04-027

CALIBRATION AND SIMULATION OF THE WATER BALANCE OF THE GUADALQUIVIR BASIN USING PARAMETERS OF THE SOILS OBTAINED IN FIELD WORK.

Villena Martínez, Esteban Manuel [1]; Alvizuri Tintaya, Paola Andrea [1][2]; Torregrosa López, Juan Ignacio [3]; Lo Iacono Ferreira, Vanesa Gladys [3]; Lora García, Jaime [3]

[1] Universidad Politécnica de Valencia / Universidad Católica Boliviana, [2] Centro de Investigación en Agua, Energía y Sostenibilidad, Universidad Católica Boliviana San Pablo, [3] Universidad Politécnica de Valencia

The hydrological simulation in basins is a complex process that requires a series of climatological, hydrological and physical data of the soils. Hydro-climatological data are generally provided by state institutions in charge of monitoring and processing this information. However, the characteristics of the soils with respect to use, vegetation cover and hydraulic properties such as humidity and infiltration are not usually available. In these cases, estimates or remote sensing are used. However, these processes have a high degree of uncertainty in the final results. The Guadalquivir basin located in Tarija, Bolivia is a basin with little information. During 2018 and 2019, a research project was developed to find the infiltration and characterization properties of the soils from work carried out in the field ""In Situ"", with the use of Minidisc infiltrometers.This article shows the process of calibrating the water balance of the Guadalquivir basin using the results of the infiltration and characterization of the soils as a result of the research work. Likewise, the results of the simulation and the calculation of the basin contributions based on the Témez model using the CHAC software are analyzed.

Keywords: Hydric balance; CHAC; Temez; infiltration; mini disc.

CALIBRACION Y SIMULACION DEL BALANCE HIDRICO DE LA CUENCA DEL GUADALQUIVIR UTILIZANDO PARAMETROS DEL SUELO OBTENIDOS EN TRABAJO DE CAMPO.

La simulación hidrológica en cuencas es un proceso complejo que requiere de una serie de datos climatológicos, hidrológicos y físicos de los suelos. Los datos hidro climatológicos generalmente son proporcionados por instituciones estatales encargadas del monitoreo y procesamiento de esta información. Sin embargo, las características de los suelos respecto al uso, cobertura vegetal y propiedades hidráulicas como humedad e infiltración no suelen estar disponibles. En estos casos, se recurre a estimaciones o a la teledetección. Sin embargo, estos procesos tienen un grado de incertidumbre en los resultados finales, elevado. La cuenca del Guadalquivir ubicada en Tarija, Bolivia, es una cuenca con escasa información. Durante 2018 y 2019 se desarrolló un proyecto de investigación para encontrar las propiedades de infiltración y caracterización de los suelos a partir de trabajos efectuados en campo “In Situ”, con la utilización de infiltrómetros Minidisc. Este artículo muestra el proceso de calibración del balance hídrico de la cuenca del Guadalquivir utilizando los resultados de la infiltración y caracterización de los suelos producto del trabajo de investigación. Asimismo, se analizan los resultados de la simulación y el cálculo de las aportaciones de la cuenca basados en el modelo de Témez que utiliza el software CHAC.

Palabras claves: Balance hídrico; CHAC; Témez; infiltración; minidisc.

Correspondencia: Vanesa Lo Iacono Ferreira valoia@upv.es Esteban Manuel Villena Martínez esteban.villena@gmail.com

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1. Introduction

Hydrology is the natural science that studies water, its origin, circulation and distribution on the earth's surface, its chemical and physical properties and its relationship with the environment and living beings. Its importance lies in providing the engineer with the methods to solve the practical problems that arise in the design, planning and operation of hydraulic works (Villón, 2004).

According to Cabrera, J. (2020), the basis of the study of Hydrology is the understanding of the hydrological cycle, its processes, and interrelations both superficial and subsurface, and this understanding implies "measuring". Although the methods and techniques for measuring flows and rainfall have evolved over time, it is also true that other components of the hydrological cycle have not suffered the same fate as they occur under the ground.

Ramos and Francés (2014), point out that hydrological modeling plays an important role in most aspects of water and environmental management. However, most hydrological models allow to simulate flows not only at the outlet of a basin, but in any part of it, but the effectiveness of these models depends on the availability of the input data.

A hydrological model seeks to represent the different processes involved in the distribution of rainfall and the generation of flows in each basin. Currently there are a wide variety of models, which have been raised under certain hypotheses whose clear understanding guarantees their correctness (Jorquera, Weber and Reyna, 2012).

The study of the water balance in basins is based on the application of the mass balance principle, which establishes that for any arbitrary volume and during any period of time, the difference between inputs and outputs will be conditioned by the variation in the volume of stored water. (UNESCO, 1981). The factors that influence the water balance are defined by precipitation, temperature, solar radiation, wind, etc., and geographical and geological parameters such as land use, slope, texture, and infiltration (C. Alvarado & M. Barahoma-Palomo, 2017).

Cabrera J. (2014, 2020) indicates that infiltration, deep percolation, subsurface flow, underground flow, among others, are processes that are usually measured indirectly and / or remotely, which leads to strong uncertainty regarding the functioning of the hydrological cycle.

Infiltration is a key process in aspects of hydrology, agricultural and civil engineering, irrigation design, and soil and water conservation. It is defined as the infiltration capacity as the maximum rate at which a soil under certain conditions absorbs the rain that falls and that varies with time, especially during the initial period of the rain, reaching at the end, a minimum infiltration capacity (Horton, 1940). The process depends on the properties of soil fall and initial and boundary conditions within the flow domain (Assouline, 2013). The infiltration rate depends on the soil surface conditions, while other authors such as Parr & Bertrand (1960) indicate that the infiltration depends on the soil mass, regardless of the surface conditions.

In the methodological guide for the preparation of surface water balances in Bolivia, Soria (2016) indicates that, for the use of coverage factors, vegetation, use and type of soils, it is a very common practice to consider several sources of information for the same factor, due to the possible existence of gaps or incomplete data.

The upper basin of the Guadalquivir River is in the Department of Tarija, located in southern Bolivia. It has an approximate area of 1700 km² and an area of 70 km. It covers 4 municipalities: San Lorenzo, Padcaya, Uriondo and Cercado; the latter being the one belonging to the Capital of the Department. Currently, the central valley of the Guadalquivir basin that circumscribes the urban area of the Cercado municipality represents the largest population in the department, generating the most important environmental and water impacts from the consumption and generation of wastewater, turning the Guadalquivir river into a permanent and constantly growing source of contamination, threatening the health of the inhabitants (Copa and Villena, 2016).

The hydrometric information in the study area is scarce. According to Espejo (2016), in the report on the surface water balance of the Guadalquivir basin, there are monitoring stations abandoned since the mid-1990s, which generates a greater information deficit in the control of the supply system in the Tarija valley.

On the other hand, information on land use and vegetation cover is also very scarce. The classification of soils for hydrological purposes is obtained from several sources, among which the study of Agroecological and Socioeconomic Zoning of the Department of Tarija (ZONISIG) that dates from the year 2000 Ministry of Sustainable Development and Planning, (2000) stands out. This study offers data on land aptitudes for the generation of land use plans at the departmental level. However, it does not offer exclusive data on the project area and technical aspects for hydrological use such as infiltration or percolation that allow determining the hydraulic conductivity of the soil, limiting technical information, and allowing only the determination of general data.

The general equation of the water balance that represents the basis of hydrological modeling is usually defined by two fundamental conditions that influence the precision of the model, the spatial limit and the time scale. However, the availability of data and the study objective that leads to the selection of the models are also factors that affect the quality of the results and the degrees of uncertainty (Stolpa, 2017).

The Témez model (1977) is an aggregate model of continuous runoff simulation, with few parameters and with a monthly flow (Ministry of the Environment and Water, 2016). The theoretical development of the Témez model is of a general nature, so in principle any time interval can be applied (hourly, daily, weekly, monthly, annually), although it must be verified that the time periods used provide an answer. consistent with the physical reality of the hydrological system under study. The most used time interval is the monthly one (Murillo and Navarro, 2011).

The Témez model is integrated into the system called Hydrometeorological Calculation of Contributions and Floods (CHAC, 2013) that has been prepared by the Center for Hydrographic Studies of Spain (CEDEX) to model the different hydrographic units of levels 3 and 4 classifieds by the Pfafstetter method. for Bolivia (Ministry of the Environment and Water, 2016).

Being essential to obtain infiltration data for the calculation and simulation of the water balance and to mitigate the uncertainty generated by the use of data estimated or obtained remotely, during 2017 and 2018 with the support of the Catholic University Boliviana Regional Tarija the research work was carried out to obtain infiltration parameters of the soils of the Guadalquivir basin (Villena, E. et al. 2018 and Villena, E. et al. 2019). This project shows the results of calibration and simulation of the water balance using the infiltration data obtained in the research project.

2. Goals

The objective of this work is to show the results of the calibration and simulation of the Water Balance of the Guadalquivir river basin using infiltration data obtained in a field research work and its implication in the calculation of water contributions in the basin.

3. Materials and methods

The methodology used for the experimental process of the project in the study sub-basins is described in this section.

3.1. Study area

The project was carried out in the upper Guadalquivir basin, located in the department of Tarija, Bolivia, and covers the municipalities of San Lorenzo and Tarija. It is made up of 8 sub-basins corresponding to the main tributaries of the Guadalquivir River (Ministerio de Medio Ambiente y Agua, 2016), Figure 1 shows the location of the basin.

Figure 1. Location of the upper Guadalquivir basin

Source: own elaboration

3.2. Hydrometeorological information of the basin and morphometric characteristics

The hydrometeorological information has been compiled from the National Meteorology and Hydrology Service [SENAMHI] (2019) of Bolivia, for the study area there are 27 rainfall stations of which 16 are inside the basin and 11 outside, 14 temperature stations, 7 relative humidity, 7 evaporation and 7 with wind information, there are also 4 hydrometric stations within the basin.

The morphometric parameters of the basin and part of the hydrological simulation have been worked with the ArcGIS 10.4 software.

3.2.1. Data criticism and missing data complementation

From the information obtained from SENAMHI, it was possible to show that some registers present discontinuities that may be caused by the absence of the operator, equipment malfunction, and others that lead to some of these stations being discarded and that others require a supplementation process. missing data. There are stations that have very short registration periods and a very low correlation, so it was decided not to use them. On the other hand, stations that are very far from the basin were discarded.

The process of complementation of missing data in the historical data series obtained from SENAMHI is carried out through the computer system for the Hydrometeorological Calculation of Contributions and Floods-CHAC (2013), the software uses a bivariate regression model with prior stationarization monthly data series.

3.2.2. Precipitation homogeneity test using the double accumulation curve

For the assessment of the consistency of the time series of precipitation, the analysis of the double accumulation curve that the CHAC (2013) uses for the correlation analysis of the data was used.

The curves show linear trends with stable series, which allows establishing consistency of the time series used for modeling.

3.2.3. Analysis period and hydrological year

Considering the hydrometeorological information and, based on the diagnosis of this, the use of 36 years of continuous data with a period from 1980 to 2016 has been defined, with monthly data series, whose hydrological year has been defined from January to December.

3.3. Hydrological Modeling.

For the modeling and simulation of the water balance of the basin, the Temez model (1977) was used, which is an aggregate model of continuous simulation of runoff, with few parameters and monthly passage (Ministry of Environment and Water, 2016). It operates by making moisture balances between the different processes that take place in a hydrological system from the moment it starts to rain until the moment when runoff is generated and the subsequent discharge from the aquifers to the rivers.

The Témez model is integrated into the software called Hydrometeorological Calculation of Contributions and Floods (CHAC) that has been prepared by the Center for Hydrographic Studies of Spain (CEDEX) to model the different hydrographic units of levels 3 and 4 classifieds by the Pfafstetter method for Bolivia (Ministry of Environment and Water, 2016).

3.3.1. Potential Evapotranspiration

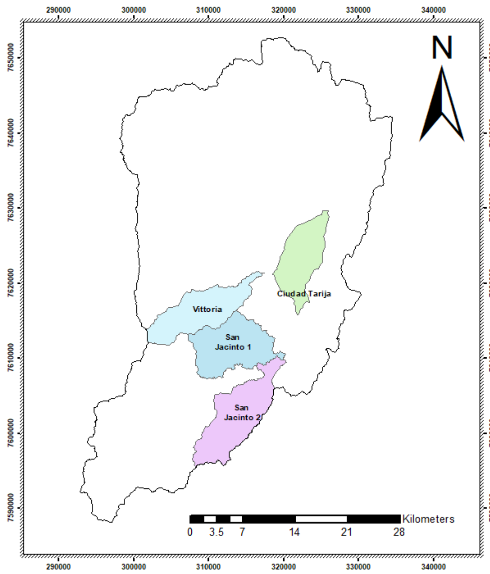
The CHAC allows the calculation of potential evapotranspiration using the Penman Monteitht method (FAO, 1990) whose conceptual basis for calculation is the use of the formula that relates Potential Evapotranspiration (ETP) with climatic factors such as precipitation, temperature, speed of wind, hours of sunshine and relative humidity.

3.3.2. Infiltration in the soils of the study basin

The first phase of infiltration measurement has been carried out in the 4 most important sub-basins of the Guadalquivir, such as Rincón de la Vittoria, Quebrada del Monte, San Jacinto 1 San Jacinto 2, Figure 2 shows the location of the study sub-basins that have allowed the determination of the infiltration parameters used in the calibration and simulation of the water balance of the basin.

For the field measurement tests, 3 brand mini disc infiltrometers were used (Decagon Devices, Inc., 2016), which applies the method of Zhang (1997a) to calculate the hydraulic conductivity, this being the most advisable for unsaturated soils that follows also a methodology proposed by the same provider company for data processing. For the classification of the soils, the infiltration parameters of Green W.H. & Ampt G.A. (1911).

Figure 2: Infiltration study Sub-basins



Source: own elaboration

4. Results and discussion

The results of the modeling of the water balance of the Guadalquivir basin, using the infiltration data measured in the field, are detailed below.

4.1. Morphometric characteristics of the basin

Table 1 details the main morphometric properties of the basin:

Table 1. Morphometric properties of the basin

DESCRIPTION	UNIT	VALUE
Area	Km²	1541.02
Perimeter	Km²	222.07
Min. Height	msnm	1827
Max. Height	msnm	4586
Media Altitude	msnm	2994
Most frequent altitude	msnm	1827
Mid-frequency altitude	msnm	2501
Average slope of the basin	%	36.32
Length of the main river – Guadalquivir	Km	60.44
Order of the water network	UNIDAD	7
Length of the water network	Km	3645
Form factor - Rf		0.48
Compactness index - Kc		1.14
Coefficient of circularity - Cc		0.39
Drainage density - Dd		2.37
Concentration time	Hr	5.10

Source: own elaboration

4.2. Model calibration

For the calibration, the hydrometric stations of Tolomosa and Obras were used because they contain a longer recording period and more reliable information, on the other hand, the values of the Obrajes station have a better representation of the basins located to the north while Tolomosa the of the southern zone, Table 2, details the gauging stations used for calibration.

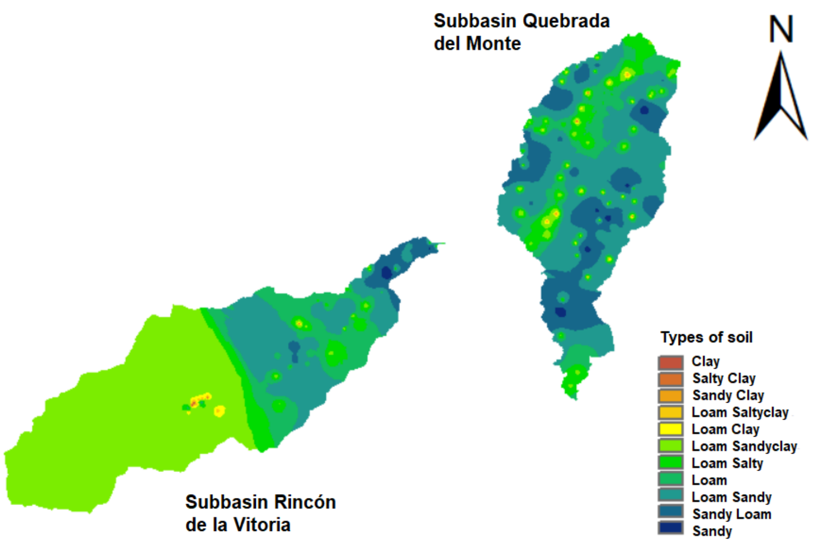
Table 2. Hydrometric stations

Station	Number of years – historical series	Average monthly flow (m^3/seg)
Canasmoro	11 (1976-1986)	4.71
Obrajes	17 (1978-1994)	10.06
San Nicolas	3 (1981-1983)	5.27
Sella Quebrada	16 (1979-1994)	7.67
Tolomosa	7 (1978-1984)	22.44

4.2.1. Basin infiltration results and calibration parameters

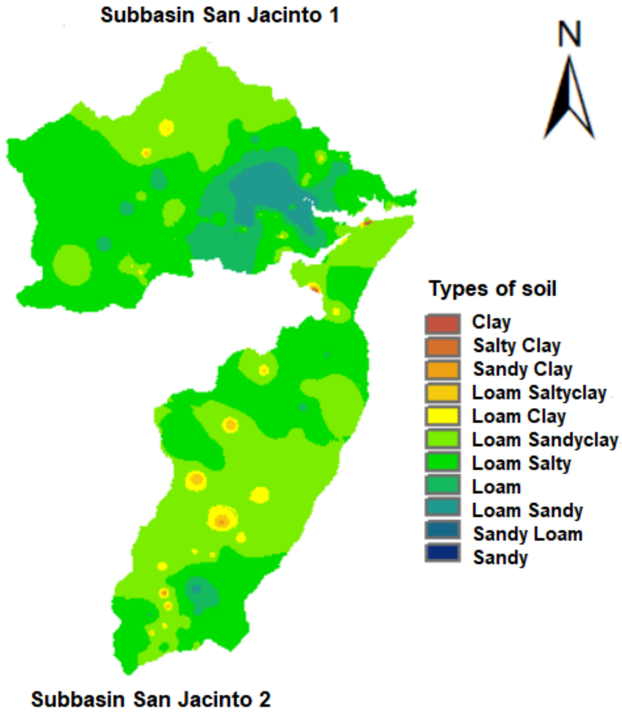
For the calibration of the model, the data obtained from the field research project carried out with the UCB were used, which has allowed a better estimation of the factors and properties of the soils. The classification of soils shows a clear trend of fine soils with typologies ranging from sandy loam to silty clay, as well as clay loam to silty clay soil, Figures 3 and 4 illustrate the infiltration maps of the study basins that allowed the classification of soils. The calibration parameters of the model obtained from the infiltration data are shown in table 3.

Figure 3: Characterization of soils for hydrological purposes in the sub-basins of La Vittoria and Quebrada del Monte



Source: own elaboration

***Figure 4:* Characterization of soils for hydrological purposes in the San Jacinto 1 and 2 sub-basins**



Source: own elaboration

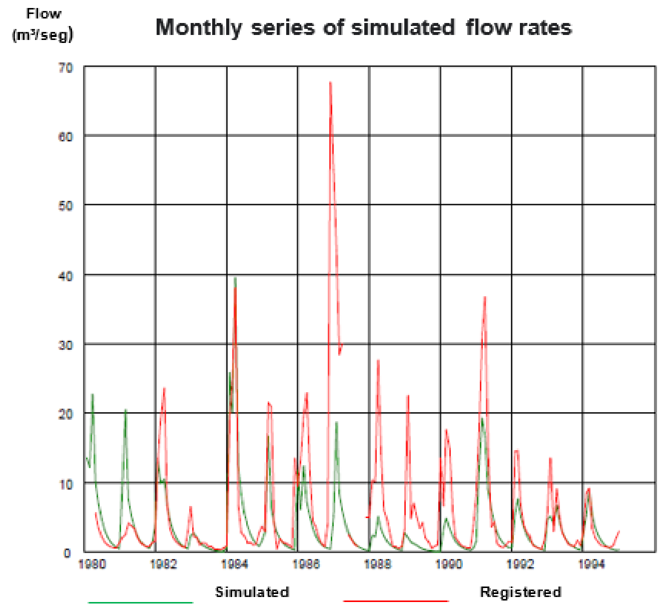
Table 3. Calibration parameters

Basin	Area (Km²)	Leave C	Maximun humidity H_{max} (mm)	Number of rainy days	Maximun infiltration I	Descarga α
Guadalquivir (Tolomosa)	**1541.4**	**0.30**	**270**	**10**	**158**	**0.013**
Guadalquivir (Obrajes)	**1541.4**	**0.30**	**350**	**10**	**223**	**0.013**
Rincón de la Vittoria	61.18	0.20	65	8	47.32	0.0079
San Jacinto 1	65.77	0.35	110	10	59.57	0.01
San Jacinto 2	72.85	0.35	85	10	63.1	0.01
Tarija (quebrada del Monte)	366.02	0.25	35	10	23.71	0.01
Obrajes	270.24	0.35	170	10	211	0.013
Sella Quebrada	185.14	0.35	195	10	112	0.013
Tolomosa	278.92	0.20	125	8	79.43	0.005
Canasmoro	241.28	0.30	235	10	141	0.010

Source: own elaboration

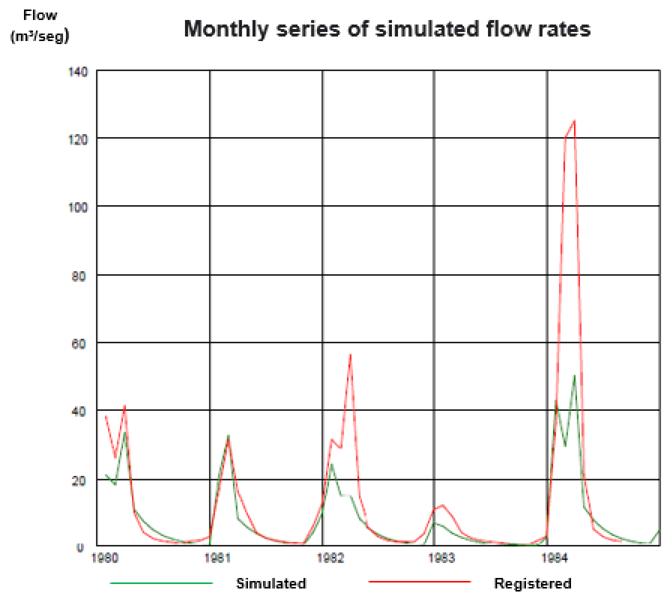
Figures 5 and 6 show the calibration and comparison curves between simulated and observed in the Tolomosa and Obrajes stations.

Figure 5: Observed Vs. simulated flows: Obrajes Station



Source: own elaboration

Figure 6: Observed Vs. simulated flows: Tolomosa Station



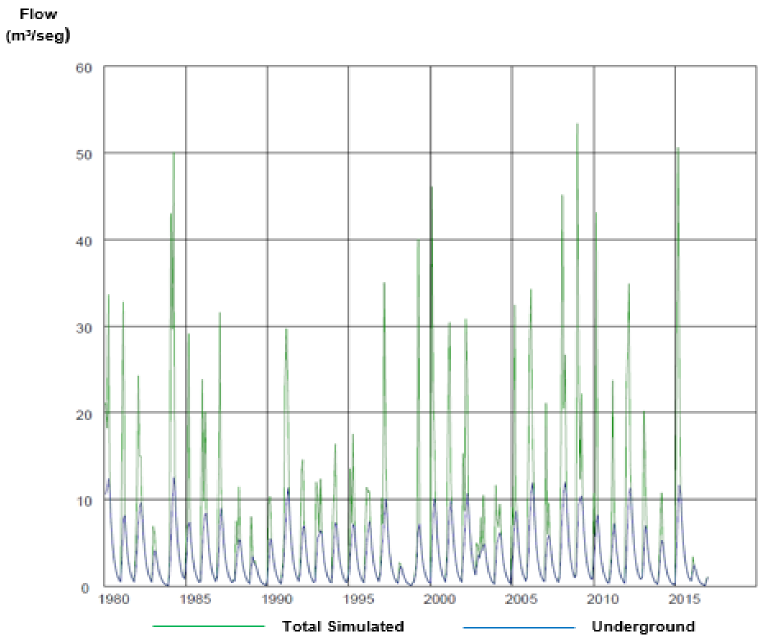
Source: own elaboration

The graphs show similar trends in the behavior of the flows, both in the dry season and in the rainy season, this allows to indicate that the parameters and calibration parameters are adjusted to the hydrological conditions and characteristics of the basin.

4.3. Simulation of the water balance of the basin

Figure 7 shows the behavior of the monthly mean flow contributions of the upper Guadalquivir basin generated by the - CHAC model for the 1980-2016 analysis period.

Figure 7. Temporal behavior of the contributions of the Guadalquivir basin



Source: own elaboration

The main results of the water balance of the basin are detailed in table 4.

Table 4. Water Balance - average monthly contributions of the Guadalquivir basin

Month	Precipitation		Evapotranspiration		Flow/Surface runoff total		
	Pv (Km^3)	Pl (mm)	Etv (Km^3)	ET(mm)	Qesp (m^3/seg)	Q (l/seg/km²)	Aportation (hm^3)
January	0.2698	175.046	0.166	107.516	15.983	10.369	42.809
February	0.2441	158.351	0.167	108.168	18.546	12.032	44.866
March	0.1875	121.651	0.178	115.668	14.035	9.105	37.591
April	0.0482	31.251	0.183	118.705	6.454	4.187	16.728
May	0.0077	4.968	0.168	109.195	4.380	2.842	11.731
June	0.0020	1.319	0.162	105.022	2.966	1.924	7.687
July	0.0017	1.086	0.142	92.100	2.008	1.303	5.379
August	0.0065	4.243	0.134	86.689	1.359	0.881	3.639
September	0.0177	11.451	0.122	78.911	0.919	0.596	2.383
October	0.0728	47.251	0.131	85.014	0.734	0.476	1.967
November	0.1378	89.414	0.142	92.222	0.921	0.598	2.388
December	0.2310	149.892	0.153	99.559	7.739	5.021	20.727

Source: own elaboration

4.4. Curve number of the Guadalquivir Basin

Based on the results obtained during the soil investigation process, the upper Guadalquivir basin presents soils with moderate and high potential runoff, good hydrological condition and different soil treatment systems where crops in the central zone of the area of This study is of relevant importance because agriculture is one of the most important productive sectors, based on these results and under a weighted analysis of the different characteristics, the NC of the basin was determined, table 5 shows the weighting carried out for the determination of the curve number:

Table 5. Determination of the Curve Number for the Guadalquivir basin

Soil type	Percentage (%)	NC	NC Weighted
A	6.2	48	2.9
B	6.7	67	4.5
C	13.5	77	10.4
D	73.4	80	58.72
		NC (weighted)	76.52

Source: own elaboration

It is assumed that the upper Guadalquivir basin corresponds to an NC = 77, which is a reasonable value for the soils of the basin.

5. Conclusions

A semi-distributed model of monthly passage and with few parameters such as that of Témez is ideal for the Guadalquivir basin considering the scarcity of data it contains, the CHAC software has allowed an adequate calibration and simulation of the monthly contributions of the basin, considering in addition, it uses the Temez model for the processing and simulation of the hydrological model.

The field research carried out by the Bolivian Catholic University has made it possible to determine the hydraulic parameters of the soils in order to estimate in a more efficient way the calibration factors of the model, such is the case of the exceedance coefficient, infiltration and soil moisture shown by soils. with a fine trend. The calibration graphs allow to visualize that the behavior of the simulated flows vs. observed maintains a similarity during the analysis period, allowing to establish that the calibration parameters are adjusted to the conditions and characteristics of the basin.

The simulation of the water balance with parameters obtained directly from the study area allows a better appreciation of the hydrological behavior of the basin when considering the real conditions of the soil, therefore, the uncertainty is lower. The infiltration data and the determination of the characteristics of the soils of the basin have allowed us to estimate a curve number for the Guadalquivir basin of 77.

Due to the magnitude of the basin and the need to have as much information as possible, future research work is scheduled to expand the infiltration research areas for model adjustments and the water balance of the basin.

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