

# Calibration of a water surface model for a basin in a semiarid region: The Rio Yaqui-Basin, Mexico

Department of Civil and Environmental Engineering

Andrea Muñoz-Hernández (906-487-3372; amunozhe@mtu.edu)

Alex S. Mayer (906-487-3372; asmayer@mtu.edu)

Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, United States

## ABSTRACT

This work consists of calibrating a detailed surface water flow model for a large arid basin located mainly in northwest Mexico. The model is based on a node-link concept, where each sub-basin is delineated using DEM data; runoff within each sub-basin is combined into a single outflow point. The node-link network includes three primary reservoirs within the basin. The network also includes nodes where all diversions occur.

Precipitation data was interpolated using data collected from forty three weather stations on a monthly basis over thirty years. Distributions of static runoff coefficients were generated based on published regional maps. The product of the precipitation and runoff coefficients were determined using GIS to find out the monthly hypothetical runoff. The monthly runoff data was merged into climatic seasons. The GIS-based seasonal runoff was further adjusted by calibrating against thirty years of seasonal inflow data collected at each of the three primary reservoirs along the river. The calibration involves fitting a simple empirical model that relates the GIS-based runoff to the reservoir inflows.

The calibration is difficult because: (a) the procedure involves merging infrequent, short-duration, and intense precipitation-runoff events to produce seasonal estimates of runoff; (b) the seasonal precipitation varies significantly from year to year; and (c) potential errors in the historical reservoir inflow data. Future work will include predicting the future flows in the rivers, accounting for uncertainty in future precipitation, and in model parameters.

## BACKGROUND

Mexico is suffering from a problem of water quantity. These shortages are most noticeable in the northern parts of Mexico where arid conditions and low rainfall have contributed to a worsening of this situation. For the purposes of this poster I will focus on a region in the northern Mexican state of Sonora called "The Yaqui Basin." The Yaqui basin is classified as an arid to semi-arid climate with average annual rainfall of less than 300 mm and a mean annual temperature above 22°C (71°F). Sometimes during the summer the temperature rises close to 50 °C (122°F). The basin consists of roughly 72,000 square kilometers of land with 58,000 square kilometers located in the state of Sonora itself. The remainder of the basin is shared between the Mexican state of Chihuahua and the American states of Arizona and New Mexico.



Localization Map

The Yaqui River Basin is a highly productive agricultural region. In fact, one of the most important agricultural fields in Mexico is located within the basin. The farmland that they service is known as the Yaqui Valley and consist of roughly 250 000 hectares. The water to irrigate this farmland comes from a series of three reservoirs constructed along the river.

The economic development within the basin consists of more than just agriculture. There are also industrial scale mining operations, and an aquaculture industry. These activities also demand significant supplies of water and have negative impacts on water quality.

Overall, the primary consumer of available water is agricultural farming. Although it is not the main source of employment within the basin, it is the basis of hundreds of businesses and services supporting a population of 250,000 people.



Basin Employment

## GOALS AND OBJECTIVES

The overall objective of this project is to develop an integrated water model of the Yaqui basin. This model will estimate the quality and quantity of both the surface and groundwater within the basin. It will be designed as a tool to support decision-makers to manage water supplies and minimize impacts to the environment. Specifically the goal of this poster is to address the creation and calibration of a surface water model which is a component of the overall project.

The goals of the surface water model are as follows:

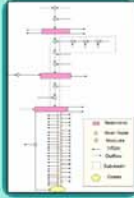
- Delineate a watershed utilizing Digital Elevations Models (DEM)
- Develop a conceptual model of water flow based on a link-node network
- Interpolate point data to create precipitation maps using GIS
- Digitize and georeference a run-off coefficient map
- Estimate the monthly hypothetical run-off within the basin using GIS
- Calibrating the estimated run-off with historical inflow data
- Determine an accurate conveyance factor of water flow between reservoirs

By providing a properly calibrated model to the farmers of the region they will have access to a tool that will allow them to better predict the future availability of water. With this information they can plan the planting size in hectares and the type of crops that would be best suited for the predicted conditions.

## PROCEDURE



The Rio Yaqui Basin



Node-link network model



GIS precipitation map



Run-off Coefficient map

### Delineation of the watershed

The first step in this project was to obtain the Digital Elevation Model (DEM) in order to delineate the watershed and sub-basin boundaries using GIS.

The basin is comprised of a total of 20 sub-basins. The sub-basins were put together and classified into an upper basin, a middle basin, and a lower basin with a single outflow point.

### Conceptual surface water model

After the basin was delineated, it was transformed into a node-link network, which is the conceptual basis for the surface water model. This node-link network includes the primary reservoirs within the basin, river reaches, locations of water demand and supply as well as the irrigation and drainage canals of the main agricultural area that can be located in the Valley.

The network will get its input from maps of distributed rainfall, runoff and evapotranspiration.

### Generation of precipitation maps

The next step in the creation of the model was the gathering of precipitation data from the Mexican National Commission of Water (Comision Nacional del Agua "C.N.A.") and the American Western Regional Climate Center. Forty three different weather stations located through out the basin were used to gather this precipitation information.

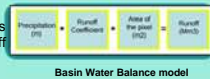
To convert the point data to surface data both Arc View and Arc GIS were used. Maps were developed on a monthly basis for a period of thirty three years from 1970 to 2003. The spatial interpolator used was Ordinary Kriging.

### Creation of the run-off coefficient map

A static run-off coefficient map was also produced based on paper maps of superficial water provided by the Mexican National Institute of Statistics, Geography, and Informatics (INEGI). In order to be able to use the maps in GIS, it was necessary to scan the maps, digitize them using Arc View, and finally georeference them using GIS.

In the Rio Yaqui basin three different run-off coefficient ranges were determined by INEGI. These coefficients are 0-5%, 5-10%, and 10-20%. The run-off coefficient ranges are based on topography, vegetation, and precipitation.

The run off was estimated on a pixel by pixel basis and was obtained by multiplying the precipitation map times the run-off coefficient.



Basin Water Balance model

### Calibration of the model

In order to calibrate the model the first step was to merge the data into climatic seasons. These climatic seasons could be twelve seasons per year, six seasons per year, four seasons per year, or three seasons per year. Then with the seasons selected, the best matches were determined between the historical data and the values obtained using GIS. In order to accomplish this a linear model of the form  $\alpha + \beta$  was used. Alpha refers to a run-off adjustment factor. If  $\alpha < 1$ , the run-off estimated with GIS must be decreased. If  $\alpha > 1$ , the run-off estimate with GIS must be increased.

The values of  $\alpha$  were found using Excel Solver when it minimized the sum of the squares of deviation between the historically observed values and the calculated values from GIS. The least square error was calculated on a season by season basis as well as an overall per basin. The overall error was calculated using the same approach.

The criteria used to determine which set of seasons are the best was (1) finding the minimum overall error per basin. (2) The grouping of months into seasons coinciding with the operational dam rules. (3) Attempting to fit as few parameters as possible.

### Conveyance Factor

In order to match the inflow data of the second dam, it was necessary to first calculate run-off data using GIS and then adding that data of the manmade releases of water from the first dam. For decades now a conveyance factor of 90% has been used and takes into account losses caused by infiltration and evaporation in the river. This factor has been considered constant through out the year for every part of the river. This model calculates the conveyance factor for each season to provide a more accurate estimate of water flow. A similar approach is used for the third dam.

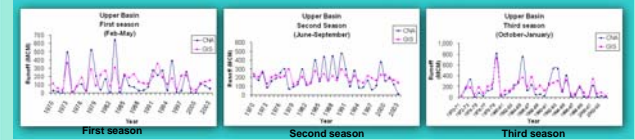
## RESULTS

The data was classified into three climatic seasons. The first corresponds to a dry season from February to May, the second season corresponds to summer precipitation from June to September and the third season corresponds to winter precipitation from October to January.

Basin	Season	$\alpha$	$\beta$	c. factor
Upper Basin	First season	2.454	0	N/A
	Second season	0.617	0	N/A
	Third season	1.142	0	N/A
Middle basin	First season	2.351	0	0.2
	Second season	1.446	0	0.2
	Third season	2.039	0	0.2
Lower basin	First season	0.214	14.531	0.7
	Second season	0.387	0	0.7
	Third season	0.139	19.41	0.7

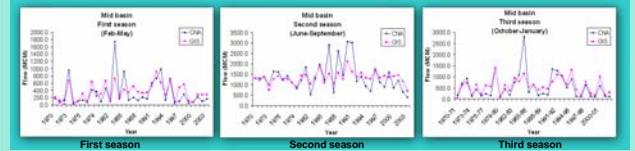
Parameters fitted with the empirical model

### Upper Basin



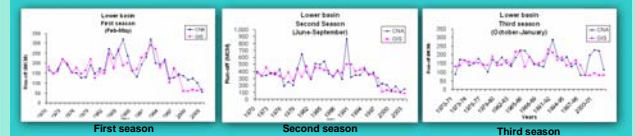
This basin was the base to select the way the climatic seasons were merged. The months coincide with the operational rules of the dam and the overall error was satisfactory. This error per basin is 7.362 %.

### Middle Basin



The overall error is 6.1 %. The conveyance factor was reduced from 90% to 20%, this represents a big difference between the calculated inflows for the farmers and the actual inflows. For example, in the period 1993-1994, the farmers would expect in the second dam 318 Million Cubic Meters (MCM) from the first dam releases when actually the inflows could have been as small as 71 MCM.

### Lower Basin



The overall error is 3.7 % and the conveyance factor is 70%. Although it is not a big decrement of the conveyance factor, it can represent a good amount of water. For example, in the period 1993-1994, the releases from the second reservoir were 2907 MCM. The farmers predicted inflows to the third dam of 2616 MCM. With a reduction of the conveyance factor, the actual amount could have been 2035 MCM.

## CONCLUSIONS

The calibration of this model is an on going process and faces certain difficulties for a variety of reasons. Some of these problems are listed below:

- The factor provided by C.N.A., which takes into account the losses for evaporation and infiltration is too high (90%). This brings two problems, first, the fitting is more difficult because the GIS values plus the releases from the dam are much higher than the observed values and the second problem is that the farmers can be misled about the amount of water that will be available for raising crops. In addressing this problem different factors will be tested in order to find better matches while maintaining the proper value range for alpha and beta.
- The releases from the first dam (La Angostura) to the second dam (El Novillo) are only available from 1987 to 2003. That produces a significant lack of estimated inflow data to El Novillo that increases the sum of the square errors; This problem is being addressed by investigating the water rights for every user of the first dam and estimating the appropriate release of water to the second dam.
- The merging of the data into seasons represents a challenge. Although some possibilities were explored in this project it is necessary to continue trying different possible combinations of month to merge the data into climatically seasons.

Future work will include assessing the agreement between the GIS-based seasonal runoff and the historical reservoir inflow data and then estimate the uncertainty in the parameters of the empirical model. A stochastic simulation approach will be applied to predict future flows in the river accounting for uncertainty in future precipitation and uncertainty in model parameters.

## ACKNOWLEDGEMENT

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