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Chapter

Water Availability for the Environmental Flow in Two Rivers of Mexico under Climate Change

Rebeca González-Villela, Alfonso Banderas Tarabay and Marco Mijangos Carro

Abstract

Adaptation to climate change requires, among others, the modification of river flow regimes to account for the change in household, agricultural, industry, and energy water consumption as well as their short/medium/long-term socioeconomic impact. In this study, the comparative analysis of the variation of the precipitation in relation to the availability of water in the Yautepec and Cuautla rivers in Morelos, Mexico, for the previous period and subsequent period is carried out, to determine the change in the availability of water in the ecosystem. In winter (February), an increase in rainfall on the Yautepec and Cuautla River was observed, where annual seasonal agriculture and Pine and Oyamel forest are the characteristic vegetation. In autumn (October), a decrease in precipitation takes place. The flows in some regions do not coincide with the increase in the percentage of precipitation (Oaxtepec and Las Estacas Stations) and point out the synergistic effect of the human use of the water resource and the effects of climate change. On Ticumán Station, the depletion of the flow only can be associated with the use of the resource by human influence. The modifications caused by alteration of a river’s flow regime and climatic change must be studied through comparative multidisciplinary studies that give to decision-makers the design of environmental flows.

Keywords: climatic change, environmental flow, vulnerability

1. Introduction

Climate change impacts on the hydrological cycle [1] with particular examples in France [2] and Central Europe [3], both fast and slow [4] where in the case of abrupt changes impacts on the ecosystem [5] and in long-term changes disrupt a pattern of inland moisture advection and convergence zone, increasing cloud base heights and reducing the total column liquid water content over high elevations [6]. Also, this impact has a strong response to global warming [7, 8], influences its extremes [9], and in turn influences via this cycle water resources [10, 11] while, conversely, the hydrological cycle influences climate [5, 12] in general and may, in case of enhancement, moderate transient climate change [13]. Climate changes impact rivers through
the hydrological cycle as seen in [14, 15] and directly on river ecosystems as seen in the Danube [16], in the United Kingdom [17, 18], the Narew river [19], and globally [20]. In terms of hydrological cycle “sojourn” river water turnover takes place in 16 days [21]. As a result, river flow is impacted as seen in Europe [22], in the United Kingdom [23], in the Balkans [24], in Ethiopia [25], in India [26], and in West Africa [27]. Precipitation and temperature scenarios of climate change based on atmospheric circulation play an important role [28] and so do diagnostic statistics of daily rainfall variability in an evolving climate [29].

Under local conditions, environmental flows (e-flows) are defined in the 2007 Brisbane conference as “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems.” [30] and resultant policies showed some moderate success [31] while the general trend of the state of aquatic ecosystems continued to deteriorate [32] due to increased dam building, particularly in ecologically sensitive areas [33]. Subsequently it was refined to “Environmental flows describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being” in the 20th International Riversymposium and Environmental Flows Conference, held in Brisbane in September 2017, to lend increased support to groundwater-dependent ecosystems (GDEs) [34]. The influence of river flow on environmental flow is seen in [35], that of flow regime type (general regime classification in [36], under a changing climate is seen in [37], in hydroecology context in [38]) on the e-flows releases, and hydropower production is seen in [39], the impact of extreme flow variability on environmental flows is seen in [40], in terms of river basin management in [41, 42], and for natural, hybrid, and novel riverine ecosystems in [43]. A review [44] determined that regarding rivers, at a global level in six world regions encompassing 44 countries, there are applied 207 different environmental flow methodologies focusing onto hydrological (e.g., the 32-parameter range of variability approach (RVA) [45]), hydraulic rating [46], habitat simulation [46], holistic [47], or combinatory approaches [48]. The future is bleak, as a good scenario solution for the year 2050 [49] leads to an 10–20% increase of global virtual water trade so as to retain a semblance of survival in country-level environmental flows.

The adaptation approach is defined as “Adapting to climate change means taking action to prepare for and adjust to both the current effects of climate change and the predicted impacts in the future” [50]. The success of an adaptation policy is measured by monitoring, reporting, and evaluation (MRE), where monitoring is “a continuous process of examining progress made in planning and implementing climate adaptation” [51], reporting is “the process by which monitoring and/or evaluation information is formally communicated, often across governance scales” [52], and evaluation is “a systematic and objective assessment of the effectiveness of climate adaptation plans, policies and actions, often framed in terms of the impact of reducing vulnerability and increasing resilience” [51].

Therefore, it is necessary to generate the appropriate analysis models and methodologies to predict trends, capture biophysical impacts and possible variations of climate change [53, 54]. In addition, it is necessary to incorporate socioeconomic elements within the analysis of ecological systems with the purpose of carrying out a sustainable management of the goods and services provided by these ecosystems [55, 56]. The alteration of the river flow regime generally is caused by human activity, an aspect that requires of the studies with a multidisciplinary approach to the analysis of the problem of global change in freshwater systems [57, 58]. In particular, regulation by interbasin transfers, dams, withdrawals, and land cover change are the main human intervention agents [59].
The adaptation to climate change makes necessary the determination of environmental flows in rivers so as to establish the change in water consumption for the population, agricultural activities, and industry and electricity generation, among others. All this is to compensate for variations in annual precipitation by the planning of the water resource security through different actions (transfer of industries to regions of greater humidity, change in the morphology of the cities to compensate for floods, availability of water for irrigation and flood control). These changes have important consequences on economic activities, population health, the ecosystem, and biodiversity [60]. In this sense, it is necessary to generate the tools for ecological, socioeconomic, and political analysis in order to achieve the rational use of aquatic resources in rivers regulated by dams [61]. In Mexico, there is little limnological information available on the country's freshwater systems and the effect that climate change is having on water quality and pollution. In this sense, in the present study, a comparative analysis of the variation of the water availability is applied through percentage of precipitation in the rivers of the Yautepec and Cuautla subbasins for the base period (preimpact) and subsequent period (postimpact) to determine the change in the availability of water in the riparian ecosystem.

2. Methodology

The methods employed are based on the RVA as seen in Richter et al. [45, 62–65], Figure 1.

![Figure 1.](image)

Range of variability approach (RVA) indicators of hydrological alteration (IHA) [45, 62, 66].

3. Materials and methods

3.1 Study area

Cuautla and Yautepec rivers discharge their waters into the Amacuzac River, main tributary of the Balsas River. Yautepec basin covers an area of 1226 km², which represents 25% of the territory of Morelos State. The total population in 2010 in
these municipalities was 242,197 inhabitants [67]. The region is characterized by the development of new tourist corridors, urban and industrial areas. There are growing problems of pollution and flood risks, which increase the destruction of historical heritage of bridges and dams, with consequences in the incidence of diseases. The Cuautla River subbasin covers an area of approximately 765 km². It is located on the slopes of the Popocatépetl volcano to the south of the Morelos State. In the basin, productive processes generate problems of the extraction of soil from the mountains and the soil loss in the upper parts. In addition, a high extraction of water for human and industrial consumption, and consequently, a strong contamination due to the water input of the users of the irrigation districts of the study area (4500), with an area of irrigated land of 10,500 hectares (Figure 2) [68, 69].

3.2 Methods

Precipitation variation percentage in the Yautepec and Cuautla river subbasins in the base period (preimpact) and subsequent period (postimpact) was estimated through the precipitation data of the ERIC III weather stations [70]. The weather stations with data from 1924 to 2010 (Table 1 and Figure 1). Eight of them are located in the Yautepec River subbasin and 11 in the Cuautla River subbasin.

The environmental flow analysis in the Yautepec River included three stations: Oaxtepec (upper part), Ticumán (middle part), and Las Estacas (lower part) of the subbasin. In the Cuautla River, the station El Almeal (high part). The comparative study of the monthly average flows of the hydrometric stations of the Yautepec and Cuautla River subbasins, for the preimpact and postimpact periods, was carried out.
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<th>Latitude</th>
<th>Years of registration</th>
<th>No. years</th>
</tr>
</thead>
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<td>18.93</td>
<td>1924–2008</td>
<td>84</td>
</tr>
<tr>
<td>Cuautla, (SMN)</td>
<td>−98.96</td>
<td>18.81</td>
<td>1926–2006</td>
<td>80</td>
</tr>
<tr>
<td>Cuautla, (DGE)</td>
<td>−98.95</td>
<td>18.80</td>
<td>1955–2009</td>
<td>27</td>
</tr>
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<td>−98.96</td>
<td>18.90</td>
<td>1970–2010</td>
<td>27</td>
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<td>18.86</td>
<td>1942–1973</td>
<td>15</td>
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<td>1955–2008</td>
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<td>1963–1985</td>
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<tr>
<td>Yecapixtla E.T.A. 118</td>
<td>−98.86</td>
<td>18.88</td>
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<td>Ocuituco E-5</td>
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<td>18.88</td>
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<tr>
<td>Tepoztlán E-12,</td>
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<td>18.98</td>
<td>1976–2009</td>
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<tr>
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<td>19.00</td>
<td>1976–1983</td>
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<td>Totalapan</td>
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<td>18.98</td>
<td>1976–2009</td>
<td>33</td>
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<tr>
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<td>18.71</td>
<td>1980–2009</td>
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<td>Temocaltco, Villa de A.</td>
<td>−98.98</td>
<td>18.63</td>
<td>1981–2009</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 1.
Location of the meteorological stations of the Yau tepec and Cuautla river basin.

Figure 3.
V7 IHA software 33 IHA parameters and their impact on the environment [73].
River Basin Management - Under a Changing Climate

Based on the information obtained from the hydrometric stations of CONAGUA (National Water Commission) [71]. Nonparametric graphical and statistical study was analyzed using the software, V7 IHA [72] under the hypothesis that there are no differences between the medians of the preimpact period and the postimpact period (Ho: $\mu_1 = \mu_2$ and Ha: $\mu_1 \neq \mu_2$). As can be seen below, the 33 IHA parameter (Figure 3), V7 IHA is compatible with Table 1 and Richter’s thesis in terms of [65].

The indicators of hydrological alteration (IHA) provided a quantitative approximation of hydrology through the characterization of intra-annual variation of flow by the use. Also, the comparative studies of hydrological regimes before and after system alteration due to human influence or the effects of climate change [74]. Hydrometric stations’ location of the Yautepec and Cuautla rivers are given in Table 2 and Figure 2.

### 4. Results

#### 4.1 Precipitation

The variation average monthly in the precipitation between the preimpact and postimpact periods in the Yautepec and Cuautla subbasins indicates the largest decreases in February for Tepoztlán (−71.58%) and Nexpa (−66.67%). However, the greatest increases in precipitation were observed in the dry season on the Nexpa station with 62.94% (March); Oaxtepec with 47.24% (February); Totolalpan with 45.49% (January); and Yautepec with 35.50% in February (Figure 4).

The months with the highest percentage decreases in precipitation during the year were: February, April, November, and December in the east of the Cuautla subbasin (Alpalocan, Tecajec, and Tecomalco, respectively). However, the northern part (Tetelcino) showed the greatest increases in the winter season (January, February, and March, with 72.76, 47.72, and 98.10%, respectively; Figure 2). The month of February was the most favored with respect to the increase in rainfall in the northern part of the Yautepec and Cuautla river subbasins, where annual seasonal agriculture predominates and the dominant vegetation is the pine and oyamel forest. On the contrary, the month of October (high part of the subbasins) was the most affected by the decreases in precipitation.

#### 4.2 Water availability for ecological flows

Flows should be interpreted as below (Figure 5).

In the upper basin of the Yautepec River (Oaxtepec Station), the monthly averages of the flows (preimpact period 1949–1979; 31 years) and the postimpact period (1980–2011; 26 years) indicate the significantly decrease in the availability of water.

<table>
<thead>
<tr>
<th>Location</th>
<th>Base period (preimpact)</th>
<th>Subsequent period (postimpact)</th>
<th>Long.</th>
<th>Lat.</th>
</tr>
</thead>
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<tr>
<td>EL ALMEAL</td>
<td>1948–1978 (31 years)</td>
<td>1979–2011 (32 years)</td>
<td>−98.95</td>
<td>18.81</td>
</tr>
<tr>
<td>OAXTEPEC</td>
<td>1949–1979 (31 years)</td>
<td>1980–2011 (26 years)</td>
<td>−98.97</td>
<td>18.90</td>
</tr>
<tr>
<td>TICUMAN</td>
<td>1951–1980 (30 years)</td>
<td>1981–2011 (29 years)</td>
<td>−99.10</td>
<td>18.79</td>
</tr>
<tr>
<td>ESTACAS</td>
<td>1968–1988 (21 years)</td>
<td>1989–2011 (22 years)</td>
<td>−99.11</td>
<td>18.73</td>
</tr>
</tbody>
</table>

Table 2. Hydrometric stations location river subbasins Yautepec and Cuautla (Morelos state) and years of registers.
Figure 4.
The percentage variation of the monthly rainfall between the preimpact and postimpact periods for the Yautepec and Cuautla river subbasins.

Figure 5.
River flow levels and ecological functions [75].
between the analyzed periods. This can be attributed to the use of the resource for agriculture and by the population after the construction of the little dams. For this hydrometric station, there is a significant decrease in precipitation of $-38.57\%$ in March and $-19.84\%$ in April, which coincides with the maximum decrease in flows in this segment in the postimpact period. However, the increase in precipitation was observed for this area in the month of February ($47.24\%$), without the increase in flows as should be expected, which is explained by the use of the resource by the population, nullifying the positive effect of climate change or increase of precipitation percentage on the availability of water for the river (Figure 6).

The average monthly flow of the Ticumán Station (middle part of the Yautepec River subbasin), for the preimpact period (1951–1980; 30 years) and postimpact period (1981–2011; 29 years), indicates a significant alteration in the hydrological regime only for the June and November months (Figure 7).

For this area, there is a nonsignificant increase in precipitation of $14.04\%$ (September) and $19.63\%$ (November) that coincides with the percentage increases in flows. However, in December, a decrease in the flows percentage of $70\%$ can associated with the use of the resource for activities of anthropic type. Therefore, these variations with a negative tendency in the flow cannot be attributed to the effects of climate change, but to human influence.

On Las Estacas Station, the precipitation percentage variation between the preimpact period and postimpact period was significant for January ($-18.8\%$) and April ($-2.9\%$).
The flows monthly average percentage for the Las Estacas Station (lower part of the Yautepec River Sub-basin), for the preimpact period (1968–1988; 21 years) and the postimpact period (1989–2011; 22 years), indicates a significant decrement in the flows on April (−5.9%), July (−4.8%), August (−8.5%), and September (−7.7%). This behavior does not coincide with the increase in rainfall from May to September (between 6.8% and 14.04%). Variations in precipitation and flows for this period (July–October) can be attributed to human influence and the effects of climate change (Figure 8).

The monthly average flows for the El Almeal Station (upper part) of the Cuautla River subbasin for the preimpact period (1948–1978; 31 years) and postimpact period (1979–2011; 32 years) indicate a significant alteration in the hydrological regime in all months of the year (Figure 9).

Coincidentally, in this area there is a significant decrease in precipitation percentages throughout the year (except November), ranging from −29.65% for January to −0.39% in August. Aspect that can be associated with the depletion of flow rates during the year for this season indicates the effects of climate change on the availability of water for the Cuautla River.

4.3 Environmental flows and indicators of hydrological alteration

Increase of low extreme flow rates, decrease of low flow rates, loss of the high flow pulses, small floods, or large floods at the Oaxtepec Hydrometric Station were observed. The hydrological changes occurred in the average monthly flows and the days with

Figure 8. The flows monthly average percentage and precipitation variation between the preimpact period (1968–1988) and postimpact period (1989–2011) on las Estacas Station.

Figure 9. The flows monthly average percentage and precipitation variation between the preimpact period (1968–1988) and postimpact period (1989–2011) at the Almeal Station.
minimum and maximum flow (Figure 10). As well as in the number and duration of low flow pulses, in the increase in high pulses, changes in the rates of variation (to negative), and reversals of the flows. The loss of the frequency, magnitude, and periodicity of the flows during the year indicates the abuse in the use of the resource for agriculture and by the population after the construction of the dams (Figure 12).

Figure 10.
List of 34-parameter environmental flow components (EFCs) [63]. Figure 11.

Figure 11.
V7 IHA software 34 IHA parameters and their impact on the environment [73].
At the Ticumán hydrometric station, the environmental flows do not observe significant changes. However, the hydrological alteration indexes indicate a decrease in the average flows of January, June, August, and September (rains), as well as in the minimum daily flows with a duration of 3, 7, and 30 days. Also, an increase in the date of the maximum flow, in the duration of the high flow pulses, and a rise in rate flow. The base flow and low flow pulses indicate a tendency toward drought conditions or a tendency to extreme climate and the synergic effect of climate with use of the water by human influence (Figure 13).

In Las Estacas hydrometric station (Yautepec River), the environmental flows show alterations in the postimpact period for the small and large floods, in the low flows and high flow pulses. The IHA show changes in the small and large floods for the postimpact period (1980–2000). Also, largest significant decreases in average flows in May, July, October, and November and increases in August and September point out a tendency to extreme weather due to climate change. In addition, decreases in the minimum and maximum daily flows with a duration of 3, 7, 30, and 90 days. The duration of high flow pulses and the rate of increase in flow can be associated with the torrential rains. On the contrary, an increase in the base flow, changes on the date of the maximum flow, and the rate flows decrease indicate shift of the start rainy season. The average flows and the number of investments of the flow can be attributed to human influence and climate change (Figure 14).

In El Almeal hydrometric station (Cuautla River), the environmental flows show great changes between the preimpact and the postimpact period. The IHA point out significant differences in all the components of ecological flow, except for the average flows.
flows of March and December, and in the number of investments of the flow. The low extreme flows increased and became more frequent, the low flows and the high flow pulses practically disappeared, as well as small and large floods in the postimpact period, modifications that can be explained by human influence. Changes in the flow averages for the whole year were observed, in the duration of the days with minimum and maximum flow, an increase in the rate of the base flow, as well as in the number of flows pulses (high and low). Also, in the flow rates (increase and decrease in flows), on investments, the shorter duration of low pulses, a situation that reflects an alteration in all components of environmental flows. Therefore, modifications that can be explained by human influence (Figure 15). The calculations above lead to the construction of the diagram below (Figure 16).

4.4 Regression analysis and R$^2$ of monthly flows

The regression analysis of monthly flows for Yautepec and Cuautla subbasins in Hidrometric Stations of study period is shown in Table 3. All hydrometric stations showed a negative trend throughout the year. Only Las Estacas (January–April, dry season) and Ticumán (May–September, rainy season) showed a positive trend in flows, respectively. These stations are located in the middle and lower part of the Yautepec subbasin where annual, permanent, and semipermanent irrigation agriculture and secondary tree, shrub, and lowland forest vegetation predominate
(Figure 17). This behavior can be explained by the use of some diversions to irrigate crops in the area during the dry season in Las Estacas and the positive tendency in Ticumán Station on rainy season could be explained for climatic change effect, as can be observed in Figure 4 during this period, above all in June and July. The Almeal Station in the intermediate part of the Cuautla subbasin with annual, permanent, and semipermanent irrigation agriculture presents the highest values of \( R^2 \) (0.23 in October to 0.54 in May) coinciding with the greatest decreases in the percentages of precipitation (Figure 4). Aspects that show the synergistic effect of climate change and human influence on the availability of water for rivers.

ARMA (autoregressive moving average) flows analysis of the hydrometric stations.

For the Oaxtepec station, the ARMA analysis of the flow data indicates a homogeneous distribution of the residues with an AR coefficient \( = -824,201 \) at \( P \leq 0.0517 \). However, some events of large floods generate some alterations on residuals and show some cyclicity (Figure 18).

For the Ticumán Station, the ARMA analysis of the flow data indicates a homogeneous distribution of the residues with an AR coefficient \( = -8893 \) at \( P \leq 0.1115 \) and shows also some cyclicity (Figure 19).

For the Las Estacas Station, the ARMA analysis of the flow data indicates a homogeneous distribution of the residues with an AR coefficient \( = -79,086 \) at \( P \leq -0.2077 \). However, some events of large floods generate some alterations on residuals (Figure 20), and the cyclicity of the large floods is not clear.

For the El Almeal Station, the ARMA analysis of the flow data indicates a homogeneous distribution of the residues with an AR coefficient \( = -8940 \) at \( P \leq -0.1069 \). However, some events of large floods generate some alterations on residuals (Figure 21).
<table>
<thead>
<tr>
<th>Month</th>
<th>Oaxtepec Regression</th>
<th>Las Estacas Regression</th>
<th>Ticumán Regression</th>
<th>Almeal Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Y = -0.0016X + 3.48$</td>
<td>$Y = 0.0098X - 12.8$</td>
<td>$Y = 0.0037X + 7.5$</td>
<td>$Y = -0.008 + 16.76$</td>
</tr>
<tr>
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<td>0.12</td>
<td>0.01</td>
<td>0.11</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>$Y = -0.0013X + 2.77$</td>
<td>$Y = 0.0181X - 29.6$</td>
<td>$Y = -0.001X + 2.13$</td>
<td>$Y = -0.010 + 21.48$</td>
</tr>
<tr>
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<td>0.04</td>
<td>0.02</td>
<td>0.40</td>
</tr>
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<td>$Y = 0.0087X - 10.7$</td>
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<td>$Y = 0.0099X + 4.77$</td>
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<td>$Y = -0.0019X + 4.04$</td>
<td>$Y = -0.0172X + 412$</td>
<td>$Y = -0.016X + 32.3$</td>
<td>$Y = -0.009X + 19.1$</td>
</tr>
<tr>
<td>December</td>
<td>$Y = -0.0015X + 3.35$</td>
<td>$Y = -0.015X + 36.42$</td>
<td>$Y = -0.006X + 12.2$</td>
<td>$Y = -0.01X + 20.67$</td>
</tr>
</tbody>
</table>

Table 3. Monthly flows regression analysis of hydrometric stations Oaxtepec and Cuautla subbasins, and value of $R^2$ during the all study period.
5. Discussion

The impact of climate change on aquatic ecosystems was seen as early as 1999 in eight US regions [77]. In the Fifth Evaluation Report of the Intergovernmental
Panel on Climate Change, MacAlister and Subramanyam mentioned that 93% of the impacts associated with climate change will affect aquatic ecosystems [78, 79]. Environmental flows, using the Brisbane definition [30], were incorporated into the “water stress” indicator 6.4.2 [80]. Environmental flows are the source of the “natural” versus “managed” ecosystem support and, as can be seen below (Figure 22), due to climate change or direct human intervention, their impact tends to zero as the managed contribution increases to a plateau.

In a study of the Huangqihai River basin in Inner Mongolia, China, it was found that environmental flow requirements (EFRs) contribute to the determination of water scarcity using the QQE indicator that combines the status of quantity, quality, and EFR [82] while if the environmental flow protection is low, 53 countries experience different levels of water shortage, and if it is high, we have an increase to 101 countries [83]. A similar result was found when water withdrawals were replaced by water consumption plus environmental flows where in a global river basin examination for the period 1996–2005, 201 out of 405 river basins examined presented intense water scarcity for at least 1 month per year [84]. Using the environmental water

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Figure 20.
ARMA analysis of flows of las Estacas Station.

Figure 21.
ARMA analysis of flows of El Almeal Station.

Figure 22.
Benefits from natural (environmental flows) and managed systems [81].
requirement (EWR) as the sum of environmental low-flow requirement (LFR) and environmental high-flow requirement (HFR) shows that if freshwater-dependent ecosystems are to stay in fair condition, 20–50% of the mean annual river flow has to be allocated to them [85]. Hence, it can be said that the constraint of finiteness of water resources imposes a socioeconomic choice regarding water allocation between human use and environmental flow at global, regional, country, and locality levels, which perhaps can be regulated via a scalable framework although the country level plays a decisive role as water is a strategic economic good. Mexico determines the volume of water that is allocated for ecological protection on the basis of the Environmental Flow Mexican Norm (e-flows, NMX-AA-159-SCFI-2012, ratified in 2017) regarding the formation and disposition of environmental water reserves (EWR) 12 of which have a 50-year duration to date (2021), and 75% of them meet up to the theoretical minimum requirement of norm implementation [86].

Annual maximum flood events depend in part on runoff generation and flow routing as seen in [87], while precision moisture estimation [88] may add to the description of the biotic state. Also rainfall and temperature trends analysis [89] plays a determinate role in this description as well. Increases in the winter rainfall in the northern and southern part of the Yautepec and Cuautla River (February) are different as shown by the historic records of the preimpact period. As well as, for the middle part of the subbasin of the Yautepec River where the shrubby secondary vegetation of low deciduous forest predominates and the permanent and semipermanent annual irrigation agriculture. The decreases in rainfall at the end of the rainy season (October) show a climate change in coincidence with other authors and pointed out as one of the most urgent threats to sustainable development worldwide [90]. The significant decrease in the percentage of precipitation for all months of the year at the Oaxtepec and Las Estacas weather stations indicates the synergistic effect of climate change and the use of the resource by the population (mainly agriculture). On the contrary, the effects on the flow depletion can only be associated with the use of the resource by human influence on Ticumán station. The impacts of climate change are exacerbated by rapid population growth, an example of which is seen below (Figure 23), rapid urbanization and chaotic economic development, particularly where water demands already exceed limited supplies.

Likewise, climate change is altering precipitation and thawing patterns, affecting the frequency and magnitude of river flows, floods and droughts, and contributing to more extreme weather events and forest fires around the world in a coincident way
in the subbasins of the Yautepec and Cuaautla River [79]. The hydroperiod determines the presence of certain plants and animals in the different strata of the riparian zone and the riverbed, being the dominant factor that makes the difference in the riverbank and riverbeds, and constitutes the most important variable in the corridor structure river [93, 94]. The changes in base flow and low flow pulses on subbasins indicate a tendency toward drought conditions or a tendency to extreme climate and the synergic effect of climate with use of the water by human influence. Moreover, the duration of high flow pulses and the rate of increase in flow can be associated with the torrential rains, as well as the increase in the base flow, changes in the date of the maximum flow, and the rate flows decrease indicate shift of the start rainy season. Variable flow was seen in 52 rivers worldwide whose patterns of flow variability were often correlated with climate [95]. Extreme events, e.g., unusual floods/droughts, may alter the physicochemical conditions under which biotic communities undergo long-term development [96]. Therefore, hydroperiod models are a useful tool in the analysis of the distributions of organisms during the year and the modifications caused by human activity. These models should be studied through comparative multidisciplinary studies to determine the real problems derived from global change in the freshwater systems and to determine the real influence of global warming on the regional climatic conditions of the planet and its influence on river ecosystems [57, 58]. Therefore, the dimensions and processes observed in the development of the watersheds, among them the environmental flows, must be approached in a systemic way, starting from integrative and articulating approaches to generate the actions for the management, conservation, and recovery of the freshwater. As well as, the vulnerability maps and lines of action for climate change adaptation [56, 97].

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