Semester Report

The Témez Model:

Application with GIS

GIS in Water Resources, Fall 2013
Dr. David R. Maidment and Dr. David G. Tarboton

By:

Antonio Cañamás Catalá

Table of Contents

1. Introduction

1.1. Water Resources Assessment

Water Resources assessment has a wide range of spatial and temporal scales. The methodology applied depends on the goals of the analysis, and of the variability of meteorological and hydrological inputs-outputs targets. Water supply systems, on which this report will focus, use a monthly or seasonal time step.

In order to implement a correct Water Resources assessment, it is necessary to characterize the Natural Regime. This means water resources under predevelopment, that is, if there were not any influences upstream from the location studied. The two main reasons for this step are:

- To perform a correct assessment of the available resources
- To obtain the Inflow Time Series for river basin management models

The Basin hydrology is represented in a management model as an input sequence of streamflows at each specific location. In this report, we will simulate long time series of streamflows (and other hydrological parameters) to determine how well a system might perform in the future.

1.2. Objectives

The main objectives of this report are enumerated as follows:

1. Description and characterization of the Témez Model.
2. GIS application of the Témez Model on two water basins of two different countries: Spain and United States.
3. Research of the different GIS databases in Spain and how they compare with the existing ones in the U.S.
4. Discussion of whether the results obtained describe the behavior of the sub basins studied.
5. Application of the model: streamflow prediction with a climate change scenario.

2. Témez Model Description

2.1. Definition

Hydrological models respond to the following classification:

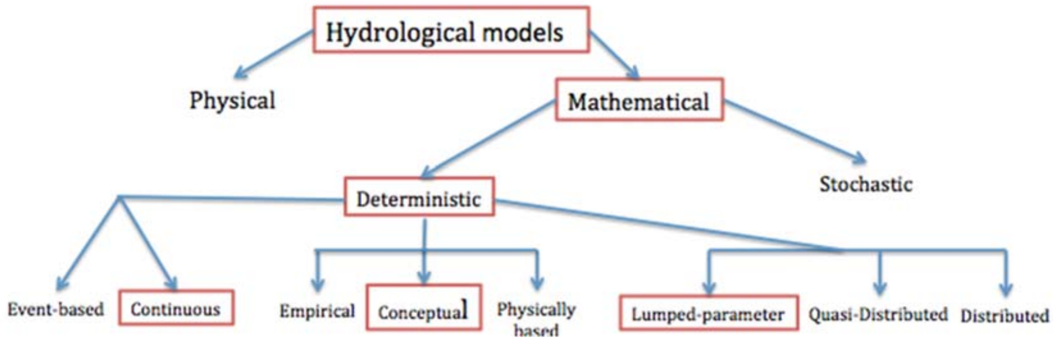


Figure 1: Hydrological Models Classification

As it can be seen in Figure 1, the Témez Rainfall-Runoff Model is a Mathematical Deterministic Hydrological model:

- Continuous: simulates completely the Hydrological Cycle continuously in time.
- Conceptual: based on water balances.
- Lumped-Parameter: variables and parameters lumped.

2.2. Water cycle parameters

The following parameters, which explain the Hydrological Cycle, are contained in the Témez Model.

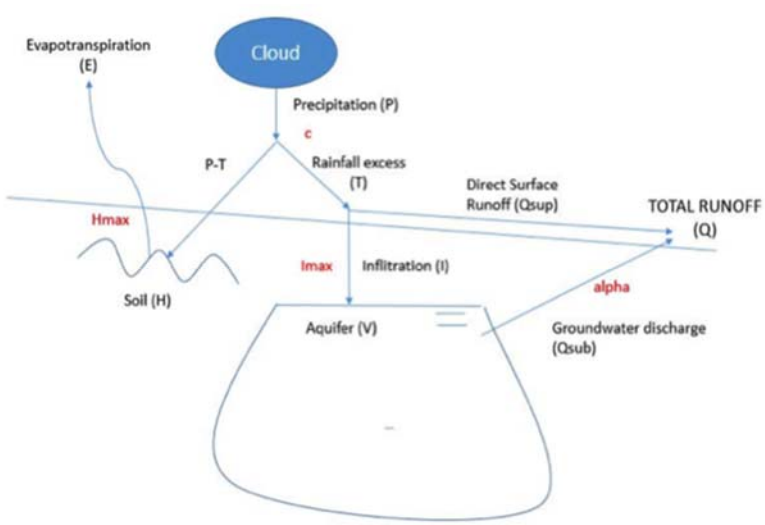


Figure 2: Témez Model Parameters

As shown in Figure 2, two different storages are considered:

1. Superior: non-saturated zone (soil, H).
2. Inferior or aquifer: saturated, underground reservoir with discharge into the drainage basin.

The parameters that characterize the basin, which we will calibrate to simulate the basin's behavior, are written in red in the sketch:

H_{max} → Maximum soil moisture

I_{max} → Maximum infiltration

C → Excess coefficient

α → Groundwater discharge parameter

2.3. Formulation

The expressions, based on mass water balance equations, necessary to run the model and that characterize each of the embedded parameters are:

1. Rainfall Excess (T):

$P_i \leq P_0$ $\quad T_i=0$

$P_i > P_0$ $\quad T_i= (P_i - P_0)^2 / (P_i + \delta - 2P_0)$ $\quad$ where: $\delta= H_{max} - H_{i-1} + PET_i$

$P_0 = C\ (H_{max} - H_{i-1})$

Where,

- P_i: precipitation in month i
- T_i: water excess in month i
- H_{i-1}: soil moisture in month i-1
- PET_i: potential evapotranspiration in month i

2. Soil moisture balance and actual ET:

ET_i= min (PET, $H_{i-1} + P_i - T_i$)

H_i= max (0; , $H_{i-1} + P_i - T_i - ET_i$)

3. Infiltration (aquifer recharge):

$I_i = I_{max}\ (T_i / T_i + I_{max})$

where I_i is the infiltration in month i

4. Direct Runoff ($Q_{sup\ i}$)

$Q_{sup\ i} = T_i - I_i$

5. Groundwater Discharge ($Q_{sub\ i}$)

Linear Reservoir model: The aquifer is assumed to behave as a tank where the outflow depends on the volume.

$R_i = A * I_i$

where A is the area of the basin and R_i the recharge in month i.

$V_i = V_{i-1}\, e^{-\alpha} + R_i\,(1 - e^{-\alpha}) / \alpha$; where V_i is the water volume of the aquifer in month i

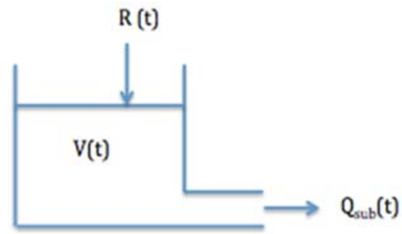


Figure 3: Linear Reservoir Model

$Q_{sub\ i} = V_{i-1} - V_i + R_i$

6. Total Runoff

$Q_i = Q_{sup\ i} + Q_{sub\ i}$

where Q_i is the total runoff in month i.

2.4. Implementation

The equations associated with the model are implemented in an Excel file (or similar), with a distribution similar to Figure 4:

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
			Hmax	c	Imax	alpha	H0	V0							
	Area (Km2)	1396	200	0,01	180	0,5	20	60							
Month	Precip (mm)	Pot. ET (mm)	delta	P0i	Ti	ETi	Hi	Ii	Recharge	AQ Vi	Rsub	Rsur	Month	Rtotal	Streamflow (Hm3/month)
oct-1990	110	67,51167832	247,5117	1,8	33,07955	67,511678	29,40877	27,94411	39,00998	53,6498	45,36019	7,16907127	oct-1990	52,52926	32,02
nov-1990	110,435	33,62476812	204,216	1,705912	37,9837	33,624768	68,2353	31,36503	43,78558	51,91092	45,52446	9,23965746	nov-1990	54,7641171	20,31
dic-1990	37,2975	17,27179727	149,0365	1,317647	7,047137	17,271797	81,21387	6,781631	9,467156	35,67382	25,70426	0,37064635	dic-1990	26,0749028	10,81

Figure 4: Sample Implementation in Microsoft Excel

A) Steps

1. **Data** collection, analysis and preprocessing.
2. **Calibration** of the parameters: the objective is to minimize the difference between the observed streamflows and those that are calculated (at least 20 years of data). This is accomplished by:

   a) Previous parameter estimations.
   b) Parameter adjustment by comparison: use of monthly value graphs, annual values graphs and mean monthly values graph.

3. **Validation** of the model: comparison with values of recent years (5-10 years).
4. **Scenario Simulation**

B) Necessary Input Data

The input data for the model are

- Monthly Time Series of at least 25 years for the Precipitation (P_i)
- Potential Evapotranspiration (PET_i)
- Observed Streamflows

It will also be necessary to obtain information relevant to the Surface of the basin, the initial Soil Moisture (H_0) and the initial Aquifer Volume (V_0).

The effects of the initial Soil Moisture and Aquifer Volume are confined to the streamflows of the first few months. The values of these two parameters can be approximated by observing the initial differences between the calculated and observed streamflows.

3. Sub basins

3.1. Spanish sub basin

As explained in the Water Resources Assessment section, for the proper functioning of the model, there must not be any influences upstream from the drainage point of the basin. It was quite difficult to find a basin that fulfilled this requirement and had the required data for the model available. After extensive research, it was decided that the Upper Mijares in the East Coast of Spain (Figure 5) be modelled for the Spanish sub basin. In the delimitation of the watershed (see section 4), a reservoir just downstream of the outflow gage can be observed.

Using GIS, the area of the sub basin was found to be 1396 km^2 and the outflow streamflow gage, as well as the rain gages located inside the sub basin, were identified.

Figure 5: Upper Mijares Sub Basin in Spain

3.2. U. S sub basin

For the U. S., a well-known sub basin was chosen: Upper Blanco River in the area of Austin and San Antonio (Figure 6). The surface of this sub basin is found to be 921.16 km^2.

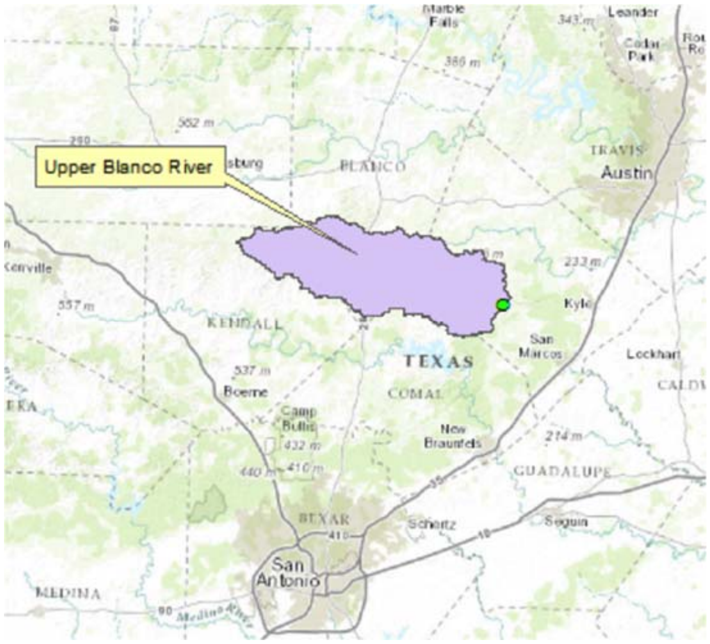


Figure 6: Upper Blanco River Sub Basin in the Austin and San Antonio Area

4. Data Sources

4.1. Precipitation and Streamflows

GIS has been used in this report as a data extraction tool.

For the Spanish sub basin, a GIS desktop (developed by the Agricultural, Alimentation and Environmental Spanish Government Department) has been used for the extraction of both the Precipitation and Streamflow Time Series. This was made possible thanks to the identification of the gages located within the Upper Mijares sub basin through the Shapefiles obtained from the same Spanish Government Department. At this point, it is noteworthy that the data found for this sub basin was available only from the year 1990 onward.

On the other hand, the NLDAS tool enables us to extract hourly, monthly and yearly data for several parameters from the Hydrological Cycle. In this case, the Precipitation monthly Time Series were extracted in packages of 10 years (more years oversaturated the computer capacity). The Zonal Average was done with the phyton code provided by Dr. Tarboton in Exercise 5. The Streamflow Time Series were obtained using the USGS database which contains a large number of records of monthly Streamflow data for different sites. In our case, the utilized site was called: Blanco Rv at Wimberley, Tx

The following table summarizes the data sources:

Variable	Spain	U.S
P	SAIH	LDAS tool
Streamflow	Anuario de Aforos	USGS science for a changing world
PET	No direct source	No direct source

4.2. Potential Evapotranspiration

The PET data was not found directly for any of the sub basins. To overcome this obstacle, the simple Thornthwaite formula was employed:

$PET_i = 16\ (L/12)\ (N/30)\ (10\ T_i/I)^{\alpha}$

Where,

- L is the mean daylight hours of the month
- N is the no. of days in the month
- T_i is the mean monthly temperature
- I and α two parameters that depend on T_i

The temperature data was obtained from a Spanish meteorological website. On the other hand, for the U.S., the LDAS tool also allowed us to extract the mean skin temperature in the sub basin.

5. Results

5.1. Spanish Watershed

The steps explained in section 2 (Implementation) were followed to simulate the basin's flows.

A) Calibration

The two methods followed to calibrate the parameters of the sub basin are:

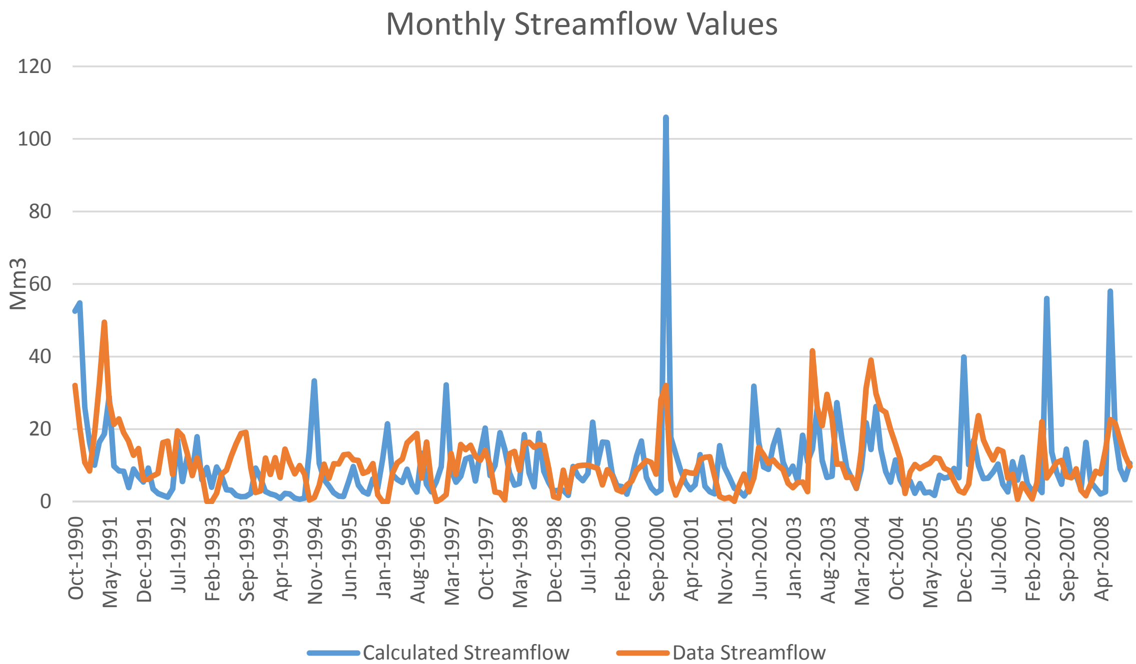
1) Visual analysis: adjust the calculated streamflow to the data streamflow using the Monthly Values and Mean Monthly Values graphs
2) Optimization: minimize the error (mean square difference) between the calculated streamflow and the data streamflow using the *Solver Tool* with the following conditions: c, H_{max}, I_{max}, $\alpha > 0$ and $c < 1$.

The values obtained for the parameters are the following:

		H_{max}(mm)	c	I_{max}(mm)	α	H_0(mm)	V_0(mm)
Area (Km^2)	1396	200	0.01	500	0.5	20	60

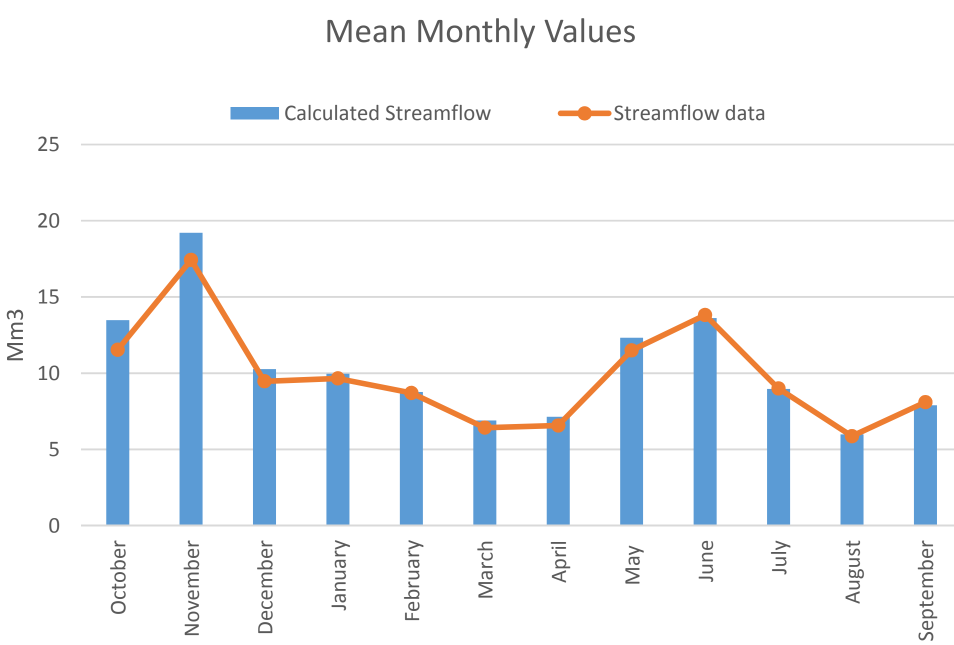
The groundwater discharge parameter is the major parameter that contributes to the base flow of the basin (flow during periods without storms). The value obtained for α (0.5) is very high. This can mean that the aquifer located below the basin is highly permeable. This is consistently related to the value of the surface coefficient (c=0.01), which is very low, and the I_{max} value (500 mm).

The graph below shows the results from the calibration process:



From the Monthly Streamflow Values graph, we can conclude that the model has not yet reached a good calibration, due to the insufficient data available (only from 1990 onwards). The Temez model is primarily developed to model the baseflow and not to simulate well the peak flows. This is evident for October 2000 where the difference in the calculated streamflow and the data streamflow is noticeable.

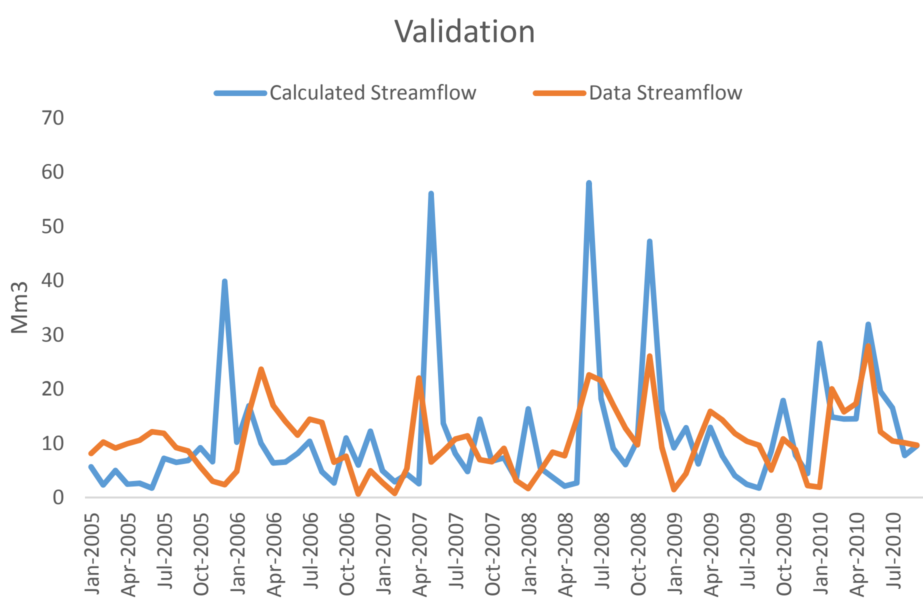
On the other hand, the mean monthly values adjust very precisely to the data as shown in the chart below.



The main differences can be found in October and November. Due to the Mediterranean Climate, major storms occur during these months. These storms are strong in magnitude (mm of rain) and short in duration, making the error between the calculated and the real streamflows larger. For the rest of the months, as said before, the results are quite satisfactory.

B) Validation

In order to validate the parameters obtained during the Calibration process, the last 5 years of data (2005-2010) have been used as shown in the chart below. It can be observed that for the last year (2010) the model is starting to simulate the streamflows very well (need for more data).



5.2. U.S. Watershed

The same procedure explained for the Upper Mijares Sub basin has been used in the Upper Blanco river sub basin.

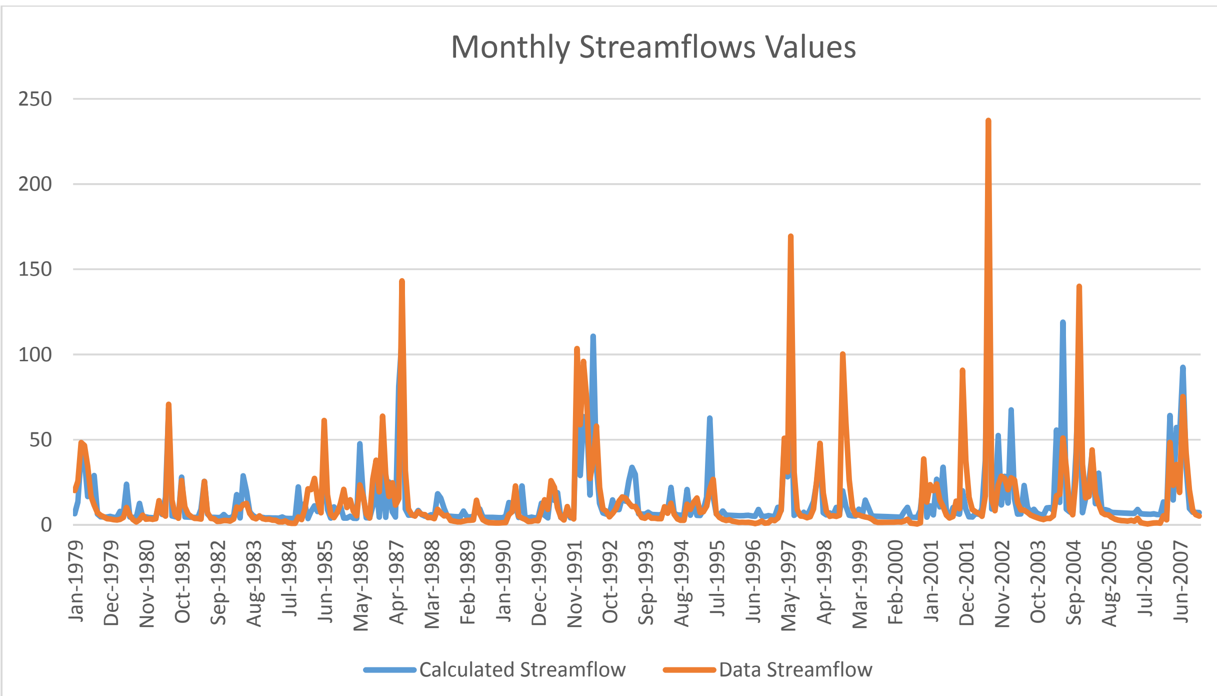
A) Calibration

In this case, the results of the parameters can be used to conclude that the sub basin has a smaller contribution to the aquifer (α=0.013) and a bigger to the surface runoff (c = 0.1789) than the Upper Mijares sub basin. The maximum soil moisture content (H_{max} = 426 mm) has been found to be very high in the area of the sub basin.

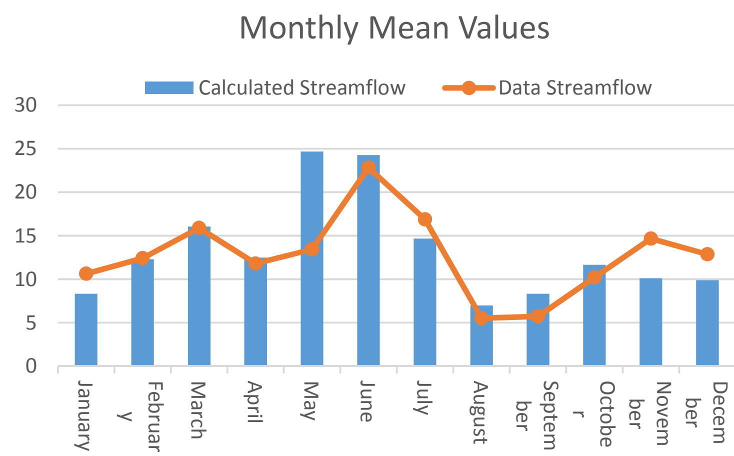
		H_{max}(mm)	c	I_{max}(mm)	α	H_0(mm)	V_0(mm)
Area (Km^2)	921.16	426	0.1789	290	0.013	260	300

The Monthly Streamflow Values graph shows the very good calibration of the model. Even though the peaks are again badly simulated, the baseflow is found to approximate accurately the streamflow data.

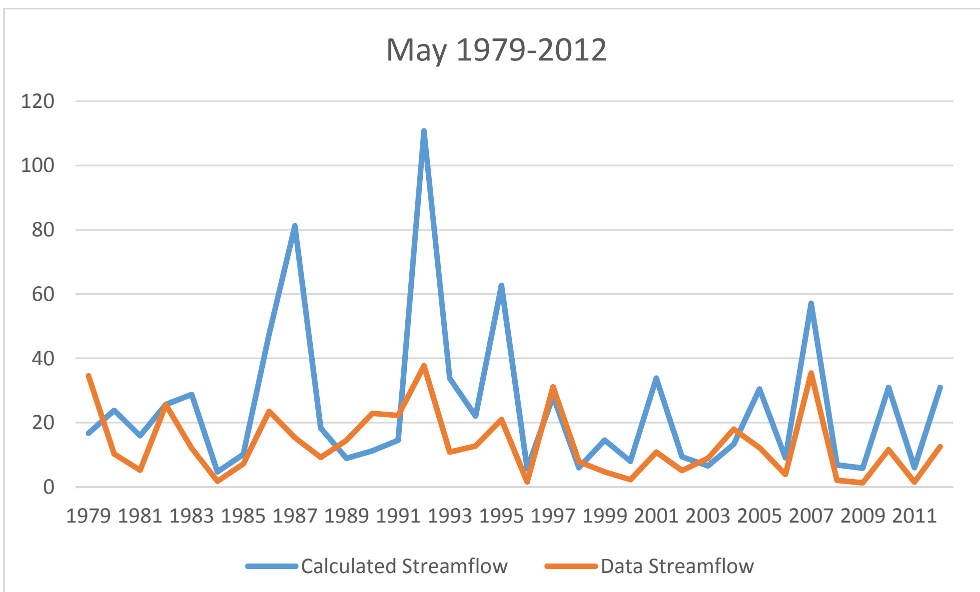
The data available for this basin was more extensive (1979 – 2013) and this explains the better performance of the model.



In the Monthly Mean Values plot shown below, more or less all months adjusted to the data, but with bigger differences than for the Upper Mijares basin. However, a huge difference between the results of the model and the real data was found in May.



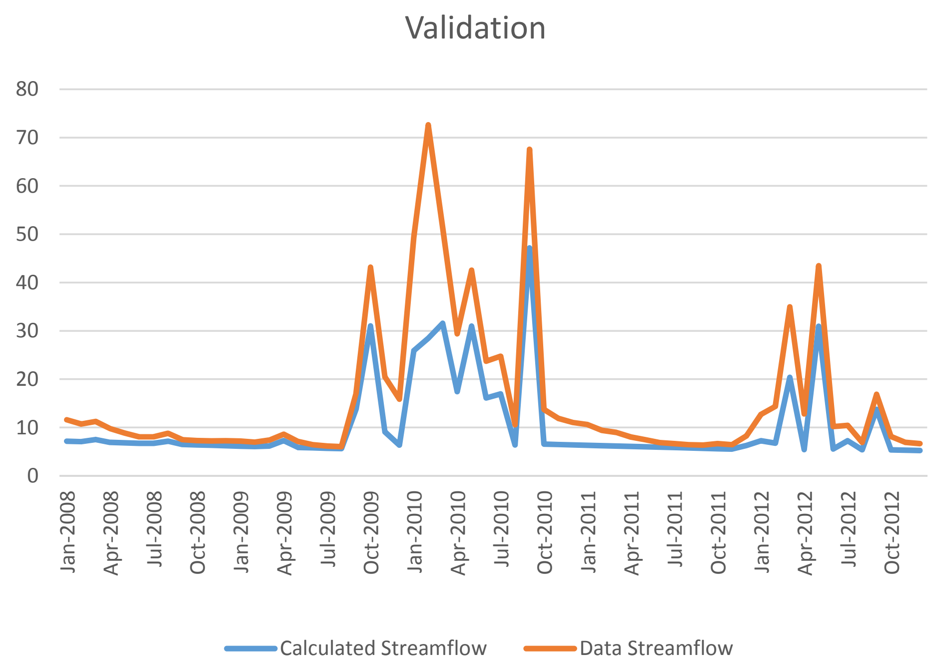
To determine the sources of error during this month, the results and data for May were plotted in a separate graph:



A possible explanation can be that the errors usually compensate in a positive and negative matter (sometimes the model gives a bigger result and others a smaller one), but for this month all the results seem to be overestimated. Nevertheless, no specific explanation to why this is happening has been found.

B) Validation

The last four years were plotted to validate the model. The results show a much better approximation of the basin's behavior than for the Upper Mijares sub basin. The availability of more data (12 years more) justifies the better quality of model outputs.

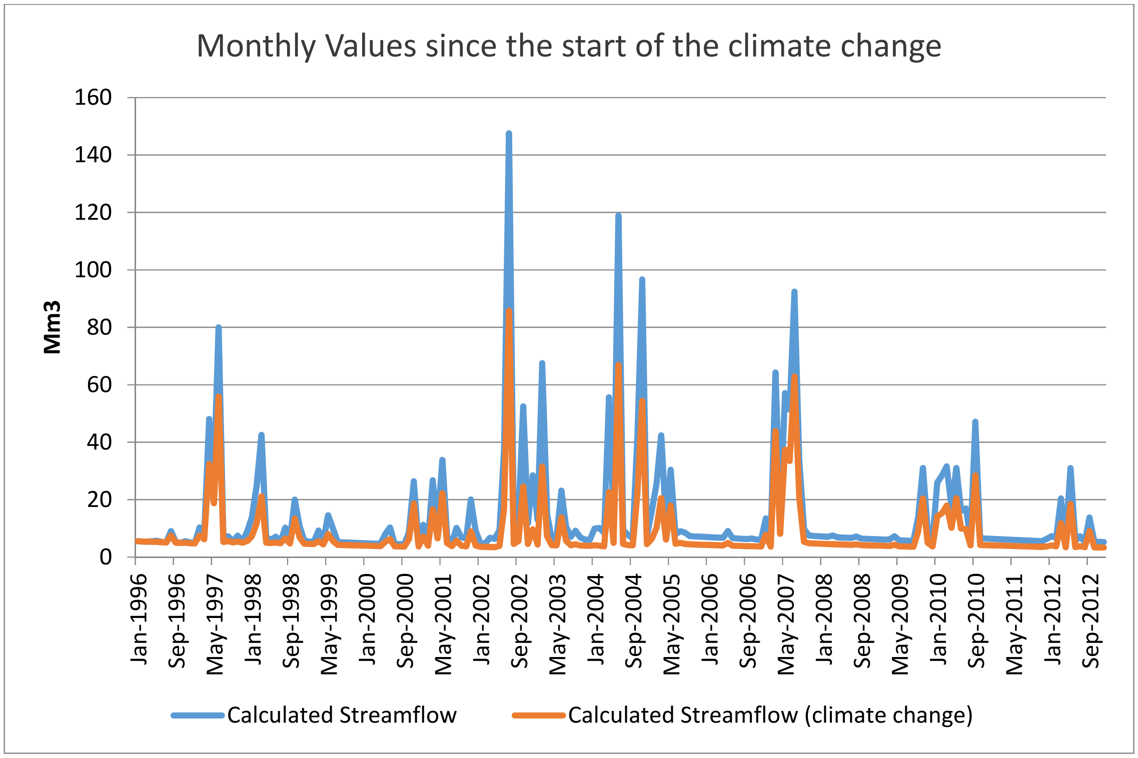


6. Climate Change Simulation

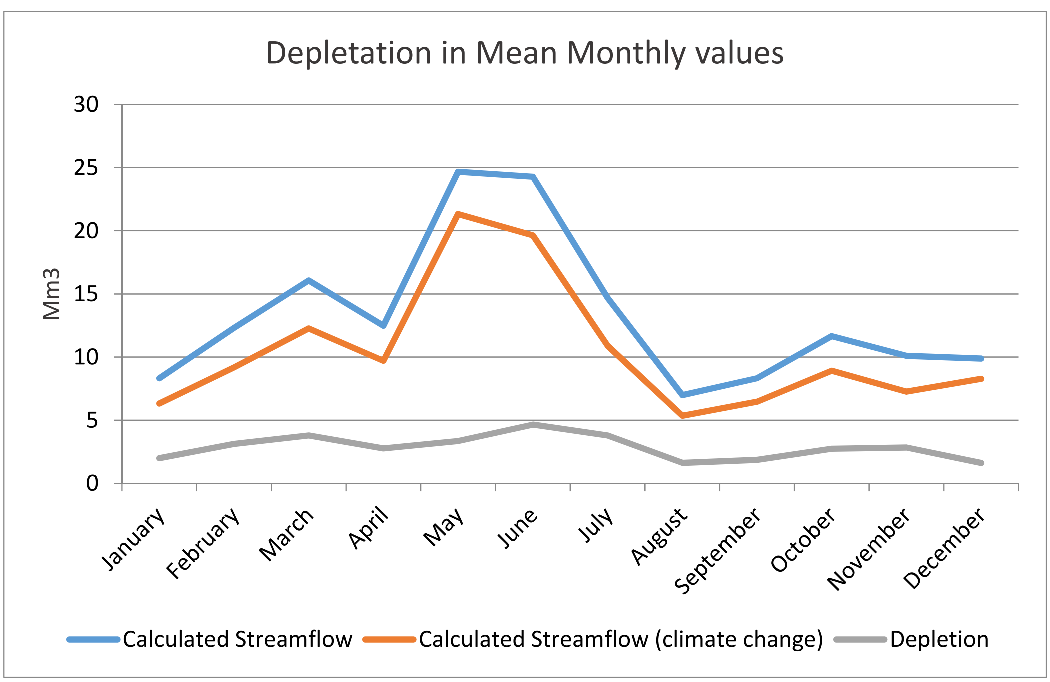
A Climate Change Scenario has been simulated for the Upper Blanco River Sub basin.

To simulate the conditions of this hypothetical scenario, the precipitation and potential evapotranspiration input data has been decreased and increased, respectively. The data obtained from the Zonal Average from 1996 onwards has been multiplied by 0.9 (10 % decrease). On the other hand, the evapotranspiration data has been multiplied by 1.12 (12% increase). These modifications simulate the reduction in rain and the increase in evapotranspiration, due to the increase in the global temperature.

In order to analyze the results, the calculated streamflow with the climate change simulation data has been plotted against the calculated streamflow for the base scenario in the graph below.



In the above graph it can be observed that the climate change effects in the baseflow (depletion) start to be noticed after, more or less, 2 years of data (1998). The Mean Monthly Values shows us more clearly the importance of the depletion:



In terms of numbers the mean depletion per monthly value was:

Mean depletion per month:	
5.69 Mm3	35.30%

7. Conclusions

The Temez Model has been showed to perform a good simulation of the river basin's baseflow when the necessary data is available. The data found for the U.S. sub basin ranges from 1979 to 2013 (i.e 33 years), and at the end of this period, we can conclude that the model is working properly. On the other hand, the Spanish data was only 20 years long (1990-2010), and the performance of the model was not satisfactory (the Calibration step is not yet over with that number of years).

The application of this model to simulate hypothetical scenarios (e.g. Climate Change, Pumping…) is a useful tool for Water Resources Management. One can analyze the impact of the new conditions in the basin and how this affects the water resources available for supply. In the scenario proposed in Section 6, the impact of a reduction in rain and an increase in potential evapotranspiration reduces more than a 35% the availability of the Water Resources in the basin. Such analysis can help the Water Authorities to prioritize the allocation of Water Resources and take preventive measures to avoid scarcity.

8. References

- Water Resources Planning and Management course documents, Universidad Politecnica de Valencia
- Ministerio de Agricultura, Alimentacion y Medioambiente, Spanish Government Department (http://www.magrama.gob.es)
- Confederación Hidrográfica del Júcar, (http://www.chj.es)
- IMPLEMENTACIÓN DEL MODELO HIDROLÓGICO DE TÉMEZ PARA LA EVALUACIÓN DE RECURSOS HÍDRICOS CON GRASS GIS. FASE SUPERFICIAL Y SUBTERRÁNEA; A. Pontenciano de las Heras y J. J. Villaverde Valero
- USGS website (http://www.usgs.gov)