Water use and production in the Central Highlands, Aguascalientes and the Lerma-Chapala watershed

This remote sensing study was sponsored by the Bank Netherlands Water Partnership Program (BNWPP) of the World Bank This short document was prepared by Sander Zwart, Irrigation and Remote Sensing specialist at WaterWatch (Wageningen, the Netherlands).

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1. Introduction

This chapter describes the method followed and materials used to quantify biomass production and actual evapotranspiration in the Central highlands of Mexico, including the state of Aguascalientes and (a part of) the Lerma-Chapala watershed. First, a short overview will be given of the materials used, followed by an overview of the results, the discussion of the results and some conclusions.

2. Area description

A large area was selected located in Central Mexico between longitude 100 and 105°W and latitude 20 and 27°N (see also figure 2). The central part is located at an altitude of approximately 2000 meter. The clouds that come from both the Pacific as well as the Gulf of Mexico do not reach these central highlands. As a result the central highlands are dry and arid with less than 500 mm of rainfall that occurs mainly between June and October. Annual rainfall on the lee sides of the mountains is more than 1000 mm.

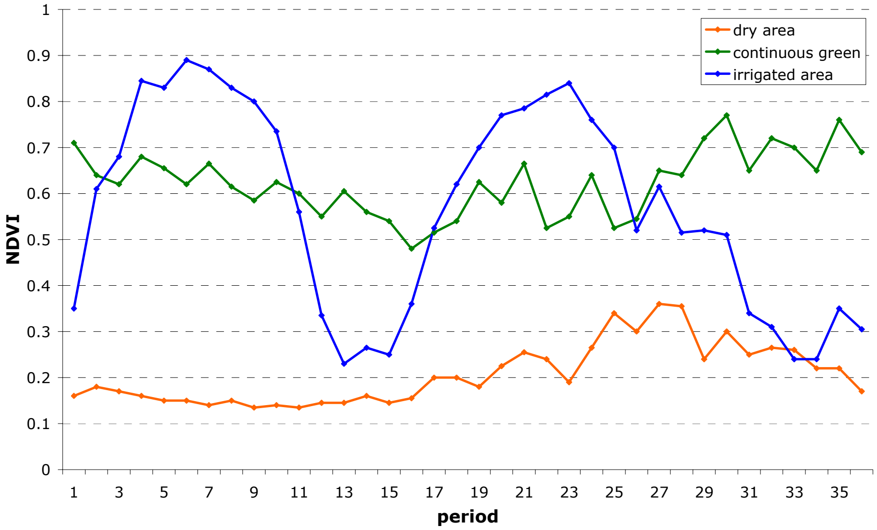

Figure 1. Profile of the NDVI from the SPOT-Vegetation satellite for 36 decades in 2003. Depicted are the values for 1) a typical continuous green vegetation on the pacific coast, 2) an irrigated area in Lerma-Chapala watershed, and 3) a dry area in the central highlands.

The lee sides of the mountains are covered by continuous green forest (see figure 1 with the NDVI profiles). The central highlands are mostly bare soil with sparse vegetation. As can be witnessed from the NDVI some vegetation develops during the rainy season (decade 17-29) and it dries out during the months after. Besides the natural vegetation irrigated agriculture is centered around three major areas: 1. Region Lagunera (around Torreon), 2. Pabellon (Aguascalientes/Zacatecas), and 3. Lerma-Chapala (east of the Lago di Chapala). In figure 1, the NDVI of a typical irrigation pattern with two distinct seasons is depicted.

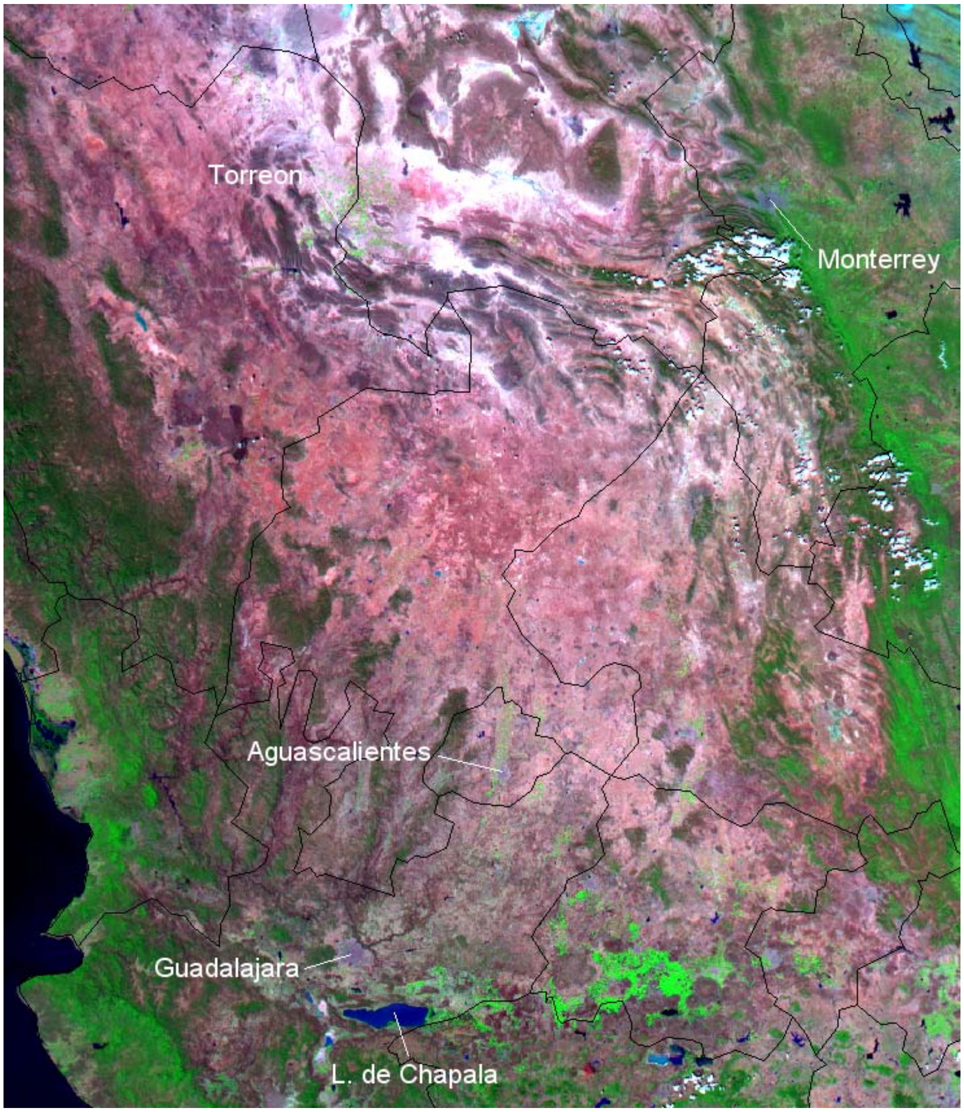

Figure 2. An overview of the entire study area as seen by the MODIS Aqua sensor on March 16, 2003.

3. Materials and methods

SEBAL was applied for the 2003 year on images from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. It was decided to calculate evapotranspiration (ET) for 24 bi-monthly periods running from January 1 (2003) to December 31 (2003). Thirteen MODIS acquisition days were selected for further ET analysis and are specified in Table 1. It was attempted to use one cloud free image for each period. There are two MODIS sensors operational, the MODIS Terra and MODIS Aqua. The overpass time of the Terra sensor is approximately between 10 and 11 a.m. local time, while the Aqua acquires images between noon and 1 p.m. The MODIS Aqua data is more favorable for ET studies and was thus used for this study (see table 1 for an overview of the images used). The major contribution of the daily evapotranspiration originates from midday and the afternoon. For the period between the second half of April to the first half of October no cloud free images were available. This was solved by averaging the biophysical parameters of the preceding and succeeding image.

Table 1. MODIS acquisition days and time (GMT)

Date	Julian day	Sensor	Acquisition time (GMT)
02/01/2003	2	aqua	2015
18/01/2003	18	aqua	2015
16/02/2003	47	aqua	1945
23/02/2003	54	aqua	1950
02/03/2003	61	aqua	1955
16/03/2003	75	aqua	2005
12/04/2003	102	aqua	1950
10/05/2003	130	aqua	2015
14/05/2003	134	aqua	1950
28/10/2003	301	aqua	1955
22/11/2003	326	aqua	1950
01/12/2003	335	aqua	1945
22/12/2003	356	aqua	2000

Meteorological data were obtained from the archives available at www.wunderground.com. Data from 11stations located in the area were downloaded and prepared for the SEBAL calculations. One station (Culiacan) is located at sea level, while the other station are between 422 and 2216 meters above sea level (see table 2).

Table 2. Location and altitude of the meteorological stations.

Station	latitude	longitude	altitude
Aguascalientes	21.9 N	102.3 W	1888
Culiacan	24.8 N	107.4 W	56
Del Bajio	21.0 N	101.5 W	1815
Durango	24.1 N	104.5 W	1871
Monterrey airport	25.9 N	100.2 W	422
Monterrey Gen Maria	25.8 N	101.1 W	953
Saltillo	25.5 N	101.0 W	1527
San Luis Potosi	22.1 N	101.0 W	2216
Tepic	21.5 N	104.9 W	950
Zacatecas airport	22.9 N	102.7 W	2164
Torreon	25.5 N	103.4 W	1166

4. Results and Discussion

Figure 4 depicts the total annual evapotranspiration and biomass production in the study area. Evapotranspiration and biomass production in the central highland part of the area (Zacatecas and San Luis Potosi) are very low. Evapotranspiration ranges from 100 to 300 mm, while biomass production is between 1 and 2 tons per ha. The highest values are found in the coastal mountain ranges in the southwest and north east where biomass goes as high as 30 to 40 tons per hectare and evapotranspiration is between 1000 and 1800 mm per year. The spatial pattern of evapotranspiration strongly follows the annual rainfall pattern as can be witnessed from figure 3 where the 2003 total annual rainfall measured by the TRMM sensor is depicted.

Bimonthly biomass production in the drier areas is close to zero, but increases during the wet season. Similar pattern can be witnessed for continuous forest where limited water availability during January to April causes the total biomass production per period to decrease. During the rainy season biomass production increases again.

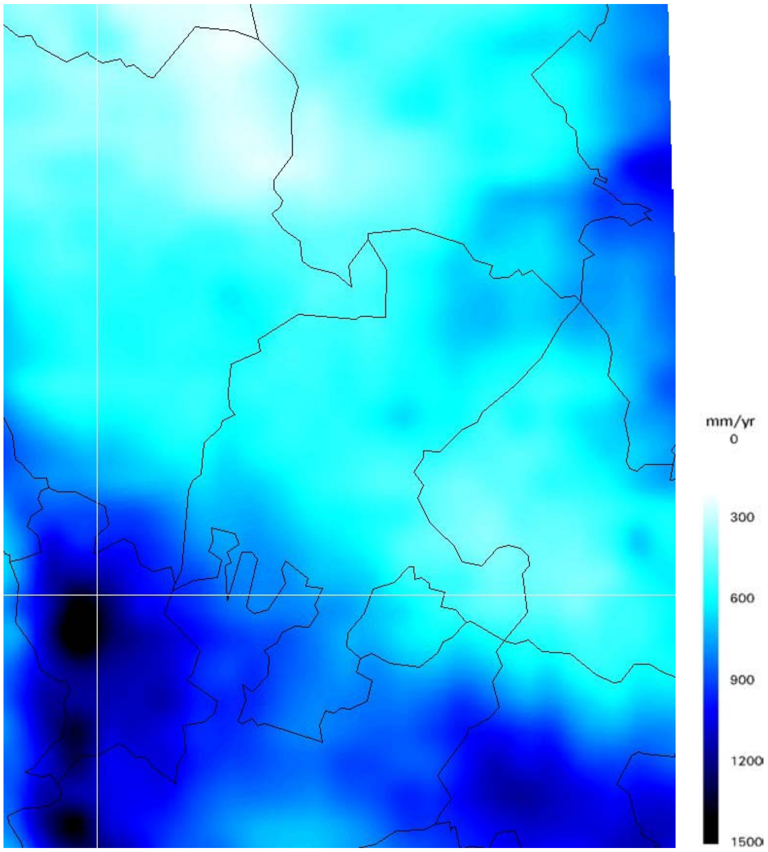

Figure 3. Calibrated annual precipitation in 2003 according to the TRMM sensor.

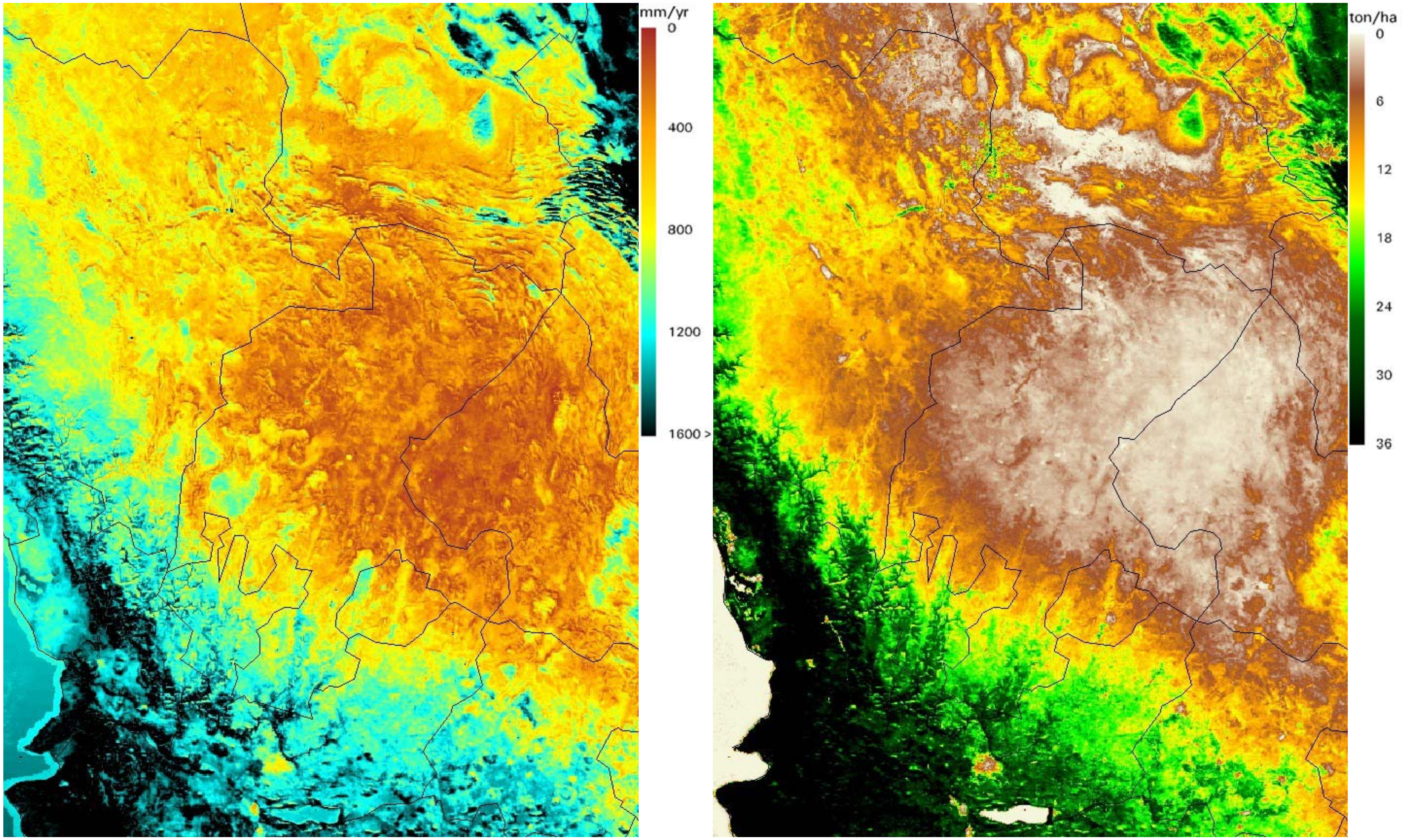

Figure 4. Total SEBAL annual evapotranspiration (left) and total annual biomass production(right).

Three intensively irrigated areas in the study area were further analyzed: 1. Region Lagunera (around Torreon), 2. Pabellon (Aguascalientes/Zacatecas), and 3. Lerma-Chapala (east of the Lago de Chapala). The Alto Rio Lerma system has two distinct agricultural seasons, the spring season starts early in January and ends at the end of April. The summer season starts in April/May and ends early in November (see figure 5). The Pabellon system has no spring season, while the summer season starts and ends slightly later than the Alto Rio Lerma system. The Region Lagunera system is characterized by agriculture throughout the year with no distinctive agricultural season.

These differences in agricultural patterns is reflected in annual biomass production and evapotranspiration. In figure 6 evapotranspiration is plotted against monthly precipitation. Annual evapotranspiration in Alto Rio Lerma is almost 1300 mm, while evapotranspiration in Region Lagunera and Pabellon is less: 873 and 789 mm resp. (see also table 3). During June to September monthly precipitation exceeds monthly evapotranspiration in the Alto Rio Lerma and Pabellon systems. In Region Lagunera, however, precipitation is always lower than evapotranspiration throughout the year. Figure 7 depicts the cumulative biomass production in 2003, which shows that the Alto Rio Lerma district is the most productive scheme: on average more than 22 ton/ha biomass is produced here, while annual biomass production is around 15 ton/ha for the other two schemes (see also table 3). Kloezen[1] reports wheat yields of 5.5 to 7.0 ton/ha in two districts in the Lerma-Chapala system. Assuming that approximately half of the annual biomass production is produced during the spring season and taking into account a harvest index of 0.45 for wheat, average wheat production is approximately 5 tons per ha. This is rather low, but this figure represents an area average at 250 meter resolution, which includes also non-agricultural areas. If analyzed at field scale, SEBAL yields will be higher.

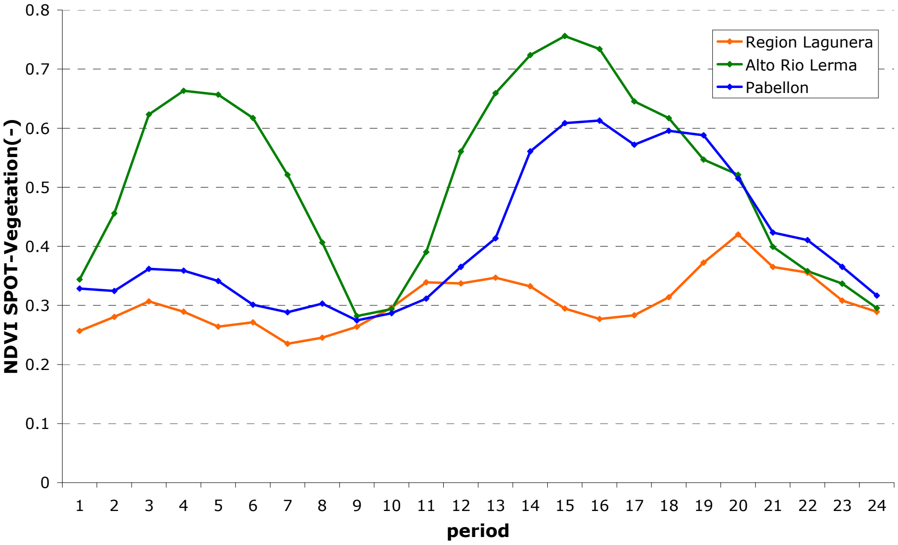

Figure 5. Average NDVI from SPOT-Vegetation for three different irrigation systems.

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[1] W.H. Kloezen, 2002. Accounting for water – Institutional viability and impacts of market-oriented irrigation interventions in Central Mexico. PhD thesis, Wageningen University, Wageningen, the Netherlands.

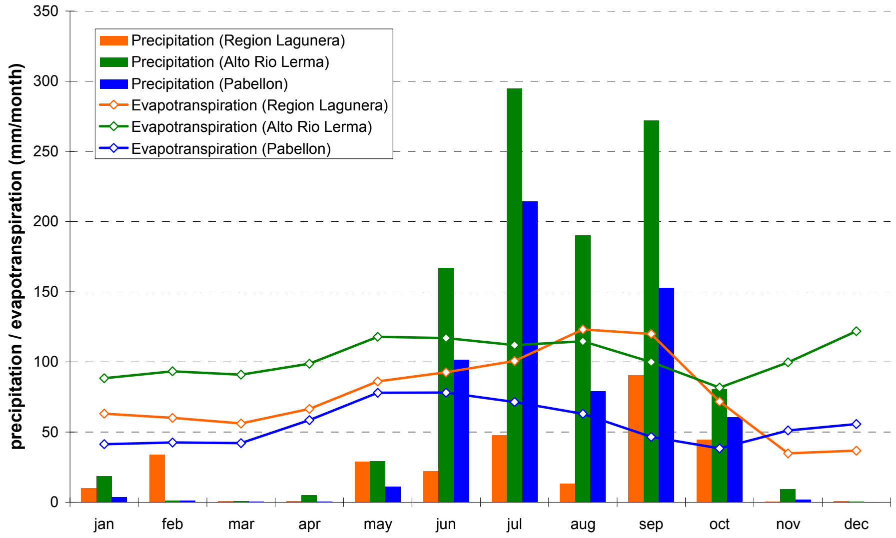


Figure 6. Average monthly evapotranspiration and precipitation in three different irrigated agricultural areas.

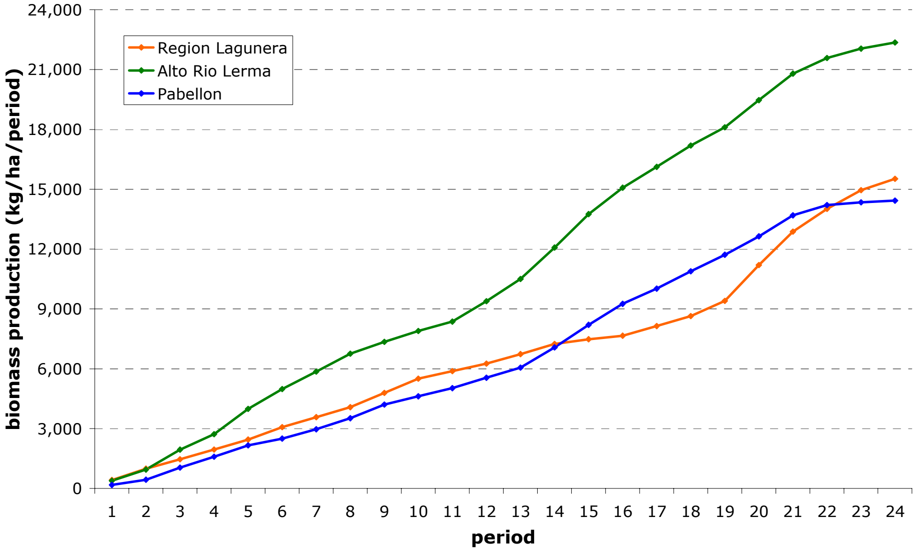
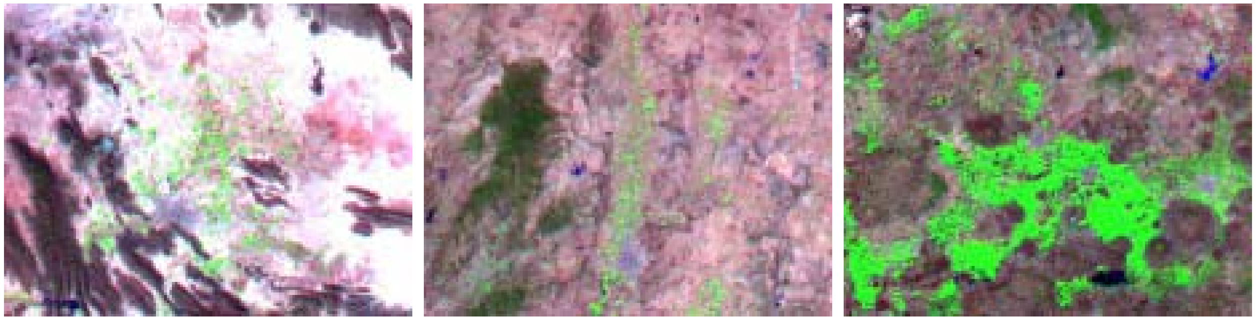


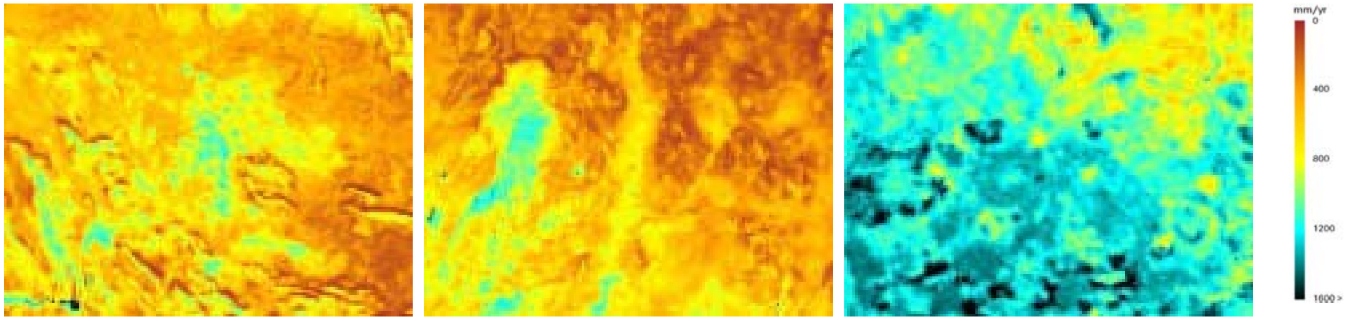
Figure 7. Average accumulated biomass production in three irrigated agricultural areas.

Table 3. Average actual and potential evapotranspiration, biomass production and soil moisture in the root zone for three irrigation districts.

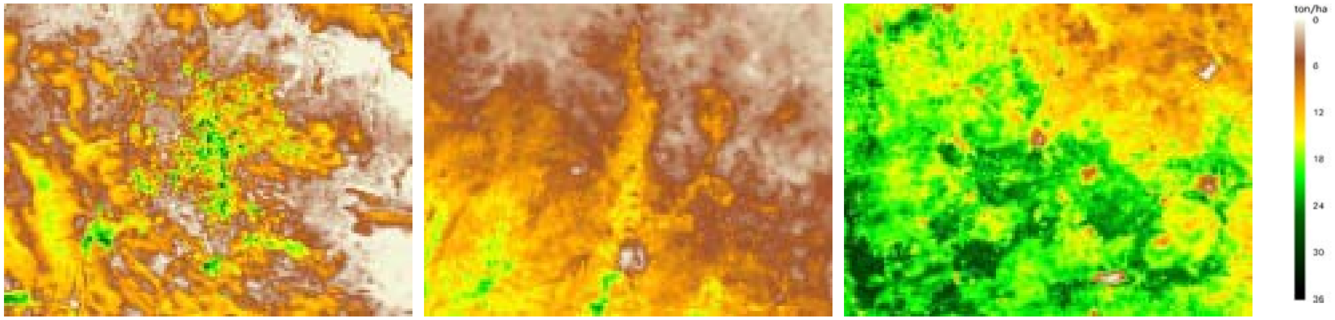
	area (ha)	ET_a (mm)	ET_p (mm)	biomass production (ton/ha)	soil moisture (-)
Region Lagunera	89,756	873	893	15.5	0.39
Rio Lerma-Chapala	341,894	1288	1149	22.3	0.52
Pabellon	20,006	789	786	14.4	0.35



Region Lagunera *Pabellon* *Lerma-Chapala*



actual evapotranspiration



biomass production

Figure 8. Annual actual evapotranspiration and biomass production in three different irrigation schemes.

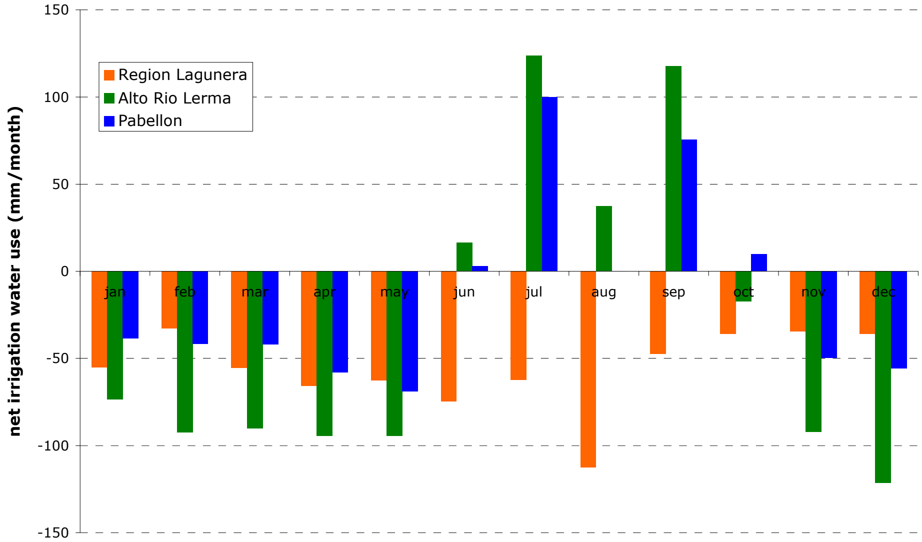


Figure 9. Monthly net irrigation water use defined as 80 percent of the total precipitation minus the actual evapotranspiration.

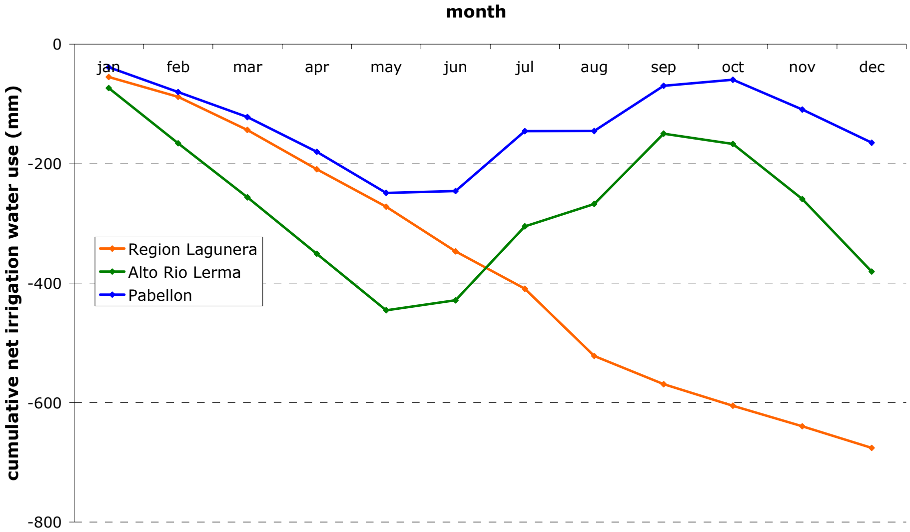
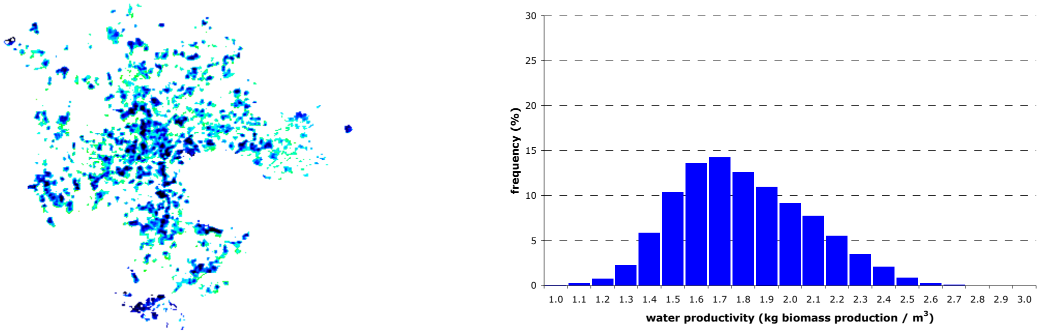
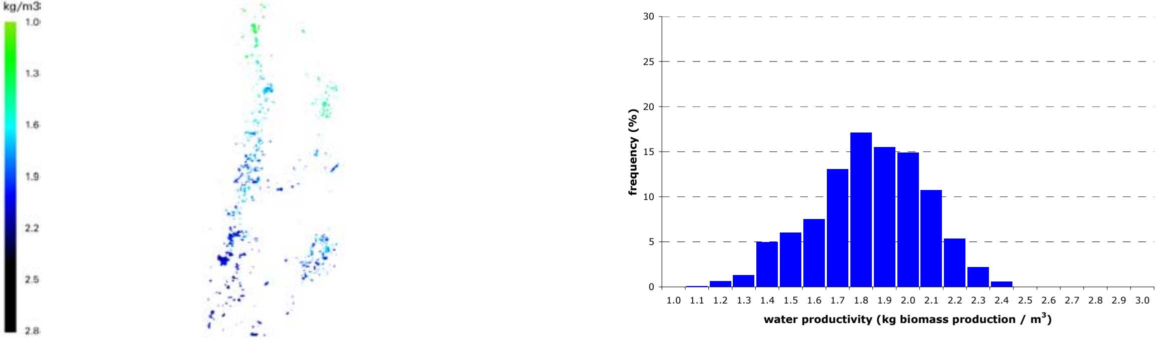


Figure 10. Cumulative monthly net irrigation water use.

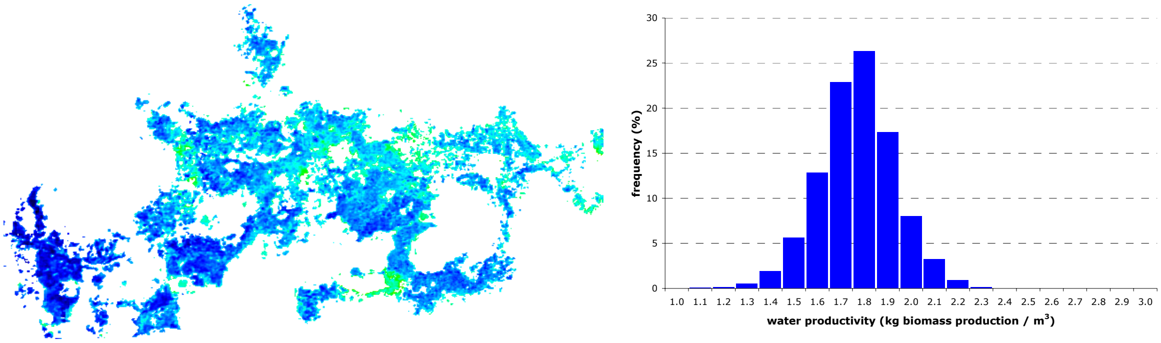
As a simple indicator of monthly irrigation water use, the actual evapotranspiration is deducted from 80 per cent of the precipitation to depict water deficits or surpluses. In the systems of Pabellon and Region Lagunera the summer season water demand is almost fully met by the precipitation and in July and September recharge can take place as precipitation is higher than water demand. On the other hand, in the region Lagunera system water demand by irrigation is always higher than precipitation and net irrigation water use is almost 700 mm. This indicates a strong dependence on ground water resources and/or surface water from the western mountain range.



Region Lagunera



Pabellon



Lerma-Chapala

Figure 11. Annual water productivity of the biomass production in three irrigation districts.

Finally the water productivity of the biomass production was analyzed. Water productivity is defined for this study as kg biomass production per unit of water consumed by evapotranspiration. Average water productivity for the systems is between 1.7 and 1.8 kg/m^3. From the frequency histograms in figure 11 it can be concluded that the scope for improvement of water productivity is lowest in the Lerma-Chapala system (standard deviation is 16.2; the other two systems have a considerable higher standard deviations of 24.1 and 27.8 for Region Lagunera and Pabellon resp. In the Lerma-Chapala system, regions can be identified where water productivity is low (yellow to lime green colors in figure 11) and where interventions on the improvement of water management should be focused.

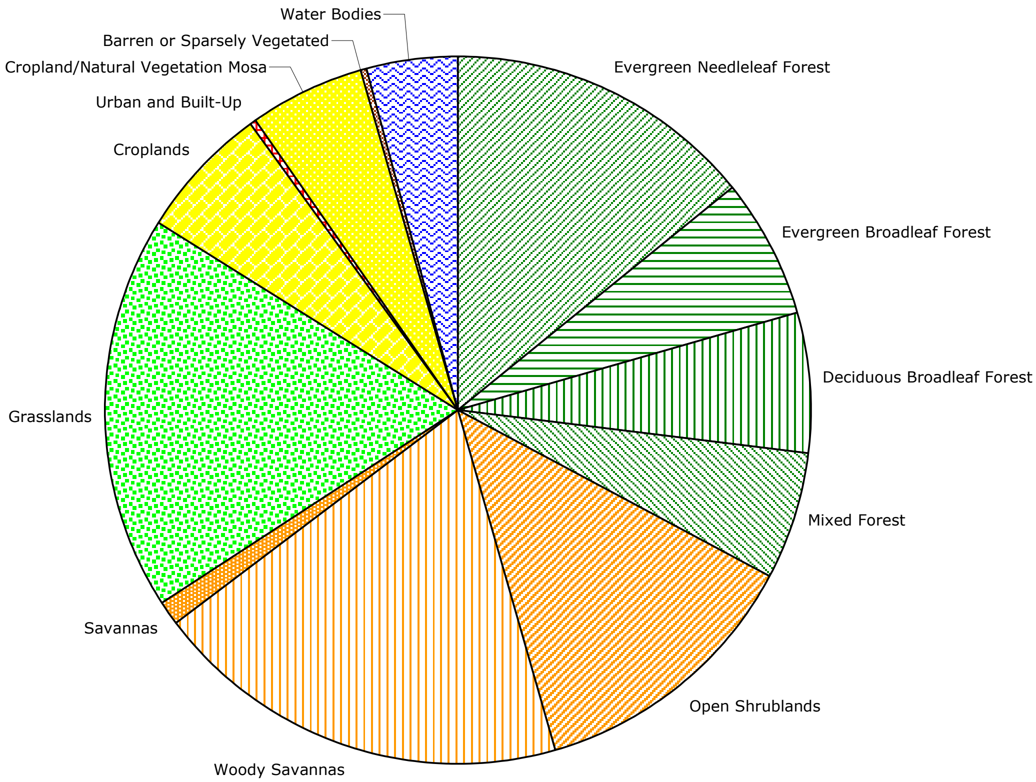


Figure 12. Water consumption by IGBP land use class.

In figure 12 the water consumption is compared with the land use classes that were identified by the International Geosphere-Biosphere Programme (IGBP). Approximately 34 per cent of the total water consumption in the area is related to forest and another 51 per cent is consumed by grasslands, shrub lands and savannas. Water consumption by water bodies includes a part of the Pacific ocean and will be considerably lower if only inland lakes are accounted for. Finally, water use by (irrigated) agriculture accounts for 10 per cent of the total water consumption.