Migration Letters

Volume: 20, No: S8(2023), pp. 534-547

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Evaluation of hydrological models in SWAT and HEC-HMS with potential application to the particular characteristics of the sub-basin of the Quillcay River-Peru

Flor Jara[1], Abel Mejía[2], Pedro Colonia[3], Teófanes Mejía[4], Gerardo Revelo[5]

Abstract

Geospatial geographic information technologies, together with hydrometeorological information, have made it possible to make increasingly accurate and detailed studies of the behavior of the hydrological cycle worldwide, especially with the use of models such as SWAT (Soil & Water Assessment Tool) or HEC-HMS (Hydrologic Modeling System). In this paper, SWAT model is used in the Quillcay sub-basin in Ancash (Peru), which has 247.38 km2, from geographic information such as the Digital Elevation Model (DEM), vegetation cover, soil type and curve number, in addition to climatic information, to perform an analysis of the SWAT model performance for a period of 34 years (1983-2016), with an emphasis on the estimation of the monthly flow rate, with HEC-HMS for 30 years (1986-2016), daily precipitation data and monthly average evapotranspiration data. Detailed tables with daily flows, peaks, and date of record are obtained, the maximum obtained was 40.60 m3/s using the Green and Ampt method, and with SWAT it was 31.48 m3/s using Curve Number.

Keywords: *Quillcay Sub-basin, Hydrological modeling, SWAT, HEC-HMS*

1. Introduction

The Quillcay River sub-basin is located between the districts of Independencia and Huaraz, both districts in the northeastern part of the province of Huaraz. It borders the provinces of Huari and Carhuaz, presenting an area of 247.38 km2, a perimeter of 110.10 km, and an average altitude of 4232.24 masl (Jara et al., 2023). It belongs to the Santa River basin; the main riverbed (Quillcay in the lower basin) is 32.85 km long and originates in the lakes and snow-capped mountains in the upper basin; the sub-basin is formed by mountain ranges of the Cordillera Blanca Mountain range; the soil texture is sandy practically throughout the entire sub-basin, and the average slope is 58%, especially in the middle and upper basin.

[1] Universidad Nacional Santiago Antúnez de Mayolo, Av. Universitaria s/n, Independencia, Huaraz, Ancash, Perú. Doctorate Program in Water Resources, Universidad Nacional Agraria La Molina (UNALM), Lima, Perú, fjarar@unasam.edu.pe,

[2] Doctorate Program in Water Resources, Universidad Nacional Agraria La Molina (UNALM), Lima, Perú, jabel@lamolina.edu.pe

[3] Universidad Nacional Santiago Antúnez de Mayolo, Av. Universitaria s/n, Independencia, Huaraz, Ancash, Perú, pcoloniac@unasam.edu.pe

[4] Universidad Nacional Santiago Antúnez de Mayolo, Av. Universitaria s/n, Independencia, Huaraz, Ancash, Perú, tmejiaa@unasam.edu.pe

[5] Universidad Nacional Santiago Antúnez de Mayolo, Av. Universitaria s/n, Independencia, Huaraz, Ancash, Perú, grevelos@unasam.edu.pe

On the north side, the Cojup Stream is a tributary of the Paria River, which in turn is a tributary of the Quillcay River, the Cayesh Stream flows into the Auqui River, which together with the Shallap Stream converges to form the Quillcay River (Jara et al., 2023).

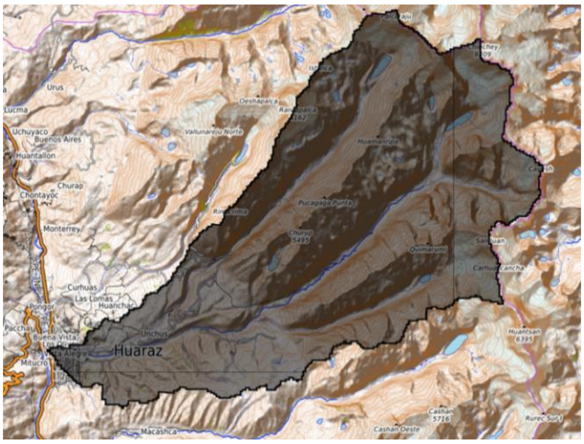


Figure 1. Study area, Quillcay River sub-basin.

Source: (Jara et al., 2023).

Data source

Table 1. Virtual stations within the sub-basin.

Name	Latitude	Longitude
EV1	9° 25' 34.720"	77° 20' 10.636
EV2	9° 30' 46.536"	77° 22' 21.733
EV3	9° 26' 55.706"	77° 25' 49.733
EV4	9° 31' 54.540"	77° 28' 32.911

2. Methodology with SWAT

2.1. General description of the model

The Soil and Water Assessment Tool (SWAT) is a semi-distributed process-based model (Arnold et al., 1998), capable of predicting outflow in hydrograph units on a continuous temporal scale (daily, monthly, or annual). In this model, each hydrograph unit is divided into subunits, then these subunits are divided into Hydrologic Response Units (HRU), which are heterogeneously structured entities resulting from the overlap of the same land use, soil type, and slope.

SWAT simulations are based on the water balance equation for the terrestrial phase of the hydrological cycle, expressed as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad (1)$$

Where, SW_t is the final water content in the soil (mm), SW_0 is the initial water content on the day i (mm), t is the time (days), R_{day} is the amount of precipitation in the day i (mm), Q_{surf} is the amount of surface runoff in the day i (mm), E_a is the amount of evapotranspiration during the day i (mm), W_{seep} is the amount of water accumulated in the unsaturated zone of the soil profile on a given day i (mm), and Q_{gw} is the amount of return flow in the day i (mm). Detailed information on simulation methods is available in the theoretical documentation of the SWAT model (Neitsch et al., 2011).

2.2. Methodology procedure

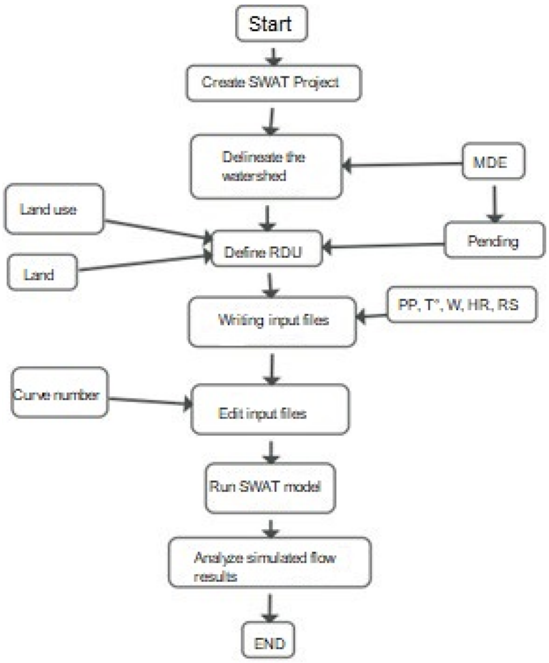


Figure 2: Flowchart representing modeling in SWAT.

The SWAT hydrologic modeling procedure of the research consists of the following steps: (1) project setup, (2) watershed delineation, (3) HRU analysis, (4) writing and editing input tables, and (5) model execution, which are shown in Figure 2.

2.3. Geographic and climatic information

The details of the information used in the model are described in Table 2.

Table 2. Geographic and climatic information supplied to the model.

Data type	Scale or resolution	Source	Format
MDE	12.5 m	ALOS PALSAR Radiometrically Terrain-Corrected (RTC)	Raster
Land	-	INRENA	Vectorial
Vegetative cover	1:100,000	MINAM	Vectorial
Precipitation, maximum and minimum temperature	Daily (1983-2016)	SENAMHI HSR PISCO	Text

The climatic information obtained from the gridded product PISCO (Peruvian Interpolated data of the SENAMHI's Climatological and hydrological Observations) corresponds to 4 virtual stations (VE) that are located within the study area (Table 1). Information related to solar radiation, relative humidity, and wind speed, also required by the model, was obtained from the SWAT Global Weather Database, although it was only available until 2014.

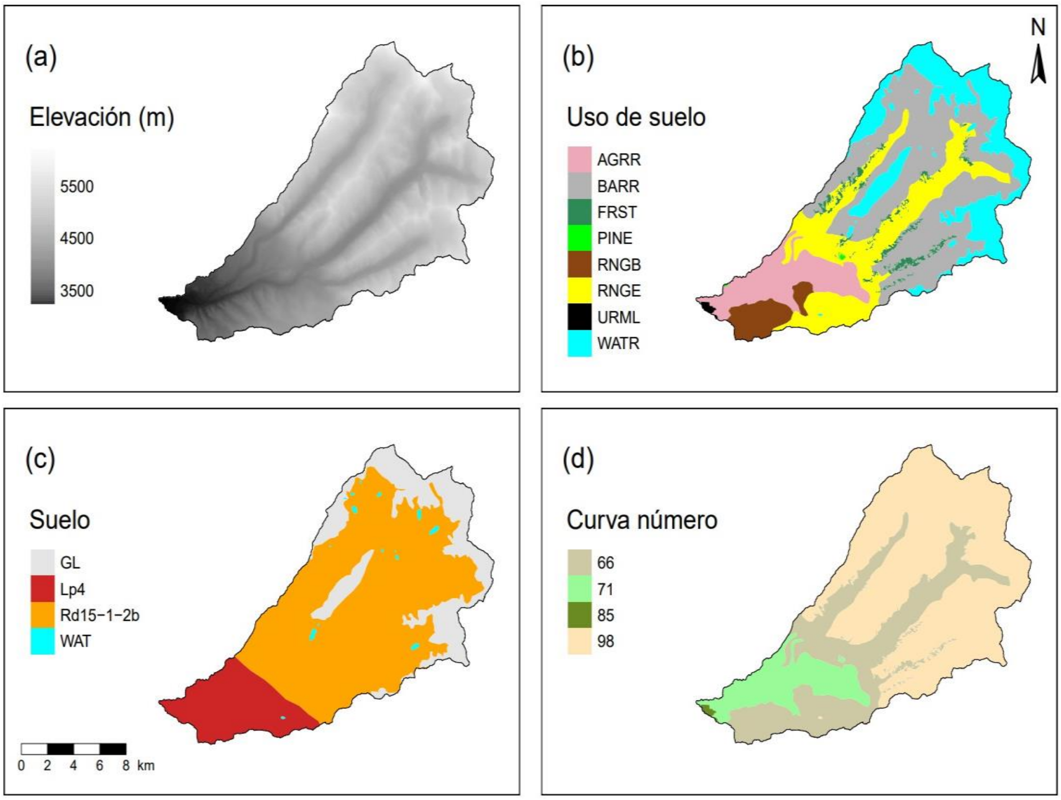


Figure 3. (a) Digital elevation model, (b) land use, (c) soil, and (d) number curve of the Quillcay sub-basin.

2.4. Systematization of information

a. Digital Elevation Model (MDE)

The digital elevation model (DEM) is used to define topographic parameters such as several sub-basins, drainage networks, and slopes. The corrected elevation data of the 12.5 m terrain was used from the Advanced Land Observation Satellite-Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR). Based on the above, SWAT delimited the Quillcay sub-basin with 247.38 km2 distributed in 9 subunits, while the slope was divided in five classes (0%-12%, 12%-25%, 25%-50%, 50%-75% y >75%).

b. Land Use

Based on the National Map of Vegetation Cover provided by the Ministry of Environment, each type of cover was assigned an identification code through a reclassification based on the criteria of the methodology developed by Valladares (2017), see Table 3.

Table 3. Reclassification of vegetation cover in the sub-basin.

Vegetative cover	Equivalent land use SWAT	SWAT Code
Coastal and Andean agriculture	Agricultural Land-Row Crops	AGRR
High Andean area with scarce and no vegetation	Barren	BARR
Urban area	Residential-Med/Low Density	URML

High Andean relict forest	Forest-Mixed	FRST
Glacier	Water	WATR
Lagoons, lakes, and oxbow lakes	Water	WATR
Shrub thicket	Range-Brush	RNGB
Andean Pajonal	Range-Grasses	RNGE
Forest Plantation	Pine	PINE

c. Land

Based on the Land Map, each soil type was assigned an identification code using a reclassification based on the criteria of the methodology developed by Valladares (2017).

Table 4. Reclassification of soil in the sub-basin.

Land	FAO Soil	FAO Soil Number
Glacier	GLACIER	6998
Lake, lagoon, or oxbow lake	WATER	6997
Districts Leptosol - Lithic Outcrop	Lp4	1532
Dystric regosol - Lithic outcrop	Rd15-1-2b	929

For SWAT to work, a series of parameters are required depending on the type of soil in the hydrological unit under study (soil granulometry, permeability, bulk density, amount of organic matter, etc.), and since the default ArcSWAT database (SWAT2012.mdb) only includes soil data from the U.S.A.

In the table usersoil, global soil data were imported from the MWSWAT database (mwswat2012.mdb), which was provided by the Food and Agriculture Organization of the United Nations (FAO).

Therefore, within the Quillcay sub-basin, 2 soil types were identified (Lp4 and Rd15-1-2b); however, given that the imported usersoil database included the glacier (GLACIER) and water (WATER) categories, the Vegetation Cover Map was used to create another map with 4 soil types, as detailed in Table 4.

d. Curve Number

The Number Curve (NC) map for normal antecedent moisture conditions (Condition II) was obtained using Geographic Information Systems (GIS) tools, by applying reclassification tables and superimposition operations of the thematic maps of Cover, Soil and Digital Elevation Model (Maurtua & Zelada, 2016).

e. Reclassification of thematic maps

The information used for the Cover, Soil, and Digital Elevation Model is the same as that used previously and its details are described in Table 2.

f. Vegetative cover

A classification code is assigned to each cover description. See Table 5.

Tabla 5. Clasificación de la cobertura vegetal para CN.

Vegetative cover	Equivalent coverage	Code
Coastal and Andean agriculture	Crops/Areas intervened	4
High Andean area with little or no vegetation	Snowy	2
Urban area	Populated centers	3
High Andean relict forest	Woody tree savanna	7
Glacier	Snow-covered	2
Lagoons, lakes, and oxbow lakes	Water bodies	1
Shrub thicket	Open shrub thicket	5
Andean scrubland	Open shrub thicket	5
Forest plantation	Crops/ Intervened areas	4

g. Land

According to the soil type, the hydrological soil group to which it belongs was assigned (Table 6).

Table 6. Clasificación del suelo para CN y grupo hidrológico correspondiente.

Suelo	Simbología	Grupo hidrológico
Districtic Leptosol - Lithic Outcrop	LPd-R	B
Dystric regosol - Lithic outcrop	RGd-R	B

2.5. Application of the Methodology

It required the application of the HEC-GeoHMS extension for ArcGIS and the development of the following steps:

- The correction of null or erroneous cells of the Digital Elevation Model with the tool Fill.
- The modification of the Attribute Table of the thematic information of Cover and Soil, by creating new fields with the classification codes detailed in Tables 5 and 6.

- Graphical overlay with the use of the Union geoprocessing tool, to generate a new vector file.
- The application of Hec-GeoHMS, specifically its Generate CN Grid tool, in which the corrected DEM, the previously generated general file, and Table 7 (Values of the hydrological groups), which is necessary to obtain the Number Curve map under normal conditions, must be loaded.

Table 7. Values of hydrological groups.

Description of land use	Hydrological group			
	A	B	C	D
Bodies of water	100	100	100	100
Snow-capped mountains	98	98	98	98
Populated centers	77	85	90	92
Crops / Intervened areas	62	71	78	81
Open bush scrub	45	66	77	83
Grassland in cold climate zone	68	79	86	89
Woody tree savanna	45	66	77	83
Hydromorphic savanna	25	55	70	77
Tropical rainforest	25	55	70	77
Tropical rainforest with bamboo	25	55	70	77
Temporary broadleaf rainforest	25	55	70	77
Hydrolytic rainforest	39	61	74	80
Desert in arid climate zone	72	81	88	91

a. SWAT hydrological model

The information required by the model was entered sequentially in the ArcSWAT interface within ArcGIS and the Quillcay sub-basin was divided into 247 HRUs. In addition, it was taken into consideration that the meteorological data (precipitation, maximum and minimum temperature) were from the year 1983, so the monthly scale simulation period of the SWAT model was established for the period 1983-2016 where the first 3 years (up to 1986) were used as the model warm-up period, to mitigate the initial unknown conditions. This means that the model generated output flow results (m3/s), for each of the 9 hydrological subunits delimited by SWAT from the DEM, from January 1986 to December 2016.

b. Hydrologic model HEC-HMS

Modeling in HEC-HMS requires the following information: daily precipitation data from the virtual stations within the sub-basin area; monthly average evapotranspiration data from the above-mentioned stations; information on the average soil texture of the sub-basin; and information on land use in the sub-basin.

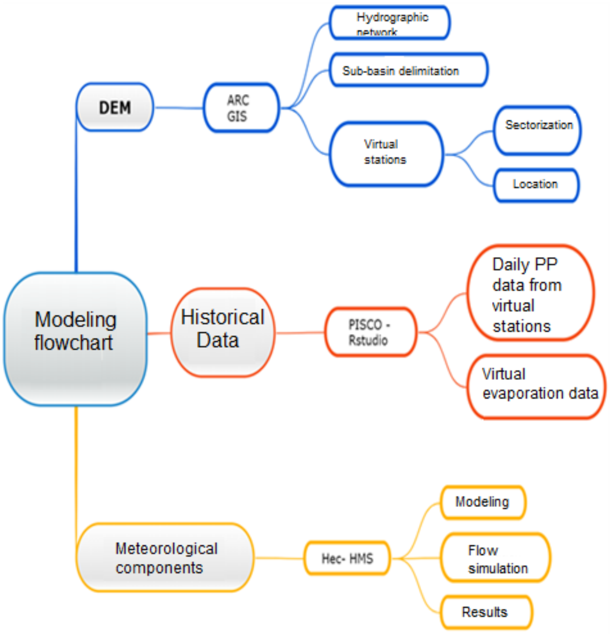


Figure 4. Modeling flowchart.

c. Procedure and application of the methodology

Using GIS software, the 12.5m DEM is processed, and the delimitation of the hydrographic sub-basin is obtained. The basin characterization parameters are calculated and the water network of the basin is obtained. The sub-basin is divided into micro-basins under the criterion of homogeneity in the geomorphological aspect and the confluence points.

The period to be modeled is 1986-2016, using daily precipitation data and monthly average evapotranspiration data from the PISCO tool (Peruvian Interpolated data of the SENAMHI's Climatological and hydrological Observations).

The HEC-HMS software was developed by the U.S. Army Corps of Engineers. It is used for hydrologic modeling and calculation of peak flows at specific points.

The basin model (Basin Models) is created in which the sub-basins and points of interest will be created. The software allows adding to the viewer window shapefile files in schematic form for the location of the points/water zones of interest within the sub-basin. Using the Subbasin Creation Tool, four sub-basins are located. With the Junction Creation Tool two confluence points are created. The Sink Creation Tool is used to create a final sink point located in the city of Huaraz through which all the flow of the sub-basin will flow before its confluence with the Santa River. For the sections between the confluence and sinkhole points, two segments are created using the Reach Creation Tool.

With all the points of interest joined together, the basic graphic model of the sub-basin has been created (Figure 5).

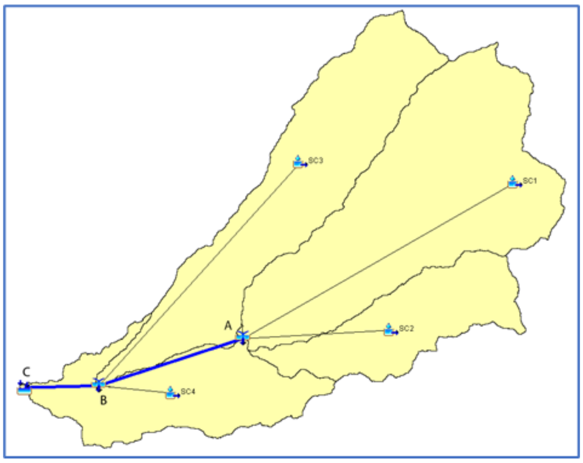


Figure 5. HEC-HMS plot with points of interest.

For each point of interest created, a row will be automatically added in the left side panel. For the sub-basins, the Loss Method, which calculates the amount of precipitation infiltrating into the soil; and the Transform Method, which will use the unit hydrograph to calculate the redistribution of effective precipitation within the sub-basin, will be selected. These are the fundamental methods for modeling. In addition to these there are additional methods that consider foliage, surface irregularities, and initial flow.

In the first tab Loss, the area of the sub-basin in Km2 is entered, regarding the loss method, the method to be selected is Green and Ampt, which is considered as the main parameter of the average soil texture of the sub-basin, the one corresponding to the basin is the sandy texture. Four other parameters are derived from the definition of this parameter: porosity, effective porosity, suction potential of the wet front, and hydraulic conductivity. The corresponding values are shown in Figure 6.

In the transform tab, the Clark Unit Hydrograph is selected, the parameters to be entered are the time of concentration and the storage coefficient. The time of concentration is calculated with the Temez Equation.

Clase de suelo	Porosidad η	Porosidad efectiva θ_e	Potencial de succión del frente húmedo ψ cm	Conductividad Hidráulica K cm/h
Arena	0,437 (0,374-0,500)	0,417 (0,354-0,480)	4,95 (0,97-25,36)	11,78
Arena margosa	0,437 (0,363-0,506)	0,401 (0,329-0,473)	6,13 (1,35-27,36)	2,99
Marga arenosa	0,453 (0,351-0,555)	0,412 (0,283-0,541)	11,01 (2,67-45,47)	1,09
Marga	0,463 (0,375-0,551)	0,434 (0,334-0,534)	8,89 (1,33-59,38)	0,34
Marga limosa	0,501 (0,420-0,582)	0,486 (0,394-0,578)	16,68 (2,92-95,39)	0,65
Marga arcillo-arenosa	0,398 (0,332-0,464)	0,330 (0,235-0,425)	21,85 (4,42-108,0)	0,15
Marga arcillosa	0,464 (0,409-0,519)	0,309 (0,279-0,501)	20,88 (4,79-91,10)	0,10
Marga arcillo-limoso	0,471 (0,418-0,524)	0,432 (0,347-0,517)	27,30 (5,67-131,50)	0,10
Arcilla arenosa	0,430 (0,370-0,490)	0,321 (0,207-0,435)	23,90 (4,08-140,2)	0,06
Arcilla limosa	0,479 (0,425-0,533)	0,423 (0,334-0,512)	29,22 (6,13-139,4)	0,05
Arcilla	0,475 (0,427-0,523)	0,385 (0,269-0,501)	31,63 (6,39-156,5)	0,03

Figure 6. Green and Ampt Soil Class Chart.

Source: (Infiltration With The Green Ampt Model | It's The Water, n.d.)

Témez equation for the calculation of the time of concentration

$$t_c = 0.3 \left(\frac{L}{i^{0.25}}\right)^{0.76} \quad (2)$$

Source: (Upegui & Gutiérrez, 2011)

Where tc is the time of concentration in hours (hr), L is the length of the main river channel in kilometers (km) and i is the average slope of the basin (%).

Regarding the storage coefficient, this parameter must be calculated with field data. According to the software manual, this can be approximated to 75% of the time of concentration. The procedure is repeated for the remaining three sub-basins, entering the parameters in each of the corresponding tabs.

For the segments linking the confluence points, under Routing Method, select Lag. In this tab, you can also select the release point in the Downstream option. In the following tab (Routing) the delay time in minutes is entered (Lag).

In the case of the final sump point (C), it is not necessary to enter any parameter since it will only receive all the accumulated flow.

Next, the Time-Series Data module is created. Here the daily precipitation data is added. Four Precipitation Gages modules are created, and the time interval is 1 day. The start and end time and date of the data to be entered are entered. Consider subtracting a time interval from the start date, in this case, the start date of the data is 01/01/1986 and the date entered is 12/31/1985. The end date is 12/31/2016. In the next tab enter the precipitation data in millimeters. Note that the first row will be empty. Repeat the procedure for the remaining virtual stations.

Next, create the Meteorologic Models, in the Precipitation field select Specified Hyetograph and in the Evapotranspiration field select Monthly Average, in the Replace Missing field select Set To Default.

In the Basins tab, assign the corresponding sub-basins to the model. With this, subfields will have been enabled in the meteorological model, in Specified Hyetograph link each of the virtual stations with the corresponding micro basin. In the subfields of the micro basins, enter the monthly average evapotranspiration for each of the micro basins. In this case, the data obtained is not from the field, so in the Coefficient, the value 1 is entered; if the data had been obtained from an evaporimeter in the field, the value would be between 0.7 - 0.8. The procedure is repeated for each micro-watershed.

The Control Specifications module is created in which the time and date on which the model will be run and the results will be displayed will be indicated. This date does not necessarily have to be the same as the date entered in the Time Series Data. Generally, the end date assigned for this purpose is later than the end date of the time series data because the process of precipitation, soil saturation, and runoff to the output point may extend several hours after the onset of precipitation.

In the Compute / Create Compute / Simulation Run tab, a simulation model will be created, and the basin, the meteorological model, and the control specifications will be selected. In the corresponding field, the simulation is selected and an icon will be enabled to start the process. Once finished, the results can be observed in detail in the Results tab on the left panel, the data will be divided by each point of interest located within the sub-basin, and in each sub-tab, the flow rates can be observed in summary and in detail for each assigned time interval as well as hydrographs, also the peak flows in m3/s, the date and time in which they occur, etc. For each sub-basin, graphs of resulting flows, precipitation, soil infiltration, excess precipitation, lost precipitation, etc. will be generated.

3. Results and discussion

In SWAT, modeled with 34 years of data from 4 virtual stations located within the sub-basin, a maximum flow of 31.48 m3/s was obtained for hydrographic subunit 9 (city of Huaraz) and recorded in February 1999, this flow is the result of a monthly precipitation for this subunit of 291.20 mm, as shown in Figure 8. The total accumulated precipitation for the 1986-2016 time period is 31,138.20 mm (Figure 7).

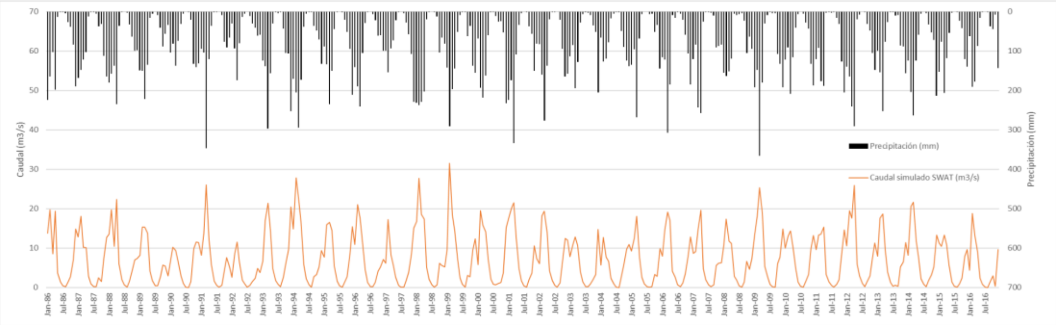


Figure 7. Precipitation and simulated flow for hydrographic subunit 9 (city of Huaraz).

In subunit 8, which runs longitudinally along the Auqui River that flows into the Quillcay River, the maximum flow obtained in the hydrologic model is 21.86 m3/s recorded in February 1999. In subunit 6, which runs longitudinally along the Shallap stream that flows into the Quillcay River, the maximum flow obtained in the hydrologic model is 4.75 m3/s recorded in February 1999. In subunit 7, which runs longitudinally along the Cojup stream that flows into the Paria River, the maximum flow obtained in the hydrologic model is 9.17 m3/s recorded in February 1999. In subunit 5, the maximum flow obtained in the hydrologic model is 15.74 m3/s.

The HEC-HMS was modeled with 30-year data from 4 virtual stations located within the sub-basin, with a maximum flow of 40. 6m3/s for sump point C (city of Huaraz) and recorded on February 28, 2016, this flow is the product of 2 days of considerable precipitation: on 02/27/2016 of 36mm, 29mm 56mm, and 49mm for virtual stations EV1, EV2, EV3 AND EV4 respectively, and on 02/28/2016 of 38mm, 32mm, 25mm, and 19mm for virtual stations EV1, EV2, EV3 AND EV4 respectively. The total accumulated volume of precipitation for the 1986-2016 time period is 11909mm.

In micro-basin 1, longitudinally traversed by the Auqui river that flows into the Quillcay river, the maximum flow obtained in the hydrological model is 14.8 m3/s recorded on 02/28/2016. In micro-basin2, run longitudinally by the Shallap stream that flows into the Quillcay river, the maximum flow obtained in the hydrological model is 9.0m3/s recorded on 12/26/1995. In micro-basin3, traversed longitudinally by the Cojup stream that flows into the Paria river, the maximum flow obtained in the hydrological model is 13.8 m3/s recorded on 02/28/2016. In the microbasin4, the maximum flow obtained in the hydrological model is 6.1 m3/s, this flow is the product of the effective precipitation, it does not consider the flows coming from upstream. For point A, where Shallap Creek and the Auqui River meet, the maximum flow obtained in the hydrological model is 22.3 m3/s recorded on 26/12/1995. For point B where the Paria River flows into the Quillcay River, the maximum flow obtained is 40.6 m3/s recorded on 02/28/2016 (Figure 8).

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
AB	132.77	22.2	26dic.1995, 00:00	11563.34
SC3	72.21	13.8	28feb.2016, 00:00	13136.33
SC4	42.38	6.1	09mar.1991, 00:00	10905.50
B	247.36	40.6	28feb.2016, 00:00	11909.82
BC	247.36	40.6	28feb.2016, 00:00	11909.80
SC1	97.80	14.8	28feb.2016, 00:00	10617.66
SC2	34.97	9.0	26dic.1995, 00:00	14208.26
A	132.77	22.3	26dic.1995, 00:00	11563.38
C	247.36	40.6	28feb.2016, 00:00	11909.80

Figure 8. Global summary - HEC-HMS

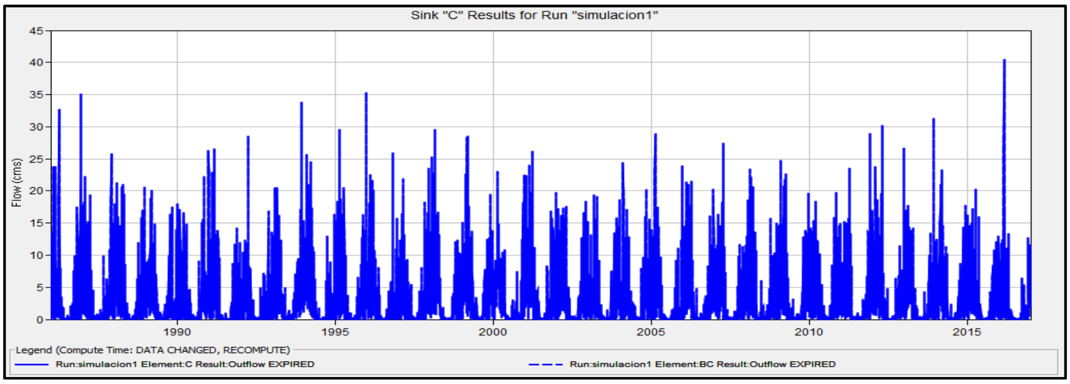
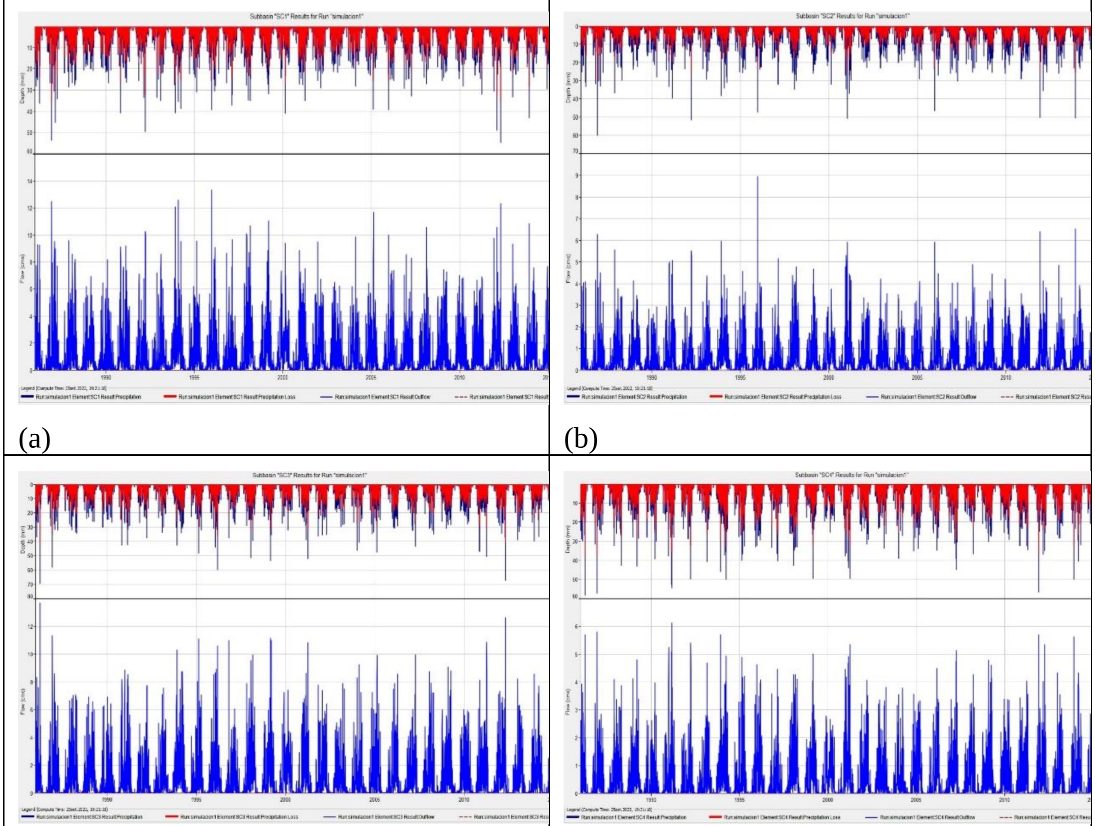


Figure 9. Resulting flow graph for sump point (C).



(a) (b)

(c) (d)

Figure 10. Simulation of precipitation with flows of the 4 sub-basins, a) SC1, b) SC2, c) SC3 and d) SC4

Table 8: Comparison of flow rates obtained

Software	Flow (m^3/s)	Date of registration
SWAT	31.48	Feb/1999
HEC-HMS	40.6	28/Feb/2016

4. Conclusion

In this study, the formulation of the SWAT hydrological model based on the availability of geographic and climatic data represented physically and spatially the Quillcay river sub-basin, allowed the model to be able to simulate monthly flows. In the period 1986-2016, the maximum flow was 31.48 m3/s for hydrographic subunit 9, recorded in February 1999.

In the HEC-HMS software, the maximum flows were obtained for each of the points of interest within the sub-basin. In the period 1986-2016, the maximum recorded is 40.6 m3/s recorded in February 2016 from the total area of the sub-basin.

The difference in flow rates obtained is due to the algorithm used by each software and the methods selected for the calculation. For SWAT, the loss method is the Curve Number and HEC-HMS is Green and Ampt.

For a more accurate contrast, field information on the measurement of the resulting flow rates at the sink point is required, since actual flow data are necessary to calibrate and validate the hydrological modeling.

References

Antequera Cochachin, M. R. (2014). DETERMINACIÓN DE CAUDALES MAXIMOS APLICANDO LAS METODOLOGÍAS HIDROMETEREOLOGICOS Y ESTADÍSTICOS EN LA SUB CUENCA DEL RIO QUILLCAY. 96.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area hydrologic modeling and assessment Part I: model development. Journal of the American Water Resources Association, 34(1), 73-89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

Cabrera Cabrera, J. W. (2012). Modelos Hidrológicos. Modelos Hidrológicos. http://www.imefen.uni.edu.pe/Temas_interes/modhidro_1.pdf

Flor Jara, Abel Mejía, Teófanes Mejía, & Gerardo Revelo. (2023). ESTIMATION OF DEGLACIATION IN THE SUB-BASIN OF THE QUILLCAY RIVER – PERU, IN THE FACE OF CLIMATE CHANGE. Ann. For. Res, 66(1). https://doi.org/10.5281/zenodo.7860578

La infiltración con el modelo de Green Ampt | Es el agua. (s. f.). Recuperado 28 de septiembre de 2022, de http://eselagua.com/2018/10/27/la-infiltracion-con-el-modelo-de-green-ampt/

Maurtua, M. P., & Zelada, C. V. (2016). Generación de mapa de número de curva con sistema de información geográfica. Apuntes de Ciencia & Sociedad, 6(1), Article 1. http://dx.doi.org/10.18259/acs.2016029

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resources Institute. https://swat.tamu.edu/media/99192/swat2009-theory.pdf

Ochoa-Tocachi, B. F., Cuadros-Adriazola, J., Arapa Guzman, E., Aste Cannock, N., Ochoa-Tocachi, E., Bonnesoeur, Bonnesoeur, V. (2022). Guía de modelación hidrológica para la infraestructura natural. Forest Trends, Lima, Perú.

Upegui, J. J. V., & Gutiérrez, A. B. (2011). ESTIMACIÓN DEL TIEMPO DE CONCENTRACIÓN Y TIEMPO DE REZAGO EN LA CUENCA EXPERIMENTAL URBANA DE LA QUEBRADA SAN LUIS, MANIZALES. 14.

Valladares, E. (2017). Respuesta hidrológica de la cuenca del río Santa en condiciones de cambio climático [Universidad Nacional Agraria La Molina]. https://repositorio.lamolina.edu.pe/handle/20.500.12996/3367