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Articles

Simulation of the supply guarantee for the water demands in Mexicali, B.C.

Simulación de las garantías de abastecimiento para las demandas de agua en Mexicali, B.C.

Raymundo Rangel-Parra[1], ORCID: https://orcid.org/0000-0001-8984-8494

Xan Neira[2], ORCID: https://orcid.org/ 0000-0002-1141-6023

Jorge Dafonte[3], ORCID: https://orcid.org/0000-0003-4305-1521

[1]Department of Agroforestry Engineering, Higher Polytechnic School, Universidad de Santiago de Compostela, Lugo, España, rangel.ray@hotmail.com

[2]Department of Agroforestry Engineering, Higher Polytechnic School, Universidad de Santiago de Compostela, Lugo, España, xan.neira@usc.es

[3]Department of Agroforestry Engineering, Higher Polytechnic School, Universidad de Santiago de Compostela, Lugo, España, jorge.dafonte@usc.es

Corresponding author: Raymundo Rangel Parra, rangel.ray@hotmail.com

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Abstract

In this research work, a simulation exercise is carried out for the guarantees in the water demands in Mexicali, considering a control scenario with period from 2005 to 2018 and a future scenario with projection from 2020 to 2040. In said projections the reductions in water deliveries to Mexico stipulated in Minute 323 of the IBWC are included. The AQUATOOL water resources management software has been used, with which the guarantees in the water supply to the control scenario and in the future have been evaluated, also including a new industrial demand with an amount of up to 20 Hm^3 per year. This new demand was evaluated both in the future scenario and in the control period, to simulate what could have happened if it had existed previously. The result shows that there are occasions in the control scenario in which there are some failures in the supply guarantees. The current situation of stress and pressure on water resources, added to the effects of climate change, in the Colorado River basin and especially in the city of Mexicali, make it unwise to add new demands to the system, since this intensifies competition by water resources.

Keywords: Water resources management, Colorado river, AQUATOOL, supply guarantees.

Resumen

En este trabajo de investigación se realiza un ejercicio de simulación para las garantías en las demandas de agua en Mexicali, considerando un

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escenario de control con periodo del 2005 al 2018 y un escenario futuro con proyección del 2020 al 2040. En dichas proyecciones se incluyen las reducciones en las entregas de agua a México estipuladas en el Acta 323 de la CILA. Se utilizó el *software* de gestión de recursos hídricos AQUATOOL, con el que se evaluaron las garantías en el abastecimiento de agua al escenario de control y al futuro, incluyendo también una nueva demanda industrial con una cantidad de hasta 20 Hm^3 anuales. Se evaluó esta nueva demanda tanto en el escenario futuro como desde el periodo de control para simular qué podría haber pasado si hubiera existido previamente. El resultado muestra que hay ocasiones en que en el escenario de control se presentan algunos fallos en las garantías de abastecimiento. La actual situación de estrés y presión sobre los recursos hídricos, sumados a los efectos del cambio climático en la cuenca del río Colorado y en especial en la ciudad de Mexicali, hacen poco recomendable agregar nuevas demandas al sistema, ya que esto intensifica la competencia por los recursos hídricos.

Palabras clave: gestión de recursos hídricos, río Colorado, AQUATOOL, garantías de abastecimiento.

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Introduction

The Colorado River reaches Mexico between the border limits of California and Arizona of the USA, where it crosses the Mexican territory between the cities of Mexicali and San Luis Río Colorado. The image of the Colorado River in northwestern Mexico is that of a dry riverbed for more than 50 years. However, the volume of water carried annually on the Colorado River in the US varies around 17,000 Hm^3, but all the water is controlled in a dam system on the USA side. The water resources between the two countries are managed through an International Water Treaty (IWT), which establishes that Mexico is entitled to 1,850 Hm^3 per year.

As a result of the IWT, the International Boundaries and Waters Commission (IBWC or CILA by its acronym in Spanish) is created as a binational, multidisciplinary body in the technical-diplomatic area, which functions as a basis for the application of the agreements that are made in the meetings of the commission and that are reflected in the Minutes. From 1889 to 2017, 323 Minutes have been signed. In this way, international water management is performed in the Colorado River basin. As part of the adaptive management process of the river, both countries agree to Minutes that are annexed to the IWT. As Hinojosa-Herta and Carrillo-Guerrero (2010) comment, these Minutes generally contain specifications or topics not included in the body of the treaty per se, such as water quality, implementation of hydraulic infrastructure maintenance projects, and more recently, environmental aspects. In 2017, with the so-called Act 323, a series of measures and projects have been established through a contingency and investment plan, to face the scarcity of the resource.

The Colorado River is the source of life for the southwestern United States and northwestern Mexico, but it has particular characteristics in the natural availability of water resources. The Colorado transboundary basin covers an area of more than 630,000 km^2 where more than 85% of the volume of available water is captured in the mountains of the state of Colorado, in an area that covers only 15% of the basin in total (Adler, 2007). The volume of water carried annually in the Colorado River varies around 17 000 Hm^3, however, 70% of the annual volume flows in the thaw season (May to July) (Cohen & Henges-Jeck, 2001). The total water rights assigned in the Colorado River basin (in both countries) is 21,586 Hm^3 / year (Luecke *et al*., 1999), therefore, there is an over-allocation of water resources of approximately 27 %. These quantities do not include or consider the ecological flow.

The importance of management in the river basin of the Colorado river is critical as it is in a region where rainfall is minimal in most of its territory, high average temperatures, and continuous population and economic growth. In addition, various investigations (Christensen, Wood, Voisin, Lerrenmaier, & Palmer, 2004; Ficklin, Stewart, & Maurer, 2013; USBR, 2016; Udall & Overpeck, 2017; Gautam & Mascaro, 2018) agree that climate change projections will cause increases in the average annual temperature, as well as decreases in precipitation and runoff.

Since 2000, according to data from the United States Bureau of Reclamation (USBR, 2019a), the levels of the Hoover dam (dam that is used as a reference level to classify the situation of the water resources in the basin) located in Lake Mead, are below 327 masl (2015-2016), considered as a condition of scarcity. This led to the IBWC signing Minute 323 in 2017, which establishes a series of measures and projects through a contingency and investment plan, to face the scarcity of the resource (CILA, 2017a).

The actual availability of Colorado River water in Mexico is through the coordination of CILA from both countries and on a planned agenda based on an Annual Operating Plan (AOP). The actual year-over-year distribution of Colorado basin water for both countries is based on the future official projection of availability by the USBR. It is a report with a 24-month study with projections for January 1st of each year. The resulting annual operations for Lake Mead are reported at the AOP for Colorado River storage for the following year (CILA, 2017b).

Currently, we have technological tools that allow us to automate simulation and optimization, two essential approaches to basins modeling. As mentioned by McKinney, Cai, Rosegrant, Ringler, and Scott (1999), in the simulation the behavior of water resources is simulated based on a set of rules governing water allocations and infrastructure operation, while, in optimization, allocations are optimized based on an objective function and associated constraints.

The objective of this work is to carry out a simulation exercise to analyze the guarantees of water supply in the demands in Mexicali, for a

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control scenario and another in the future. This seeks to provide a new perspective on how the technological tools available are an essential aid for water resource management. Because the real availability of water from the Colorado River to Mexico is determined each year by the USBR's AOP, this work only functions as an exercise to test water resource management and planning software, analyze results and their degree of reality, as well as identify data collection challenges for the specific Mexicali and Baja California study area.

Study area

Mexicali is a city with nearly one million inhabitants located in the state of Baja California (B.C.) in northwestern Mexico, on the border with the USA. The climate is warm dry, very arid, with an average annual temperature of 22.3 ºC and a very low annual rainfall estimated at 76.9 mm, which causes an almost zero natural input of water. Surface water resources arriving in Mexicali are only for the last stretch of the Colorado River route, ranging from 80 to 90 % of 1 850 Hm^3 per year of the IWT.

The Colorado River arrives from the USA to Mexico between the cities of Mexicali and San Luis Río Colorado, as shown in Figure 1. Other important elements for water resource management in the Mexicali

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system include the Colorado River Aqueduct (ARCT) and the extension of the Colorado aquifer. The ARCT entered into operation in 1982, fulfilling the purpose of supplying water to the urban demand of the other cities of the state of Baja California, Tecate, Tijuana, Playas de Rosarito, and recently also Ensenada.

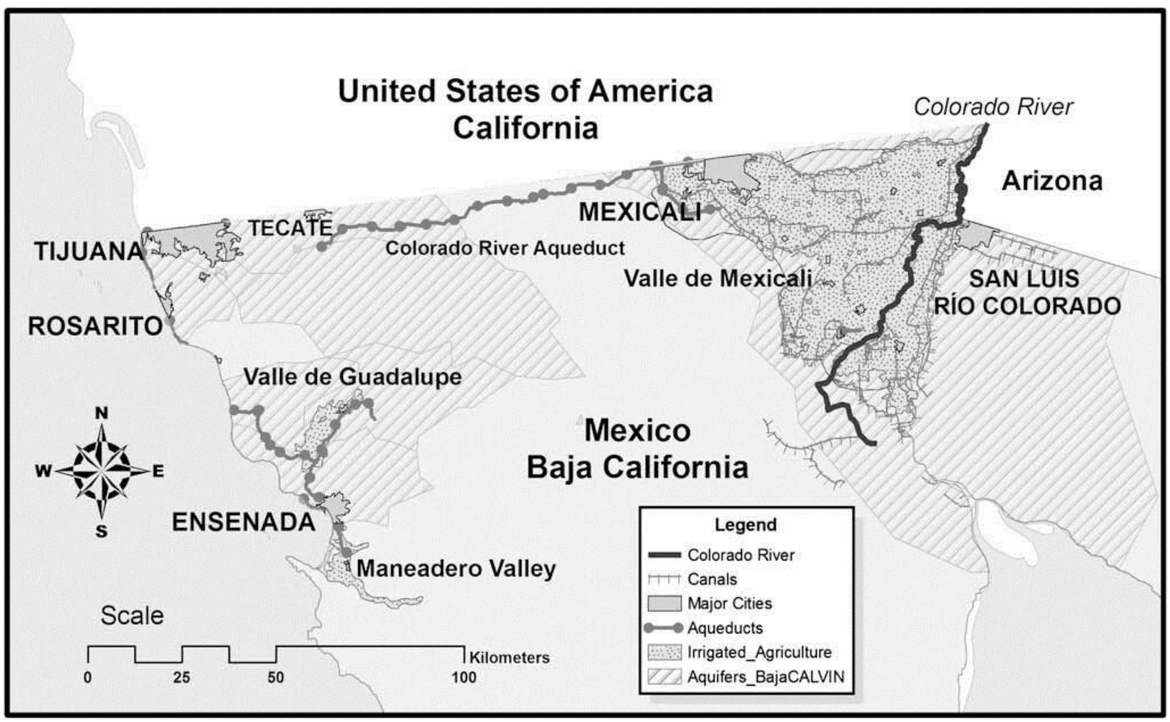

Figure 1. Colorado River tract in the Mexican part. Source (Medellín-Azuara, Mendoza-Espinosa, Lund, Harou, & Howitt, 2009).

From the volume of water of the Colorado River agreed in the IWT, 1 677.5 Hm^3 is received annually by the point called Lindero Norte (LN) in the Morelos Dam and 172.7 Hm^3 by the point called Lindero Sur (LS) in the Sánchez Mejorada channel.

Regarding underground resources in the Mexican part, water is extracted each year based on concessions from federal wells (500 Hm^3) and individuals (200 Hm^3) in aquifers 0210-Mexicali Valley and 2601 - San Luis Río Colorado, which is part of the Colorado aquifer. In addition, groundwater volumes are also allocated for other cities of B.C. (Tijuana, Tecate, Rosarito, and Ensenada), which are sent by the Colorado-Tijuana River Aqueduct (ARCT) with the extraction of about 148.96 Hm^3 per year. Therefore, there is also an over-allocation of underground resources, with 520 Hm^3 being the annual recharge of the aquifer. One important aspect is that there is currently no groundwater treaty between Mexico and the USA and that there are differences between the two countries concerning groundwater law and jurisdiction.

The amounts of demands and origin of water resources in the Mexicali system are shown in Table 1, information that was collected according to the limited official data found. The largest demand is agriculture in DR-014, requiring about 90% of resources, followed by ARCT with more than 5 % and then urban demand for Mexicali (UDU_Mexicali) with approximately 2.5 %. Annual industrial and commercial demand (UDI_Mexicali) as of 2017 was estimated at 16.36 Hm^3 gross resource. There are also three so-called rural demands (UDRs), which correspond to population centers located in the DR-014 agricultural area. A large amount of water intended for agricultural activity is notable, also due to the large territorial extension of DR-014.

Table 1. Summary of annual water demands in the Colorado River system in Mexicali. Prepared from CEABC (2017) and CEABC (2016).

Water demand (2017)	Superficial supply (Hm^3)	Underground supply (Hm^3)	%
UDU_Mexicali	68.41	-	2.52
UDI_Mexicali	16.36	-	0.60
Losses UDU y UDI	16.52	-	0.61
Sum of 3 UDRs (Mexicali Valley)	10.98	-	0.40
Agricultural demand DR-014	1 753.19	700	90.38
Aqueduct ARCT (Mesa Arenosa)	-	148.96	5.49
Subtotal	1 865.46	848.9	
Grand total	2 714.36		100

Despite the natural limitation and high degree of pressure on water resources in Mexicali, there are still no cuts in the daily water supply. However, this does not mean that water is guaranteed for the near future. Another important feature to note is that there are no water reservoirs of any kind to store resources. The climatic and terrain conditions do not allow to have dams beyond that existing at the border boundary, the Morelos Dam, which is worth mentioning that the water resources stored there are not managed at will by Mexico.

Since 2016, Mexicali has had a conflict between social groups and the state government, due to the authorization of new industrial demand. This controversy has reached international scenarios where water availability is questioned to support the industrial demand declared at 20 Hm^3 per year.

The climate in Mexicali and climate change in the Colorado River basin

In Mexicali, there have been high thermal contrasts, with temperatures as high as 54.3 ºC, and as low as -7 ºC (SPABC, 2012). SRES projections reported by the Secretary of Environmental Protection of B.C. (SPABC by the acronyms in Spanish) for Mexicali indicate that the average annual maximum temperatures for scenarios A2 and B2 would increase from 2010 to 2100 at 5 and 4 ºC respectively, compared to the period 1961-1990.

In March 2016 the USBR published a technical report of ″RECLAMATION – Managing in the West" entitled "West-Wide Climate Risk

Assessments: Hydroclimate Projections". This report identifies climate change as a growing risk to water management in the west and mentions warmer temperatures, changes in precipitation, snow cover, and the time and quality of runoff in major river basins as threats to water sustainability. Reductions in spring runoff and early summer could result in a drop in water supply to meet irrigation demands and adversely impact hydropower operations on USA reservoirs.

Currently, the management of the Colorado River faces a drought situation affecting both countries, which is 2017 under Act 323 have established a series of measures and projects through a contingency and investment plan, to address the scarcity of the resource. The Binational Contingency Plan is specified, in which two relevant things are marked; (1) actions to be taken to, high levels in Lake Mead with increases in delivery and, for low levels with reductions (for Mexico would be 51 to 185 Hm^3 in total delivered) in availability for both countries; 2) conservation projects and new water sources in both Mexico and USA.

Materials and methods

AQUATOOL software and its SIMGES module, developed by the Polytechnic University of Valencia, have been used as a simulation tool.

Solera-Solera, Paredes-Arquiola, and Andreu- Álvarez (2015) describes it as an interface or working environment for the development and analysis of decision support systems in basin planning and management. The program is a series of interactive tabs that allow the editing of the data necessary for the analysis of water resources management alternatives of basins.

In AQUATOOL, the simulation and management of the surface system are carried out at a time by using a conservative flow network optimization algorithm. This algorithm is responsible for determining the flow in the system by trying to meet the multiple deficit minimization targets to the maximum (Andreu, Solera, Capilla, & Ferrer, 2007). Therefore, the first task of the model after reading input data is to adapt the user schema as a conservative flow network. To do this it is necessary unfolding each element of the system. The result is an "internal flow network", much more complex than that of the user, which is already conservative, and which is the one that will handle the model without external significance to the user. Once this internal network is made, it is entered into the dynamics of the simulation, in which for each month of the simulation period the flow network is resolved with the values of contributions, demands, and management parameters corresponding to that month, iterates between the last two steps, and stores values for its annual writing and statistics. Finally, once the testing period is over, statistics and calculations of guarantees are made (Andreu *et al*., 2007).

The criteria used by AQUATOOL to evaluate guarantees have been those of the Hydrological Planning Instruction (IPH by the acronyms in

Spanish) (IPH, 2008) of 2008 (BOE, Order ARM/2656/2008) of the Government of Spain for urban and agricultural demands (UTAH DWR criterion):

> "For urban demand, it is considered a failure when the deficit in a month is more than 10% of monthly demand. For agricultural demand, it is considered a failure when the deficit in a year is more than 50% of annual demand. (D.A)., is considered a failure when in two consecutive years the sum of the deficit is greater than 75% of the D.A. and is considered a failure when in ten consecutive years the sum of the deficit is more than 100% of the D.A.".

Scheme for water simulation in the Mexicali system

The availability of the Colorado River water resource for Mexico is determined by the 1944 TAI, the operation of deliveries is estimated by the USBR throughout the basin in general and flows are monitored by IBWC (CILA, 2018). For this reason, it is not appropriate to perform the hydrological simulation in the Colorado River basin upstream of the delivery point to Mexico to know the volume of water available to Mexicali monthly. This volume of water can be known with the data of deliveries of recent years in the LIN get an average delivery for each month, which can be considered as the corresponding monthly availability. The amount of water retained in the LIN is not managed by Mexico but through diplomatic negotiations between IBWC of both countries.

A series of simulations were planned to analyze the guarantee of sourcing current and future demands in Mexicali. Minute 323 stipulates a series of reductions to the 1,850 Hm^3 in the event of levels of the Hoover Dam (Lake Mead) continuing to decline. According to the USBR projections and the amounts set out in Act 323, the first reduction in 2017 of 51 Hm^3 and in 2019 the second additional reduction of 37 Hm^3 should be applied. Using a linear drop in dam levels, a factor of monthly variation in water deliveries to Mexico, and the additional reductions applicable under Minute 323, reduced water deliveries to Mexico were calculated until 2040. For these projections by 2040, future conditions in the Colorado River basin that would lead to a reduction in water resources are assumed, as agreed by climate projection studies conducted in the Colorado basin.

About special considerations for defining some demands, the ARCT has been one of them, since the water pumped by the aqueduct is based on demand, and in this way, the guarantee and failures can be evaluated.

At the time of the completion of this work (2017-2018), no detailed information was found on the detailed distribution in time and space of agricultural demand, nor the underground water resources mainly used in dr-014 located in the Mexicali Valley. Because of this situation, an indirect estimate was chosen with the information of water deliveries in the LIN and LIS, since it is understood that the delivery must be based on demand. An estimate of the average water delivery per month results in a time variation factor that, multiplied by the total annual use of agricultural demand declared by Conagua (2018), calculates water use for each month.

Mexicali system scenario with new water demand

To assess the future scenario, new industrial demand was added to Mexicali's water flow system. The volume of 20 Hm^3/year of water for production, is published by the company that requires the demand for water (on its website http://www.cbrands.mx/nuestra-historia/unidades-de-negocio).

The scenarios established for the simulations consisted of a period of control with actual data of water deliveries, from 2005-2020, and a future scenario (2020-2040) with projections of reduced water deliveries for Mexico. These scenarios simulated guarantees in the supply of Mexicali's current demands and until 2040.

Subsequently in another separate simulation, the new industrial demand of 20 Hm^3 was added, both in the control scenario and in the future, to evaluate its behavior in a period of actual data and with data projected respectively. This new demand was planned in two phases, one of 5 Hm^3 and one of 20 Hm^3, as this was planned the industrial operation that would start with 5 and increase up to 20. The source of supply for this new industrial demand is surface resources, as the impact on these resources can only be assessed because they are the only ones with more or less detailed information. After all, groundwater extraction data are minimal or absent.

Results

The scheme in Figure 2 represents in a simplified way the flow of water in the system in the city of Mexicali, since the scheme in AQUATOOL is too extensive to be represented in this document. The scheme was made with the sources of information available in reports and publications of CEABC and IBWC, as well as studies done in the USA involving the Colorado River part in Mexicali. The orientation of flow schemes has been used as found in the investigations of Medellín-Azuara *et al*. (2009); Howes, Burt and Feist (2012), and Carrillo-Guerrero, Glenn and Hinojosa-Huerta (2013).

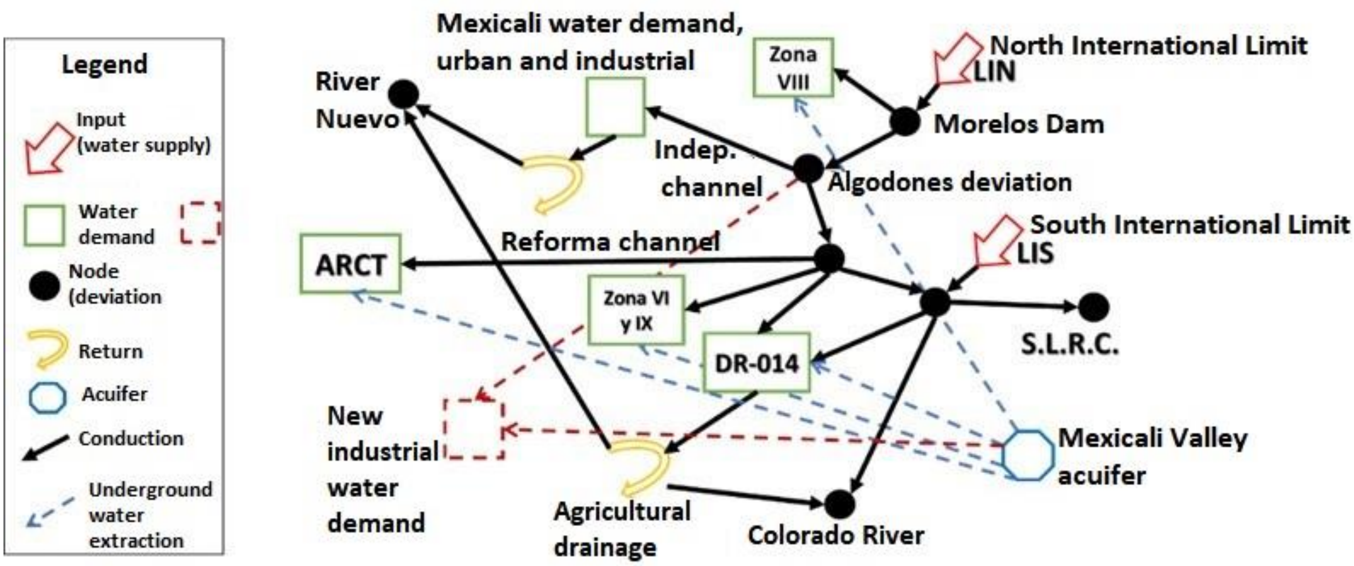

Figure 2. AQUATOOL "Simplified" Scheme for the Mexicali Water Flow System.

Table 2 and Figure 3 present the monthly, average, minimum, maximum, standard deviation, and percentage of distribution of water deliveries from the Colorado River to Mexico in the period 2005-2018. A Time Variation Factor (FVT) (eq.1) is calculated to be able to calculate other demands from which only annual quantities are available, such as agricultural demand. It can be seen that in March and April it is when Mexico receives the most water and in October the least amount.

$$FVT = \frac{\overline{Q_i}}{\sum_{i=1}^{n} \overline{Q_i}} \quad (1)$$

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Where "i" is the month and "n" is the total number of months "i". In this case, "Q" is the average of each month in the period 2005-2015.

Table 2. Monthly statistics of water deliveries to Mexico 2005-2018 and FVT.

Average monthly water deliveries to Mexico					
	(Q) Hm³	**Hm³**	**Hm³**	**Hm³**	**% (FVT)**
Month (*i*)	**Average**	**Min**	**Max**	**Std.Dev.**	**Distribution**
Jan	167.39	147.50	214.62	17.38	0.089
Feb	196.87	173.02	229.09	16.25	0.105
Mar	253.94	220.10	286.66	16.22	0.136
Apr	240.32	211.85	258.21	14.64	0.128
May	133.86	104.17	152.07	11.82	0.072
Jun	138.37	105.68	166.47	15.63	0.074
Jul	147.74	119.75	163.40	12.19	0.079
Aug	125.00	114.53	145.22	7.35	0.067
Sep	114.32	109.79	127.05	4.17	0.061
Oct	89.88	72.11	130.34	16.40	0.048
Nov	118.96	98.25	142.35	11.81	0.064
Dec	145.28	109.52	173.11	19.36	0.078
Total	1871.93				1

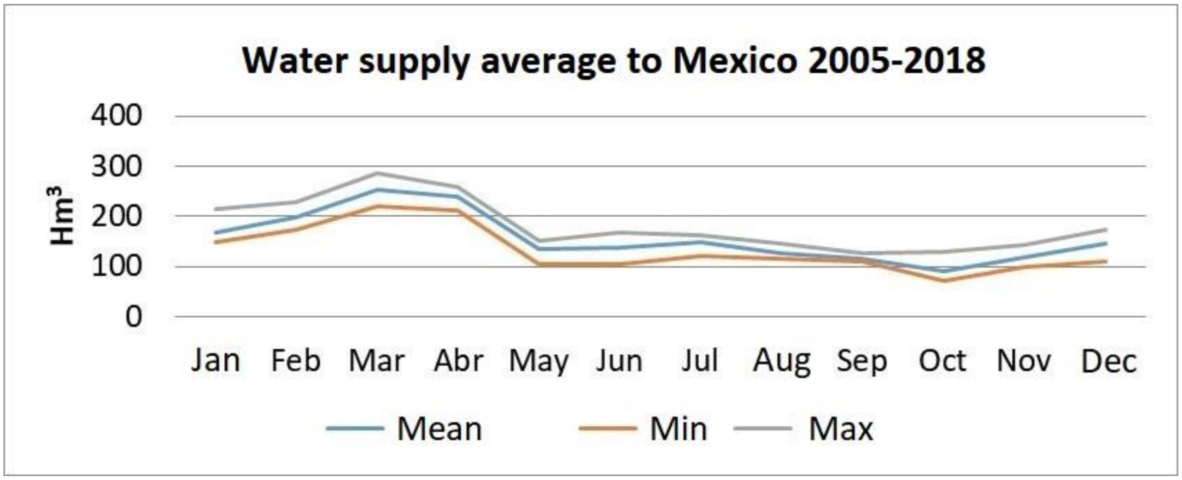

Figure 3. Average, minimum, monthly maximum of Colorado River water deliveries to Mexico, 2005-2018.

In the absence of monthly agricultural demand data, an indirect calculation has been used to determine it, using the FVT in Table 2 and multiplying it by the annual amount reported for 2015-2016 (1450 Hm^3 surface and 700 Hm^3 underground) in this agricultural demand according to Conagua data (Conagua, 2018). As shown in Table 3, in this way you can get a monthly distribution of agricultural demand from which no monthly data are available.

Table 3. Monthly distribution of agricultural demand in the DR-014.

Month	FVT in LIN and LIS deliveries	Hm^3 Surface Demand	Hm^3 underground demand	Total demand DR014 Hm^3
January	0.089	129.67	62.594	192.262
February	0.105	152.50	73.618	226.122
March	0.136	196.71	94.959	291.673
April	0.128	186.17	89.867	276.034
May	0.072	103.70	50.058	153.756
June	0.074	107.19	51.741	158.927
July	0.079	114.45	55.247	169.694
August	0.067	96.83	46.744	143.578
September	0.061	88.56	42.749	131.306
October	0.048	69.62	33.610	103.235
November	0.064	92.15	44.485	136.640
December	0.078	112.54	54.328	166.873
Total	1.000	1450.100	700.000	2150.100

Figure 4 presents the graph with the distributions of Mexicali's water demand (sum of urban, industrial, and rural demand), agricultural demand, and demand for the aqueduct that goes to the city of Tijuana and other cities in the state of B.C. A much higher proportion of agricultural demand can be seen compared to the other two.

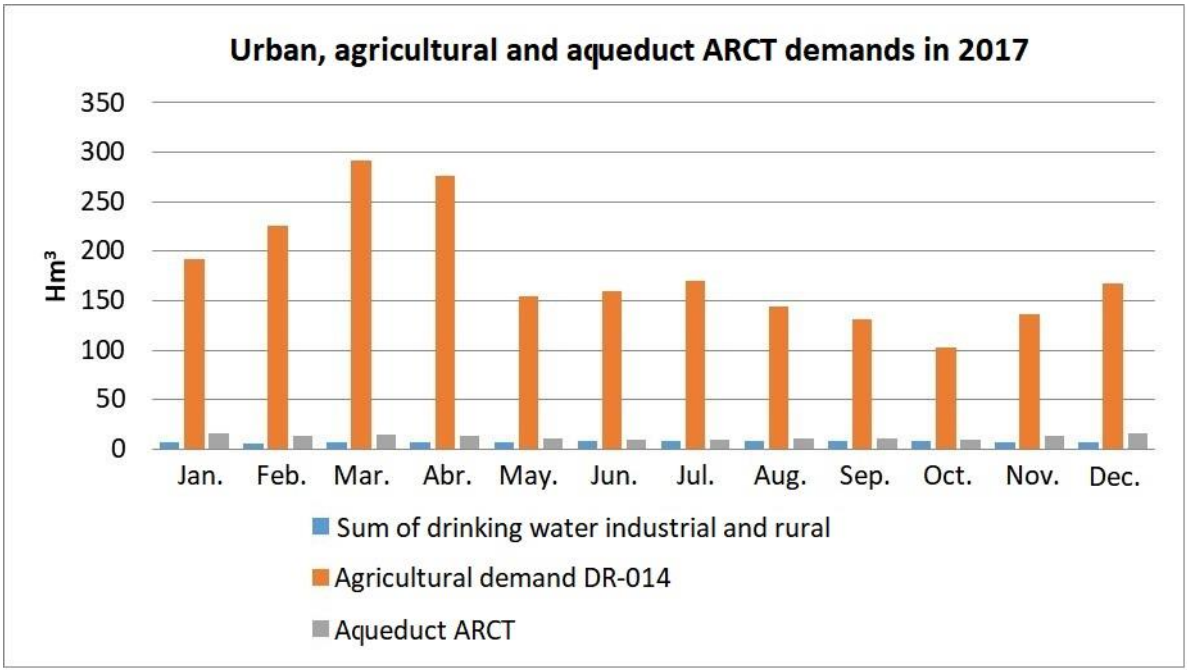

Figure 4. Monthly demand for urban, agricultural, and ARCT Aqueduct for 2017 in Mexicali.

With the specifications of the applicable reductions set out in Minute 323, the 2040 projected levels of the Hoover Dam, and the water deliveries to Mexico observed from 2005-2018, the projections of water deliveries have been estimated until 2040. Figure 5 shows the graph of the projections, where reductions would begin in October 2017 with 51 Hm^3 per year, subtracted from the annual total of the duties of 1 850 Hm^3, until the level of the reference dam goes up or down to the next category. This first reduction means a monthly decrease of between 1.49 and 4.20 Hm^3 depending on the month. Subsequently, the following additional reductions (since they are cumulative) are estimated in May 2019 with 37 Hm^3 and until July 2026 that the maximum reduction stipulated in Minute 323 of 185 Hm^3 would be achieved. To witness predictions of the effects of climate change on the Colorado River basin estimated by the USBR and the other studies mentioned that coincide in a decrease in the availability of water resources throughout the basin, a reduction was applied to water deliveries following the trend of the table set out in the Minute, until 2040. Water deliveries to Mexico for both the observed and projected periods are considered as the inputs for the AQUATOOL software.

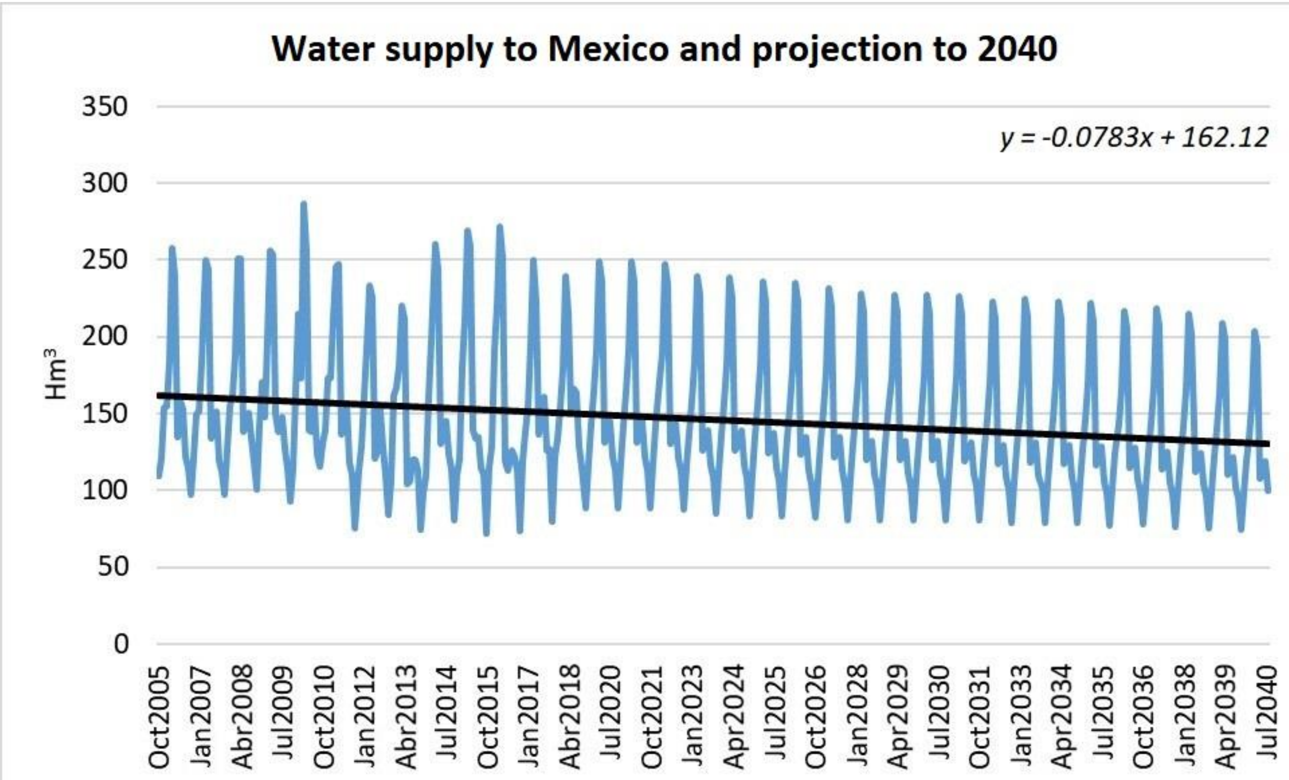

Figure 5. Actual monthly water delivery Mexico 2005-2018 and projection with reductions by 2040.

Simulations with current demands

Once the distribution of agricultural water demand and projected inputs for the future scenario 2020-2040 were estimated, it was possible to carry out the simulations both in the control scenario and in the future. The simulated period in AQUATOOL corresponds to 35 hydrological years from 2005 to 2040. For the order of priority of supply in AQUATOOL software, the highest priority has been given to urban and industrial demands (including ARCT) over agricultural demand.

The results in simulations with AQUATOOL show that only agricultural demand DR-014 has 9 failures in the supply guarantee in scenarios 2005-2020. Subsequently, this same demand, plus that of the ARCT aqueduct and two rural demands, present even more failures for the future period 2020-2040 with water reductions. These failures in agricultural supply, it can be thought that they were most likely satisfied by greater extraction of groundwater by users or some measure of irrigation adaptation. However, there is no public data on accurate control over groundwater extraction. For the 2020-2040 scenario, with only current water demands, there are 18 DR-014 failures generated by the estimated decreases in deliveries to Mexico through 2040. The ARCT aqueduct has 18 failures in the period 2020-2040, although despite this, the guarantees appear to be above 90 %. Rural demands UDR_Zona_VIII and Zona_IX a total of 12 failures in the period 2020-2040. Even with these estimated failures, the volumetric guarantee in these water demands remains above 97 % (Table 4).

Table 4. Result of failures in the simulation of the 2005-2020 and 2020-2040 guarantees in the Colorado River system in Mexicali.

Demand	No. Fails 2005-2020	No. Fails 2020-2040	Guarantee (%)	Volumetric guarantee (%)	Max. Monthly deficit (Hm^3)	Max. deficit in two months (Hm^3)
UDA_DR-014	9	18	93.6	98.9	94.96	107.58
ARCT	0	18	95.7	97.3	14.659	25.28
UDR_ZONA_VIII	0	12	97.1	97.2	0.421	0.726
UDR_ZONA_IX	0	12	97.1	99.3	0.287	0.391

Simulations with new industrial water demand

The alleged new industrial water demand was added to the water flow system in Mexicali to assess behavior and determine whether there would be failures to comply with its guarantee. The new two-phase demand was added to the AQUATOOL schema. The first phase is supplied with 5 Hm^3/year and the second with 20 Hm^3, both being surface water sources. Both phases were evaluated from the period of observed data to the future projection.

The results of the simulations observed in Figure 6 show that while the early years of the 2020-2040 future scenario do not show supply failures, they are presented towards the end of the period coinciding with the failures of the other demands and with the respective increases in water delivery cuts. In addition, the new industrial demand also has failures in the period 2005-2020, both for the phase of 5 and 20 Hm^{3}. This would mean that, in certain years, if the new demand had existed in the period of data observed, it would have had failures in its supply and therefore compete with the other actual claims.

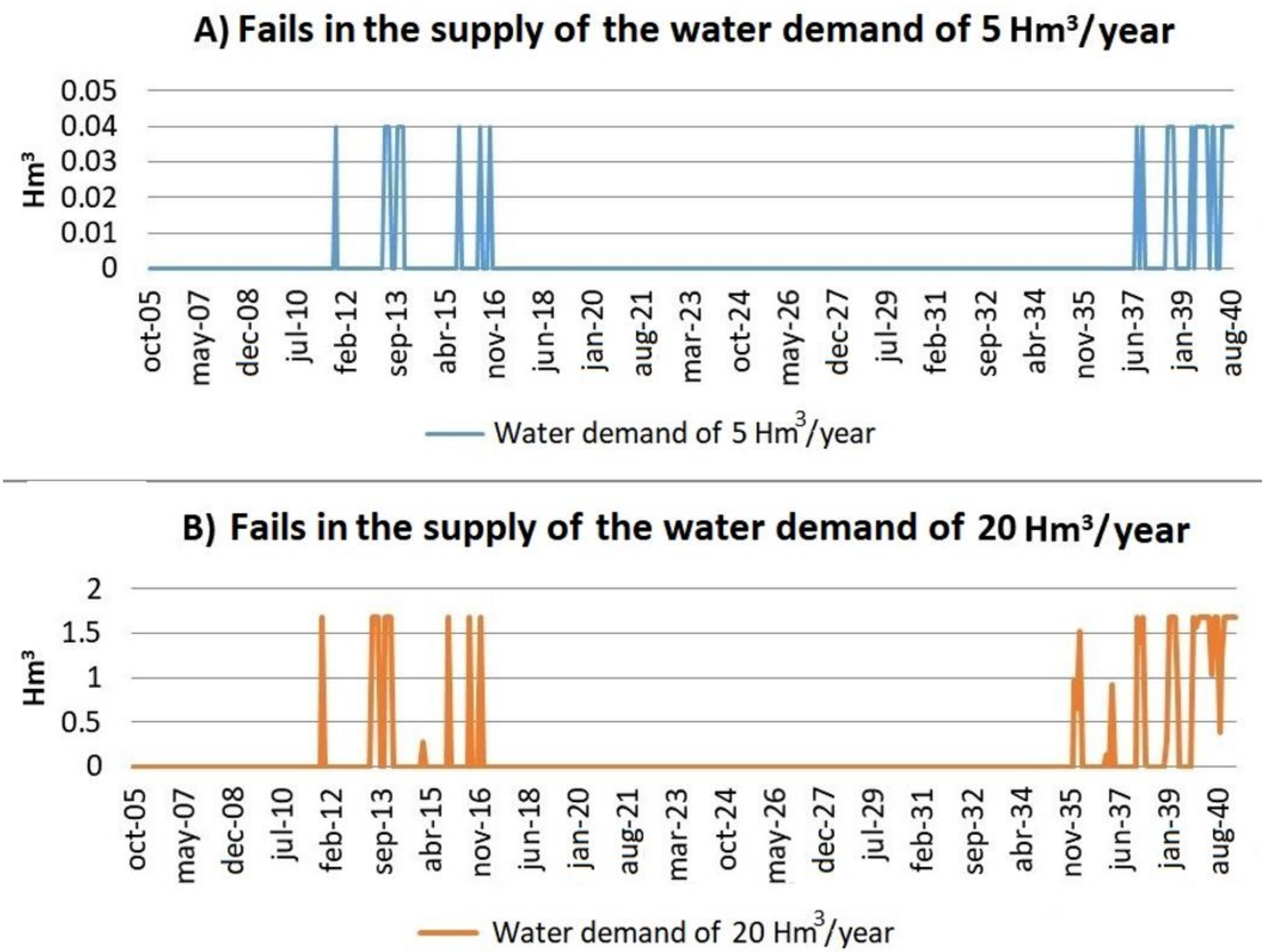

Figure 6. Failures in the guarantee of the new water demand for A) 5 and B) 20 Hm^3/year in the Mexicali system.

Failures in the new industrial demand are relatively minor for the 5 Hm^3 phase, but more significant in the 20 Hm^3 phases, remaining similar throughout the testing period. The failures presented starting in 2035 coincide with the failures in the actual demands, generating for the alleged lower water deliveries to Mexico. However, failures between 2011 and 2016, where system behavior can be considered more historical as a time range with observed water deliveries, show that, on certain occasions, the Mexicali system could not meet the new 100% industrial demand.

Discussion

With all the above steps it is possible to obtain the base model for Mexicali's water system flow, which will serve to evaluate the behavior of flows in the system, for any alternative raised about changes in management in a defined period. On this base model, you can make any type of changes, whether in contributions, demands, or any other element of the system and obtain statistical information to be able to compare results between alternatives. The number, complexity, and type of alternatives proposed to be evaluated in the base model will depend on the interests of the user.

It is important to mention that we should always seek to generate a robust model for water resource management. The more data, longer periods, and validated information, the base model will be able to better represent reality.

AQUATOOL calibration is usually checked between the result in some simulated element and observed data from the same element, such as levels of a dam or flows at a control point in a river or channel. In the case of this work, it is not possible to use the Morelos dam in the LIN, because the Mexicali system has no control over it and, in addition, water above this dam there is no natural runoff since the entire Colorado River is controlled by the USA. In the face of this situation and the absence of official and public data of flows at checkpoints within the Mexicali system, the AQUATOOL model can be considered to work correctly when it is observed that Mexicali's demands are met as is the case in reality. This situation reinforces the need for official and good quality hard data to be able to offer reliable analysis in this type of research.

After conducting the experience of searching, collecting, and processing data, simulations, and interpreting the results for the Colorado River sub-box in Mexicali, the following future works are proposed involving topics from data availability to new analysis approaches to the current and future situation. First, develop a database with as much data as possible and with the longest available period for weather parameters, water distribution flows within the system, water demands, physical subsurface, and hydrogeological parameters, flows and levels in bodies of water, groundwater extraction, water deliveries in the LIN and LIS, agricultural data of extensions, crops and application of irrigation, irrigation efficiency, water treatments, river returns, etc. Second, it could be shown on a GIS platform in which all elements are identified as in the AQUATOOL schema and where the database information is contained, visible, and available. Third, generate and calibrate a base model such as that presented in this thesis work, which will serve to evaluate the behavior from proposals to improve efficiency in the use of water resources, to assess the impact of climate change, or the cost-benefit of for example projects such as those proposed in Minute 323 for the generation of water sources or some type of water reservoirs for Mexicali.

Another demand that is not being considered is to incorporate the needs of environmental flows into the natural channel of the Colorado River estimated by Hinojosa-Herta and Carrillo-Guerrero (2010). This is between 390 and 600 Hm^3 per year, which would require adjustments to the demands of the Mexicali system. This demand for environmental flows would cause greater competition for water and complicate compliance with the guarantees of the other demands. Following the examples of other basins in the world, ecological demand is second in hierarchy only after urban demand, resulting in another reason to improve efficiency in agricultural demand volumes.

With the expected effects of climate change, increasing temperatures expect a decrease in water resources in the Colorado River basin by evaporation, which at the same time would increase the amounts to meet demands due to losses in the system. This condition makes even more evident the need to improve water resource management systems both internationally and locally in Mexicali.

Conclusions

Attention to the issue of water in Mexicali and Baja California (as it should be in all cities) is urgent and important. Although there have not yet been any cuts in water supplies in Mexicali, if it happens to date in Ensenada, B.C., where water supply from the Colorado River cannot be guaranteed.

Failures in agricultural demand are difficult to verify as there is no detailed information on deliveries and agricultural users. What, if it is a reality, is the current nonconformity of farmers on a variety of issues in this regard, including water management.

Adding a new water demand of between 5 and 20 Hm^3 per year to the Mexicali system could lead to surface water system failures, as happens if demand is added in the control period. While new industrial demand fails in quantities less than 10% of what it would demand, it is proof that its supply may be limited at certain times. In addition, a demand of 20 Hm^3 represents a significantly higher amount than other existing demands. Even a new initial demand for 5 Hm^3 should be carefully analyzed. Although the company's installation that would require this new demand has now been suspended, it is important to consider that current water needs in Mexicali and B.C., may not be guaranteed soon.

There is no complete source of data information required for this type of study. While you have to go to the relevant offices to get some data, many do not exist or are not available to anyone. The Colorado River basin in the Mexican part has a low availability of official data and scientific studies conducted in the region. Because of this, they have to make important assumptions and indirect estimates to be able to carry out this type of research. This results in a decrease in the certainty of the results, reducing them to being strictly indicative.

Increasing the efficiency of the DR-014 irrigation system and reducing agricultural demand is the area of greatest opportunity to increase availability in the system.

Despite possible reductions in water supplies to Mexico, as determined by Minute 323, if current demands are maintained, they could be supplied in the short term.

The application of AQUATOOL in the water flow system in Mexicali and the results obtained, show the usefulness to develop a myriad of analyses of "what if...?", as in the case of adding the new industrial demand or assuming a modification of the quantities, etc.

The current situation of conflict over water in Mexicali since 2016, shows the lack of communication and cooperation between users.

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