CONAGUA, 2015, pp. 3-4).

According to the results of the population and housing censuses, conducted by the National Institute of Statistics and Geography, for the year 2000, the total population in the area comprising the Libres-Oriental aquifer, amounted to 308,903 inhabitants, in the year 2005, was of 323,073 inhabitants and in the year 2010, it added 349,101 inhabitants [6].

The main localities located in the area of influence of the aquifer are Ciudad Serdán, the most important in the east of the State, Ciudad de Libres, San Salvador El Seco, Rafael Lara Grajales, Oriental and Guadalupe Victoria.

By the 2030 year, the urban population will reach 200,225 inhabitants, 33,746 more inhabitants than there were in 2010, while the total population will increase from 349,101 inhabitants in 2010 to 419,848 inhabitants at the end of the year 2030; On the other hand, the rural population will present an increase in the number of inhabitants, from 182,622 inhabitants to 219,622, although it should be considered that in years after 2010 some will stop being rural to become urban [6].

At the end of 2030, the population that lives within the demarcation of the aquifer will require 22.98 million cubic meters per year to supply drinking water, under an inertial scenario; which represents 3.87 million cubic meters more than those used in 2010, considering endowments per inhabitant of 150 liters per day [6].

The crops pattern established under irrigation in 2015, was made up of 18 annual and perennial crops, highlighting the corn grain in terms of area sown with 7,603.40 hectares, followed by alfalfa, potatoes, forage corn, carrots, beans and the grain bean with 2,832.40, 2,758.52; 1,792.00; 1,104.50, 1,100.60 and 1,088.30 has, respectively.

The total planted area was 20,816.20 hectares, obtaining a total of 462,027.76 tons of agricultural products, with a production value of $ 1'097,423,110.00, which represented 4.72% of total gross domestic product (GDP) by primary activities of the state of Puebla, which was 23,272.54 million pesos [8]; highlighting the potato with a contribution of $ 327'275,630.00, representing almost 30% of the value of the total production in the Libres-Oriental aquifer (Table 2).

**Table 2 2015 agricultural statistics of annual and perennial crops established under irrigation in the area of influence of the Libres-Oriental aquifer [9].**

| Crop | Sown area (ha) | Harvested area (ha) | Production (Ton) | Yield (Ton/ha) | PMR ($/Ton) | Production value (Thousands Pesos) |
|---|---|---|---|---|---|---|
| Grain corn | 7,603.4 | 7,603.4 | 35,997.97 | 3.77 | 3,913.14 | 147,162.70 |
| Alfalfa | 2,832.4 | 2,832.4 | 177,829.41 | 73.29 | 679.56 | 88,807.25 |
| Potatoes | 2,758.5 | 2,758.5 | 63,625.80 | 18.85 | 5,563.43 | 327,275.63 |
| Forage corn | 1,792.0 | 1,792.0 | 90,660.30 | 43.52 | 867.26 | 84,722.57 |
| Grain bean | 1,088.3 | 1,088.3 | 1,863.86 | 1.59 | 16,276.27 | 32,513.40 |
| Carrot | 1,104.5 | 1,104.5 | 27,751.30 | 24.46 | 2,667.60 | 68,079.56 |
| Bean | 1,100.6 | 1,100.6 | 1,810.06 | 1.46 | 11,716.25 | 19,720.89 |
| Green bean | 708.4 | 708.4 | 3,275.64 | 4.48 | 4,158.01 | 15,105.07 |
| Green tomatoes | 504.3 | 504.3 | 5,569.62 | 8.61 | 3,839.44 | 28,835.04 |
| Broccoli | 437.2 | 437.2 | 7,218.75 | 18.47 | 3,030.94 | 27,759.73 |
| Lettuce | 299.4 | 299.4 | 6,260.79 | 20.31 | 1,631.25 | 9,585.87 |
| Red tomatoes | 155.2 | 155.2 | 32,885.66 | 170.75 | 6,080.42 | 229,065.15 |
| Zucchini | 112.0 | 112.0 | 1,339.50 | 11.97 | 4,661.11 | 6,218.55 |
| Forage oats | 96.0 | 96.0 | 1,366.00 | 14.15 | 517.62 | 856.82 |
| Ebo | 95.5 | 95.5 | 2,472.10 | 18.42 | 826.17 | 2,143.68 |
| Green pepper | 44.0 | 44.0 | 1,606.00 | 3.65 | 15,000.00 | 2,409.00 |
| Garlic | 82.5 | 79.5 | 477.00 | 18.00 | 43,673.74 | 6,946.20 |
| Strawberry | 2.0 | 2.0 | 18.00 | 9.00 | 12,000.00 | 216.00 |
| | **20,816.2** | **20,813.2** | **462,027.76** | **25.82** | **7,616.79** | **1'097,423.11** |

The information consulted and generated allowed the construction of scenarios on the availability and demand of groundwater in the Libres-Oriental aquifer in the period 2015-2070, while making comparisons and conclusions between the same scenarios constructed and finally elaborating a series of recommendations to follow, especially with regard to the use of water in agricultural activities, tending, the same, to be carried out at all times, a more efficient and rational use of water.

Due to the lack of surface information and irrigation sheets per crop, it was considered that 40% of the volume used for irrigation returned to the aquifer in the form of induced recharge, due to the presence of high permeability strata in the subsoil. Considering that the volume of water destined for agricultural use was 127.72 million $m^3$ per year, 19.16 million $m^3$ for domestic and urban use, and 12.77 million $m^3$ for industrial use and other uses, yielding a total volume of concessioned underground water (VCAS) of 159.65 million $m^3$ per year.

However, part of the analysis carried out in this study and the need to have information on surfaces and irrigation sheets by crop, focused on determining the volumes of water required by the pattern of crops established under irrigation in the year 2015 in the area of influence of the Libres-Oriental aquifer, according to data from the Agri-Food and Fisheries Information Service (SIAP), a decentralized agency of the Secretariat of Agriculture, Livestock, Fisheries and Food (SAGARPA) of the Federal Government, based on the Estimation of irrigation sheets by crop.

To do this, both the water needs and the irrigation requirements of the crop pattern were estimated, using the Penman-Monteith estimation method (Table 3).

The crops water needs are associated with the concept of crop evapotranspiration (ET), which considers the loss of water in the form of steam from a soil with vegetation cover through evaporation and through the crop transpiration itself during an interval of certain time [10].

Fernández, Martínez, Tavarez, Castillo, and Salas (2009) [11], defined the consumptive use or evapotranspiration as the sum of the water volumes used by the vegetative growth of a certain area for transpiration and vegetable tissue formation and evaporated from the adjacent ground, coming from the snow or from the rainfall intercepted in the area at any given time, divided by the surface of the area.

**Table 3 Needs and requirements for irrigation of the crop pattern established in the Libres-Oriental aquifer in 2015.**

| Crop | Hydric requirements (mm) | Irrigation requirements (mm) |
|---|---|---|
| Grain corn | 560.3 | 360.8 |
| Alfalfa | 1,079.7 | 818.4 |
| Potatoes | 312.6 | 283.0 |
| Forage corn | 560.3 | 360.8 |
| Carrot | 358.3 | 255.1 |
| Beans | 363.8 | 257.7 |
| Grain bean | 750.7 | 561.4 |
| Green bean | 750.7 | 561.4 |
| Green tomatoes | 476.4 | 362.9 |
| Broccoli | 557.0 | 386.1 |
| Lettuce | 366.2 | 274.1 |
| Red tomatoes | 476.4 | 362.9 |
| Zucchini | 265.8 | 167.8 |
| Forage oats | 634.7 | 451.6 |
| Ebo | 634.7 | 451.6 |
| Garlic | 453.0 | 353.6 |
| Green pepper | 570.7 | 382.3 |
| Strawberry | 356.1 | 258.1 |

They mention that the requirement of crop irrigation (RR) or net needs, is defined as the sum of the corrected real evapotranspiration or evapotranspiration of the corrected crop (ETc correg) minus the effective precipitation (Pe).

In the construction of the scenarios regarding the availability and demand of water in the Libres-Oriental aquifer, according to its use by the different productive sectors (primary and secondary) and the supply to the population of the localities and municipalities that are part of the area of influence of the aquifer, the following procedure was followed:

With information from the publications "Sociodemographic Panorama of Puebla, Tomos I and II", of the year 2011, the existing population was counted in 2010 in each of the 31 municipalities that are part of the area of influence of the aquifer; while with information from the National Institute of Geography, Statistics and Informatics [8] the existing population for the years 2011, 2012, 2013, 2014 and 2015 was counted and finally, with information from the National Population Council (CONAPO) and according to the birth rates for the municipalities studied, and using linear and least squares trends, the projection of population growth was made up to the year 2070.

The total population was divided, for its particular analysis, into urban population and rural population, corresponding 72% of the total to urban population and the remaining 28% to rural population.

The demand or consumptive use of the population used in the construction of the first scenario — current scenario — was determined considering that the urban population has a demand of 150 liters per inhabitant per day. For its part, the rural population demands 75 liters per inhabitant per day, demands well below the 320 liters per inhabitant per day reported by CONAGUA available to every mexican today and closer to 50 to 100 liters per person per day Reported by the World Health Organization (OMS) should provide a person to cover their basic needs and avoid most health problems [12].

On the other hand, in the construction of the second scenario — an adjusted scenario — the demand or consumptive use of the population was determined considering a water demand by the urban population of 100 liters per inhabitant per day and 50 liters per inhabitant per day per part of the rural population.

According to official information from CONAGUA, the demand or consumptive use of water for industrial activities and others, corresponds to 8% of the volume of groundwater concession (VCAS) by the Commission itself. For public-urban consumption, 12% of VCAS was considered and for agricultural use the remaining 80% of VCAS. For the construction of the current scenario, it was considered 66.89% for agricultural use, 23.29% for public-urban use and 9.81% for industrial use. Finally, an adjusted scenario considered 72.52% for agricultural use, 16.84% for public-urban use and 10.64% for industrial use.

The scenario of consumptive use of water with respect to land use (general weighted), for the period 2015-2017, was constructed from surface information in hectares dedicated to each of the substantive activities of analysis for the use of water of the Libres-Oriental aquifer, namely: agricultural use, public-urban use and industrial use and other uses.

The consumptive uses of water by substantive activity, were taken from the calculations made in the sheets corresponding to volumes of water required by the established pattern of crops — which corresponds to the consumptive agricultural use — the consumptive use made by the population and the consumptive use made for the industry.

The sum of these consumptive uses represents the total demand for water, which was plotted against the availability of groundwater reported by CONAGUA in its study "Update of the average annual water availability of the Libres-Oriental aquifer as of April 20, 2015" Same procedure was followed for the construction of the consumptive use scenario calculated or adjusted.

Finally, a weighted analysis of the consumptive uses of water in the Libres-Oriental aquifer was carried out, considering as baseline the agricultural area planted and harvested, the volume of water required by the established crop pattern, and projected increases of 21% and 50% of the agricultural area planted in the area of influence of the aquifer.

The public-urban and industrial consumptive uses and other uses were the same reported in the official and calculated or adjusted scenarios.

## 3. Results and Discussion

In the construction of the consumptive use scenarios, considering the volumes of water according to the planted surface and required by each of the established crops, the required volumes or consumptive uses of the corn, potato and bean crops stand out, this according to the area sown and harvested of each one of these crops, while the rest of the crops showed a more or less uniform tendency in terms of their irrigation requirements. The crops established in the area of influence of the Libres-Oriental aquifer, had a total consumptive use of 87,045.8 thousand $m^3$ of water in the 20,816.2 has been sown, consumptive use that represented almost 55% of the total volume of groundwater concession (Table 4).

With a water consumption of 150 liters per day per inhabitant of urban areas and 75 liters per day per inhabitant of rural locations, the 31 municipalities that make up the Libres-Oriental aquifer, with a total population of 607,504 inhabitants, demanded in the year 2010, a total water volume of 28,604.3 thousand m3. By 2015, the projected population would be 643,756 inhabitants, which would demand a total water volume of 30,311.3 thousand m3; 36,252 more inhabitants compared to the year 2010 and 1,707 thousand $m^3$ of additional water.

**Table 4 Surfaces and consumptive uses of the crop pattern under irrigation in the Libres-Oriental aquifer in 2015.**

| Crop | Irrigation | | Irrigation net demenad | UC total |
|---|---|---|---|---|
| | Hectares | % | $m^3$/ha | thousands of $m^3$/year |
| Grain corn | 7,603.4 | 36.53 | 3,608 | 27,433.1 |
| Alfalfa | 2,832.4 | 13.61 | 8,184 | 23,180.4 |
| Potatoes | 2,758.5 | 13.25 | 2,830 | 7,806.6 |
| Forage corn | 1,792.0 | 8.61 | 3,608 | 6,465.5 |
| Carrot | 1,104.5 | 5.31 | 2,551 | 2,817.6 |
| Beans | 1,100.6 | 5.29 | 2,577 | 2,836.3 |
| Grain beans | 1,088.3 | 5.23 | 5,614 | 6,109.7 |
| Green beans | 708.4 | 3.40 | 5,614 | 3,976.8 |
| Green tomatoes | 504.3 | 2.42 | 3,629 | 1,830.1 |
| Broccoli | 437.2 | 2.10 | 3,861 | 1,688.0 |
| Lettuce | 299.4 | 1.44 | 2,741 | 820.7 |
| Red tomatoes | 155.2 | 0.75 | 3,629 | 563.2 |
| Zucchini | 112.0 | 0.54 | 1,678 | 187.9 |
| Forage oats | 96.0 | 0.46 | 4,516 | 433.5 |
| Ebo | 95.5 | 0.46 | 4,516 | 431.3 |
| Garlic | 82.5 | 0.40 | 3,536 | 291.7 |
| Green peppers | 44.0 | 0.21 | 3,823 | 168.2 |
| Strawberry | 2.0 | 0.01 | 2,581 | 5.2 |
| | 20,816.2 | 100.00 | 69,096 | 87,045.8 |

For the 2070 year, the projection according to CONAPO data and the results obtained by applying linear and least squares trends, the total population will be 882,015 inhabitants, which will demand a total water volume of 41,529.7 thousand $m^3$; 238,259 more inhabitants than in 2015 and 11,218.4 thousand $m^3$ of additional water in the same year (Table 5).

With a water consumption of 100 liters per day per inhabitant of urban areas and 50 liters per day per inhabitant of rural locations, the 31 municipalities that make up the Libres-Oriental aquifer, with a total population of 607,504 inhabitants, demanded in the year 2010, a total water volume of 19,069.6 thousand $m^3$. By 2015, the projected population would be 643,756 inhabitants, which will demand a total volume of water of 20,207.5 thousand $m^3$; 36,252 more inhabitants compared to the year 2010 and 1,137.9 thousand m3 of additional water.

For the 2070 year, the projection according to CONAPO data and the results obtained by applying linear trends (least squares method), the total population will be 882,015 inhabitants, which will demand a total water volume of 27,686.4 thousand $m^3$; 238,259 more inhabitants than in 2015 and 7,478.9 thousand $m^3$ of additional water in the same year (Table 6).

The main consumptive use of groundwater falls on agricultural activity, which according to CONAGUA data occupies 80% of the total volume of water concessioned, followed by public-urban and industrial and other uses.

According to calculated data, the percentages of concessioned volumes would change to 66.89%, 23.29% and 9.81% for consumptive agricultural, public-urban and industrial uses and other uses, respectively. On the other hand, VCAS would be adjusted to 130,129.2

thousand $m^3$, 29,522.4 thousand m3 less than the official VCAS (Table 7).

**Table 5 Population and consumptive public-urban use of the municipalities in the area of influence of the Libres-Oriental aquifer. Period 2015-2070**.

| Municipality | INEGI | CONAPO projections | | Linear trends (least squares) | |
|---|---|---|---|---|---|
| | 2010 | 2015 | 2030 | 2050 | 2070 |
| Aljojuca | 6,288 | 6,663 | 7,483 | 8,306 | 9,129 |
| Chichiquila | 24,148 | 25,589 | 28,737 | 31,899 | 35,060 |
| Chilchotla | 19,257 | 20,406 | 22,917 | 25,438 | 27,959 |
| Guadalupe Victoria | 16,551 | 17,539 | 19,697 | 21,863 | 24,030 |
| Lafragua | 7,767 | 8,230 | 9,243 | 10,260 | 11,277 |
| Mazapiltepec de Juárez | 2,633 | 2,790 | 3,133 | 3,478 | 3,823 |
| Oriental | 16,575 | 17,564 | 19,725 | 21,895 | 24,065 |
| Quimixtlán | 21,275 | 22,545 | 25,318 | 28,103 | 30,888 |
| Rafael Lara Grajales | 14,052 | 14,891 | 16,723 | 18,562 | 20,402 |
| San José Chiapa | 8,087 | 8,570 | 9,624 | 10,683 | 11,741 |
| San Nicolás Buenos Aires | 9,185 | 9,733 | 10,931 | 12,133 | 13,335 |
| Tlachichuca | 28,568 | 30,273 | 33,997 | 37,737 | 41,477 |
| Tepeyahualco | 16,390 | 17,368 | 19,505 | 21,651 | 23,796 |
| San Salvador El Seco | 27,622 | 29,270 | 32,872 | 36,488 | 40,103 |
| Ocotepec | 4,825 | 5,113 | 5,742 | 6,374 | 7,005 |
| Libres | 31,532 | 33,414 | 37,525 | 41,653 | 45,780 |
| Cuyoaco | 15,367 | 16,284 | 18,288 | 20,299 | 22,311 |
| Nopalucan | 27,292 | 28,921 | 32,479 | 36,052 | 39,624 |
| San Juan Atenco | 3,416 | 3,620 | 4,065 | 4,512 | 4,960 |
| Chalchicomula de Sesma | 43,882 | 46,501 | 52,222 | 57,966 | 63,711 |
| Soltepec | 11,706 | 12,405 | 13,931 | 15,463 | 16,996 |
| Chignautla | 30,254 | 32,059 | 36,004 | 39,964 | 43,925 |
| Ixtacamaxtitlán | 25,326 | 26,837 | 30,139 | 33,455 | 36,770 |
| Tlatauquitepec | 51,495 | 54,568 | 61,282 | 68,023 | 74,764 |
| Atzitzintla | 8,408 | 8,910 | 10,006 | 11,107 | 12,207 |
| Zautla | 19,438 | 20,598 | 23,132 | 25,677 | 28,221 |
| Aquixtla | 7,848 | 8,316 | 9,340 | 10,367 | 11,394 |
| Esperanza | 13,785 | 14,608 | 16,405 | 18,209 | 20,014 |
| Tetela de Ocampo | 25,793 | 27,332 | 30,695 | 34,072 | 37,448 |
| Zacapoaxtla | 53,295 | 56,475 | 63,424 | 70,401 | 77,377 |
| Zaragoza | 15,444 | 16,366 | 18,379 | 20,401 | 22,423 |
| Total[1] | 607,504 | 643,756 | 722,963 | 802,489 | 882,015 |
| Urban population | 437,403 | 463,504 | 520,533 | 577,792 | 635,051 |
| Consumptive use (l/d/inhab) | 150 | | | | |
| Consumptive use ($m^3$/d) | 65,610 | 69,526 | 78,080 | 86,669 | 95,258 |
| Rural population | 170,101 | 180,252 | 202,430 | 224,697 | 246,964 |
| Consumptive use (l/d/inhab) | 75 | | | | |
| Consumptive use ($m^3$/d) | 12,758 | 13,519 | 15,182 | 16,852 | 18,522 |
| Aquifer consumptive use (thousands $m^3$/year) | 28,604.3 | 30,311.3 | 34,040.7 | 37,785.2 | 41,529.7 |

Source: INEGI, CONAPO and own calculations using linear trends and least squares.

**Table 6 Population and adjusted public-urban consumptive use of the municipalities in the area of influence of the Libres-Oriental aquifer. Period 2015-2070**.

| Municipality | INEGI | CONAPO projections | | Linear trends (least squares) | |
|---|---|---|---|---|---|
| | 2010 | 2015 | 2030 | 2050 | 2070 |
| Aljojuca | 6,288 | 6,663 | 7,483 | 8,306 | 9,129 |
| Chichiquila | 24,148 | 25,589 | 28,737 | 31,899 | 35,060 |
| Chilchotla | 19,257 | 20,406 | 22,917 | 25,438 | 27,959 |
| Guadalupe Victoria | 16,551 | 17,539 | 19,697 | 21,863 | 24,030 |
| Lafragua | 7,767 | 8,230 | 9,243 | 10,260 | 11,277 |
| Mazapiltepec de Juárez | 2,633 | 2,790 | 3,133 | 3,478 | 3,823 |
| Oriental | 16,575 | 17,564 | 19,725 | 21,895 | 24,065 |
| Quimixtlán | 21,275 | 22,545 | 25,318 | 28,103 | 30,888 |
| Rafael Lara Grajales | 14,052 | 14,891 | 16,723 | 18,562 | 20,402 |
| San José Chiapa | 8,087 | 8,570 | 9,624 | 10,683 | 11,741 |
| San Nicolás Buenos Aires | 9,185 | 9,733 | 10,931 | 12,133 | 13,335 |
| Tlachichuca | 28,568 | 30,273 | 33,997 | 37,737 | 41,477 |
| Tepeyahualco | 16,390 | 17,368 | 19,505 | 21,651 | 23,796 |
| San Salvador El Seco | 27,622 | 29,270 | 32,872 | 36,488 | 40,103 |
| Ocotepec | 4,825 | 5,113 | 5,742 | 6,374 | 7,005 |
| Libres | 31,532 | 33,414 | 37,525 | 41,653 | 45,780 |
| Cuyoaco | 15,367 | 16,284 | 18,288 | 20,299 | 22,311 |
| Nopalucan | 27,292 | 28,921 | 32,479 | 36,052 | 39,624 |
| San Juan Atenco | 3,416 | 3,620 | 4,065 | 4,512 | 4,960 |
| Chalchicomula de Sesma | 43,882 | 46,501 | 52,222 | 57,966 | 63,711 |
| Soltepec | 11,706 | 12,405 | 13,931 | 15,463 | 16,996 |
| Chignautla | 30,254 | 32,059 | 36,004 | 39,964 | 43,925 |
| Ixtacamaxtitlán | 25,326 | 26,837 | 30,139 | 33,455 | 36,770 |
| Tlatauquitepec | 51,495 | 54,568 | 61,282 | 68,023 | 74,764 |
| Atzitzintla | 8,408 | 8,910 | 10,006 | 11,107 | 12,207 |
| Zautla | 19,438 | 20,598 | 23,132 | 25,677 | 28,221 |
| Aquixtla | 7,848 | 8,316 | 9,340 | 10,367 | 11,394 |
| Esperanza | 13,785 | 14,608 | 16,405 | 18,209 | 20,014 |
| Tetela de Ocampo | 25,793 | 27,332 | 30,695 | 34,072 | 37,448 |
| Zacapoaxtla | 53,295 | 56,475 | 63,424 | 70,401 | 77,377 |
| Zaragoza | 15,444 | 16,366 | 18,379 | 20,401 | 22,423 |
| Total [1] | 607,504 | 643,756 | 722,963 | 802,489 | 882,015 |
| urban population | 437,403 | 463,504 | 520,533 | 577,792 | 635,051 |
| Consumptive use (l/d/inhab) | 100 | | | | |
| Consumptive use ($m^3$/d) | 43,740 | 46,350 | 52,053 | 57,779 | 63,505 |
| Rural population | 170,101 | 180,252 | 202,430 | 224,697 | 246,964 |
| Consumptive use (l/d/inhab) | 50 | | | | |
| Consumptive use ($m^3$/d) | 8,505 | 9,013 | 10,121 | 11,235 | 12,348 |
| Aquifer consumptive use (thousands $m^3$/year) | 19,069.6 | 20,207.5 | 22,693.8 | 25,190.1 | 27,686.4 |

Source: INEGI, CONAPO and own calculations using linear trends and least squares.

**Table 7 Comparative table of official, calculated and adjusted consumptive uses of the Libres-Oriental aquifer.**

| Official data 2015 | | | Calculated | | Adjusted | |
|---|---|---|---|---|---|---|
| VCAS | | 159,651.6 | | 138,785.5 | | 120,025.5 |
| DOF April 20, 2015 | % | Thousands $m^3$ | % | Thousands $m^3$ | % | Thousands $m^3$ |
| Agricultural | 80.00 | 127,721.3 | 66.89 | 87,045.8 | 72.52 | 87,045.8 |
| Domestic | 12.00 | 19,158.2 | 23.29 | 30,311.2 | 16.84 | 20,207.5 |
| Industry and others | 8.00 | 12,772.1 | 9.81 | 12,772.1 | 10.64 | 12,772.1 |
| Total | 100 | 159,651.6 | 100 | 130,129.1 | 100 | 120,025.4 |
| | | | Considerations:<br>150 l/inhab/day urban use<br>75 l/inhab/day rural use<br>20,816.2 hectare | | Considerations:<br>100 l/inhab/day urban use<br>50 l/inhab/day rural use<br>20,816.2 hectare | |

Source: CNA, 2015 and own elaboration.

Adjusted data, yield 72.52% of the volumes concessioned for agricultural use, 16.84% for public-urban use and 10.64% for industrial use and other uses. Resulting an adjusted VCAS of 120,025.4 thousand $m^3$; 39,626.2 thousand $m^3$ less than the official VCAS.

Regarding the scenario of consumptive use according to land use (weighted) of each of the consumptive uses of groundwater of the Libres-Oriental aquifer, for the years 2015, 2030, 2050 and 2070, it was found that the area sown by 2015, it was 20,816.2 hectares, 28,146.3 hectares occupied by urban and rural areas, 400 hectares occupied by industrial parks and other uses, with a total consumptive use of 120,025.4 thousand $m^3$ of water (Table 8).

By 2070, the agricultural area will be 25,302.2 hectares; the surface occupied by urban and rural areas will be 34,212.1 hectares, while that occupied by industrial parks will be 450 hectares. The total consumptive use will be 147,316.1 thousand $m^3$; 27,290.7 thousand $m^3$ more than the total consumptive use of 2015.

The volume concessioned or extracted from groundwater of the Libres-Oriental aquifer (VCAS) and the availability of groundwater (DAS), were affected by factors 0.98 for the year 2020 and 0.97 for the years 2030, 2050 and 2070. The results they indicate total volumes of 159.65 million $m^3$ for the year 2015, decreasing this volume in subsequent years until reaching 142.79 million $m^3$ for the year 2070.

According to the above, the availability of groundwater for the period 2015-2070 was 24.82% for the year 2015, gradually reducing it in the following years until reaching 5.23% availability approximately for the year 2050. As of the year 2063 the demand will exceed the availability; presenting a water deficit that will reach 3.17% by the year 2070. (Table 9 and Fig. 2).

**Table 8 Scenario of land use and consumptive uses for the years 2015, 2030, 2050 and 2070 of the Libres-Oriental aquifer.**

| Description | 2015 (ha) | Consumptive use (thousands $m^3$/year) | 2030 (ha) | Consumptive use (thousands $m^3$/year) | 2050 (ha) | Consumptive use (thousands $m^3$/year) | 2070 (ha) | Consumptive use (thousands $m^3$/year) |
|---|---|---|---|---|---|---|---|---|
| Agricultural use | 20,816.2 | 87,045.8 | 22,949.9 | 95,968.0 | 24,097.4 | 100,766.4 | 25,302.2 | 105,804.7 |
| Public urban use | 28,146.3 | 20,207.5 | 31,031.3 | 22,693.8 | 32,582.9 | 25,190.1 | 34,212.1 | 27,686.4 |
| Industrial use and others | 400.0 | 12,772.1 | 420.0 | 13,288.1 | 430.0 | 13,553.9 | 450.0 | 13,825.0 |
| | 49,362.5 | 120,025.4 | 54,401.2 | 131,949.9 | 57,110.3 | 139,510.4 | 59,964.3 | 147,316.1 |

**Table 9 Groundwater availability and demand, in thousands of m3, of the Libres-Oriental aquifer, in the period 2015-2070.**

| Year | Availability | Demand | % | Surplus/Deficit |
|---|---|---|---|---|
| 2015 | 120,025.5 | 159,651.6 | 75.18 | 24.82 |
| 2020 | 125,586.3 | 156,458.6 | 80.27 | 19.73 |
| 2030 | 131,949.9 | 151,764.8 | 86.94 | 13.06 |
| 2050 | 139,510.4 | 147,211.9 | 94.77 | 5.23 |
| 2070 | 147,316.1 | 142,795.5 | 103.17 | -3.17 |

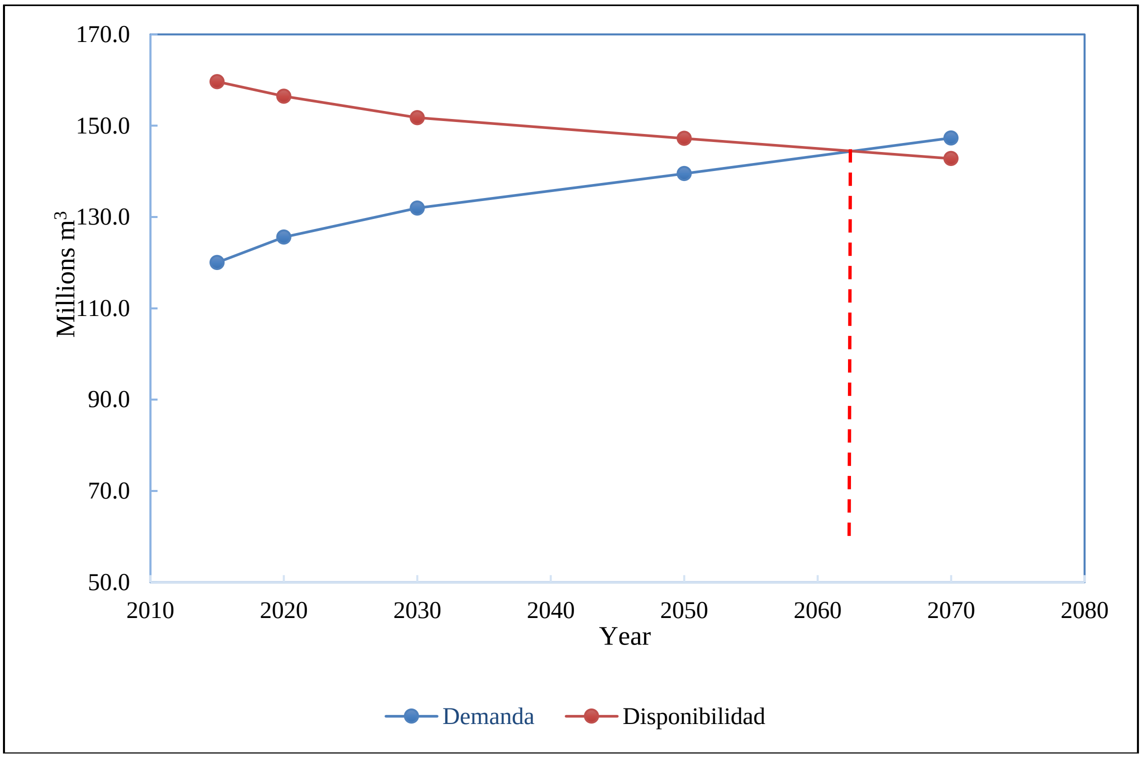


**Fig. 2 Groundwater availability and demand of the Libres-Oriental aquifer, in the period 2015-2070.**

With regard to the consumptive use scenario according to adjusted data and according to the land use (weighted) of each of the consumptive uses of groundwater of the Libres-Oriental aquifer, for the years 2015, 2030, 2050 and 2070, It was found that the area sown to 2015 was 20,816.2 hectares, 28,146.3 hectares occupied by urban and rural areas, 550 hectares occupied by industrial parks and other uses, with a total consumptive use of 130,129.2 thousand m3 of water.

By 2070, the agricultural area will be, according to adjusted data, 25,302.2 hectares; the surface occupied by urban and rural locations will be 34,212 hectares, while that occupied by industrial parks will be 600 hectares. The total consumptive use will be 161,159.4 thousand $m^3$; 31,030.2 thousand $m^3$ more than the total consumptive use of 2015 (Table 10).

According to the above, the availability and demand of groundwater, according to adjusted data, for the period 2015-2070, show an availability of around 18.49% for the year 2015, gradually decreasing in the following years until reaching 5.58% availability for the year 2030. As of year 2043, the aquifer will present a growing deficit of availability of groundwater, first of 3.32% for the year 2050 and finally of 12.86% for the year 2070, which means that they will have to adopt urgent measures tending to their protection, conservation and sustainable use practically from the beginning of the decade of 2030 (Table 11 and Fig. 3).

**Table 10 Scenario of land use and consumptive uses for the years 2015, 2030, 2050 and 2070 according to adjusted data from the Libres-Oriental aquifer**.

| Description | 2015 (ha) | Consumptive use (thousands $m^3$/year) | 2030 (ha) | Consumptive use (thousands $m^3$/year) | 2050 (ha) | Consumptive use (thousands $m^3$/year) | 2070 (ha) | Consumptive use (thousands $m^3$/year) |
|---|---|---|---|---|---|---|---|---|
| Agricultural use | 20,816.2 | 87,045.8 | 22,949.9 | 95,968.0 | 24,097.4 | 100,766.4 | 25,302.2 | 105,804.7 |
| Public urban use | 28,146.3 | 30,311.3 | 31,031.3 | 34,040.7 | 32,582.9 | 37,785.2 | 34,212.0 | 41,529.7 |
| Industrial use and others | 550.0 | 12,772.1 | 570.0 | 13,288.1 | 580.0 | 13,553.9 | 600.0 | 13,825.0 |
| | 49,512.5 | 130,129.2 | 54,551.2 | 143,296.8 | 57.260,3 | 152,105.5 | 60,114.2 | 161,159.4 |

**Table 11 Availability and demand of groundwater, in thousands of $m^3$, of the Libres-Oriental aquifer, according to adjusted data, in the period 2015-2070.**

| Year | Availability | Demand | % | Surplus/Deficit |
|---|---|---|---|---|
| 2015 | 138,785.5 | 159,651.6 | 81.51 | 18.49 |
| 2020 | 145,231.2 | 156,458.6 | 87.03 | 12.97 |
| 2030 | 153,018.2 | 151,764.8 | 94.42 | 5.58 |
| 2050 | 162,896.2 | 147,211.9 | 103.32 | -3.32 |
| 2070 | 173,019.5 | 142,795.5 | 112.86 | -12.86 |

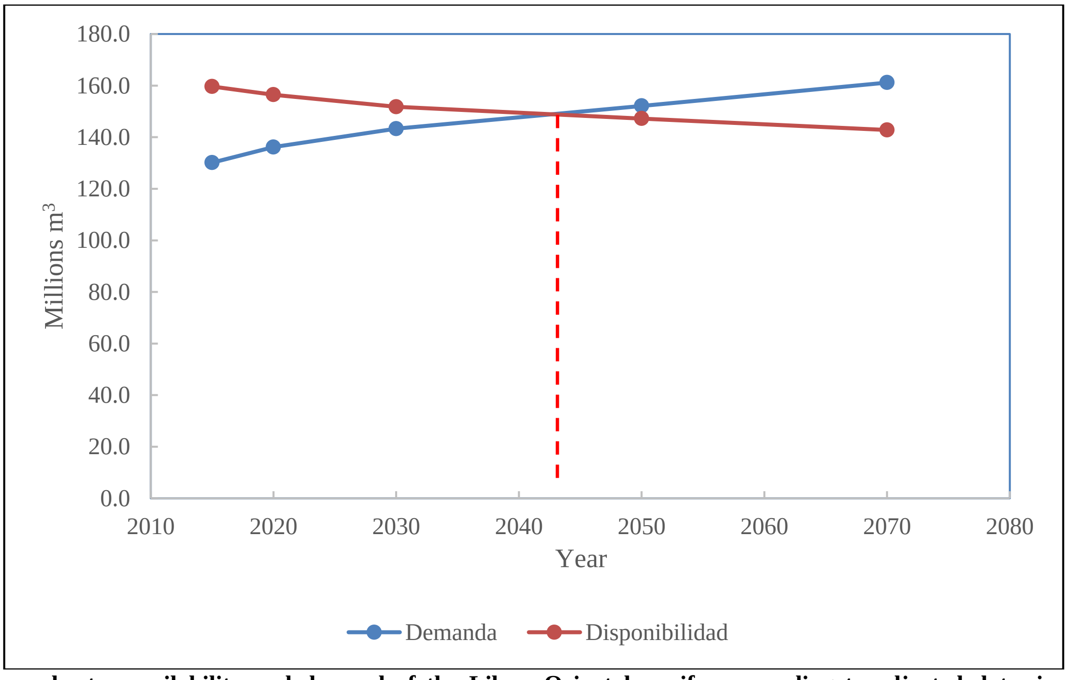


**Fig. 3 Groundwater availability and demand of the Libres-Oriental aquifer, according to adjusted data, in the period 2015-2070.**

According to a weighted scenario, considering the official information and the information calculated and adjusted in this study, with respect to the consumptive use of water in agricultural activities, the baseline shows an agricultural area of 20,816.2 hectares, with a consumptive use of groundwater of 87.05 million $m^3$. Also as a baseline, there is a consumptive use of groundwater of 20.21 million m3 for public-urban use and a consumptive use of groundwater of 12.77 million $m^3$ for industrial use and other uses (Table 12 and Fig. 4).

**Table 12 Weighted scenario of the consumptive use of water in the Libres-Oriental aquifer.**

| | Agricultural activities water use | Population water use | Industry water use |
|---|---|---|---|
| | Millions of $m^3$ | | |
| Baseline 20,816.2 ha. | 87.05 | 20.21 | 12.77 |
| 21% 25,187.6 ha. | 105.33 | 20.21 | 12.77 |
| Potential agricultural vocation 32,500 ha. | 135.91 | 20.21 | 12.77 |

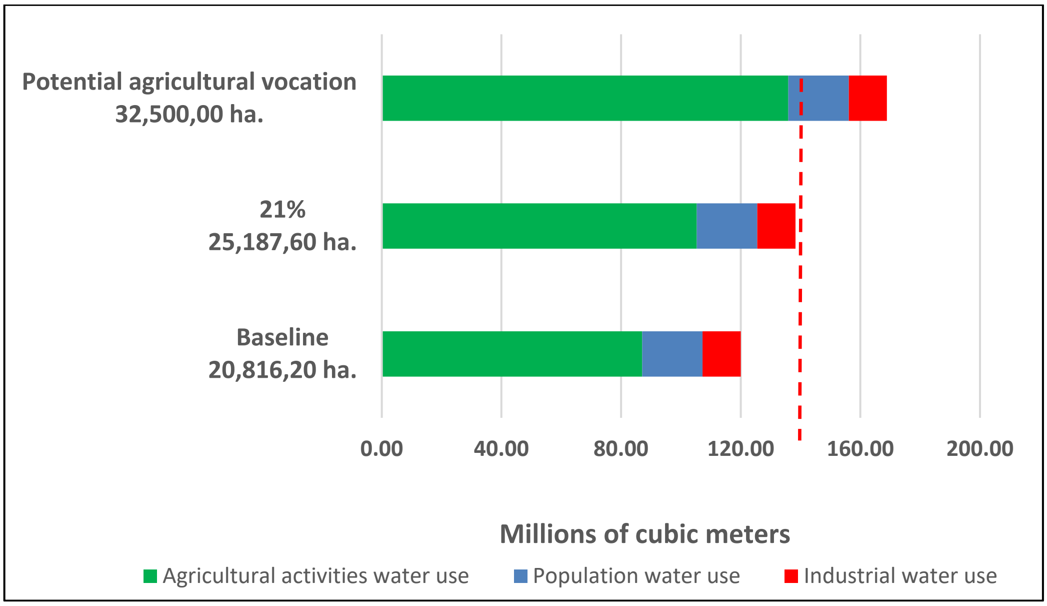


**Fig. 4 Current and potential consumptive use of water in the Libres-Oriental aquifer.**

In this weighted scenario, the agricultural area is first increased by 21%, deriving this increase in 25,187.6 ha and a change in consumptive use in this activity to 105.33 million cubic meters of water, yielding an increase of 18,280 thousand cubic meters of water. The consumptive use of the population and that of industry and other uses, remain unchanged.

Finally, it is considered that, in the area of influence of the Libres-Oriental aquifer, there is a potential surface with agricultural vocation of 32,500 hectares, with a potential consumptive use of groundwater of 135.91 million $m^3$.

The CONAGUA published in the DOF in 2016, results of studies that indicated that by the year 2030, the urban population will reach 200,225 inhabitants, 33,746 more inhabitants than there were in 2010, while the total population will increase from 349.101 inhabitants in 2010 to 419,848 inhabitants at the end of the year 2030.

Results of this study, using projections from CONAPO indicate that the urban population will reach 520,533 inhabitants, 83,130 more inhabitants than there were in 2010, while the total population will increase from 607,504 inhabitants in 2010 to 722,963 inhabitants at the end of the year 2030.

The same Commission mentions in the DOF that at the end of the year 2030, the population that lives within the demarcation of the aquifer will require 22.98 million cubic meters per year to supply drinking water, under an inertial scenario; which represents 3.87 million cubic meters more than those used in 2010, considering endowments per inhabitant of 150 liters per day.

In this regard, results of this study, considering an endowment of 100 liters per day per inhabitant in urban areas and 50 liters per day per inhabitant in rural areas, indicate that by the end of 2030, the total population of the area of influence of the aquifer, will require 22.69 million cubic meters per year for the supply of drinking water, which represents 3.62 million cubic meters more than those used in 2010. Results in line with those obtained by CONAGUA and published in the DOF in 2016.

In the same way, results of the present study according to adjusted data, considering an endowment of 150 liters per day per inhabitant in urban areas and of 75 liters per day per inhabitant in rural areas, indicate that at the end of the year 2030, the total population of the area of influence of the aquifer, will require 34.04 million cubic meters per year for the supply of drinking water, which represents 5.43 million cubic meters more than those used in the year 2010.

In the present study, only the consumptive uses related to public-urban use, agricultural use and industrial use were considered as the demand for groundwater, totaling the same, the volumes extracted and concessioned to users by CONAGUA and as availability those volumes of water stored in the aquifer, results of the average annual recharge of the aquifer and of the natural discharges committed.

These last two aspects, especially the one that has to do with the average annual recharge of the aquifer, in a climate change scenario, this recharge would be affected by the variability in time and space of rainfall. By decreasing the recharge, the storage of the aquifer would be negatively affected and, therefore, the extraction volumes and those granted to the users.

Another aspect to consider as a viable alternative to satisfy part of the water demand of the urban and rural population, is the collection of rainwater, since with the establishment of this type of systems can solve the problem of water shortage in populations far from the cities, even meet the needs of the peri-urban population, constituting, in addition, an alternative to reduce the exploitation of aquifers [13].

## 4. Conclusions

The Libres-Oriental aquifer presents a deficit of availability of groundwater, to the year 2016, of 351,629 $m^3$.

Considering a per capita water consumption of 150 l/inhab/day in urban areas and 75 l/inhab/day in rural areas; the total volume of groundwater demanded by the population, would decrease by 18.5% of the official volume granted in 2015.

Adjusting per capita water consumption to 100 l/inhab/day in urban locations and to 50 l/inhab/day in rural locations; the total volume of groundwater concessioned would decrease by 24.8% of the official volume concessioned in 2015.

The availability of groundwater for the period 2015-2070 was almost 25% for 2015, gradually reducing it in subsequent years until reaching 5.23% availability for the year 2050. By the year 2070, a groundwater availability deficit of 3.17%.

The availability and demand of groundwater, according to adjusted data, for the period 2015-2070, show an availability of around 18.49% for the year 2015, gradually decreasing in the subsequent years until reaching 5.58% availability for the year 2030. After this year, the demand will exceed the availability, first, in 3.32% for the year 2050 and finally in 12.86% for the year 2070.

According to the results obtained, it can be observed that the industrial and domestic water demand will increase much faster than the agricultural demand, although the agricultural activity will continue to be the main water user of the aquifer.

Results and considerations of the present study are similar to the projection made by Grecko (2018) [14], that an availability of 50 liters of water per person per day, could be mitigating to some extent, the serious shortage facing large cities such as Ciudad from the Cape, Sao Paulo, Bengaluru, Beijing, Cairo, Jakarta, Moscow, Istanbul, Mexico City, Lonfres, Tokyo and Miami, giving up, of course, to most of the things in which one uses water.

In the same way, according to the projections of experts backed by the UN, the global demand for potable water will exceed the supply by 40% by the year 2030, thanks to a combination of factors such as climate change, human action and population growth [15].

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