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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OBJECTIVES

GENERAL

Develop an Integrated Hydrologic-Economic-Institutional Water Model for the Yaqui River Basin.

SPECIFIC

Determine the impacts of climate change and variability on precipitation and reservoir storage in the Yaqui Basin.

TASKS

• Develop a water balance model to determine storage in the reservoirs on a monthly basis.

•Create and calibrate a seasonal rainfall-runoff model.

•Incorporate climate change and climate variability into the water balance model.

BACKGROUND

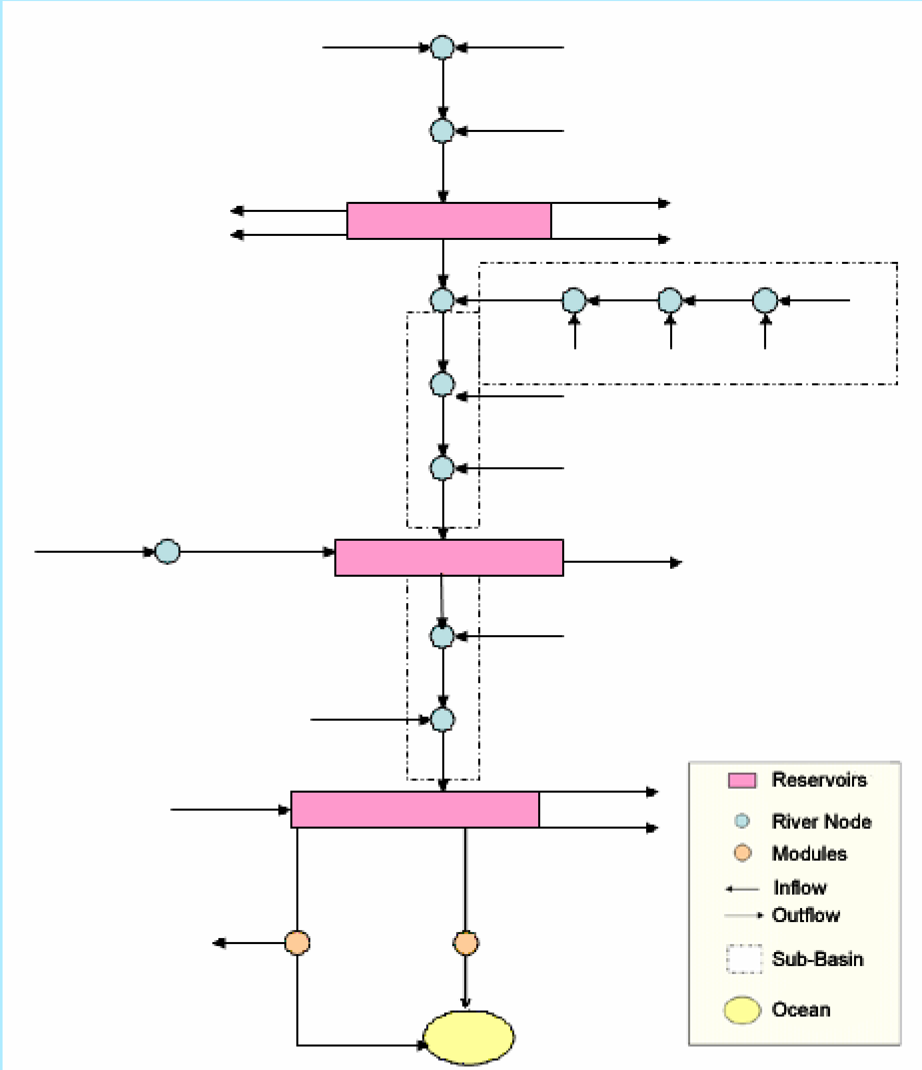
The Yaqui basin is characterized by semi arid conditions.

The basin consists of roughly 72,000 square kilometers.

One of the most important agricultural regions in Mexico is located within the basin.

Water users include farmers, rural and urban municipalities, industries, and mines.

WATER BALANCE MODEL



A node- link network is the conceptual basis for the model.

This node-link network includes the primary reservoirs within the basin, river reaches, locations of water demand and supply, and the Yaqui Valley.

WATER BALANCE MODEL

A MATLAB code was developed in order to estimate the monthly storage of the main reservoirs.

Reservoir	Capacity* (MCM)	Water Rights (MCM/yr)
La Angostura	880	57
El Novillo	2,799	NA
El Oviachic	2,782	2,800
Total	6,462	2,857

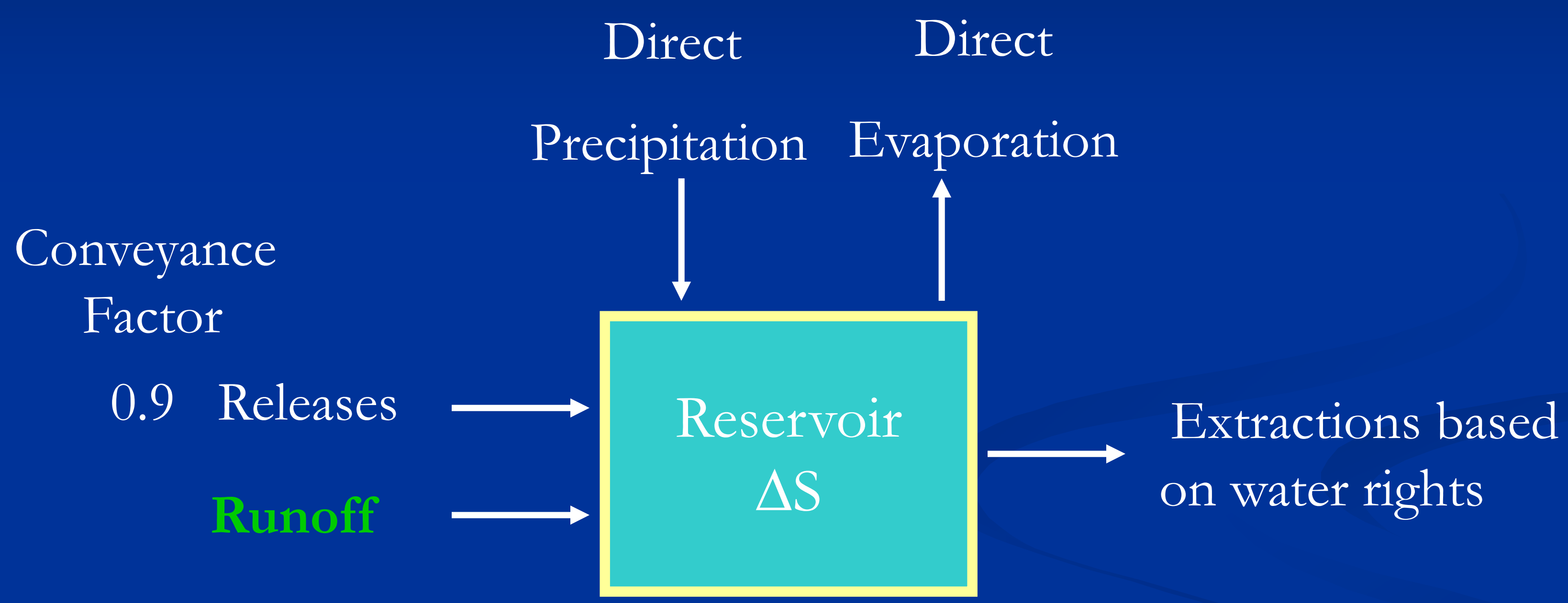
*less dead storage

The model considers each surface water rights holder within the basin and takes into account priorities in allocating the water.

The operating rules include the release of water downstream once the water needs have been met.

The main objective was to determine the storage in the reservoirs in October of every year, when cropping decisions are made.

WATER BALANCE MODEL



$\Delta S_i = \Delta S_{i-1} +$ **Runoff** $+$Precipitation$+$ 0.9 Releases - Evaporation – Extractions

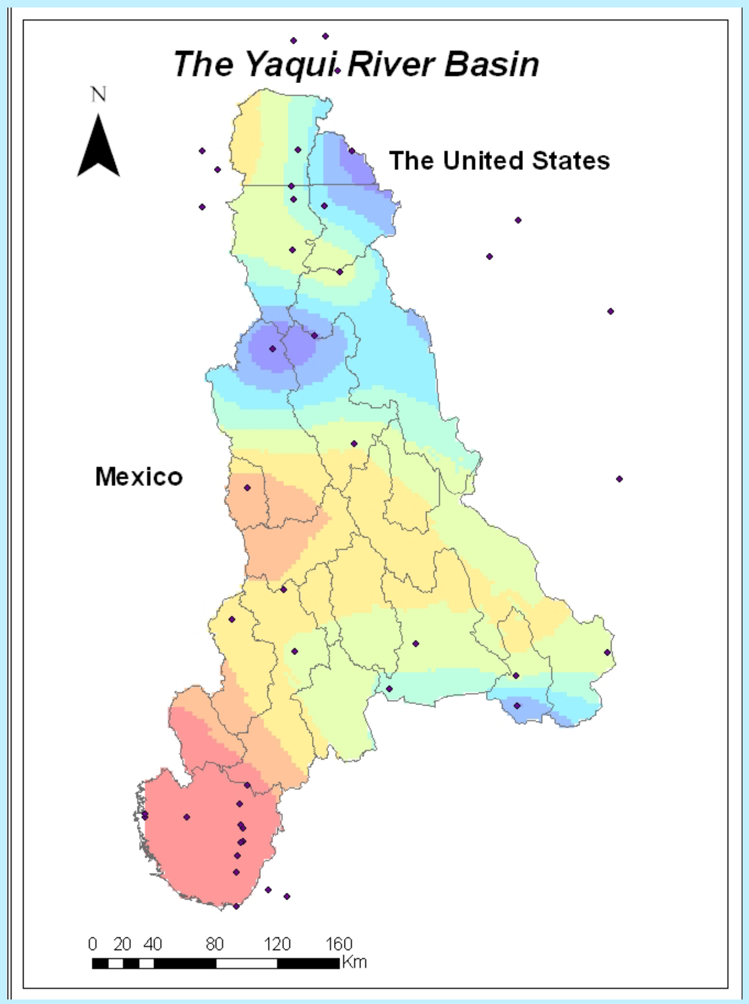
$$\text{RUNOFF} = Y_{ij}$$

CREATION AND CALIBRATION OF THE RAINFALL-RUNOFF MODEL

The watershed and sub-basin boundaries were delineated using GIS based on DEMs.

The sub-basins were aggregated and classified into an Upper basin, a Middle basin, and a Lower basin each with a single outflow point.

PRECIPITATION MAPS



Precipitation data was interpolated on a monthly basis over a 33-year time span using GIS.

The precipitation data was merged into three climatic seasons:

Spring season: February-May.
Summer season: June-September
Winter season: October-January

A static runoff coefficient map was also produced based on published data.

PIXEL-BASED RUNOFF MODEL

2500 m | Precipitation (m) * Runoff coefficient * Area of the pixel (m^2) = Runoff (Mm^3)

2500 m

$$P_{ij}^{GIS} * C^{GIS} * A = X_{ij}$$

i=Sub basin
J=Season

CALIBRATION OF THE MODEL

$$P_{ij}^{GIS} * C^{GIS} * A = X_{ij}$$

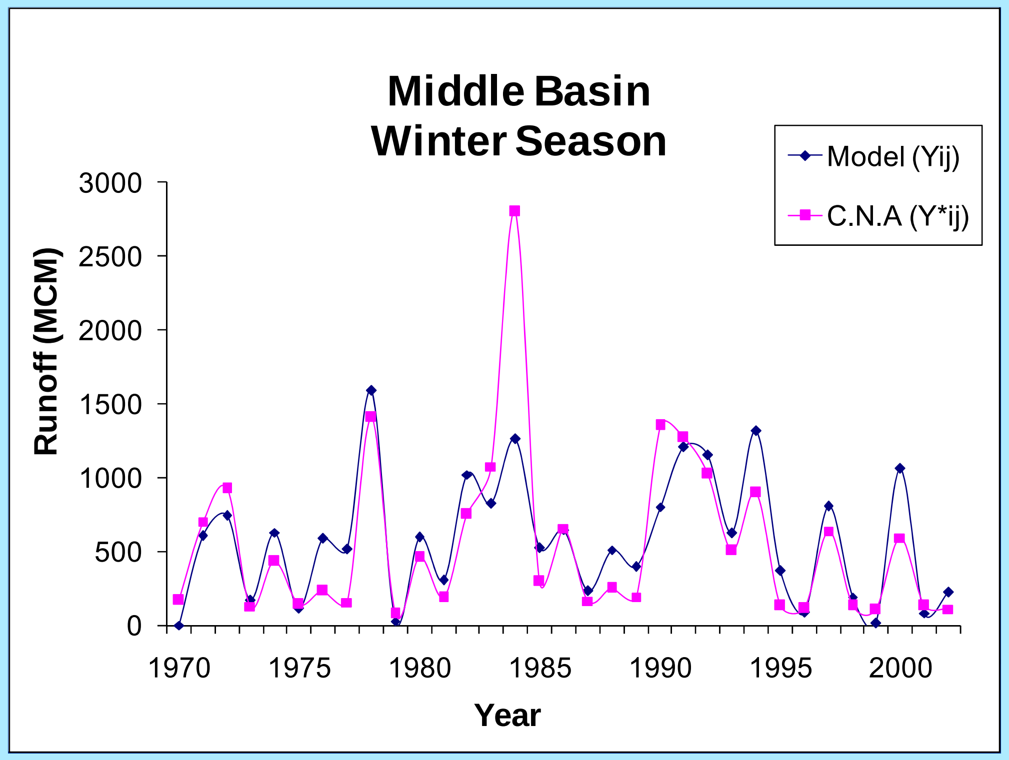
$$Y_{ij} = \beta_{ij} X_{ij} + \alpha_{ij}$$

$$Min = \sum (Y_{ij} - Y^*_{ij})^2$$

i=Sub basin
J=Season

Alpha and Beta were found minimizing the sum of the square errors.

RESULTS: CREATION AND CALIBRATION OF THE MODEL



The timing of the peaks matches reasonably well, but the model tends to under predict the runoff in the wettest year (1984).

RESULTS: CREATION AND CALIBRATION OF THE MODEL

Sub-Basin	Season	β	α (MCM/ month)	R^2
Upper	Spring	3.28	-58	0.73
	Summer	1.05	-122	0.65
	Winter	2.45	-108	0.82
Middle	Spring	2.88	-60	0.74
	Summer	2.48	-893	0.74
	Winter	2.53	-183	0.79
Lower	Spring	1.03	141	0.53
	Summer	0.97	42	0.45
	Winter	0.23	137	0.41

This table shows all the parameters fitted with the linear model. In most cases, the R^2 values indicate reasonable fits.

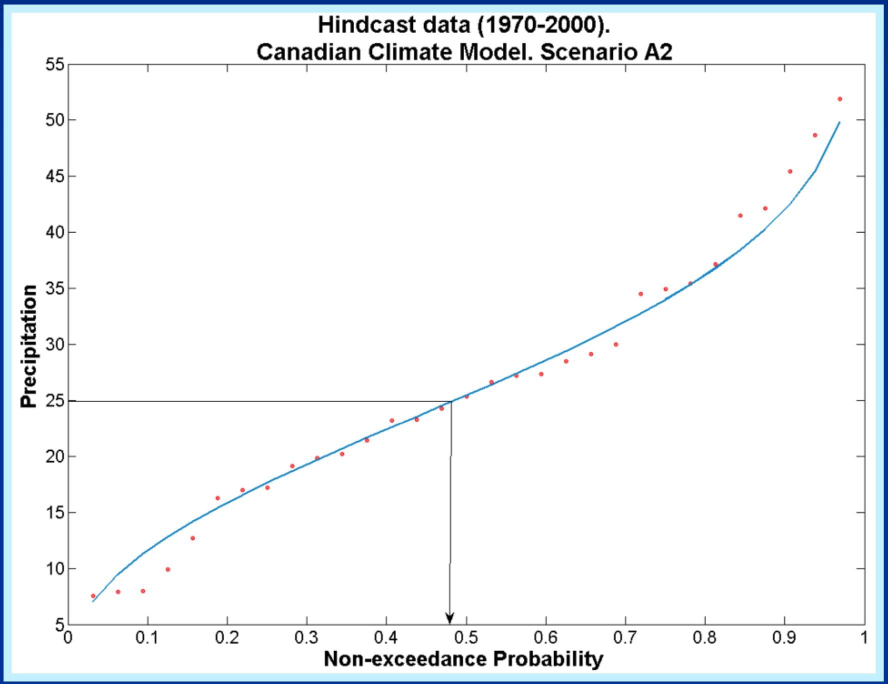
CLIMATE CHANGE

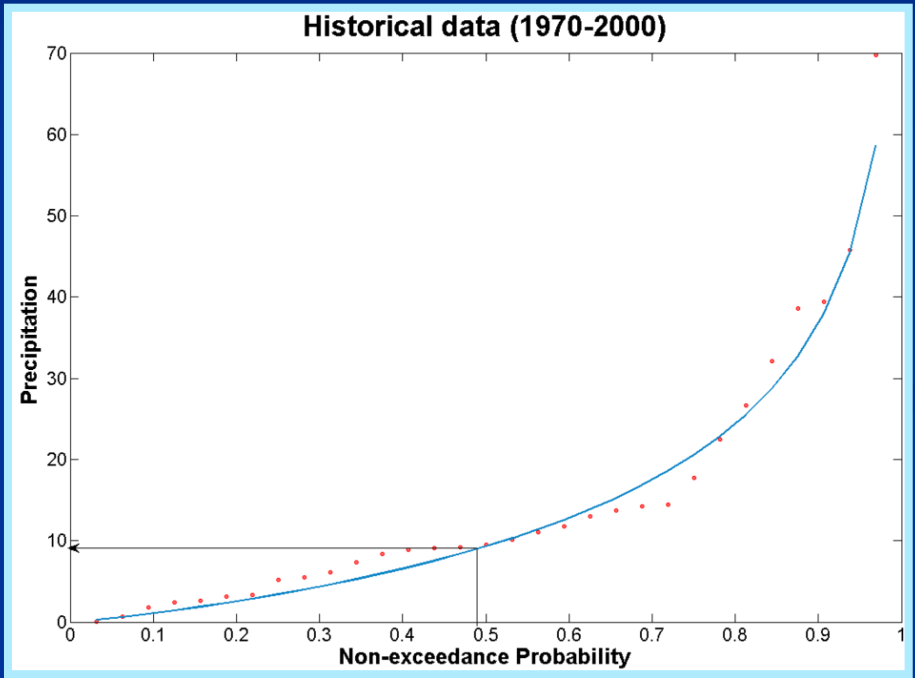
- Two Global Climate Models were used : the UK's Hadley Center model (HADCM3) and the Canadian Center for Climate Modeling and Analysis (CGCM) for the period 2011-2100.

- A regional model was used for comparison for the period 2011-2040: Providing Regional Climates for Impact Studies (PRECIS).

- Two SRES (Special Report on Emissions Scenarios) scenarios were used: A2 (high emission) and B1(low emission).

BIAS CORRECTION AND DOWN-SCALING

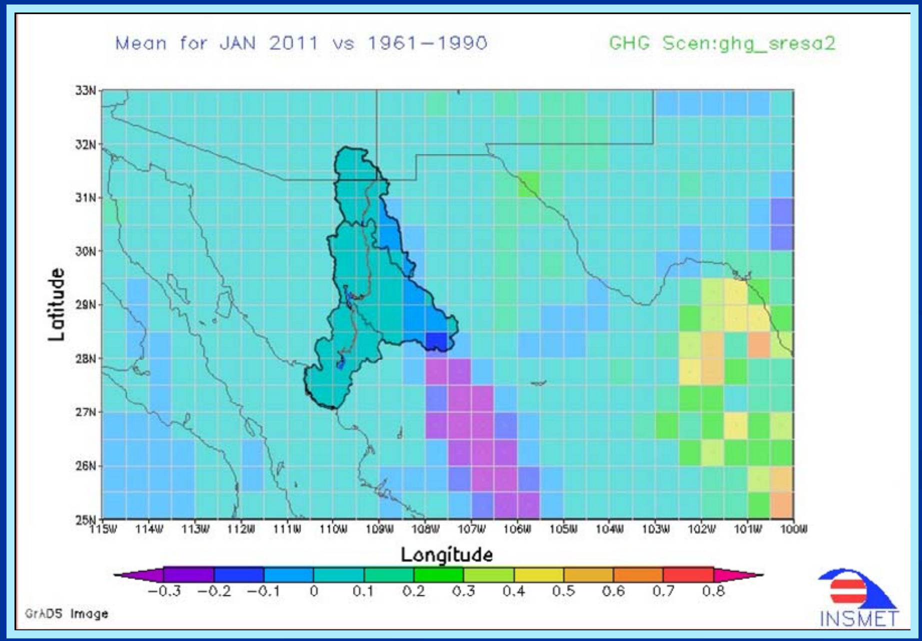




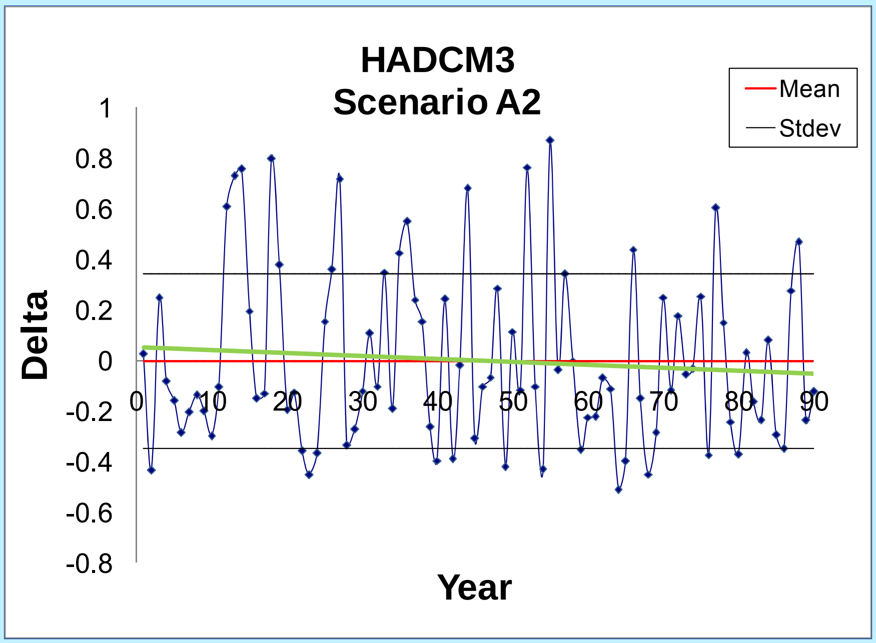
- The bias-correction and downscaling approach developed by Wood et al (2002) was used to downscale the GCMs.

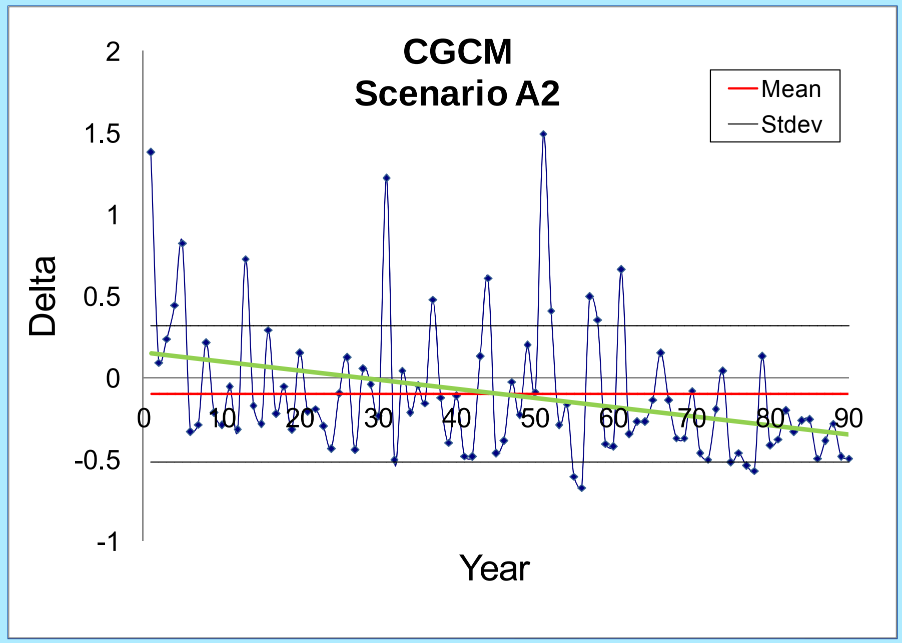
DOWNSCALING

For PRECIS, monthly percentage changes based on the 1961-1990 record were calculated. These percentage changes were then applied to our baseline period (1970-2000), assuming that this record would be repeated in the future.



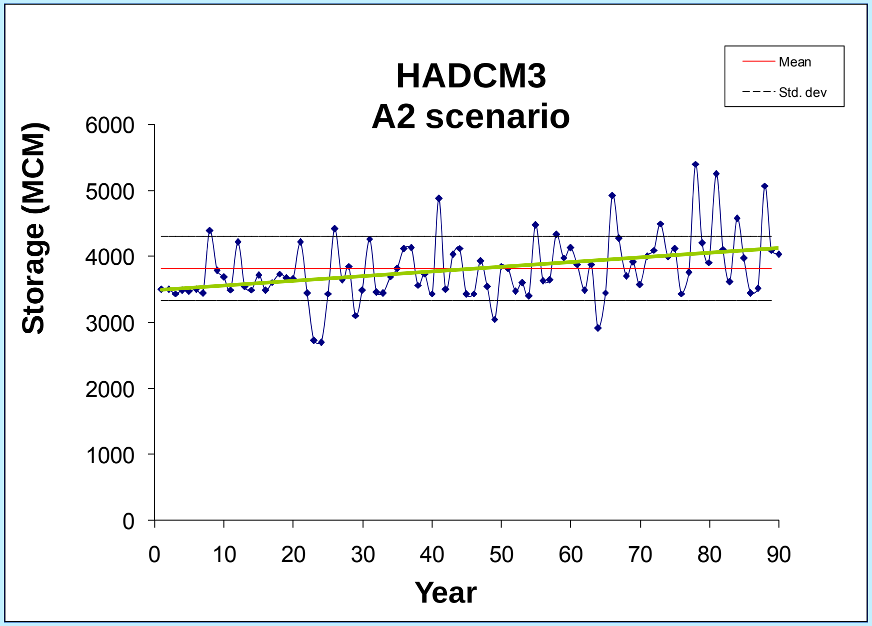
CHANGE ON PRECIPITATION

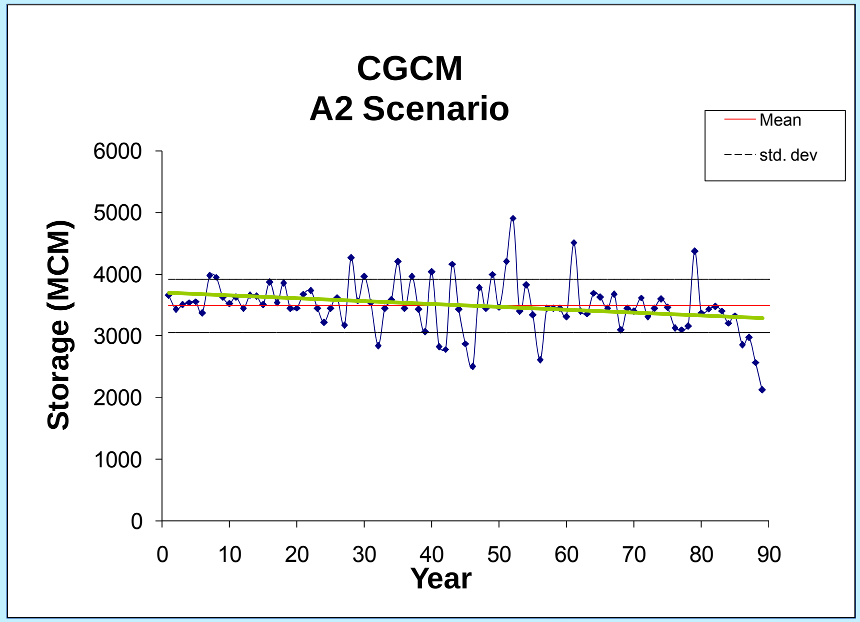




The CGCM model predicts a drier future than the HADCM3 model

RESULTS:
CLIMATE CHANGE





The forecasted precipitation is reflected in the total storage for the period 2011-2100.

RESULTS:

CLIMATE CHANGE

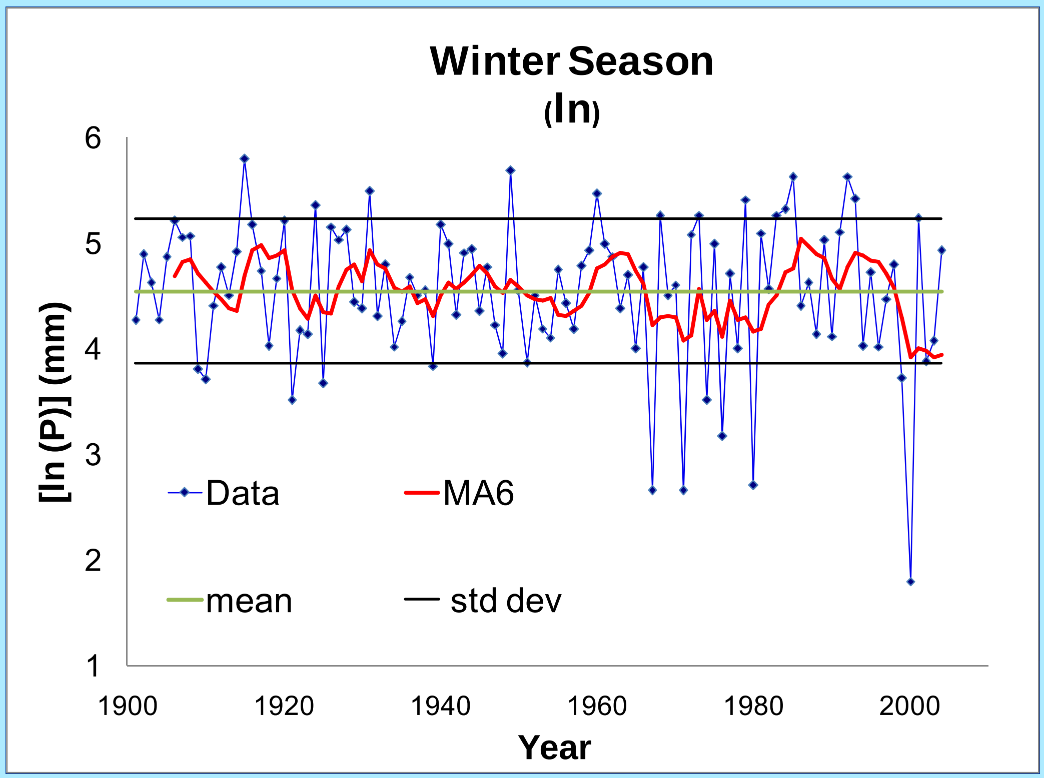
Model	Scenario	μ (MCM)	σ (MCM)	%
Historical	**NA**	**3531.7**	**360.4**	**3.3**
CGCM	A2	3483.5	430.9	11.1
	B1	3538.1	442.0	11.1
HADCM3	A2	3814.5	486.9	3.3
	B1	3761.5	394.3	2.2
PRECIS	A2	3895.8	460.8	0.0
	B1	3615.8	356.3	3.3

- This table shows the percentage of times the reservoir storage falls below the users needs compared to the historical period.

- The storage varies depending on the climate model and the scenario used.

CLIMATE VARIABILITY

To assess the effects of year-to-year correlations in precipitation a longer precipitation data set (104 years) was used (Nicholas et al, 2007).



CLIMATE VARIABILITY

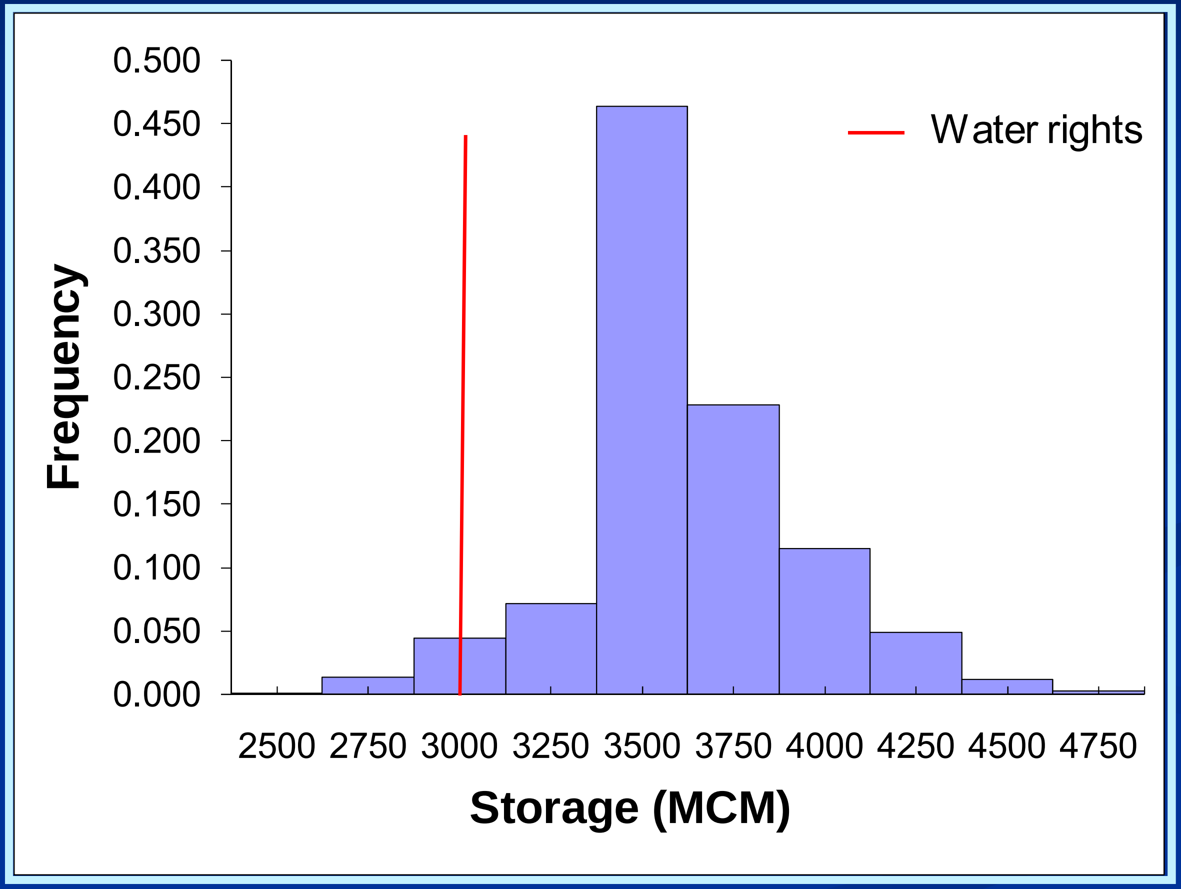
An auto-regressive model approach (AR) was fitted to the smoothed, log-transformed precipitation and used to generate, on a monthly basis, precipitation for a period of thirty years using the following approach:

$$y_t = \mu + \sum_{j=1}^{p} \phi_j \left(y_{t-j} - \mu\right) + \varepsilon_t$$

Where μ is the mean of the data, p is the order of the model, φ_j are fitted parameters and ε_t is a uncorrelated normal random variable.

RESULTS:

CLIMATE VARIABILITY



There is a small, but significant probability that the storage can fall below the water user's needs.

CONCLUSIONS

- The results show that there is sufficient surface water to meet users' needs for a wide range of conditions (uncertainty, climate change, and climate variability), but this is not always the case.

- The rainfall-runoff model produces acceptable results when compared with historical data. The best and worst matches are obtained in the middle and lower basin, respectively.

CONCLUSIONS

- The storage estimates obtained from the incorporation of climate change into the water model shows that the basin could suffer from water shortages during some years depending on the climate model or the scenario used. The use of different GCMs or SRES scenarios that are more optimistic or pessimistic might produce different results.

- Future assessments of climate variability should consider season to season correlation and different ways of classifying precipitation levels and corresponding probabilities.

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1. Minjares J.L. 2004. Sustainable operation of the Yaqui River Multiple Reservoir System. Ph D. dissertation. New Mexico State University. Las Cruces, New Mexico.

2.Nicholas and Battisti (2007) Drought Recurrence and Seasonal Rainfall Prediction in the Rio Yaqui Basin, Mexico. In press, J. App. Meteor. Hydro.

3. PRECIS http://precis.insmet.cu/menu_page.htm

4. Wood, A. W., E. P. Maurer, A. Kumar, and D. P. Lettenmaier, 2002: Long range experimental hydrologic forecasting for the eastern U.S. J. Geophys. Res., 107, 4429, doi:10.1029/2001JD000659.

Thank You

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:

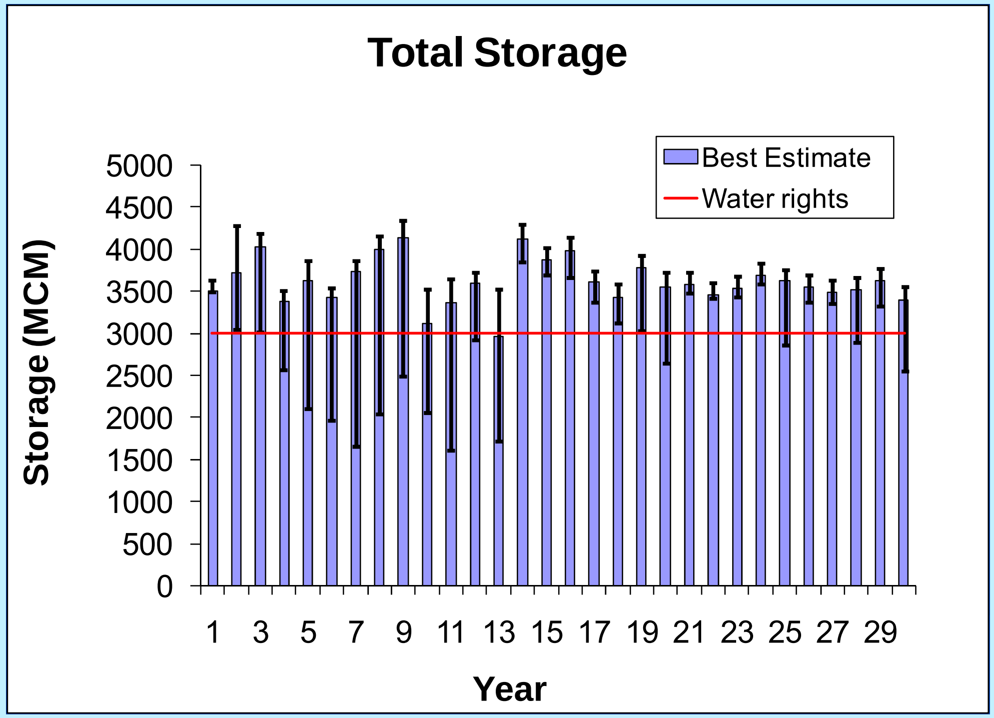
$$Y = \alpha + \beta \pm t_{n-2,1-\alpha/2} S_{YXo}$$

where α and β are best estimates, $t_{n-2,1-\alpha/2}$ is the t statistic, and S_{YXo} is the standard error of the estimate.

In the Monte Carlo simulations, 100 values of $1-\alpha/2$ were randomly generated from a uniform distribution.

RESULTS:

MONTE CARLO



Based on the results, there is enough surface water to satisfy current water rights every year for the best estimates and, in some cases, for the 10% confidence interval.