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Water supply and demand scenarios in the San Juan watershed

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RESUMEN

México está listado dentro de los países con problemas de falta de agua para el año 2020. La sequía de los 1990's ha reducido la disponibilidad del agua para satisfacer los usos tradicionales en el norte de México. Los conflictos internos entre usos, entre usuarios y entre entidades políticas por las aguas no se han hecho esperar en varias cuencas. La cuenca del río San Juan es un ejemplo clásico de esta problemática, donde los recuersos hidrológicos son de importancia fundamental para el desarrollo sustentable regional. El objetivo de este estudio fue predecir el suministro y demanda futura de agua sobre el cauce principal del río San Juan desde el embalse El Cuchillo hasta su confluencia con el Río Bravo. Las suposiciones fueron que la demanda de agua por el sector municipal (doméstico, industrial, comercial) incrementa paulatinamente con el crecimiento de la población del área metropolitana de Monterrey; que el suministro del agua es dependiente de las condiciones hidroclimáticas caracterizadas por las variaciones del pasado y que el suministro de agua para uso agrícola es dependiente de estas variaciones y del incremento en la demanda para el uso municipal. Los resultados mostraron que la disponibilidad de agua para irrigación se reduce dramáticamente en condiciones de hidrología normal o de sequía histórica. Por consiguiente, se espera que las áreas agrícolas del Distrito de Riego 026 se compriman en el mediano plazo en un 56 a un 65% bajo las condiciones hidroclimáticas supuestas y el incremento en la demanda de agua para uso municipal. Se recomiendan alternativas para implementar el manejo sustentable de los recursos hidrológicos como herramienta que puede potencialmente reducir el impacto de las variaciones en el suministro de agua para la agricultura y para el uso ambiental de la cuenca baja del río San Juan.

PALABRAS CLAVE: Escenarios de hidrología normal y sequías, contracción de la superficie irrigada, degradación de ecosistemas acuáticos, manejo sustentable de recuersos hidrológicos, nordeste de México.

ABSTRACT

Mexico is listed among the countries predicted to have freshwater shortages for the year 2020. The drought spell of the 1990's has reduced fresh water availability in northern Mexico. Conflicts between users, and political entities have appeared in several watersheds. The río San Juan watershead is a classic example where water resources are of paramount importance for sustainable development. We aimed to predict future water supply and demand along the main of the río San Juan, from El Cuchillo reservoir to the confluence with the Rio Bravo. Monotonic increases in municipal water demand sector in the Monterrey Metropolitan Area and future water supplies predicted under normal and dry conditions were assumed in assessing future water allocation. The results indicate that water allotted for irrigation dramatically decrease under normal and dry conditions, shrinking the size of irrigated lands. We recommend implementation of sustainable management of water resources to buffer the potential contraction of irrigated lands and the disappearance of riparian ecosystems in the lower watershed f the río San Juan.

KEY WORDS: Normal hydrology and drought spell scenarios, shrinkage of irrigated land area, degradation of aquatic ecosystems, sustainable management of water resourses, northeastern Mexico.

INTRODUCTION

The San Juan watershed currently faces a complex set of issues concerning the sustainable management of water resources. The main water uses within the watershed are agricultural and municipal (domestic, industrial, and commercial). Marte R. Gómez Reservoir supplies water to the Bajo San Juan irrigation district. El Cuchillo and Rodrigo Gómez reservoirs supply part of the water demand for 5 million inhabitants the watershed, of which 50% are concentrated in the Monterrey Metropolitan Area (SARH-SEP, 1989; ERL, 1991; INEGI, 1995).

Surface water of the río San Juan supplied 42% of the total municipal surface water demands of Metropolitan Monterrey during the period of 1990-1996 (Agua y Drenaje, 1997). Reservoirs El Cuchillo and Rodrigo Gómez accounted for 60% of the supply and the remaining 40% was transferred from the adjacent río Limón watershed through Cerro Prieto reservoir (Agua y Drenaje, 1997; CNA, 1997). Water supplied to the Bajo San Juan irrigation ranges from 375 to 575 Mm^3 per year (SARH, 1981; ERL, 1991).

The río San Juan discharges into the Lower Rio Bravo at an average rate of approximately 342 Mm^3 $year^{-1}$ (ERL, 1991). Estimates conducted by Návar (1998) suggest that the flow rate has been lower during the period of 1980-1993 with an average of 218 Mm^3 $year^{-1}$. The latter figure accounts for approximately 30% of all gauged streamflow of the Rio Bravo below Brownsville, TX (Návar, 1998).

Environmental concerns are important issues facing the río San Juan watershed in response to increasing diversions of the river's flow to meet municipal and agricultural demands. The number of native fish species has been reduced (Edwards and Contreras, 1998), as a result of the systematic construction of reservoirs in the watershed, associated to a reduction of river discharge (Contreras and Lozano, 1994). Water pollution at several locations along the main stem of the river, reported by Flores (1997) and Vogel and Armstrong (1998), may also be contributing to disturbance of aquatic ecosystems. In particular, the instability of the bentonic insect community appears to be associated to both streamflow quality and quantity (Guerra, 2000). Thus, environmental concerns are playing and will continue to play a pivotal role in modulating the use of surface water resources in the basin.

Discharge along the main stem of the río San Juan is also highly variable in space and time. The drought spell of the 1990's has reduced streamflow by 30% of the long-term average (Návar, 1998). This drought episode, which has still not ended (Schmand *et al.*, 1998), has resulted in internal conflicts regarding the headwaters of the río San Juan. Storage of reservoirs El Cuchillo and Marte R. Gómez have fallen to their lowest levels since their construction, stressing relations between the various water users in the watershed (agricultural versus municipal sectors and state versus state). Given the current state of affairs, it is likely that any future drought episodes, coupled with increased municipal water demand will result in even further tensions between the agricultural and municipal water users within the watershed.

The purpose of this report is to determine whether there will be sufficient water supply to meet the demand for agricultural and municipal water use under i) the worst drought episode on record and ii) normal hydrologic conditions. Future water supply scenarios were examined under a fixed irrigation supply and increasing demands for municipal use within the Monterrey Metropolitan Area during the periods of 1990-2005; 2010-2025; and 2030-2045.

GEOGRAPHICAL DESCRIPTION OF THE SAN JUAN WATERSHED

The San Juan River watershed is located in northeastern Mexico and belongs to the Rio Bravo-Río Conchos basin. The drainage watershed covers an area of approximately 33 000 km^2 in the states of Coahuila (40 %), Nuevo León (57 %), and Tamaulipas (3 %). The basin also includes a number of smaller tributary basins such as río Salinas, río Pesquería, río Santa Catarina, río San Juan, río Ramos and río Pilón. All rivers originate in the southwestern portion of the río San Juan watershed in the eastern Sierra Madre mountain range and drain in an eastward direction towards the lower Rio Bravo at Camargo in the State of Tamaulipas. The río San Juan watershed borders the Rio Bravo basin to the northeast, the río Alamo watershed to the north, the río San Fernando watershed to the southwest and the río Salado watershed to the southwest and northwest (Figure 1).

The climate may be described as semi-arid to arid with the majority of annual rainfall delivered during the summer months. Average annual precipitation ranges from 300-500 mm in the arid eastern and northeastern portion of the watershed, with an average annual temperature of 22-24° C. In the central portion of the watershed a semi-arid climate is found in which annual precipitation depth ranges from 500 to 700 mm and average annual temperature ranges from 18 to 21°C. In the eastern portion of the watershed, in the eastern Sierra Madre average annual precipitation is between 1000 to 1300 mm and average annual temperature ranges from 12° to 16°C (INEGI 1995). The Sierra Madre represents a more positive, or less negative, water balance than the rest of the watershed (Návar *et al.,* 1994).

Land use in the río San Juan watershed is dominated by native scrub forests (arid and semi-arid vegetation including Tamaulipan thornscrub and montane scrub). This scrub forest vegetation type covers approximately 71.5% of the watershed. Temperate forests (oak, mixed pine-oak, and pine) located in the eastern Sierra Madre represent approximately 6.4% of the cover, while irrigated and non-irrigated agricultural lands make up approximately 18.2% of the total area. Other land uses such as water bodies and urban areas represent the remaining cover within the watershed (Aranda *et al.,* 1998). Soils of the watershed are varied. Yermosols and xerosols, located in the most arid western and northwestern portion of the watershed, cover an area of 32%. Vertisols, located in the semi-arid to subhumid lands of the watershed, located in close proximity to the Sierra Madre mountain range and the southern portion of the watershed cover an area of 12%). Lithosols, regosols, and rendzins, located in the Sierra Madre and hilly mesetas of the plains cover an area of 47% (Aranda *et al.,* 1998). The geology of the plains developed during the Pleistocene and may be characterized by a terracing system formed by coarse sands, sands, and silts of the Beaumont and Lissle formations. The Sierra Madre developed during the Low Cretaceous period and is characterized by limestones of the Mendez formation (SOP, 1975).

The population of the watershed is about 5 million, of which 50 % are within the Monterrey Metropolitan Area

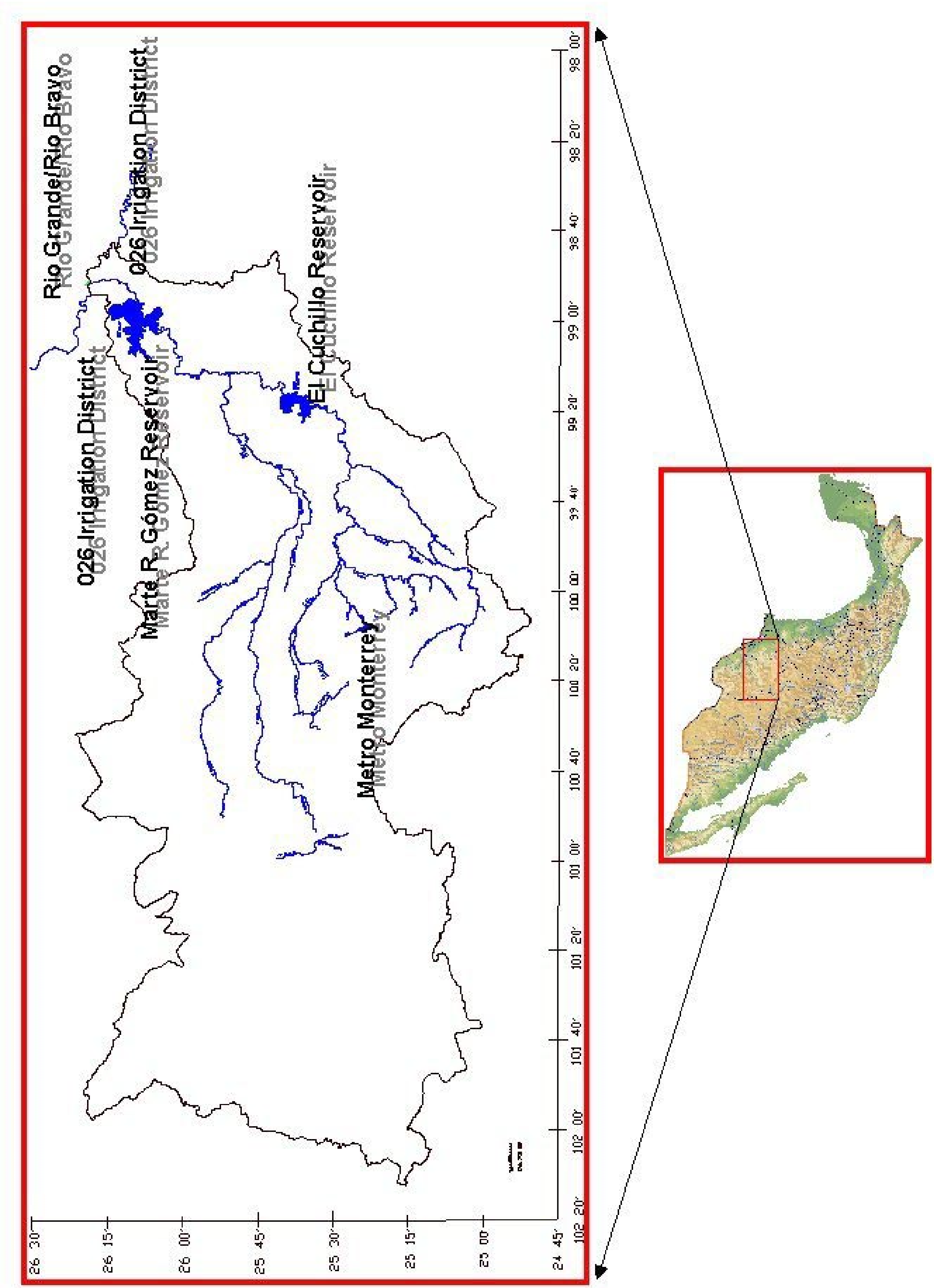

Fig. 1. The location of the río San Juan watershed in northeastern Mexico.

(MMA), which covers an area of approximately 360 km^2. The population in the area was expected to double by the year 2000 (SARH-SEP, 1989; ERL, 1991). The MMA represents the second largest industrial city within Mexico and was growing steadily until the economic crisis at the end of 1994. Currently the watershed houses 10 000 industries which by 1989, had a total water demand of approximately 2.0 m^3 seg^{-1} (ERL, 1991).

The future water demand and supply scenarios in the río San Juan watershed were assessed by running a full water balance along the main stem of the río San Juan. Discharge was traced from El Cuchillo reservoir to its outlet into the Rio Bravo. Monotonic increasing municipal demands in the MMA, variable irrigation supplies in the Lower San Juan irrigation district were coupled by the future presence of normal and dry spells for the periods of 1990-2004; 2010-2024 and 2030-2044.

DATA

(a) Population and per capita water supply in the MMA. To estimate the total public water demands the following data was collected:

Population figures from 1920 to 1995 (Source: INEGI, 1996).
Population forecasting for the years 2000 to 2020 (Source: CONAPO, 1996).
Domestic water supplies from 1990-1996 (Source: Agua y Drenaje, 1996).

Per capita water use for the period of 1990-1996 approached 290 liters day^{-1} $inhabitant^{-1}$ and it is slightly lower than that reported by Soley *et al.* (1998) for the entire USA for domestic water demand (300 liters day^{-1} $inhabitant^{-1}$). Future public water demand was then estimated with population figures and the per capita water use. Because of the total water demand for the MMA, 42% is supplied by reservoirs La Boca (15%), Cerro Prieto (40%) and El Cuchillo (45%) (CNA, 1998), total water demand from the main stem was estimated with the proportion which corresponds to El Cuchillo reservoir. Observed and estimated total water supply and future demands for domestic use delivered exclusively from El Cuchillo reservoir is presented in Figure 2.

(b) Normal Hydrology and Drought Spells. The presence and magnitude of past dry and normal hydrology episodes was assessed by running a water balance at El Cuchillo previous to its construction, as well as by observing the standardized cumulative deviations of precipitation and discharge of the rivers San Juan and Pilon. To run the water balance prior to the construction of the reservoir, a water budget was first run during the period of operation (1993- 1996) to quantify the terms of poorest accuracy to account for these errors into the full water balance. Monthly data was used to run the water budgets because this time scale smoothes the daily variations and retains the long-term tendencies of hydrological parameters.

Hydrologic and hydrometric data utilized was as follows:

1. El Cuchillo reservoir. The water balances (1993-1996 and 1939-1993) were run with the following information.

Monthly discharge into the reservoir from the San Juan river (1939-1996) (Source: CNA, 1998).
Monthly precipitation at El Cuchillo (1939-1996) (Source: CNA, 1998).
Monthly pan evaporation at El Cuchillo (1940-1996) (Source: CNA, 1998).
Monthly temperatures, mean, minimum, and maximum at El Cuchillo (1940-1996) (Source: CNA, 1998).
Monthly percolation, discharge for public supply to MMA, irrigation of the Las Lajas district, storage, and delivery to Marte R. Gómez reservoir (1993-1996) (Source: CNA, 1998; Agua y Drenaje, 1998).

The following assumptions were made for the water balance prior to the construction of El Cuchillo reservoir:

1.1.- Percolation was a function of storage.
1.2.- Lake to pan evaporation was weighted by a factor of 0.75. This ratio was a function of temperature.
1.3.- Discharge to Marte R. Gómez reservoir was fixed at a rate of 12.96 Mm^3 $month^{-1}$, to meet the previous agreement accorded between the States of Nuevo Leon and Tamaulipas.
1.4.- Discharge to MMA was 45% of the surface water demands.

The water balance for the period of 1993-1996 resulted that estimated and observed reservoir storage had a standard error of 36 Mm^3, or 13% of coefficient of variation. The main source of error was attributed to gauged inflows. Therefore a regression analysis was conducted to predict inflows as a function of the observed ones with the equation of -3.883+0.849319(Observed Inflows), which had a coefficient of determination of 0.90 and a standard error of 10.0 Mm^3. That is observed inflows appear to be smaller, on the average 84%, than predicted ones.

The results showed that trends in dry and wet spells could be observed on precipitation and streamflow records (Figure 3). A type of normal hydrology is observed from 1939 to 1948, stressing seasonal as well as biannual dry and wet type of cycles.

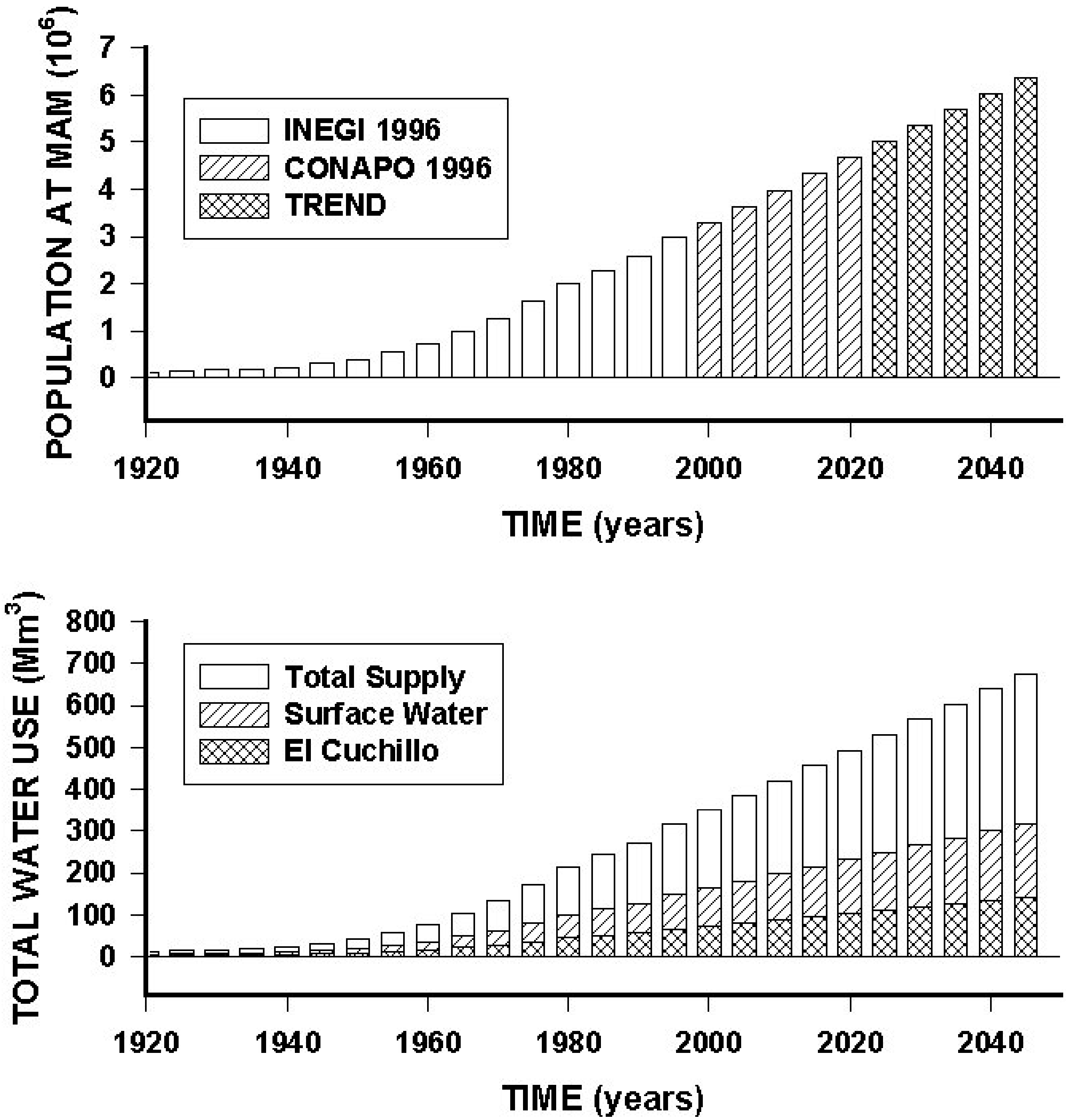

Fig. 2. Population and public water demand by source of supply in the Monterrey Metropolitan Area of northeastern Mexico.

A downward and upward trend in precipitation and discharge of both rivers can be observed from 1949-1965 and 1966-1979, respectively. The reservoir storage responds well to the dry episode of the 1950's (Figure 4). A normal precipitation trend extends from 1978 to 1990 and a dry spell starts in the early 1990's. Therefore the worst drought spell on record proposed for this study was that of 1949-1964. A wet spell was assumed to be that of 1965-1979, while a normal hydrology spell was proposed as that from 1979-1992. Discharge, precipitation and temperature from these spells provided information for running the future water balances.

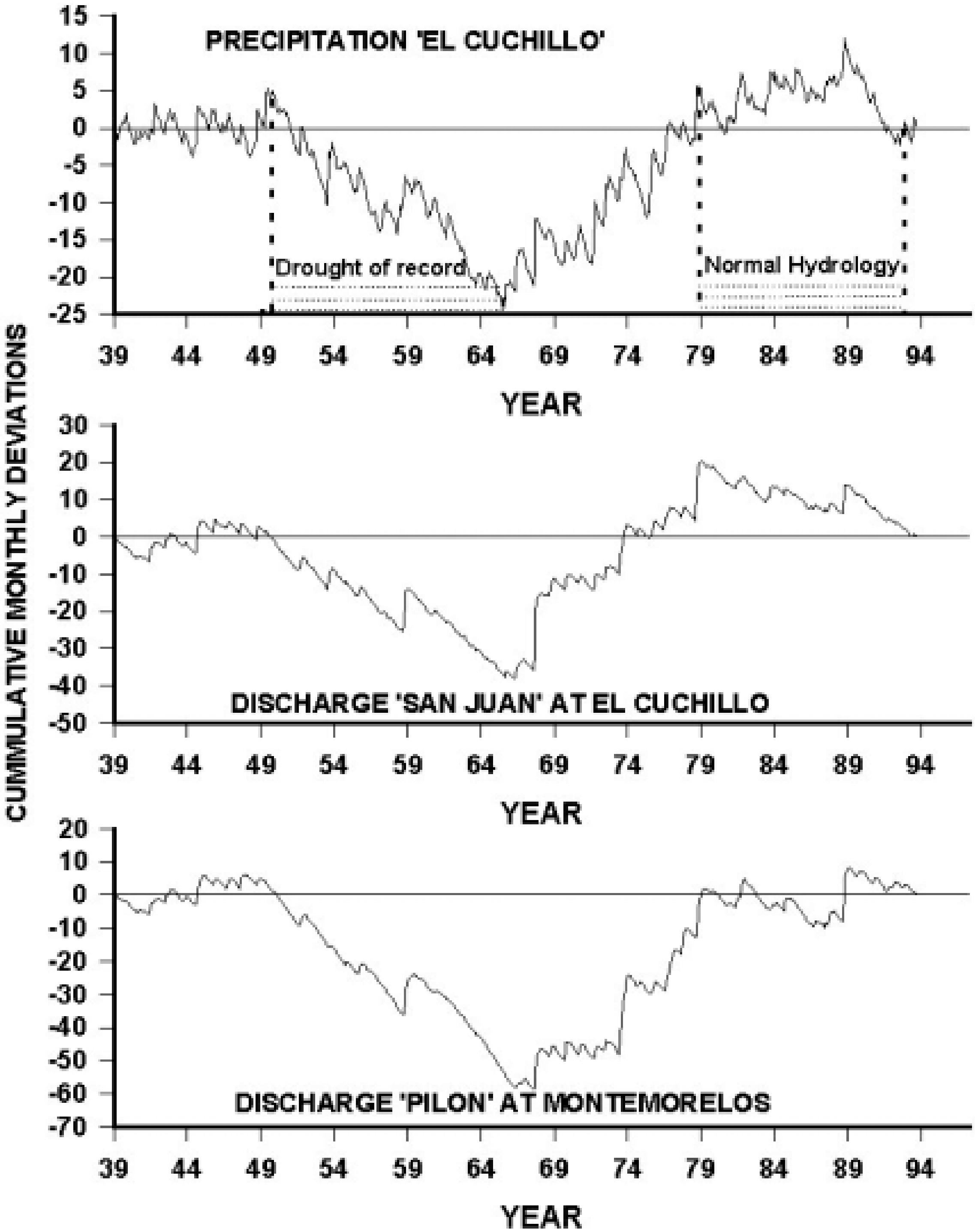

Fig. 3. Standardized cumulative deviations of monthly precipitation and streamflow for gauging stations of El Cuchillo and Montemorelos.

The results for the long term water balance of El Cuchillo showed that the resevoir responds well to dry and wet spells. Average inflows and storage for the entire time series are 49 and 729 Mm^3 $month^{-1}$, with standard deviations of 101 and 285 Mm^3 $month^{-1}$, respectively. The statistics for the worst drought (1948-1963) and the normal hydrology (1978-1992) scenario had monthly precipitation and streamflow averages of 38mm and 43mm and 35Mm^3

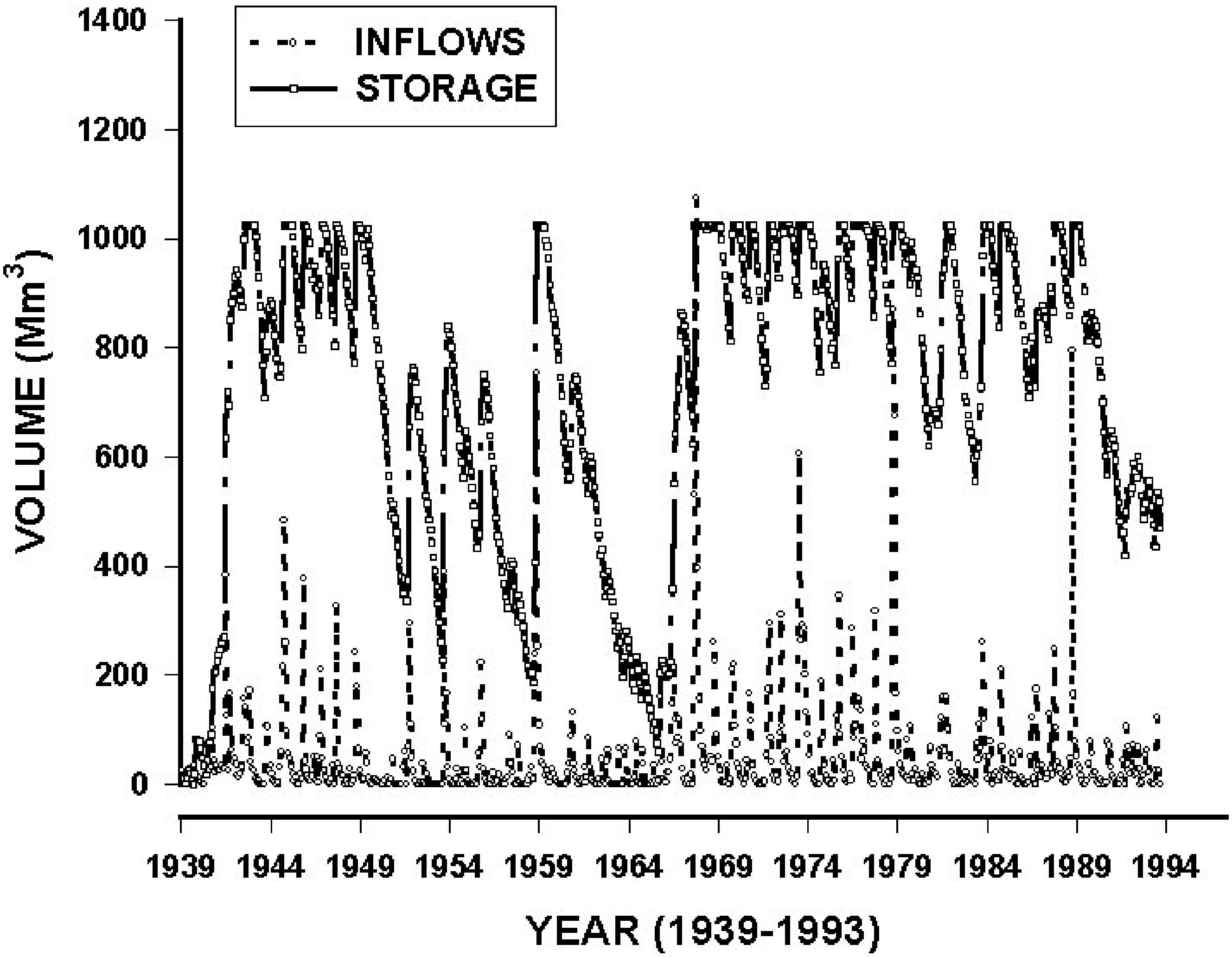

Fig. 4. Water balance for El Cuchillo reservoir run prior to its construction from 1939 to 1993.

month^{-1} and 48 Mm^3 month^{-1}, respectively. That is a reduction of 5 mm in monthly precipitation produced a reduction of 13 Mm^3 month^{-1} of streamflow. Large reductions on streamflow may have been the result of changes in rainfall frequency and intensity. Note that estimated discharge for the entire time series is similar to the average discharge for the proposed normal hydrology scenario.

2.- The water balance for reservoir Marte R. Gómez was run with the following information:

Monthly precipitation at Comales for 1980-1993 (Source: CNA, 1994).
Monthly pan evaporation at Comales for 1980-1993 (Source: CNA, 1994).
Monthly delivered discharge from El Cuchillo at a rate of 12.96 Mm^3 month^{-1}.
Monthly water spills from El Cuchillo.
Montly discharge from the Pesqueria river at Los Herreras from 1942-1997 (Source: CNA, 1998).
Monthly reservoir storage for 1980-1993 (Source: CILA, 1980-1993).
Monthly spills and percolation from Marte R. Gómez gauged entering the río San Juan into the Rio Bravo for 1980-1993 (Source: CILA, 1980-1993).

This procedure assumed that the water balance is closed and deliveries for irrigation of the Bajo San Juan, were estimated as the dependent variables. Other major assumptions for the future scenarios were the following: Percolation was a function of storage; the volume of irrigation supply was constant from year to year and weighted from month to month, according to historic deliveries. The rate of irrigation supply was a function of storage with a minimum normal storage of 0 Mm^3.

The latest batimetric information of Marte R. Gómez was considered for the water balance and future scenarios. Water spills from El Cuchillo for the worst drought spell and normal hydrology scenario were considered.

The estimated average and standard deviation of the annual water supply for irrigation was 675 and 340 Mm^3, respectively. The average is close to the total water required for irrigation for a bi-seasonal cropping period of maize or sorghum with water requirements of 0.4-0.55m m^{-2} per season (Návar, 1998). SARH (1991) reported an average of 440 Mm^3 $year^{-1}$ and ERL (1991) reported an average of 540 Mm^3 $year^{-1}$ of volume delivered for irrigation. In this reseach we used an average of 500 Mm^3 per year of reservoir storage to meet irrigation demands of the 026 district. The balance also predicts that most irrigation volume is supplied in April and May, in agreement with irrigation schedules of most crops.

During this period of observations, recorded discharges (water spills and percolation from Marte R. Gómez) into the Rio Bravo had a monthly average and standard deviation of 9.53 and 50.58 Mm^3, respectively. ERL (1991) reported an average discharge rate of 28.5 m^3 $month^{-1}$ to the Rio Bravo for a different time period of observations.

RESULTS

1.- El Cuchillo reservoir.

1.1.- The worst drought spell scenario.

The resulting water balance for the worst drought scenario showed that only in 12 months, 1.8% of the time, El Cuchillo reservoir will spill water into Marte R. Gómez (Figure 5). The average reservoir storage would be 415, 341, and 325 Mm^3 $month^{-1}$, for 1990-2010, 2010-2030, and 2030-2050, respectively. These estimates are slightly larger than average storage recorded during the present drought spell of the late 1990's. The number of months without storage would be 1, 3, and 4% of the time for the three time periods, respectively. The average time of reservoir storage with less than 100 Mm^3 $month^{-1}$ would be 5, 9 and 10%, for 1990-2010, 2010-2030, and 2030-2050, respectively.

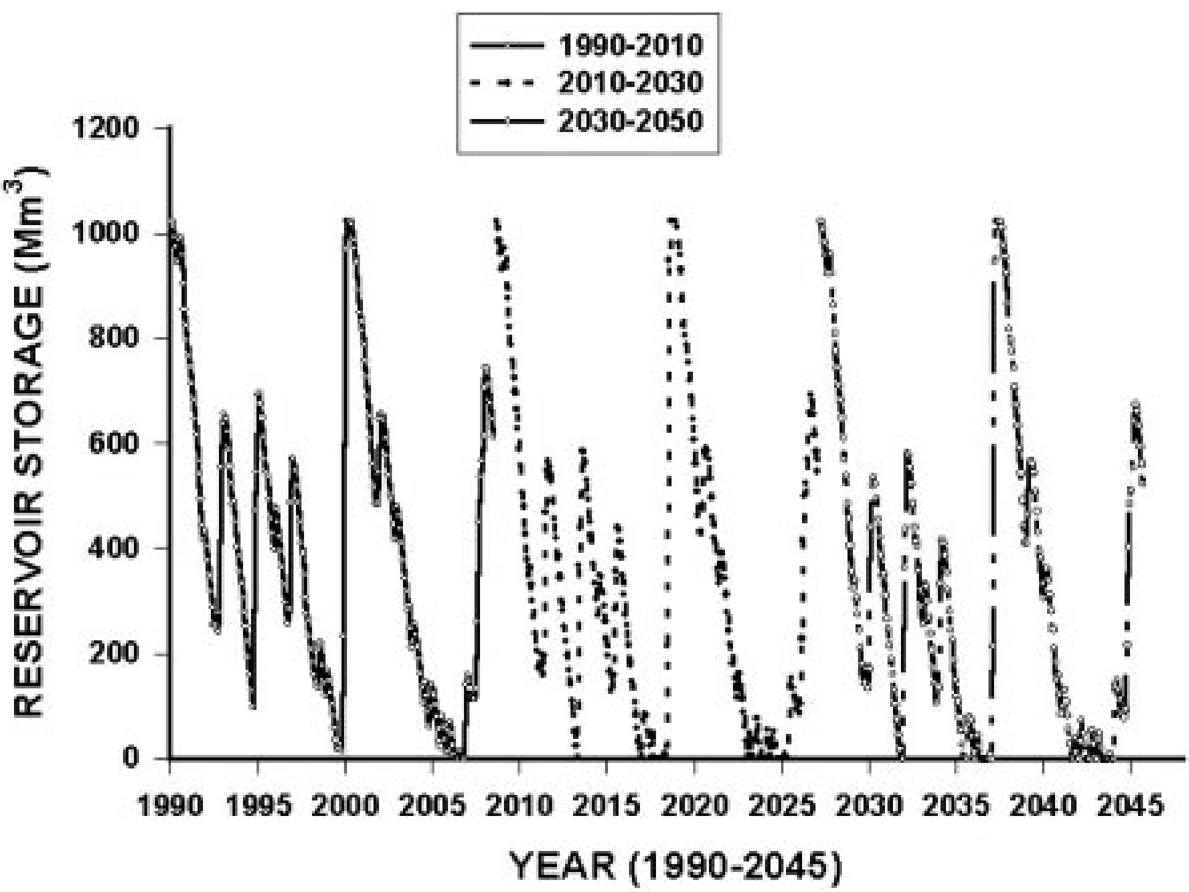

Fig. 5. The storage behaviour of El Cuchillo reservoir for the worst drough scenario for the period of 1990-2045.

1.2.- The normal hydrology scenario.

In a normal hydrology scenario, the average storage of El Cuchillo would be 798, 741 and 705 Mm^3 $month^{-1}$ with standard deviations of 195, 222, and 222 Mm^3 $month^{-1}$ for the time periods of 1990-2005, 2010-2025, and 2030-2045, respectively.

Monthly reservoir storage would never drop below 200 Mm^3 for any of the three time periods. The number of months which the reservoir would spill water is 27, 15, and 14 for the three time periods of simulation (Figure 6).

El Cuchillo reservoir can, under normal hydrology conditions, meet other water requirements, including environmental water demands, as well as additional supplies to Marte R. Gómez reservoir. This is accounted for in the new agreement between the Mexican States of Tamaulipas and Nuevo León.

2.- Marte R. Gómez Reservoir.
2.1.- The worst drought scenario.

In this scenario, the reservoir showed an average and standard deviations of 86 and 196 Mm^3 $month^{-1}$. The frequency of zero storage was high, 66% of the time and it increases with time of simulation (Figure 7). The frequency of full reservoir storage is quite small and it happens exclusively during the presence of heavy hurricanes. The rest of the simulation time, the reservoir storage hardly surpasses 100 Mm^3 $month^{-1}$. Therefore the number of months with less than 200 Mm^3 $month^{-1}$, dominates de frequency histogram (82%) and indicates a lack of volume of storage for planning the next year area of irrigated agriculture. The presence of 0 storage, 66% of the time, indicates that there is not water left in the reservoir to meet monthly irrigation schedules of the Lower San Juan district.

2.2.2.- Normal hydrology scenario.

The reservoir had an average and standard deviation of 68 and 292 Mm^3 $month^{-1}$, respectively (Figure 8). The number of months with zero storage was reduced from 66% to 55% for the normal hydrology conditions and the number of months with full storage was increased from 3 to 9. However monthly storage with less than 100 Mm^3 still dominates the frequency distribution (70%).

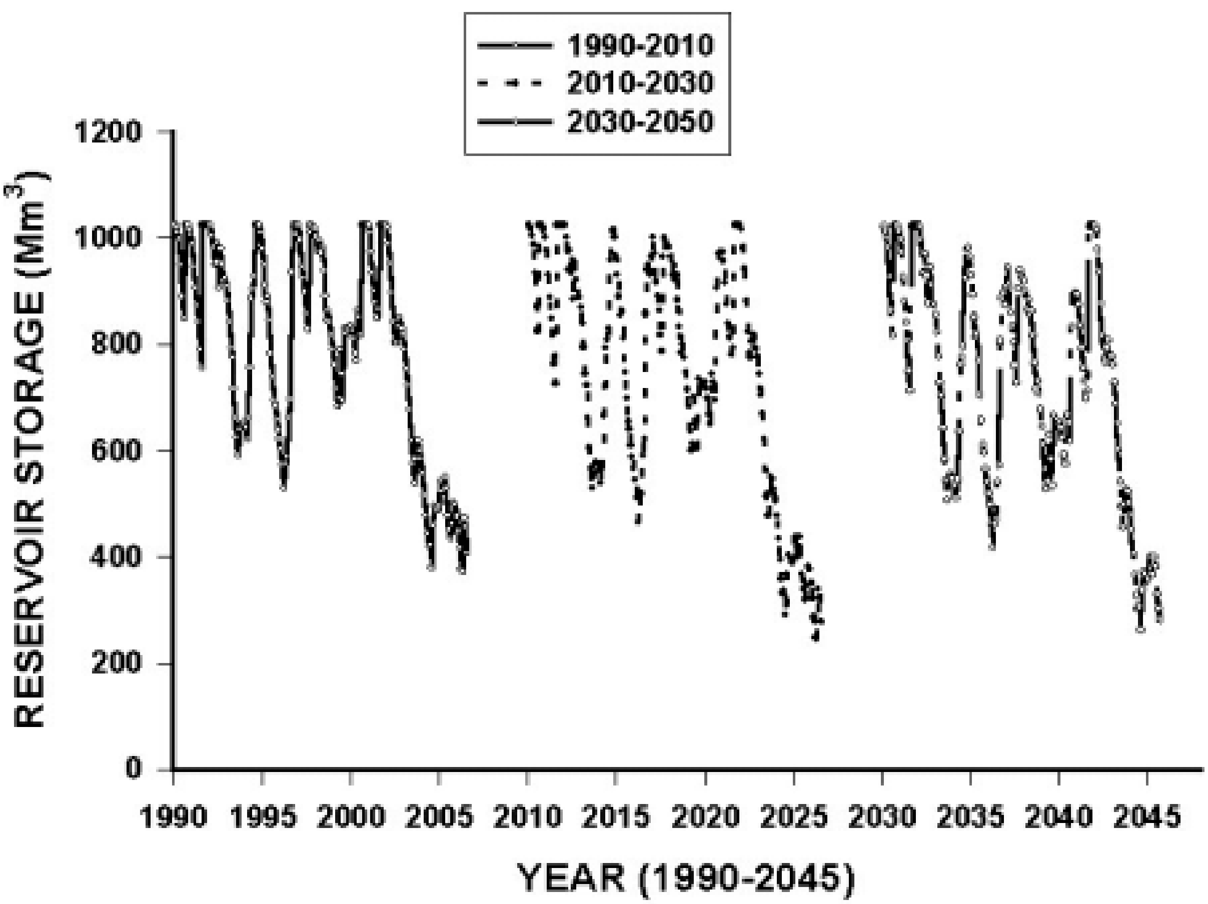

Fig. 6. El Cuchillo storage for the normal hydrology scenario for three time periods (1990-2045).

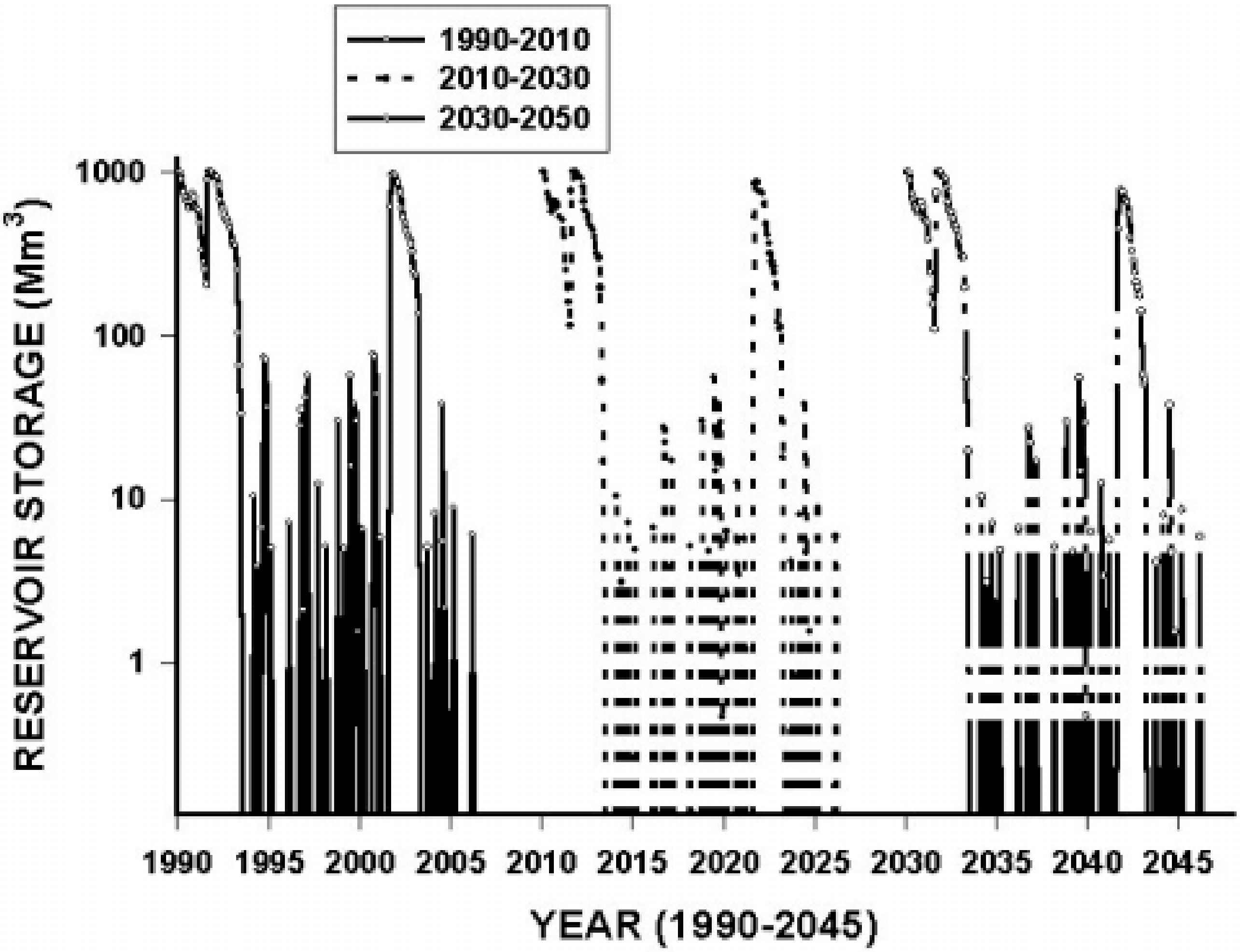

Fig. 7. Marte R. Gómez reservoir storage for three time periods for the worst drought scenario.

Considering the scenario's normal hydrology and worst drought spell conditions, the coefficient of variation of monthly storage is increased from 176% in the former scenario to 227 in the second one, consistent with larger variations of hydrology during dry spells. However, on the average 55% of the time there would not be stored volume of water to meet or plan irrigation requirements of all the agricultural land available.

2.3.- The discharge contribution of the San Juan River to the Rio Bravo.
2.3.1.- The normal hydrology scenario.

The average and standard deviation of monthly discharge into the Rio Bravo for this scenario are 3.89 and 39 Mm^3 $month^{-1}$, respectively. The former figure is the equivalent to 1.50m^3 seg^{-1}, and it is comprised mostly of the low percolation rates and three water spill events from Marte R. Gómez reservoir.

2.3.2.- The worst drought episode scenario.

The average and standard deviation of monthly discharge into the Rio Bravo for this scenario are: 1.17 and 16.34 Mm^3 $month^{-1}$, respectively. The former figure lowers to 0.45 m^3 seg^{-1}.

DISCUSSION

The drought spell of the 1990's in northern Mexico and southwestern USA, where the río San Juan watershed is located, has prompted renewed efforts to cope with present water shortages to meet the traditional water demands for public and irrigation supplies. This drought episode, however, has not yet attained the magnitude of the drought spell of the 1950's (i.e the downward trend of the standardized deviations of the 1990's is less steep and shorter in time than that of the 1950's). The presence of drought episodes has also concerned society in other regions of the world (i.e the Saharan and

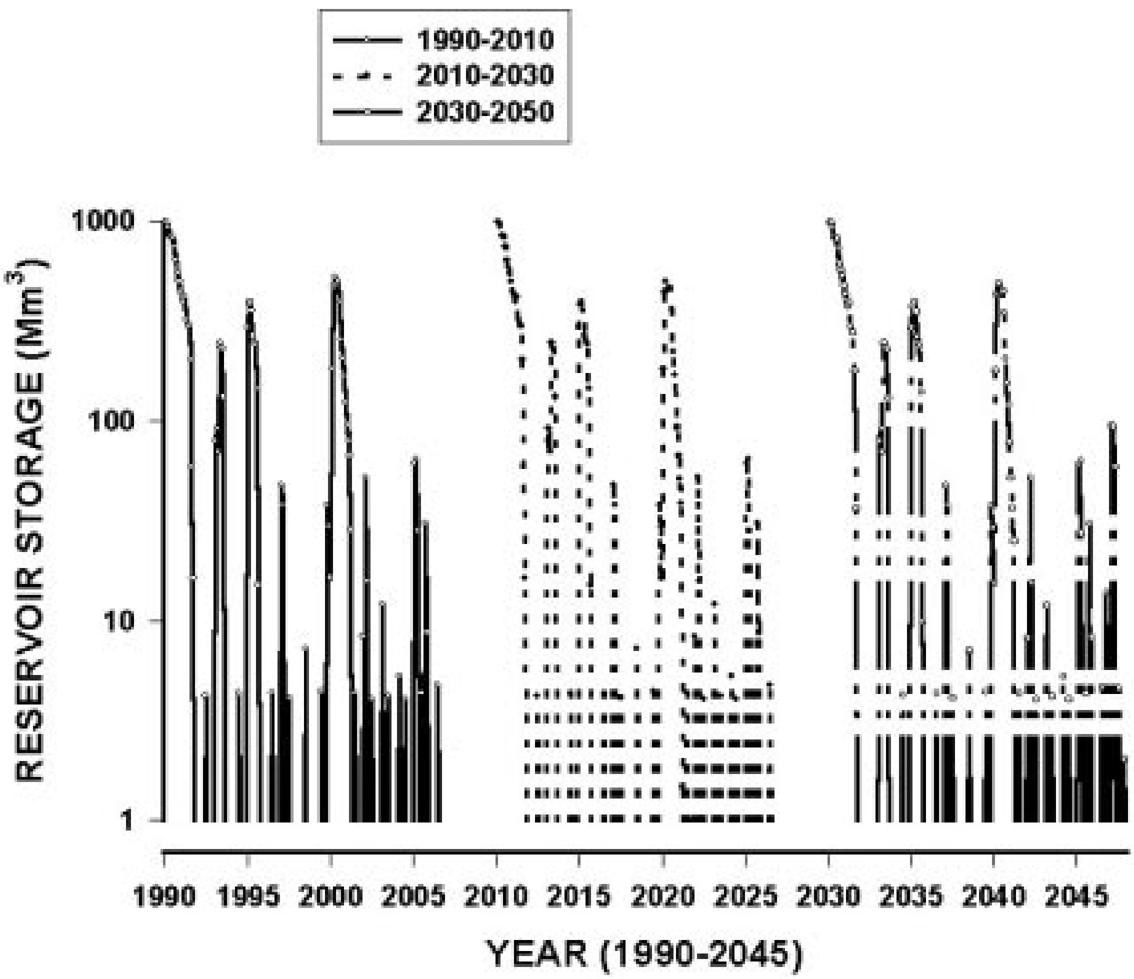

Fig. 8. Marte R. Gómez reservoir storage: three time periods of simulation for the normal hydrology scenario.

Sahelian countries, the southwestern portions of Australia, northeastern Brazil, and northwestern India) (Lamb, 1977; Lockwood, 1977; Hare, 1986).

The Marte R. Gómez reservoir, in a drought or normal scenario, would not meet irrigation demands on the average 65 and 56% of the time, respectively. On annual basis, in only one year, the reservoir would supply irrigation demands for 11 consecutive months. In 7 out of 15 years, the reservoir would supply less than three monthly irrigation schedules. In a normal hydrology scenario, the reservoir would meet all monthly water demands for irrigation in 3 of 16 years, less than 3 monthly irrigation schedules in 7 of 16 years and less than 5 irrigation schedules in 10 of 16 years.

The storage uncertainty of Marte R. Gómez reservoir would reduce the size of irrigated lands in the 026-irrigation district on the average between 65 and 56% of the present land. This tendency has already been observed in the 1990's. The Lower Rio Bravo irrigation district has also reduced its irrigated lands in the 1990's. The World Meteorological Organization noted that Mexico is listed among the countries to suffer from recurrent drought spells and that the importance of these episodes would increase by the first quarter of the next century.

The concept of sustainability should be promptly implemented on the integrated management of water resources of the río San Juan watershed of northeastern Mexico. The sustainable management of water resources is a key component to meet traditional as well as environmental water supplies. The holistic approach states, according to UNCED (1992), that integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. To this end, water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perennially of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. Beyond these requirements, however, water users should be charged appropriately. Therefore there is an urgent need for the promotion of action along the four fronts stated by UNCED (1992) where addressing these issues between users and uses of the San Juan headwaters could be one of the best ways to prepare for sustainable development (Schmand *et al.*, 1998).

The second approach deals with the plannification for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national and economic development policy. To this end, preliminary technical observations suggest that saving water resources in the public and agricultural sectors could ameliorate the potential reduction of irrigated lands in the 026 district as well as to conserve riparian ecosystems. The public sector has to be more efficient in channeling and distributing public water supplies. There is an increasing evidence that volume loses in the water distribution system of most cities can be as high as 30% (CNA, 2000). Therefore, by tapping all losses in the water distribution system of the MMA, the volume of water supply for irrigation of the 026 irrigation district would increase by 49, 69 and 89 Mm^3 $year^{-1}$ for the time periods of 1990-2004; 2010-2024; and 2030-2044, respectively. These estimates are 31, 44 and 57% of the assumed annual volume supplied for irrigation from El Cuchillo reservoir (155.5 Mm^3 $year^{-1}$) to the Lower San Juan irrigation district. Because the MMA treats all its municipal black water and it is discharged into the San Juan River, there is little hope to work on this area of increasing water supplies. However, pollution problems along the main stem of the San Juan river persists after diverting all municipal black waters to the Ayancual and Pesquería rivers (Flores and Návar, in process). To conserve riparian ecosystems, increased stream water quality has to be enforced along the San Juan River.

The reduction of water demands for irrigation through more efficient conveyance, distribution and irrigation technologies is, however, one of the most important areas to tackle in the Lower San Juan irrigation district. Demands are dependent on climate, the crop consumptive water and soil physical characteristics. Crop water requirement is important to control water savings and increase the irrigated land. Water consumption estimations conducted by the approach described by Schwab *et al.* (1981) suggested that planting alfalfa or cotton would require 56 and 14% more volume of water than planting corn. That is by using the same volume of water, 56 and 14% more area would be planted with corn than by planting alfalfa or cotton. Sorghum, a less water demanding crop (10 and 25% less irrigated volume used than corn and cotton, respectively) is being extensively planted in the Lower Rio Bravo irrigation district in the 1990's as a response to shortage of water allotted for irrigation. Other economic and social considerations must be accounted when shifting crops in the 025-irrigation district.

The irrigation efficiency given by (1) the water conveyance, (2) water application efficiency, and (3) water use efficiency is also critical in water savings in the 026 irrigation district. The main system of water conveyance has an efficiency of 71%, the secondary drain system between 75-80%, and at the individual farms the efficiency is 65% (SARH, 1981). The overall estimated efficiency lies in the range of 32 to 36% and by increasing it to a feasible range of 60%, the total irrigated area would increase between 24 and 28%. The surface irrigation system has an average efficiency of 70% (Schwab *et al.*, 1981). The water use efficiency is also in the range of 60% because of the high water table (Reyes, 1986). Therefore the irrigation-excess is drained into the Rio Bravo, as well as into the Gulf of Mexico (data from CNA, 1998). Other irrigation technologies may also improve the water application efficiency and increase the size of irrigated lands.

CONCLUSIONS

In the future, under either the normal hydrology or the drought on record scenarios, the storage of Marte R. Gómez reservoir would be reduced and the irrigation land areas of the 026 district would contract because of increased water demands for public use in the Monterrey Metropolitan Area. The prompt implementation of sustainable management of water resources in the río San Juan watershed is required to ameliorate the contraction of irrigated lands as well as the potential disappearance of riverine ecosystems.

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BIBLIOGRAPHY

AGUA Y DRENAJE DE MONTERREY, 1997. Departamento de Planeación y Desarrollo Económico. Datos de Uso Doméstico del Agua del Area Metropolitana de Monterrey 1990-1996.

ARANDA, R., R. ZAMARRIPA, L. ROJAS, G. NAVARRO and J. NAVAR, 1998. Ordenamiento hidrológico de la cuenca del Río San Juan. Cross Border Waters: Fragile Treasures for the 21st Century. Ninth U.S./Mexico Border Sates Conference on recreation, Parks, and Wildlife. Tucson, Arizona. June 3-6, 1998.

COMISION NACIONAL DEL AGUA (CNA), 1994. Consejo de Cuenca del Río Bravo. CNA, Región Noreste. México, D.F.

COMISION NACIONAL DEL AGUA (CNA), 1997. Datos hidrométricos y climáticos de los embalses de la cuenca del río San Juan. Gerencia Estatal Nuevo Leon. Monterrey, N. L., México.

COMISION NACIONAL DEL AGUA (CNA), 2000. Estadísticas hidrológicas de México. Periódico El Sol de Durango. 29 de enero de 2000.

CONAPO, 1996. Estimaciones y proyecciones de la población. Consejo Nacional de Población, México, D.F.

CONTRERAS, B. S. and V. M. L. LOZANO, 1994. Water, endangered fishes, and development perspectives in arid lands of Mexico. *Conservation Biology 8,* 379-387.

EDWARDS, R. J. and B. S. CONTRERAS, 1998. Ecological conditions in the Lower Rio Grande/Rio Bravo valley study area and projections for the future. HARC-ITESM Joint Reserach Project on Water and Sustainable Development in the Binational Lower Rio Grande/Rio Bravo Basin. ITESM, Monterrey, N.L. Mexico.

FLORES, L, J. S. 1997. Evaluación de la calidad del agua del río San Juan en el Estado de Nuevo Leon. Tesis de Maestría en Ciencias Forestales. Facultad de Ciencias Forestales. UANL. Linares, N.L., México.

FLORES, L., J. S. and J. NAVAR, 2000. An assessment of the stream water pollution of the San Juan River. On Review in Environmental Quality.

HARE, K., 1983. Climate and desertification. World Climate Program. WCP-44. UNEP. 149 pp.

INEGI, 1983. Síntesis geográfica del Estado de Nuevo León. Instituto Nacional de Estadística, Geografía e Informática y Gobierno del Estado de Nuevo León. Monterrey, N. L., México.

INEGI, 1995. Anuario estadístico de Nuevo León. Instituto Nacional de Estadística, Geografía e Informática y Gobierno del Estado de Nuevo León. Monterrey, N. L., México.

INEGI, 1996. Anuario estadístico de Nuevo León. Instituto Nacional de Estadística, Geografía e Informática y Gobierno del Estado de Nuevo León. Monterrey, N. L., México.

INEGI, 1997. Anuario estadístico de Nuevo León. Instituto Nacional de Estadística Geografía e Informática y Gobierno del Estado de Nuevo León. Monterrey, N.L., México.

INTERNATIONAL BOUNDARY WATER COMISSION, 1980-1994. Hydrologic bulletins of the Rio Bravo.

LAMB, P. J., 1978. Large-scale tropical atlantic circulation patterns associated with subsaharan weather anomalies. *Tellus 30,* 240-251.

LOCKWOOD, J. G., 1979. The Causes of Climate. Edward Arnold. School of Geography. University of Leeds. 292 pp.

NAVAR, J., T. CAVAZOS and P. A. DOMINGUEZ, 1994. Los balances hidrológicos mensuales con tres probabilidades de precipitación en el estado de Nuevo León. Actas de la Facultad de Ciencias de la Tierra. De. C. Pola, J.A. Ramírez F., M.M. Rangel. & I. Navarro-L. UANL. Linares, N.L. México.

NAVAR, J., 1998. Water demand and supply in the Mexican portion of the lower Rio Grande/Rio Bravo watershed. HARC-ITESM Joint Reserach Project on Water and Sustainable Development in the Binational Lower Rio Grande/Rio Bravo Basin. ITESM, Monterrey, N.L. Mexico.

SCHMANDT, J., C. STOLP and G. WARD, 1998. Scarce water: doing more with less in the lower Rio Grande. US-Mexican Policy Studies Program. Policy Report No. 8. The University of Texas, Austin, TX.

SARH, 1978. Estudio sobre el aprovechamiento de excedentes del Río Bravo, Coahuila, Nuevo León y Tamaulipas. Infraestructura, Recursos y Servicios. México, D. F.

SARH, 1981. Rehabilitación de los distritos de riego del Bajo Río Bravo (25) y del Río San Juan (26), Tamps. Resumen. Infraestructura, Recursos y Servicios. México, D. F.

SARH-CNA, 1991. Distrito de riego No 026 B.R.S.J. organización e infraestructura. Unidad de Información y

Participación Ciudadana. Cd. Gustavo Diaz Ordaz, Tamps. México.

SARH-SEP, 1989. El agua y la sociedad en el mundo, en México y en Nuevo León. Instituto de Tecnología del Agua, IMTA, Cuernavaca, Morelos, México.

SOLEY, W. B., R. R. PIERCE and H. A. PERLMAN, 1998. Estimated use of water in the United States in 1995. U.S. Geological Survey Circular No 1200.

SOP, 1975. Mapa geológico de México. Secretaría de Obras Públicas. México, D.F.

UNCED, 1992. United Nations Conference on Environment and Development, Agenda 21, Chapter 18, sections 8 and 9. Rio de Janeiro, Brazil.

VOGEL, E. and N. E. ARMSTRONG, 1997. Water quality in the lower Río Grande/Rio Bravo. HARC-ITESM Joint Reserach Project on Water and Sustainable Development in the Binational Lower Rio Grande/Rio Bravo Basin. ITESM, Monterrey, N.L. Mexico.

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