EFFECTS OF CLIMATE CHANGE ON WATER AVAILABILITY IN A HYDROLOGICAL WATERSHED LOCATED IN AN ARID REGION IN THE NORTH CENTRAL PORTION IN MEXICO.

Humberto Silva-Hidalgo[1,2], Guadalupe Estrada Gutiérrez[1], Martha Lorena Calderón Fernández[1], María de Lourdes Villalba[1], Fernando Rafael Astorga Bustillos[1]

[1]Engineering Faculty, Autonomous University of Chihuahua

[2]hsilva@uach.mx

Abstract

The northern Mexico is an arid region where water scarcity is a natural condition. “Closed Basins of the North” Hidrologic Region, in Chihuahua State, where the Carmen river basin is located, is not the exception. The annual precipitation records in the basin, shows a tendency to increase from 1968 to 1991, then a decrease from 1992 to 2012. The annual runoff coefficient for the entire period of study, showed a clear upward trend. However, natural flows have preserved relatively stable, probably because the decrease in annual rainfall was compensate by the increase in the values of the annual runoff coefficient.

1 Introduction

Natural availability of water is very low in many latitudes of the planet that exhibit an arid or semiarid climate. However, phenomena such as climate change could affect these regions even more, so increasing the knowledge of the possible effects of these alterations, is very important to make an adequate management of the water resource now, in order to minimize the adverse impacts on the people in the near future.

The observation of the physical environment for long periods can expose changes in hydrological systems behavior, to anticipate problems that will manifest themselves with greater intensity in the future. The northern part of Mexico is characterized by been an arid and semi-arid region, hence water scarcity is its natural condition; however, these areas can be even deeply affected by changes in climate (CNA, 2013). In this region, specifically the Hydrologic Region “Closed Basins of the North”, in the State of Chihuahua, the Carmen river basin is located. At the outlet of the upper zone of the basin, “Las Lajas” Dam is located, and from this dam, the Irrigation District 089 El Carmen, is supplied of surface water. The assessment of the trend of variables such: rainfall, natural flows regime and behavior of the runoff coefficient, can provide elements to delineate local policies in advance to deal with the adverse situation.

Considering these statements, the scope of this paper is to assess the effects of changes in climate, throughout the analysis of rainfall patterns, and modifications observed in the land natural coverage, in terms of natural flows time series. The results obtained could be very useful, to take preventive measures to help cope with adverse conditions opportunely.

2. Materials and methods

2.1 Description of the study zone

The upper basin of the Carmen River is located in the north - central portion of the State of Chihuahua, between latitudes 30^0 00´00” N and 28^0 30 '00” N and longitudes 107^0 15' 00” W and 106^0 30' 00” W, as shown in Figure 1. This land area of just over 4,500 km^2, from inception to where the dam “Las Lajas” is located at the outlet, belongs to the Hydrologic Region “Closed Basins of the North” (Endorheic basins zone), in the State of Chihuahua (CNA, 1997). The lower Carmen River basin discharges to an intermittent water body called "Laguna de Patos".

The upper basin of the Carmen River observes a dendritic drainage in the topographically higher areas, gradually changing to sub Dendritic in the flatter areas. The length of the main channel 160.8 km and a total drop in the order of 787 m.

The topo form systems observed in the upper Carmen River basin are sierras located in the east and west portions, and a set of hills in the southern zone. The central fringe is characterized by plateaus and continuing to the south, the topography decreases smoothly until reaching the plains where there are no prominent elevations or depressions (INEGI, 2016).

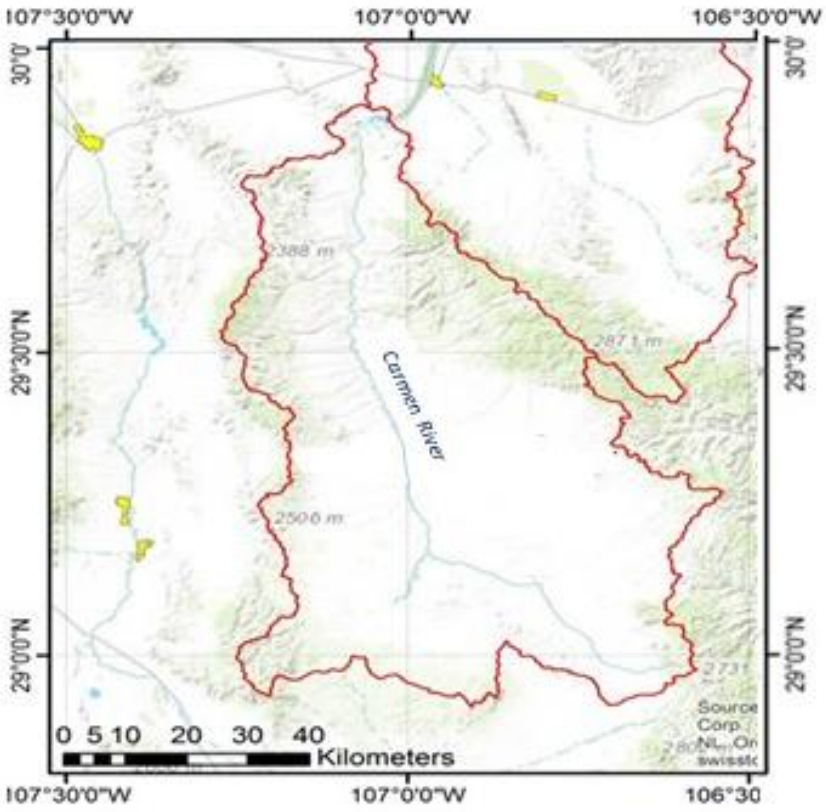

Figure 1. Upper Carmen River basin

The predominant vegetation in the basin is natural pasture, Encino forest, Pine-Encino forest, Encino-Pine forest, temporal agriculture and urban area (INEGI, 2005; INEGI, 2015).

Behavior of the vegetation cover from 1976 to the year 2000

Considering as a base reference the map of use of soil and vegetation of the year 1976 (INEGI, 1996), and comparing to the National Forest Inventory map, from the field trip on 2000 year (SEMARNAT-IG, 2001); there was possible to identify changes in vegetation coverage from 1976 to 2000 (Figure 2). Both base maps consulted, were built using the information generated from the National Institute Statistics, Geography and Informatics, by the Institute of Geography of the National Autonomous University of Mexico.

The mountainous area of the upper basin of the river of the Carmen (in the zone of header), has been lost tree surface, changing from primary forest to secondary forest. Also, some of the flatter topographically areas have changed from natural grassland to scrubland, induced grassland or agricultural area. Some of these physical changes may be due to natural causes, such as a decrease in precipitation, or anthropogenic alterations.

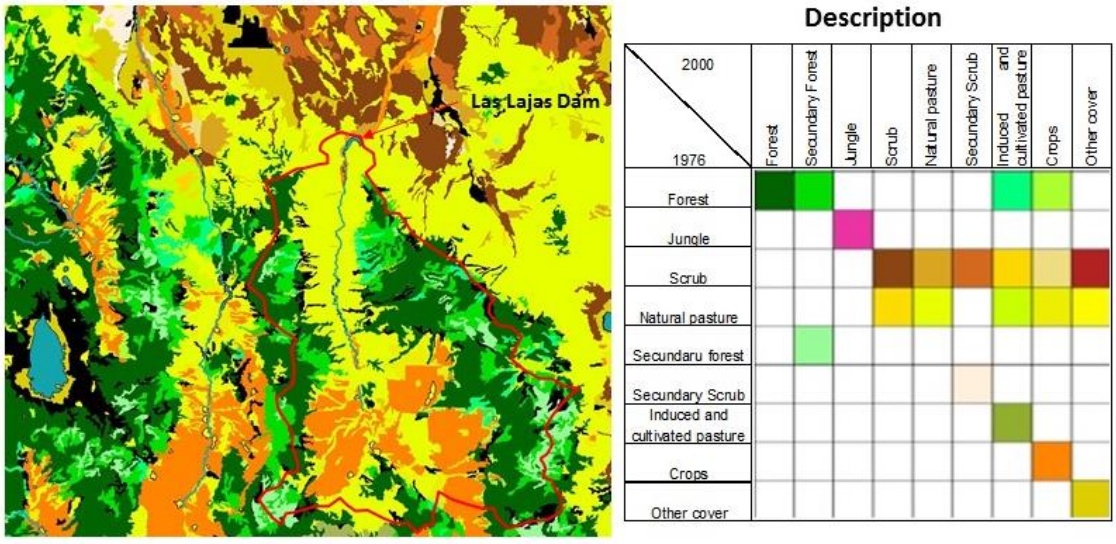

Figure 2. Change on land use and vegetal coverage from 1976 to year 2000 in the study zone.

Hydroclimatology

The mean rainfall in the basin was obtained from the historical records of three climatological stations, Las Lajas, El Tintero and Bachiniva (IMTA and CNA, 2000), using the method of polygons of Thiessen (USDA-NRCS, 2015). The average annual rainfall for the period from 1957 to 2012 was 386.79 mm. Figure 3 shows the behavior of the annual precipitation from 1965 to 2012, observing that from 1965 to 1992, the average was 414.7 mm and from this last year to 2012 decreased to 350.2 mm. The trend of annual precipitation over the entire period was to decreasing (discontinued red line in Figure 3).

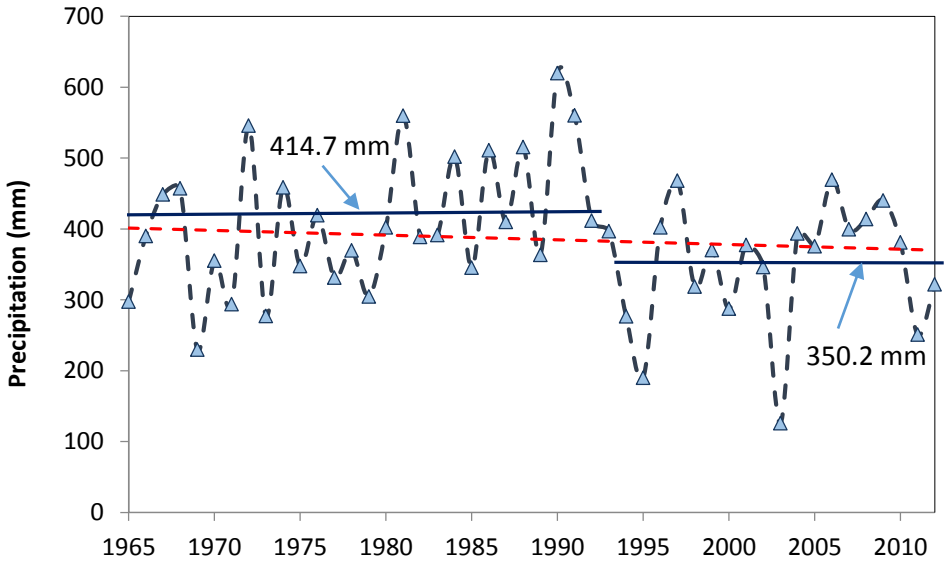

Figure 3. Annual Precipitation in the upper Carmen river basin from 1965 to year 2012.

In the basin, there are monthly time series data of hydrometry in the “La trasquila” station, from 1952 to the beginning of operation of the Las Lajas Dam in 1965, and from this year to date in the reservoir (IMTA and CNA, 2000). In the first case, monthly surface runoff volumes is available, while the stored volume, evaporated volume, extraction volume and volume of total inflows are observed in the dam.

Surface water use in the Carmen river basin

According to the data recorded in the Public Register of Water Rights from CONAGUA, in the upper basin of the Carmen River, there is a volume of surface water rights of 0.87 hm^3. Volume that is practically equal to that reported in the study of the availability of surface waters in the Hydrological Region RH 34, Cuenca Cerradas del Norte, published in the Official Gazette of the Federation on July 31, 2013 (CNA, 2013).

Evaporation and change in storage in Las Lajas Dam

The evaporation and the change in storage at Las Lajas dam was determined for the analysis period, based on the hydrometric records (IMTA and CNA, 2000). The average annual volume that evaporated in the dam from 1965 to the year 2012 is of the order of 6.47 hm^3, representing little more than 18% of the average annual volume stored in the same period.

Volume of imports and exports

In the upper basin of the Carmen River, there are no exports of water to adjacent or contiguous basins (other basins). On the other hand, the volume that comes out of this basin is accounted in the annual volume gauged to downstream (lower basin of the Carmen River).

Return Flows

Considering the very low magnitude of the volumes of water used in the Carmen River basin, there are no measurements of return flows. Although it is known that these volumes are so small that they can be omitted explicitly, and being quantified in the calculation as part of the annual natural flows.

Method to estimate natural flows

In a gauged basin, the adjustment of the hydrometric registers using the mass conservation equation is a generalized practice to determine the natural flows volumes.

This adjustment consists in removing the effects of the large artificial reservoirs that store water, the derivation and use of the liquid, as well as the return volumes, among other factors (Wurbs, 2005; Wurbs, 2006). The mass conservation equation for a water body that storage water or a river in a basin, is shown in the next mathematical expression (Wurbs, 1996):

$$E - S = V_{t+\Delta t} - V_t \quad (1)$$

Where: $V_{t+\Delta t}$ and V_t are the final and initial stored volume respectively, in a time interval Δt; E and S are the inflow and outflow volumes of the system in that same period of time.

Taking into account the possible inflows and outflows to the hydrological system and considering that there is a surface water storage at the outlet, the equation 1 transforms to:

$$C_p = A_b + E_{xb} + E_v - A_r + E_x - I_m - R + \Delta V \quad (2)$$

Where: A_r, is the gauged volume coming from the upstream basin; A_b, is the basin volume gauged downstream; E_{xb}, is the volume of surface water consumed in the basin: E_v, is the volume of water evaporated: E_x, is the volume of exports to adjacent basins; I_m, is the volume of imports from adjacent basins; R, the volume of returns flows; finally, ΔV, is the change in storage.

Runoff coefficient determination

In order to determine the annual runoff coefficient (C_e), which expresses the rainfall-runoff ratio in a hydrological basin (Aparicio, 1992; Campos, 1997), the annual volume of natural runoff (V_e), as well as the volume of water precipitated in the basin (V_p), were used, according to the mathematical expression 3:

$$C_e = V_e / V_p \quad (3)$$

Results and discussion

Natural flows in the Carmen River upper basin

The Carmen River upper basin is a header watershed, from its origin to Las Lajas Dam. This reservoir has hydrometric records available since 1965, so it was possible to determine the monthly natural flows until 2012, using the mass conservation equation, as established in the Mexican Official Standard NOM-011-CNA-2015 (CNA, 2015).

Figure 20 shows the annual hydrograph of monthly average natural flows calculated for the period from 1965 to 2012, obtaining a mean annual natural flow volume of 62.93 hm^3. Note that in the same figure, the average hydrograph presents a typical form of a basin in the natural state, with no deformations and very low flows in the dry season and with proportional increases in the months of precipitation (June to October for this region).

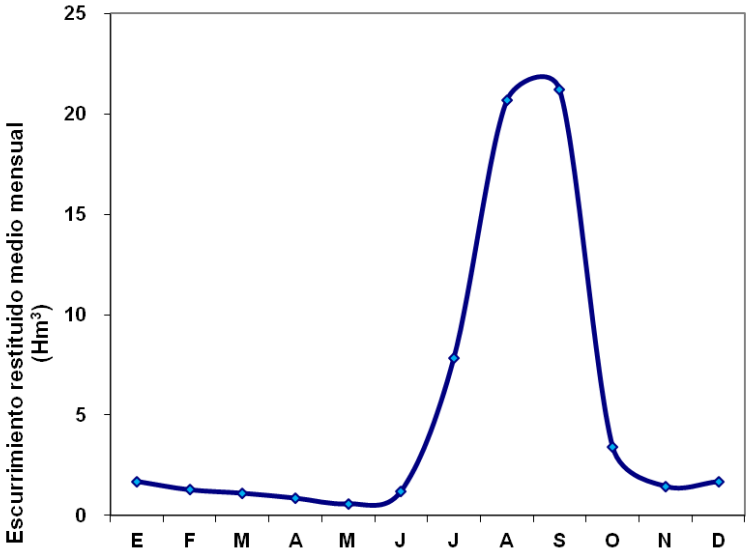

Figura 4. Hydrograph of monthly average natural flows for the Carmen River upper basin

Figure 21 shows the behavior of the annual natural runoff obtained for the analysis period. The behavior of natural flows shows a rise in the first nine years of the time series, and then a period of stability until 2012. The average evolution (red line) shows enough consistency compare to the average of the complete period of analysis (black discontinued line).

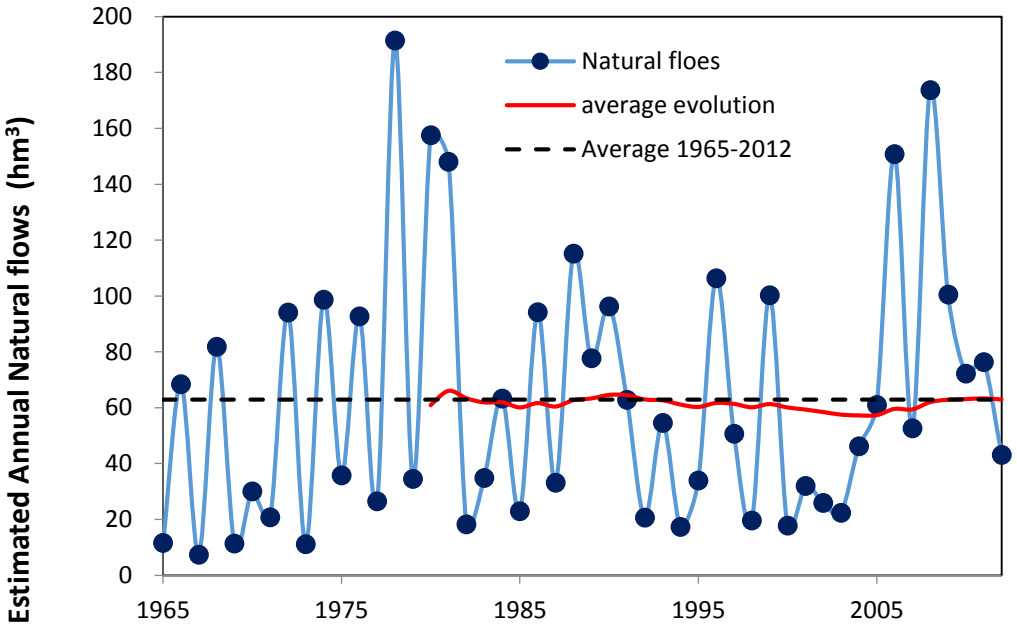

Figura 5. Annual natural flows determined for the period from 1968 to 2012 year.

Behavior of the runoff coefficient in the Carmen River upper basin

The annual runoff coefficient (C_e) was determined by equation (3), for which the annual natural runoff (V_e) determined in the previous section was used, as well as the annual rainfall depths and basin area to estimate the volume of precipitation (V_p).

Changes in the behavior of the runoff coefficient in the long term could be due either to variations (increase or decrease) in the rainfall regime, or to changes in the vegetation cover. The rainfall regime could be affected for climate change phenomena. While changes in vegetation cover could be originated by: (1) the continuous and progressive decrease of precipitation, (2) lower groundwater levels in zones with phreatophyte vegetation (due overuse of the water stored into the ground), (3) human practices of over utilization of vegetation by cattle, or (4) removal of natural vegetation cover, for the development of agricultural areas.

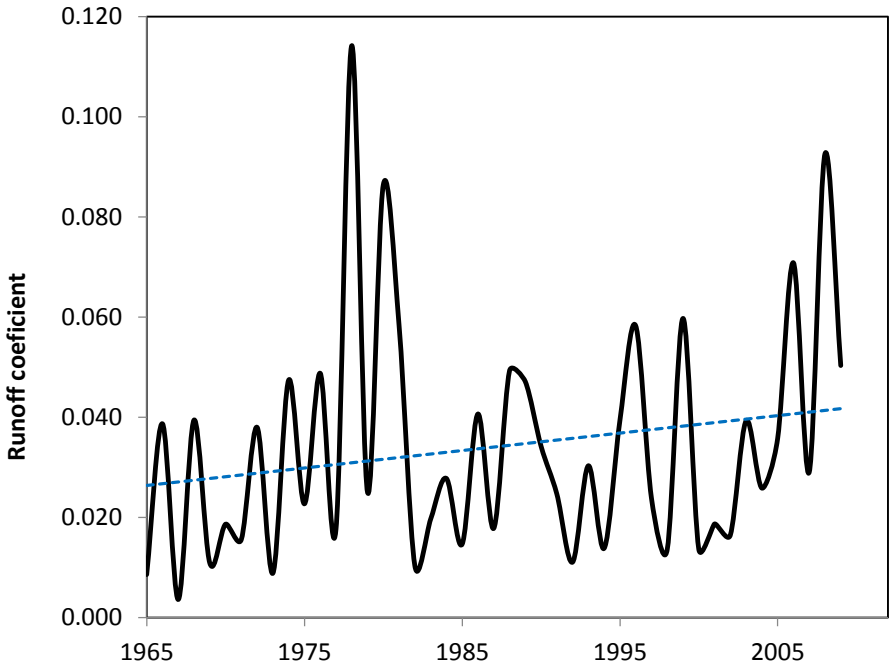

Figura 6. Behavior of runoff coefficient in the Carmen River upper basin

Figure 27 shows the behavior of the annual runoff coefficient determined in the upper basin of the Carmen River from 1965 to 2012. The trend of this variable is clearly to increase in the period analyzed. This makes sense when considering that there were also changes in the vegetation cover, exhibiting loss of native vegetation during part of this period.

Rainfall-runoff relationship

The runoff coefficient express the relationship precisely between the rain and surface runoff and exhibits high dependence on physical factors such as precipitation, vegetation cover and land use, soil type and its characteristics and geomorphological parameters of the basin, including the slope of the basin and of the main channel, among others.

Rainfall in the upper basin of the Carmen River shows a significant decrease from 1993 to 2012, as can be seen in Figure 3. As a result, natural flows could also be expected to decrease as well as rainfall, however, the average value of this variable tend to be preserved in the period from 1965 to 2012 year. This can be observed in the evolution line for this variable in Figure 5.

All of these finds an explanation when considering the changes held in the physical media (environment). The vegetation cover in the upper basin of the Carmen River has been modified in various zones, causing an increase in the potential of generation of runoff, resulting in the increase in the runoff coefficient. This has allowed, despite the decrease in precipitation manifested itself in the last two decades of the analysis period, the average natural runoff has been preserved.

The runoff coefficient increase that apparently support the natural flows stability also represents a diminishing in the infiltration rate into the ground. This behavior alteration of the surface system could have negatives effects in terms of groundwater recharge in the future.

Conclusions

Analysis of cartographic databases from the National Institute of Statistics, Geography and Informatics in Mexico, it was observed that the basin suffered modifications in its natural cover, some naturally originated probably due to changes in the regime of precipitation and temperature, and other anthropogenic such as clearing land to establish agricultural areas.

There were changes in the surface hydrologic system, both in the climate (precipitation regime) and in the physical conditions of the basin. However, natural flows have preserved relatively stable, probably because the decrease in annual rainfall was compensate by the increase in the values of the annual runoff coefficient (caused by the physical changes in the basin, or changes in the rainfall intensity). The natural flow generated in the Carmen river basin is about 65.18 hm^3, and even by now, does not shows notable changes as an annual average, the situation could be different in the future, especially if it is considered the modifications in rain patterns. These issues must be consider, for water resources planning the region.

All the knowledge regarding on how the hydrologic systems could been altered by changes in the climate, would be useful to diminish adverse effects to the socioeconomic activities. Finally, the alteration of the surface hydrologic system, surely have produced

alterations in the groundwater system that is associated to the first. This issue was outside the scope of the work, but it represents an area of opportunity for future research.

The surface water resources generated by the Carmen River basin are of greater importance for the region, especially for the Irrigation District 089 El Carmen. The average annual natural flows generated in this basin is of the order of 65.18 hm^3.

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