

# Chapter 15

## Possible Scenarios of Global-Warming Impacts on Evaporation in Mexico



Jose A. Raynal-Villasenor, Maria E. Raynal-Gutierrez,  
and Bryan Zegarra-Ybarra

**Abstract** We constructed five possible scenarios to define the impacts of global climate change on evaporation and soil-water moisture-content deficiency in the Balsas River, Bravo River, Grijalva River, Lerma River, Panuco River, and Papaloapan River basins in Mexico. They are based on forecasts of the Hadley Centre that predicts for Mexico an increase in air temperature between 3 °C and 5 °C by the end of the twenty-first century. These basins are the most important watersheds in Mexico. We used increases in air temperature 1–5 °C above the current conditions to construct five possible scenarios for two surfaces: water and short grass. Then, we analyzed the impact of each of these five possible scenarios in the potential evaporation and soil-water moisture-content deficiency for both surfaces. The results showed that, with the increases in air temperature, just mentioned, they produced an increase in potential evaporation in open water surfaces of 2.5–12.1% for 1 °C and 5 °C of increase in air temperature, respectively. The evaporation on short-grass surfaces will increase 2.6–12.7% for 1 °C and 5 °C of increase in air temperature, respectively. Soil-water moisture-content deficiency in short-grass surfaces will increase 3.3–16.0% for 1 °C and 5 °C of increase in air temperature, respectively, all of these compared with current values. In the most adverse scenario, reductions in food production in the Bravo River basin will be in the order of 28%, composed of the 16% of additional water demanded by crops plus 12.1% of additional evaporation on surface-water reservoirs located in the watershed.

**Keywords** Global warming · Global climate change · Potential evaporation · Soil water moisture content deficiency · Water · Short grass · Possible reduction of food production

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J. A. Raynal-Villasenor (✉) · M. E. Raynal-Gutierrez  
Department of Civil and Environmental Engineering, Universidad de las Americas Puebla,  
Cholula, Puebla, Mexico  
e-mail: [josea.raynal@udlap.mx](mailto:josea.raynal@udlap.mx); [maria.raynal@udlap.mx](mailto:maria.raynal@udlap.mx)

B. Zegarra-Ybarra  
Professional School of Environmental Engineering, Universidad Nacional de San Agustín,  
Arequipa, Peru

## 15.1 Introduction

There is no doubt in the scientific community that we are in the middle of global climate change and that it has, as its main driving cause, the global warming produced by the increase of the contents of so-called greenhouse gases (GHG). The GHG include water vapor, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (NO). Since the start of the Industrial Revolution, CO<sub>2</sub>, CH<sub>4</sub>, and NO have been increasing in their concentrations in the upper atmosphere in comparison with the levels observed in mid-nineteenth century. On the other hand, water vapor, which by the way is the most abundant of the GHGs, has the most beneficial effects on Planet Earth. Due to its presence in the atmosphere, Earth has an average global temperature of 14 °C, and not the −18 °C that would be the case in the absence of the water vapor in the upper atmosphere. The GHGs produced by anthropogenic activities are the main sources causing global warming and the resulting global climate change (IPCC 2014; Showstack 2009).

Gosling et al. (2017) produced scenarios for the comparison of changes in river runoff from multiple global and catchment-scale hydrological models under global-warming scenarios of 1, 2, and 3 °C.

In recent years, the problem of global climate change has been losing influence in the Mexican government's public policies. This problem was well addressed in the National Development Plan 2013–2018 (Presidencia 2013), but in the actual administration, such influence has vanished, and the importance of its considerable impact on the food economy, tourism, and environmental conservation, among others, has been neglected. It is necessary to implement a new set of strategies to enhance the actual and future environmental conditions and to promote a good quality of life for Mexican society.

During the Calderon and Peña-Nieto presidential administrations, there had not been much progress in proposing adaptation and mitigation actions to counteract the effects of global climate change. But in the Calderon administration, the problem of global climate change was thoroughly considered and a Climate Change Federal Law was promulgated in 2012. Since then, several modifications and updates to such law have been proposed and accepted, CD (2018), but very little has been done in implementing adaptation and mitigation actions in Mexico.

The Balsas River basin has important hydropower plants, namely the Infiernillo, Caracol, and La Villita dams. At the basin's very end is located the most important complex of steel production, Las Truchas, in Puerto Lazaro Cardenas in the state of Michoacan. Within the Balsas River basin is located the Cutzamala River basin, which provides 30% of the water supply of Mexico City, the capital city of Mexico (GDF 2018).

The Bravo River is the Mexican part of the Bravo/Grande River general basin. Located in Northeastern Mexico, it is the most important international basin that Mexico has. It is a key food production region for domestic consumption and for the export of vegetable produce. This watershed is extremely important for Mexico due to the demographic, economic, political, and social conditions existing in such areas. The Bravo/Grande River is a natural border between Mexico and the USA with a length of 1455 kilometers. As such, it is most important part of the border.

The water of the Bravo/Grande River in this border zone is distributed between both countries, in accordance with the 1944 Treaty of International Waters signed by these two countries. It is important to mention that the water in this watershed is totally allocated by the treaty; therefore, there is no additional water in the Bravo River/Grande basin to be considered.

The Grijalva River basin and the Usumacinta River are containing 30% of the total surface water of Mexico. Moreover, the Grijalva River basin has the most important set of hydropower plants of Mexico, namely the Nezahualcoyotl, Peñitas, Chicoasen, and La Angostura dams. The latter is the biggest dam in Mexico with a total capacity of 20,000 million m<sup>3</sup>.

The Lerma River basin, in Central Mexico, is an area of paramount importance in food production for domestic consumption and for the export of vegetable produce. The Lerma River watershed contains important areas of several states of Mexico, such as the state of Mexico, Guanajuato, Michoacan, Queretaro, and Jalisco. Also, the Lerma River basin has an important role in the demographic, economic, political, and social aspects of Mexico as a country.

The Panuco River basin is one of the largest watersheds in Central Mexico, and it is where the wastewaters coming from Mexico City, Mexico's capitol city, are deposited without much treatment. The city of Tula was named as the most polluted city of the world because of these wastewaters and by the pollution generated by the petroleum refinery located there.

The Papaloapan River basin, once one of the most important fluvial waterways of Mexico, is now a very important area for agricultural products, like pineapples. It has in its basin two very important hydropower plants, the Temascal and Cerro de Oro dams.

This paper attempts to explain the possible consequences that global climate change will have on the potential evaporation in some of the regions of Mexico considered in this study. Two types of evaporative surfaces were chosen: water and short grass.

The estimation of potential evaporation in short-grass cover is used as the crop of reference, and its results may be used to quantify the potential evaporation for other crops that are used for human and animal consumption.

## 15.2 The Penman Equation

The main mathematical equation that was used in this study is Penman's formula, and the form used here is:

$$E = \frac{\Delta}{\Delta + \gamma} \left\{ R_a(1 - alb) \left( 0.25 + \frac{0.5n}{N} \right) - \sigma T^4 \left( 0.1 + \frac{0.9n}{N} \right) (0.34 - 0.044)\sqrt{e} \right\} + \left( 1 - \frac{\Delta}{\Delta + \gamma} \right) \left\{ 0.26 \left( 1 + \frac{U}{160} \right) (e_s(T) - e) \right\} \quad (15.1)$$

The definitions of each variable contained in the Eq. (15.1) are as follows (Steward and Roberts 1984):

E = potential evaporation on an open surface water, mm/day

alb = albedo of the surface considered, mm/day: alb = 0.05 for an open water surface, alb = 0.25 for a surface covered with short grass

$\Delta$  = slope of the saturated water-vapor curve, mb/°C

R<sub>a</sub> = solar radiation measured at the top of the atmosphere, mm/day

n = actual number of hours of sunshine, hours

N = maximum number of hours of sunshine, hours

$\sigma T^4$  = outgoing longwave radiation emitted by a surface at temperature T, mm/day

T = average temperature of the daily maximum and minimum temperatures, °C

U = wind run per day, km/day

e = vapor pressure at mid-morning, mb

$e_s(T)$  = saturated vapor pressure at temperature T, mb

$\gamma$  = psychrometric constant (with a value of 0.67 mb/°C), mb/°C

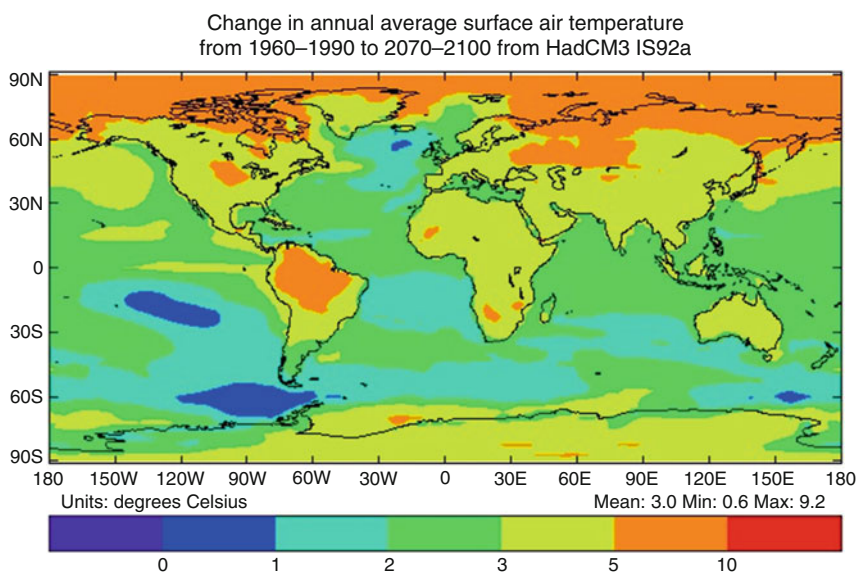
This form of the Penman formula becomes very useful where there is no information on the net radiation and maximum number of hours of sunshine, and this information may be obtained from existing tables based on the latitude of the site (Steward and Roberts 1984). By using the average daily temperature, the values of outgoing longwave radiation, the slope of the saturated vapor-pressure curve and the saturation pressure of water vapor may be obtained from existing tables (Steward and Roberts 1984). For the proposed possibility of air temperatures increase, we used the formula for two cases: an open water surface and a short-grass-covered surface. The values of potential evaporation produced by the Penman formula are the upper limits of evaporation, but their evaluation may give a good approximation of the possible behavior of the actual physical process of evaporation.

### 15.3 Discussion of the Results

With the forecasts for the increase in air temperature reported by the Hadley Centre (2005) (see Fig. 15.1), which predicts an increase for Mexico of 3–5 °C by the end of the twenty-first century, such forecasted conditions were used to construct five possible scenarios of air-temperature increase for the Balsas River, Bravo River, Grijalva River, Lerma River, Panuco River, and Papaloapan River basins in Mexico. The locations of these watersheds are shown in Figs. 15.2, 15.3, 15.4, 15.5, 15.6 and 15.7.

Five possible scenarios were constructed, with increases in air temperature of 1–5 °C above current conditions, for the potential evaporation, in several strategically distributed sites in the Balsas River, Bravo River, Grijalva River, Lerma River, Panuco River, and Papaloapan River basins. The scenarios mentioned before contain the increases in air temperature reported in the RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios proposed by IPCC (2014).

The selected sites in the Balsas River basin of Mexico were the climatological stations at Tlaxcala, Puebla, Balcon del Diablo, Chilpancingo, and Lazaro Cardenas. We observed that the Balcon del Diablo climatological station was the site with more



*Hadley Centre for Climate Prediction and Research, The Met. Office*

**Fig. 15.1** Forecast of air temperature increase due to global warming at the end of the twenty-first century. (Hadley Centre 2005)



Fig. 15.2 Location of the Balsas River basin, Mexico. (INE 2016)



Fig. 15.3 Location of the Bravo River basin, Mexico. (INE 2016)

critical results for an increase of potential evaporation of all the climatological stations considered, so only results connected with it will be reported here.

The selected sites in the Bravo River basin were the climatological stations in the Conchos River sub-basin, namely Parral, La Boquilla, Camargo, Delicias, Chihuahua, and Ojinaga. The climatological stations of Venustiano Carranza Dam, Sabinas, and Monclova are in the Salado and Sabinas River sub-basins. Monterrey, Saltillo,

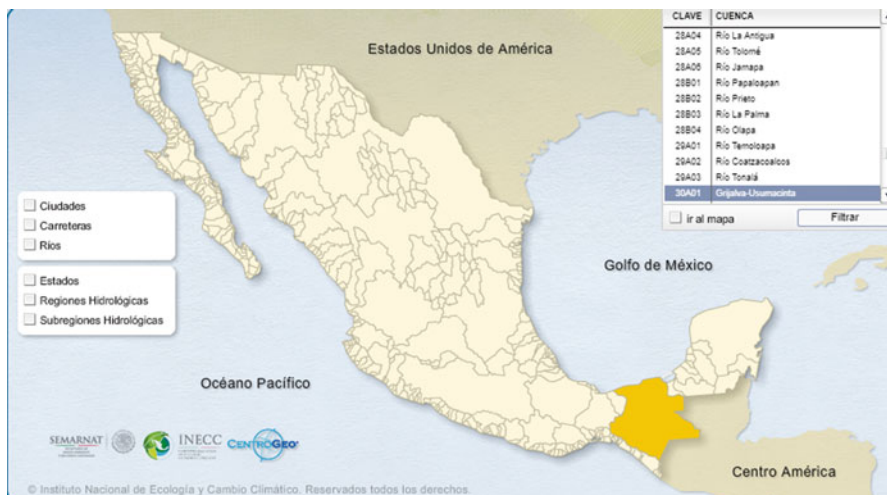


Fig. 15.4 Location of the Grijalva River basin, Mexico. (INE 2016)



Fig. 15.5 Location of the Lerma River basin, Mexico. (INE 2016)

and El Cuchillo Dam climatological stations are in the sub-basin of the San Juan River. La Amistad Dam, Falcon Dam, Piedras Negras, Matamoros, and Nuevo Laredo are in the main Bravo River Basin. We observed that the climatological station of Parral was the site with the most critical results for an increase of potential evaporation among all the climatological stations considered in this study. So, only the results of Parral climatological station will be reported here.



Fig. 15.6 Location of the Panuco River basin, Mexico. (INE 2016)



Fig. 15.7 Location of the Papaloapan River basin, Mexico. (INE 2016)

The selected sites in the Grijalva River basin were Chicoasen, Malpaso, La Angostura, and Villahermosa climatological stations. We observed that the Villahermosa climatological station was the site with the most critical results for an increase of potential evaporation of all the climatological stations considered in this study, so only its results will be reported here.



The selected sites in the Lerma River basin were the climatological stations at Toluca, Querétaro, Celaya, and Guadalajara. We observed that the Toluca climatological station was the site with most critical results for an increase of potential evaporation of all the climatological stations considered, so only its results will be reported here (Raynal-Villasenor et al. (2016).

The selected sites in the Panuco River basin, Mexico, were the climatological stations at San Luis Potosi, Tampico, Matehuala, and Tula. We observed that the Tampico climatological station was the site with most critical results for an increase of potential evaporation of all the climatological stations considered in this study, so only its results will be reported here.

The selected sites in the Papaloapan River basin were the climatological stations at Veracruz, Tlacotalpan, Coatzacoalcos, and Tuxtepec. We observed that the Veracruz climatological station was the site with most critical results for an increase of potential evaporation of all the climatological stations considered in this study, so only its results will be reported here.

The results obtained by using Penman's equation for the six selected sites in the study are shown in Table 15.1 for water-covered surfaces and in Table 15.2 for short-grass-covered surfaces.

The results obtained for the Balcon del Diablo climatological station in the Balsas River basin are graphically shown in Fig. 15.8.

The results obtained for the Parral climatological station in the Bravo River basin are graphically depicted in Fig. 15.9.

The results obtained for the Villahermosa climatological station in the Grijalva River basin are graphically shown in Fig. 15.10.

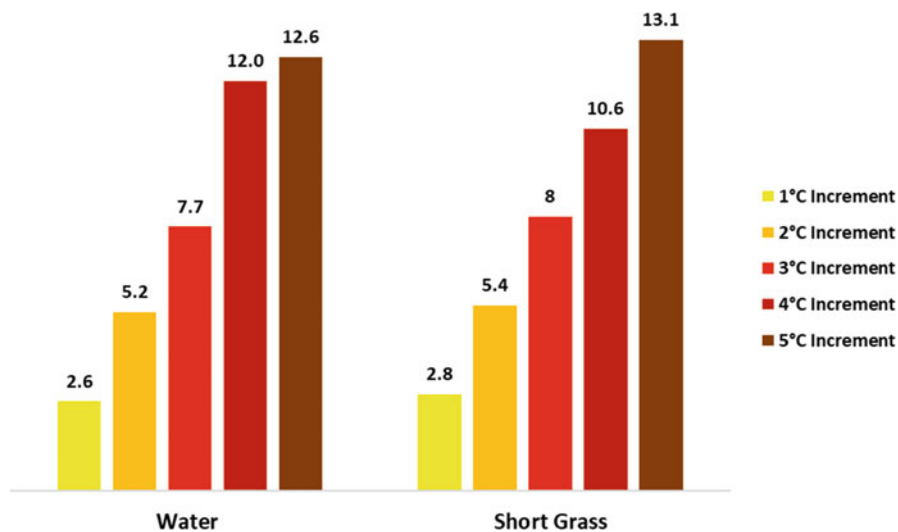
The results obtained for the Toluca climatological station in the Lerma River basin are graphically depicted in Fig. 15.11.

**Table 15.1** Results for the percentage increments of evaporation due to the five possible scenarios of increased air temperatures of water-covered surface

| Watershed        | Climatological station | Air-temperature increments |      |      |      |      |
|------------------|------------------------|----------------------------|------|------|------|------|
|                  |                        | 1 °C                       | 2 °C | 3 °C | 4 °C | 5 °C |
| Balsas River     | Balcon del Diablo      | 2.6                        | 5.2  | 7.7  | 10.6 | 12.6 |
| Bravo River      | Parral                 | 2.8                        | 5    | 7.5  | 9.9  | 12.2 |
| Grijalva River   | Villahermosa           | 2.1                        | 4.3  | 6.4  | 9.1  | 10.8 |
| Lerma River      | Toluca                 | 2.8                        | 5    | 7.5  | 9.9  | 12.2 |
| Panuco River     | Tampico                | 2.2                        | 4.4  | 6.6  | 8.8  | 11   |
| Papaloapan River | Veracruz               | 2.5                        | 4.7  | 7    | 9.8  | 11.5 |

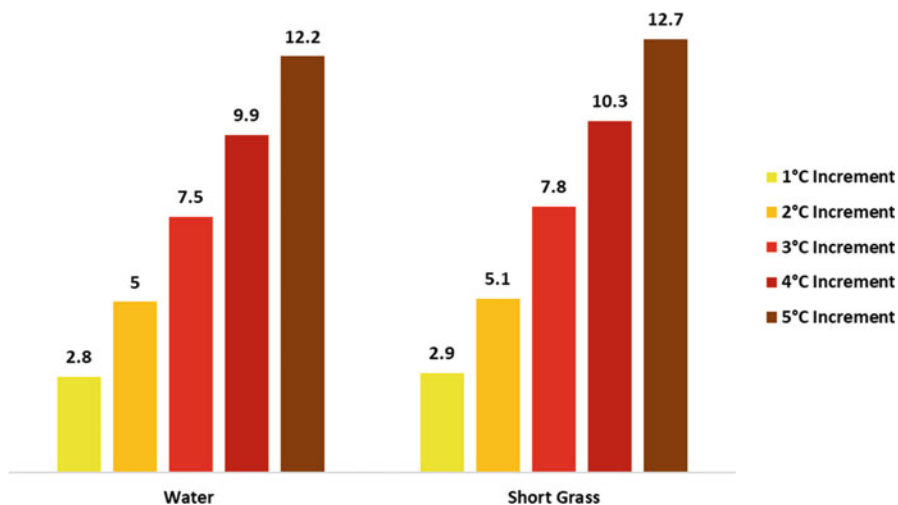
**Table 15.2** Results for the percentage increments of evaporation due to the five possible scenarios of increased air temperatures of short grass-covered surface

| Watershed        | Climatological station | Air-temperature increments |       |      |      |      |
|------------------|------------------------|----------------------------|-------|------|------|------|
|                  |                        | 1 °C                       | 2 °C  | 3 °C | 4 °C | 5 °C |
| Balsas River     | Balcon del Diablo      | 2.8                        | 5.4   | 8    | 12   | 13.1 |
| Bravo River      | Parral                 | 2.9                        | 5.1   | 7.8  | 10.3 | 12.7 |
| Grijalva River   | Villahermosa           | 2.3                        | 4.5   | 6.8  | 8.6  | 11.5 |
| Lerma River      | Toluca                 | 2.9                        | 5-5.1 | 7.8  | 10.3 | 12.7 |
| Panuco River     | Tampico                | 2.3                        | 4.7   | 7    | 9.4  | 11.8 |
| Papaloapan River | Veracruz               | 2.6                        | 5     | 7.4  | 10   | 12.2 |

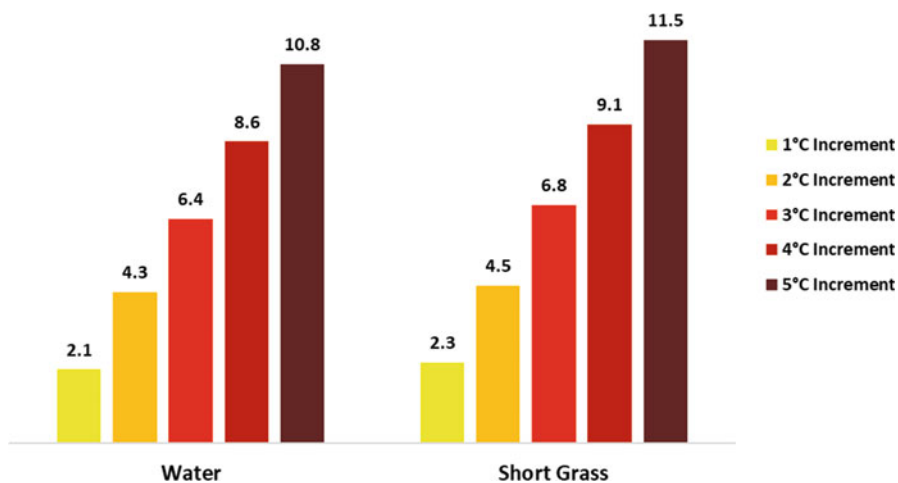
**Fig. 15.8** Percentage of increment in potential evaporation in climatological station at Balcon del Diablo, Mexico (water- and short-grass-covered surfaces)

The results obtained for the Tampico climatological station in the Panuco River basin are graphically shown in Fig. 15.12.

The results obtained for the Veracruz climatological station in the Papaloapan River basin are graphically depicted in Fig. 15.13.



**Fig. 15.9** Percentage of increment in potential evaporation in climatological station at Parral, Mexico (water- and short-grass-covered surfaces)



**Fig. 15.10** Percentage of increment on potential evaporation in climatological station Villahermosa, Mexico (water- and short-grass-covered surfaces)

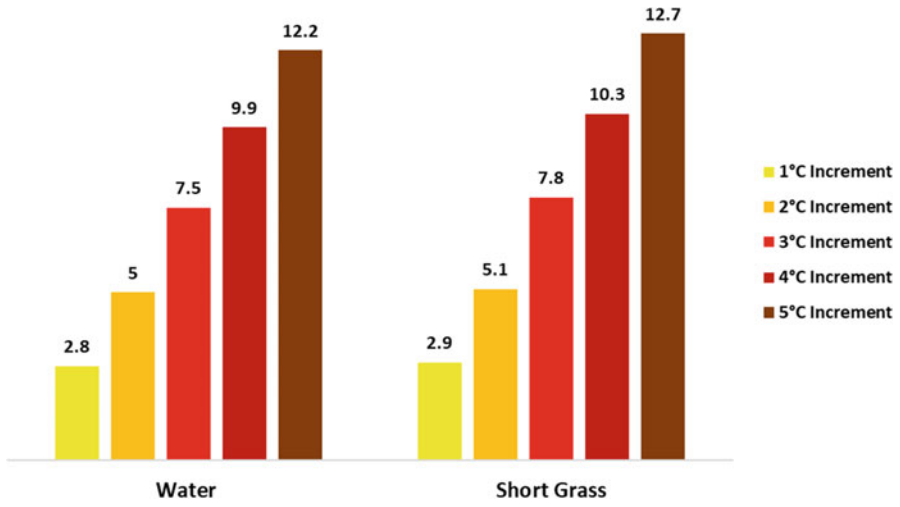


Fig. 15.11 Percentage of increment on potential evaporation in climatological station Toluca, Mexico (water- and short-grass-covered surfaces)

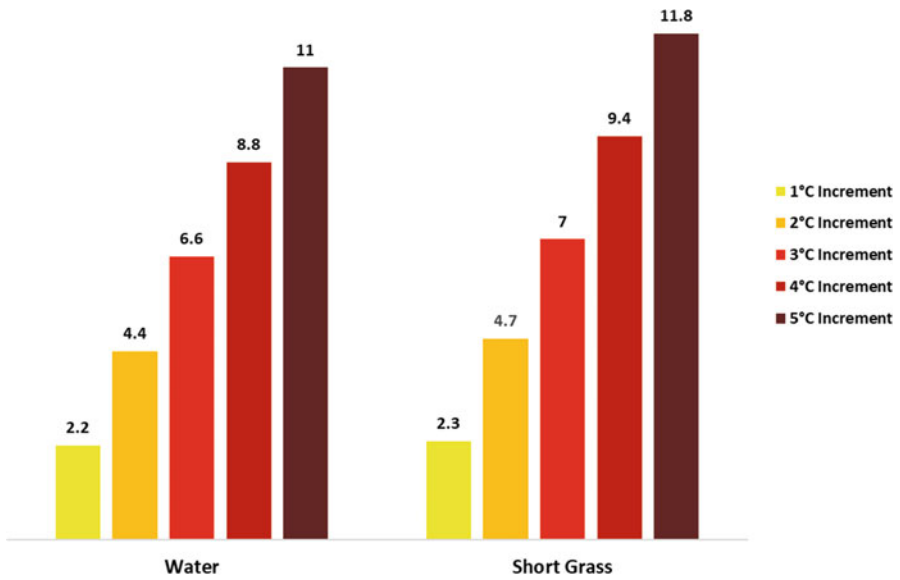
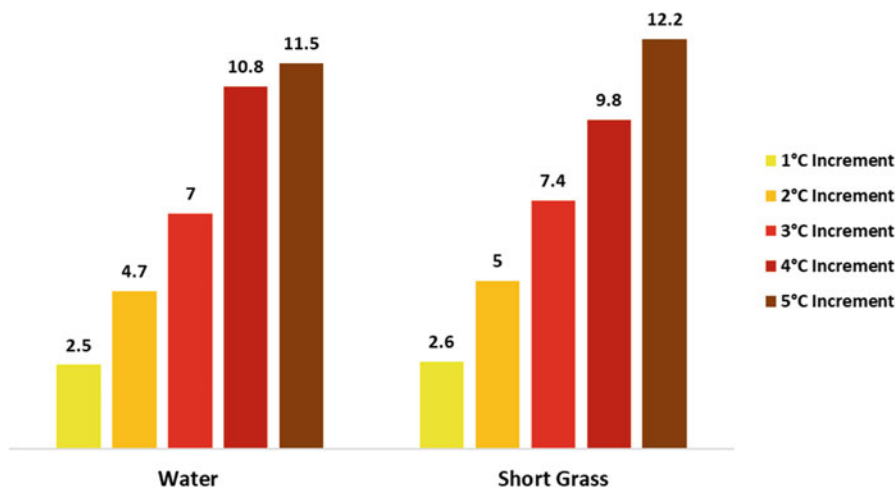


Fig. 15.12 Percentage of increment on potential evaporation in climatological station Tampico, Mexico (water- and short-grass-covered surfaces)



**Fig. 15.13** Percentage of increment on potential evaporation in climatological Veracruz station, Mexico (water- and short-grass-covered surfaces)

## 15.4 Summary and Conclusions

With the construction of five possible scenarios in each of the river basins (Balsas River, Bravo River, Grijalva River, Lerma River, Panuco River, and Papaloapan River) with increases in air temperature above current conditions from 1 °C and up to 5 °C, respectively, the results obtained showed increased increments in the potential evaporation values that ranged 2.1–2.9% for 1 °C, 4.3–5.4% for 2 °C, 6.4–8% for 3 °C, 9.9–10.6% for 4 °C, and 11–12.7% for 5 °C air temperature increases compared to current values—for the two surfaces considered (water and short grass).

This would result in an expected reduction of food production of about 2–13% in such watersheds, for global warming scenarios with 1–5 °C increases in air temperature above current conditions; this will be caused by an increased water demand of crops in such basins.

The results obtained in this study showed that the Mexican government must pay attention to the possible consequences of the scenarios constructed here and must devise action plans to mitigate the adverse impacts that global warming may generate in the Balsas River, Bravo River, Grijalva River, Lerma River, Panuco River, and Papaloapan River watersheds.

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