The Impacts of Climate Change and Variability on Water Resources in a Semi Arid Region in Mexico: The Rio Yaqui-Basin.

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background

The work consists of determining the impacts of climate change and variability on precipitation and reservoir storage in the Yaqui Basin. The Yaqui Basin is considered a semi-arid region with an average rainfall of 377 mm and a mean annual temperature of 22°C. The basin consists of roughly 72,000 square kilometers of land located mainly in northeastern Mexico (Figure 1).

The Yaqui River Basin includes one of the most important agricultural regions in Mexico, known as the Yaqui Valley (roughly 270,000 hectares). The Valley is the main water user and a vital source of economic activity. Other water users include the farmers, industries, and municipalities, and the water stored to satisfy the user demands comes from a series of reservoirs constructed along the river.

Every water user within the basin holds water rights. The agricultural users in the Yaqui Valley hold the largest water rights of 2,000 million cubic meters (MCM) per year of surface water and up to 450 MCM of groundwater per year. The yearly supply and type of crops planted is determined partially by the surface water storage available on October 1st of each year.

tasks

The overall objective of this project is to develop an Integrated Hydrologic Economic-Quality Water Model for the Yaqui River Basin II: it will be designed as a tool to support decision-makers that manage water supplies while minimizing impacts in the environment. The specific tasks related to the current work are as follows:

Develop a water balance model to determine storage in the reservoirs on a monthly basis.
Create and calibrate a seasonal rainfall-runoff model using predicted runoff against measured flows.
Estimate the uncertainty of the rainfall-runoff model using a Monte Carlo approach.
Incorporate climate change into the water balance model based on estimated changes in precipitation from Climate Models.

create a macromodel that reflects precipitation for each year.

Figure 2: Yaqui Basin Reservoirs

water balance model

The first step of the water balance model was to create a node-link network of the Rio Yaqui Basin, which is the conceptual basis for the surface water model (Figure 2).

Figure 3: Yaqui Basin network model

The node-link network includes the primary reservoirs within the basin which are La Angostura, El Nuño, and El Tulechic. It also includes the river reaches and locations of water demand. The total water rights allocated to the basin are approximately 3000 MCM (Wuebbles, 2004) as shown in Table 1.

A MATLAB code was developed in order to estimate the monthly storage of the main reservoirs for a period of thirty years. The model considers each surface water right holder within the basin and takes into account priorities in allocating the water.

The model also includes the maximum groundwater usage allowed by the Yaqui Valley farmers by their water rights since farmers are planning to be less dependent on surface water for irrigation.

Figure 4: Monthly water balance

The model solves a water balance on a month step (Figure 3). The input data such as direct precipitation, direct evaporation, and extractions comes from historical data. The runoff was obtained from a rainfall-runoff model developed in GIS.

Although the storage of the reservoirs is estimated on a monthly basis, the main objective was to classify storage in the reservoirs in October of every year, when cropping decisions are made.

creation and calibration of the rainfall-runoff model

Sub-watersheds were delineated using DEM data and were aggregated into Upper, Middle, and Lower sub-basins, each with a single outlet (Figure 4).

Precipitation data was interpolated on a monthly basis over a 32-year time span using GIS. The precipitation data was merged into three climate seasons, based on consistent temporal patterns of the reservoir operation rules:

Spring: January-March
Summer: April-June
Winter: July-December

A static runoff coefficient map was produced based on published data. Static coefficients varied as a function of topography, vegetation, land use, and precipitation. Runoff was estimated monthly on a pixel by pixel basis by multiplying the precipitation by the static runoff coefficient.

A simple linear model of the form Y = a + bX was used to predict seasonal runoff (Y) as a function of runoff estimated using the static runoff coefficients (X). Values of a and b were found minimizing the sum of the squares of the deviations from the historically observed flows from each sub-basin and the model output.

Figure 5: Sub-watersheds in the Yaqui Basin

Table 1: Parameters fitted with the linear model

Figure 6: Monthly water balance

uncertainty analysis: a monte carlo approach

Uncertainty in the rainfall-runoff model predictions were assessed using a Monte Carlo simulation approach, assuming that model errors are normally distributed. Runoff was calculated using the relationship:

\[ Q = \frac{\alpha + \beta P}{\gamma} \]

where \( \alpha \) and \( \beta \) are base estimates (\( \bar{\alpha} = 0.02, \bar{\beta} = 0.8 \)), \( \gamma \) is the statistic, and \( \xi \) is the standard error of the estimate. In the Monte Carlo simulations, 100 values of \( \xi \) were randomly generated from a uniform distribution.

Figure 7: Linear model

Figure 8: Seasonal runoff

Figure 9: Seasonal runoff

Figure 10: Seasonal runoff

Figure 11: Seasonal runoff

results

Figure 12: Trend of observed vs historical record.

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Although the storage of the reservoirs is estimated on a monthly basis, the main objective was to classify storage in the reservoirs in October of every year, when cropping decisions are made.

Figure 13: Trend of observed vs historical record.