Sustainable Groundwater and Surface Water Management in the Rio Yaqui Basin, Sonora, Mexico.

by

Andrea Munoz-Hernandez

Dr. Alex S. Mayer

Michigan Technological University,

Houghton, Michigan, USA

Center for Water and Society

Michigan Technological University

OBJECTIVE AND TASKS

- Objective: Determine the sustainability of the Yaqui Basin under different groundwater and surface water management practices, by completing the following tasks.
  - Create and calibrate a seasonal rainfall-runoff model.
  - Develop a water balance model to determine storage in the reservoirs on a monthly basis.
  - Couple the rainfall-runoff model with a groundwater model of the Yaqui Valley.
  - Explore different management practices to determine the sustainability of the basin.
  - Determine the potential impacts caused by climate change.

BACKGROUND

The Yaqui basin is characterized by semi arid conditions with an average precipitation of 526 mm/year.

The basin consists of roughly 72,000 square kilometers.

The basin includes one of the most important agricultural regions in Mexico: The Yaqui Valley.

The average area harvested in the Yaqui Valley from 1988 to 2002 was approximately 300,000 ha.

BACKGROUND

Irrigated agriculture in the Yaqui Valley is the main user of water in the basin. Other water users include rural and urban municipalities, industries, and mines.

Water stored to satisfy the user demands comes from a series of three reservoirs constructed along the river.

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

Currently, irrigated agriculture in the Yaqui Valley holds water rights of 2,500 MCM/yr of surface water and 600 MCM/yr of groundwater.

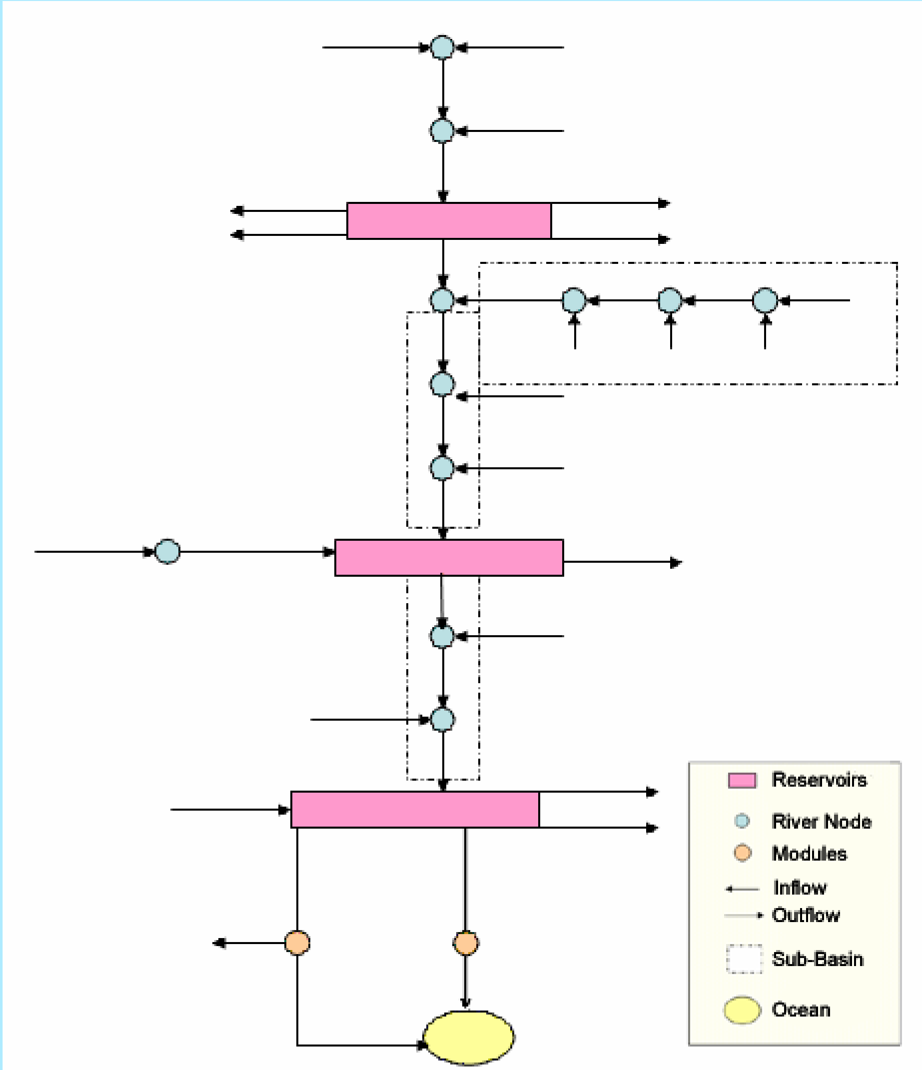
RAINFALL-RUNOFF MODEL

CREATION 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.

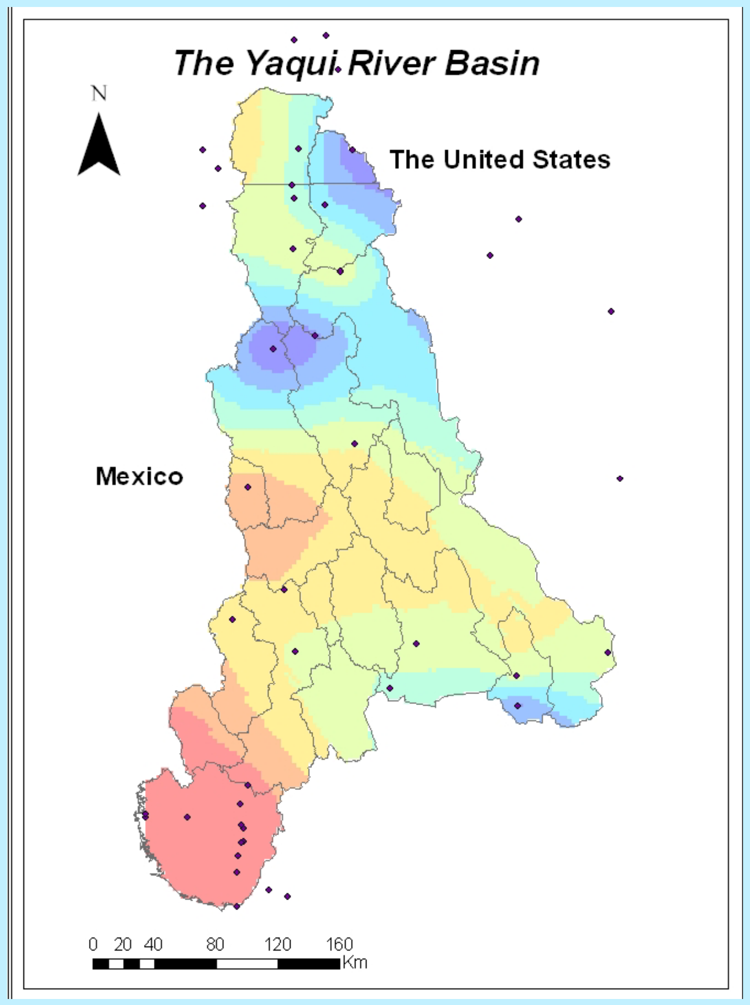
CONCEPTUAL MODEL



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

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

CREATION OF THE RAINFALL-RUNOFF MODEL



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

Preliminary runoff, *X*, is estimated monthly on a pixel by pixel basis by multiplying the precipitation by the static runoff coefficient.

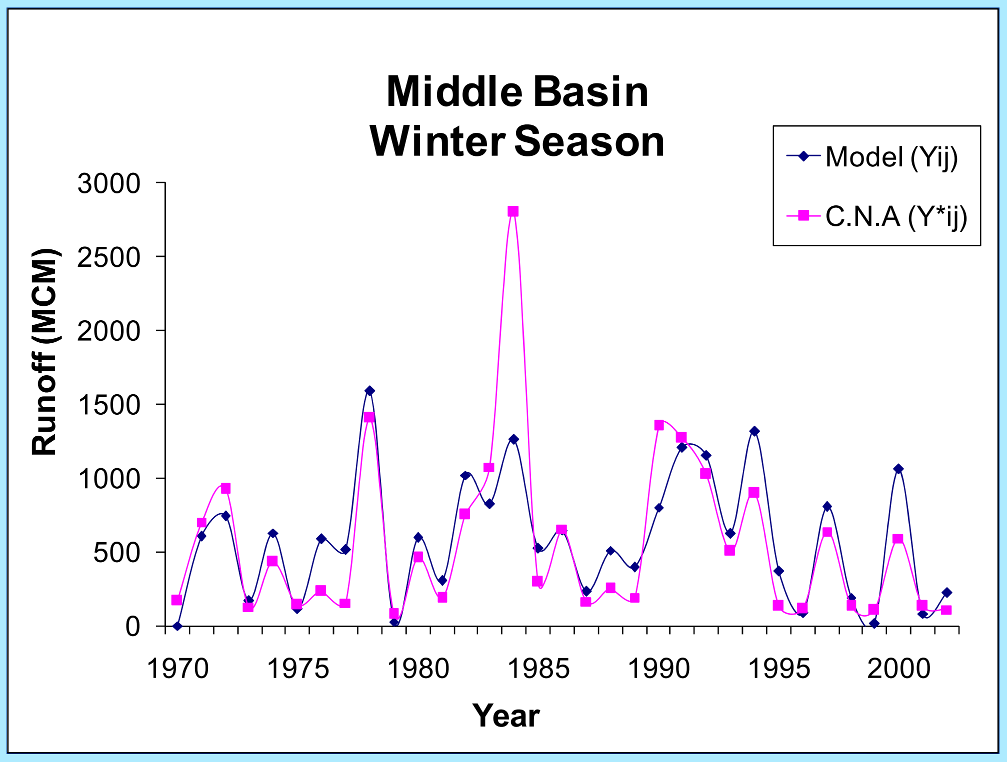
Precipitation data is merged into three seasons: spring (February-May), summer (June-September) and winter (October-January).

A linear model of the form $Y = \beta X + \alpha$ was calibrated to predict seasonal runoff (Y).

WATER BALANCE MODEL

- The runoff estimated with the linear model was incorporated into a MATLAB code that estimates the monthly storage in the reservoirs by solving a simple water balance.
- The model considers each surface water rights holder within the basin and takes into account priorities in allocating the water.
- The operating rules allow the release of all water downstream, once the water rights at the reservoir have been met.
- The main objective was to determine the storage in the reservoirs in October of every year, when cropping decisions are made.

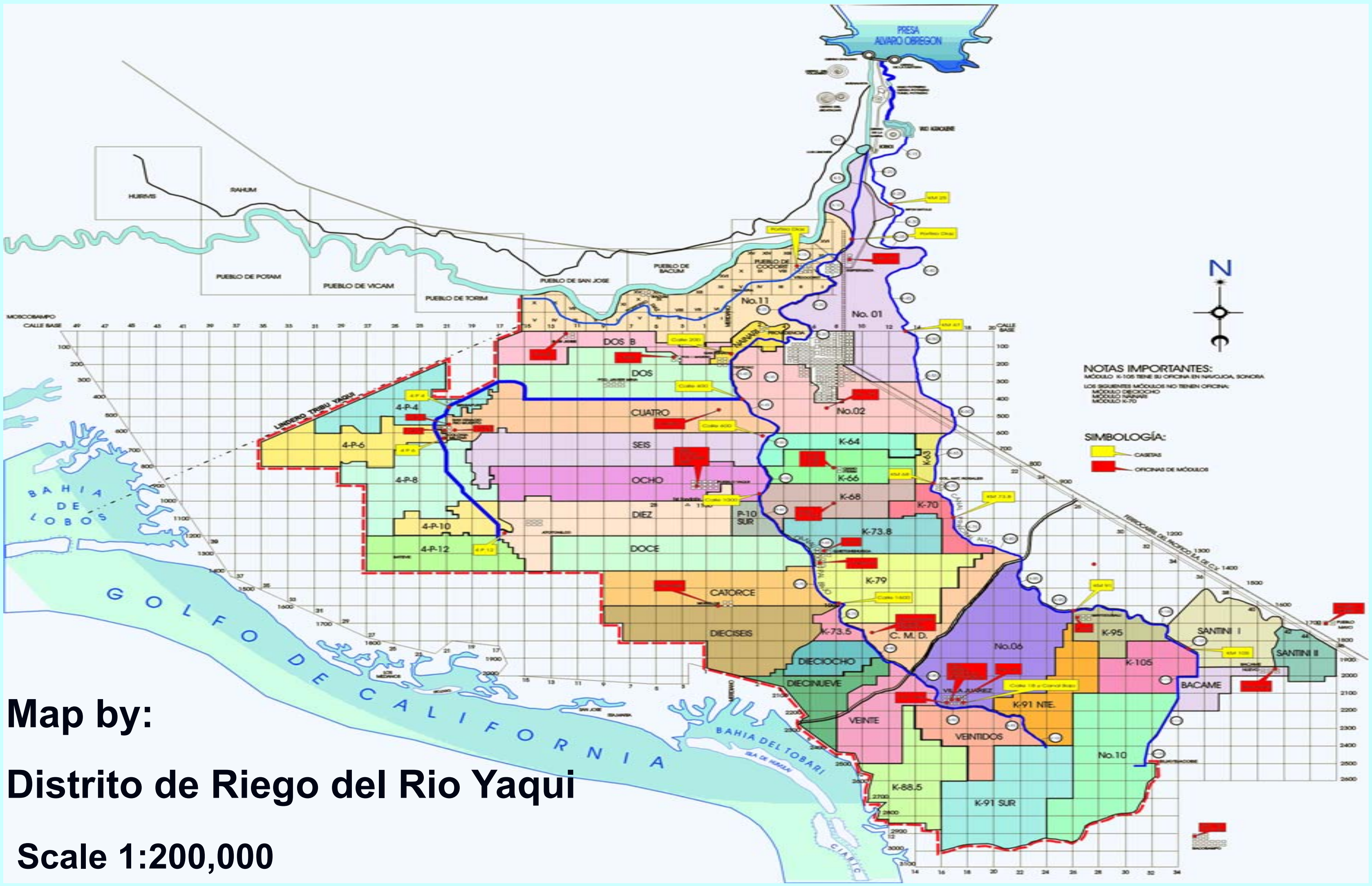
RESULTS: CREATION AND CALIBRATION OF THE MODEL



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

THE YAQUI VALLEY

THE YAQUI VALLEY

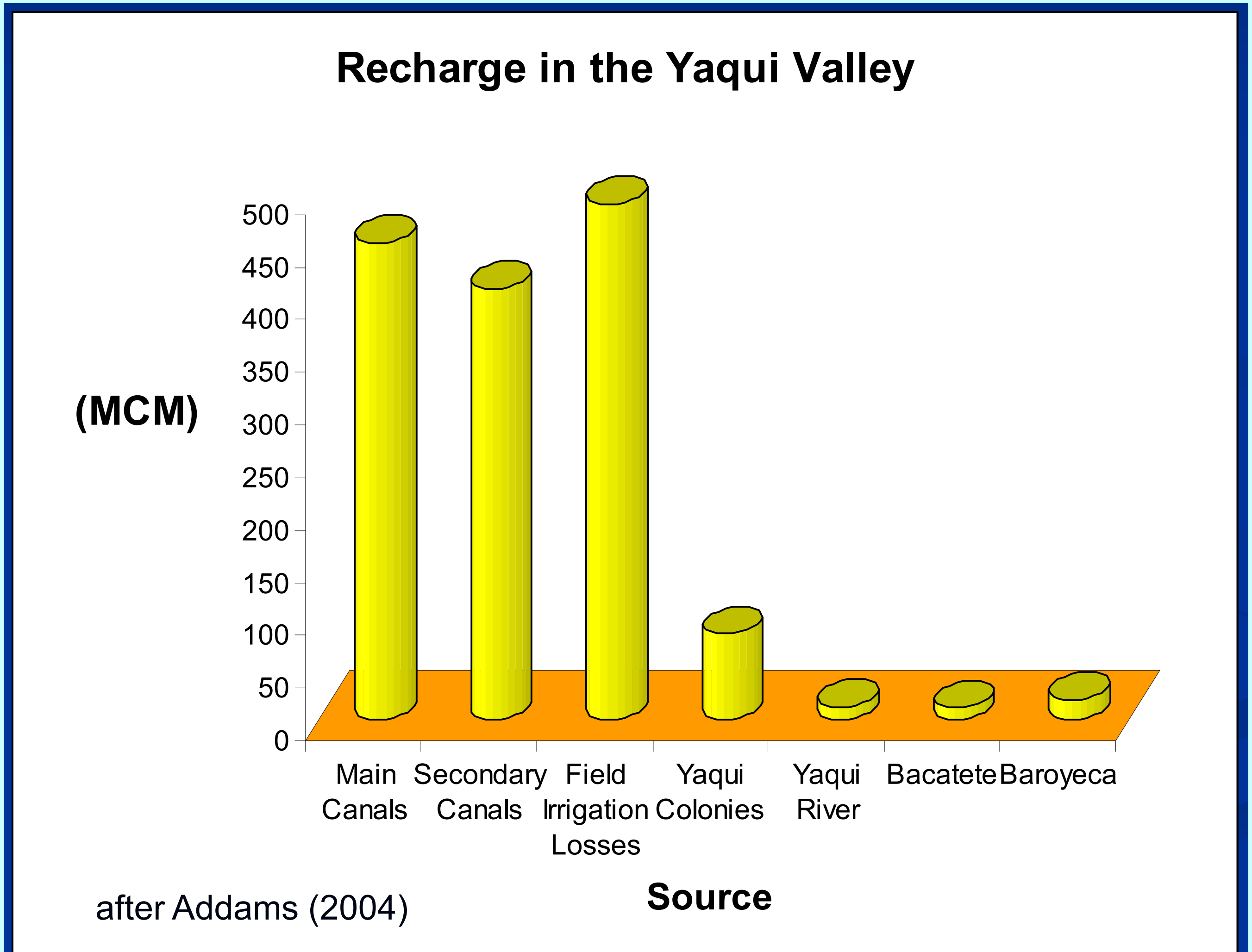


Map by:

Distrito de Riego del Rio Yaqui

Scale 1:200,000

GROUNDWATER RECHARGE

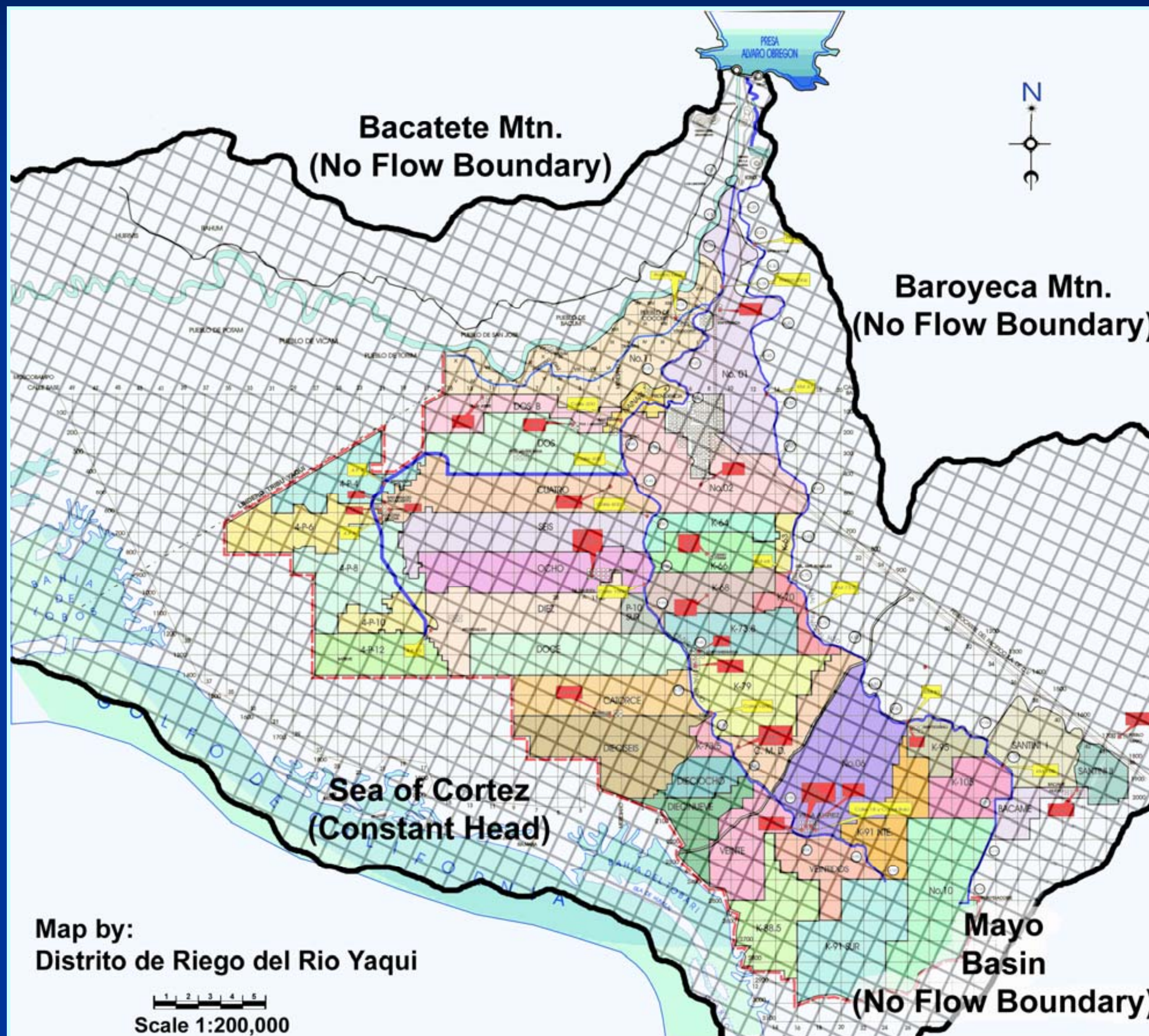


Average precipitation in the Valley is 300 mm/year. Based on the low precipitation and the high temperatures prevalent within the Valley, direct precipitation is considered negligible for recharge.

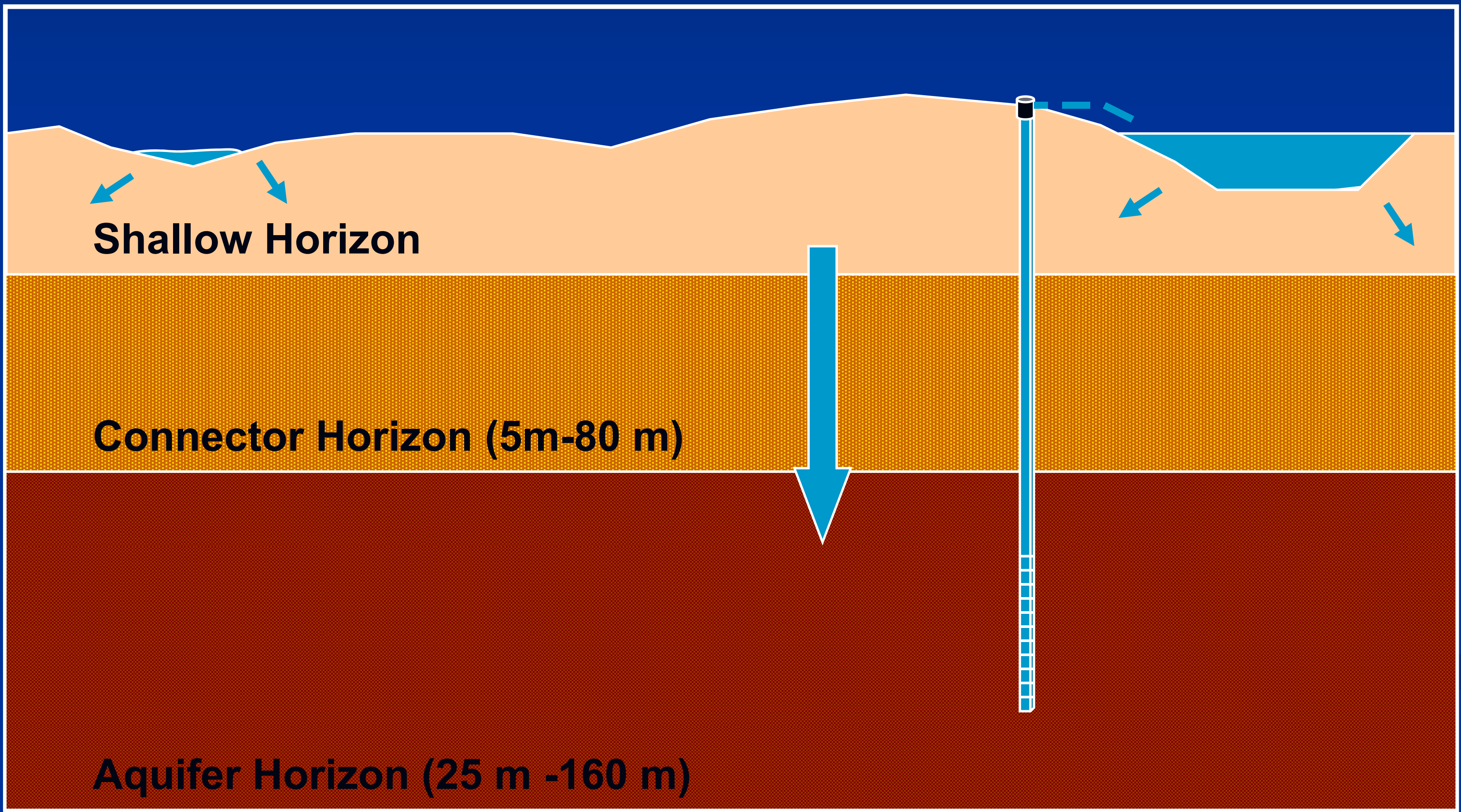
GROUNDWATER MODEL

- MODFLOW 2000 was used to model the Yaqui Valley.
- The model consists of three layers: a shallow aquifer horizon, a connector horizon and a deep aquifer horizon.
- The total grid size is 60 rows by 70 columns.
- The cell size is 2000 m. by 2000 m.
- The model includes
  - 350 wells
  - head-dependent recharge from the irrigation canals
  - head-dependent agricultural drains

MODEL BOUNDARIES



AQUIFER CROSS-SECTION



after Addams (2004)

SCENARIOS

Scenario	GW ext (MCM/yr)	Explanation	Ha max	Explanation
1	200	Average GW pumped	227,000	Winter crops
2	600	Current GW rights	227,000	Winter crops
3	200	Average GW pumped	300,000	Winter crops & Summer crops
4	600	Current GW rights	300,000	Winter crops & Summer crops
5	800	Hypothetical future GW usage	300,000	Winter crops & Summer crops

SCENARIOS BASED ON CLIMATE CHANGE

- The Canadian Center for Climate Modeling and Analysis (CGCM) was used for the period 2011-2040. The SRES A2 (high emission) was selected. The only parameter considered was precipitation.
- The bias-correction and downscaling approach developed by Wood et al (2002) was used to downscale the GCMs.

Scenario	GW ext (MCM)	Explanation	Ha max	Explanation
6	600	Current GW rights	227,000	CGCM, SRES A2 Doubling other water uses.
7	600	Current GW rights	300,000	CGCM, SRES A2 Doubling other water uses.

RESULTS

RESULTS: SURFACE AND GROUNDWATER MODEL

Scenario	GW (MCM)	Ha max	Ha	%	ΔS (MCM)
1	200	227,000	227,000	3	149.72
2	600	227,000	227,000	0	-251.92
3	200	300,000	289,925	3	150.72
4	600	300,000	300,000	3	-238.93
5	800	300,000	300,000	0	-452.19

- This table shows the percentage of times the reservoir storage falls below the users needs, the difference in groundwater storage and the average number of hectares that could be planted.

RESULTS: INCORPORATION OF CLIMATE CHANGE

- The trend on precipitation forecasted with the CGCM is to slightly decrease through time. The average decrease is approximately 0.05 % for the period 2011 to 2040.

Scenario	GW (MCM)	Ha max	Ha	%	ΔS (MCM)
6	600	227,000	227,000	0	-251.92
7	600	300,000	300,000	7	-237.62

CONCLUSIONS

- The rainfall-runoff model produces acceptable results when compared with historical data.

- There is enough surface water and groundwater to irrigate winter crops (up to 227000 ha), if the extraction is approximately 600 MCM. However, this amount won't be sufficient if the winter crops and summer crops are planted.

- Maximizing the extraction of groundwater (800 MCM) will allow the farmers to irrigate both crops without falling below the total water user's needs. However, the difference in storage is very significant.

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 if the farmers maximize the number of hectares planted.

- Different climate models and scenarios should be considered in order to explore more optimistic or pessimistic scenarios.

- The effects on temperature in the evapotranspiration should be considered for future work.

REFERENCES

Addams L. 2004. Water resource policy evaluation using a combined hydrologic-economic-agronomic modeling framework: Yaqui Valley, Sonora, Mexico. Ph.D.dissertation, Stanford University.

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

Schoups G., C.L.Addams, J.L.Minjares, and S.M.Gorelick. 2006. Sustainable conjunctive water management in irrigated agriculture: Model formulation and application to the Yaqui Valley, Mexico. Water Resources Research 42, W10417, doi:10.1029/2006WR004922.