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The effect of changes in vegetation cover on the hydrological response of the sub-basin Los Pozos

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Abstract
In the current study the SWAT hydrological simulation model was implemented in the sub basin Los Pozos, located in the Aquitania municipality, department of Boyacá, Colombia, in order to quantify the effect caused by changes from plant cover in the hydrological response. The affordmentioned was evaluated in recovery scenarios, which were formulated taking into account the territory planning instruments, and scenarios the agricultural expansion frontiers. The model was manually calibrated and validated to improve its prediction capacity by means of the coefficient of R2 determination, the Nash-Sutcliffe efficiency index and percentage bias (Percent Bias-PBIAS), making the sensitivity analysis previously, which facilitated the calibration process. Once the model hydrologically represented the subbasin the scenarios were created, allowing identifying the handling in terms of plant cover that can be implemented to favor water regulation.

Keywords: hydrological response; SWAT; subbasin; water regulation; plant cover.

Efectos del cambio de cobertura vegetal sobre la respuesta hidrológica de la subcuenca Los Pozos

Resumen
En el presente estudio se implementó el modelo de simulación hidrológica SWAT en la subcuenca Los Pozos, ubicada en el municipio de Aquitania, departamento de Boyacá, Colombia, con el fin de cuantificar el efecto que causan los cambios de cobertura vegetal en la respuesta hidrológica. Lo anterior se evaluó en escenarios de recuperación, los cuales fueron formulados teniendo en cuenta los instrumentos de planificación territorial, y escenarios de ampliación de fronteras agricolas. El modelo se calibro y validó manualmente para mejorar su capacidad de predicción mediante el coeficiente de determinación R2, el índice de eficiencia de Nash-Sutcliffe y el sesgo porcentual (PBIAS), realizando con anterioridad el análisis de sensibilidad, el cual facilito el proceso de calibración. Una vez que el modelo represento hidrológicamente la subcuenca se crearon los escenarios permitiendo identificar el manejo en cuanto a cobertura vegetal que puede ser implementado para favorecer la regulación hídrica.

Palabras clave: respuesta hidrológica; SWAT; subcuenca; regulación hídrica; cobertura vegetal.

1. Introduction

The hydrographic basins are units of the territory where the physical-biotic subsystems (soil, water, flora and fauna) and the social subsystem (man) interact. They offer goods and services to the community, mainly agricultural, livestock, forestry, recreational and the most important is the production of water.

The man with the eagerness to expand his agricultural frontiers to increase his economic production has realized felling and burning, modifying the vegetal coverages own of the zone, without considering the vocation of the soils and without concerning the affectation of the hydrological processes.

In Colombia the growth of agricultural and livestock production has been essentially due to the increase in the sown area and with a disorderly expansion of agricultural borders, both towards the jungle lowlands with towards the slopes of inter-Andean valleys up to the páramos, in both cases with serious consequences on the environment [1].

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In the sub-basin Los Pozos, located in the hydrographic basin from lago de Tota, municipality of Aquitania Boyacá, this problem has been presented. There, the expansion and intensification of onion crops is evident, with a production for the year 2010 of 180,000 tons [2]. This productive activity threatens the natural cover of páramo ecosystems and is one of the causes in the alteration of the hydrological cycle and regional water dynamics due to changes in land use [3].

The affordmentioned interventions have several effects: they reduce the infiltration capacity of the waters for the recharge of aquifers, they severely reduce the flows in the summer season between 80% and 95% with respect to the flows in winter, and they increase the erosion levels and, therefore, sediment trawling [4]. Then the hydrological response of a basin, besides being affected by the hydroclimatological parameters, it is seriously influenced by the type vegetation cover and of soil [5].

The situation presented above can be evaluated using hydrological models, which allow a simplification of reality, from these you can study the cause-effect relationship of a basin through the input and output data, achieving a better understanding of hydrological physical processes [6]. The results obtained with these models, as prediction of flows and the behavior of hydrological parameters can be of help in early warning for environmental authorities, governorates and non-governmental entities, in land planning and watershed management, which guarantees to address problems such as water scarcity. In the social context, it will generate cross-cutting proposals that are integrated into the sustainable development of water resources, benefiting the community with the continuous supply of ecosystem services such as scenic beauty, water regulation, economic development and improvement of the quality of life [7]. They also provide support for studies, projects and hydraulic engineering works, of infrastructure and the environment [8]. Because of this, hydrological simulation models have become a very useful tool in the management of watersheds; one of these is the SWAT (Soil and Water Assessment Tool). Semi-distributed model, of public domain, computationally efficient and physically based , designed to predict the impact of various land management practices on the hydrology, sediments and the transport of agricultural pollutants in large and complex basins, with different types, uses and soil management conditions, for long periods of time [9].

Therefore, en the present work the SWAT hydrological simulation model is implemented, in order to quantify the effect caused by changes in vegetation cover on the hydrological response of the sub-basin Los Pozos.

2. Materials and methods

2.1. Collection and processing of information

2.1.1. Digital Elevation Model (DEM)

It was supplied by the Corporación Autonoma Regional de Boyacá (Corpoboyacá), that obtained it from the IGAC (Instituto Geografico Agustín Codazzi), crafted in the year 2000, at a spatial resolution of 30 m. The sub-basin Los Pozos presents an altitudinal gradient that goes from 3019 to 3626 masl.

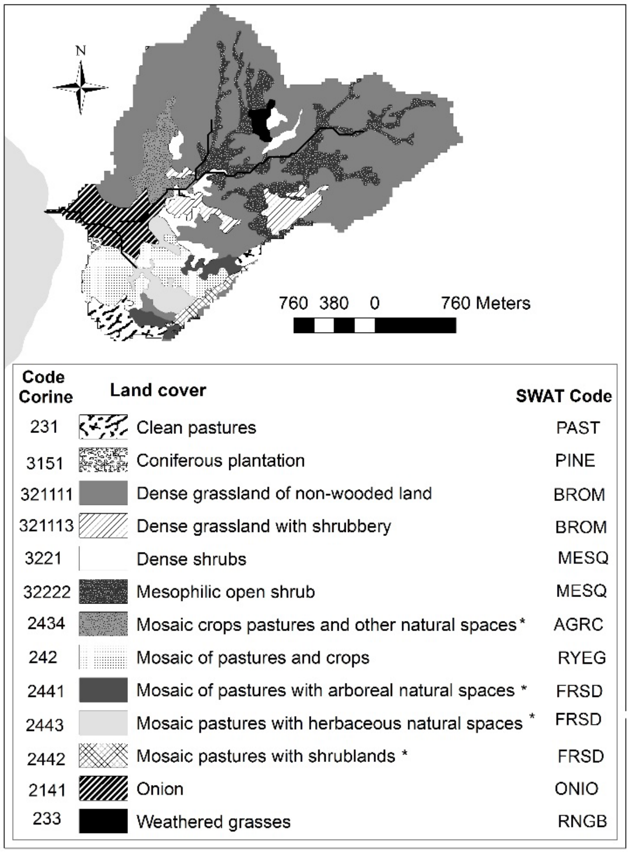

Figure 1. Plant cover map, clasification Corine Land Cover (CLC).
Source: The authors.

2.1.2. Land use and type of soils

Soil use information was obtained from the land cover map at scale 1: 25,000 from paramo from the Lago de Tota basin, crafted under the Corine Land Cover methodology adapted for Colombia -CLCC, in year 2014 by the IDEAM (Instituto de Hidrología, Meteorología, y Estudios Ambientales), completed with the land uses observed in the lower part of the subbasin. Identifying 13 plant covers, which were classified within the types that the SWAT manages through bibliographic review [7,10,11,12], Fig.1. Coverages marked with (*) are more detailed levels that were defined in the scale 1: 25,000.

Soil information was taken from the General soil study and Lands Zoning of the Department of Boyacá made by IGAC in year 2005. The map in shapefile format was supplied by Corpoboyacá at a scale of 1: 100.000. Small scale maps would hinder the adjustment process between the observed and simulated data, since the study area is not represented with detail, generating unsatisfactory results.

The SWAT model for the water balance requires 17 physical and chemical parameters for each soil sort [13]. From the information received from IGAC 9 parameters were obtained from the 3 profiles found in the subbasin Los Pozos (layers number, maximum depth of rooting, texture, depth, organic carbon, clay percentage, silt, sand and rock). The eight (8) missing (hydrological group, fraction of porosity where the anions are excluded, maximum volume of rupture of the profile soil, bulk density, soil water availability, hydraulic conductivity, soil albedo and soil erosion factor K) they were calculated using equations and with the help of the NumCur and Soil Water Characteristics programs version 6.02.74.

2.1.3. Definition of pending

The program automatically determines the slopes, generating the map in tif format. For this case 5 classes were chosen (0-7, 7-25, 25-50, 50-75 and 75-9999) according to the IGAC classification.

2.1.4. Weather

SWAT requires daily climatic data about: precipitation, temperature (maximum and minimum), wind speed, solar radiation and relative humidity. Additional it is necessary to have dew point data for the creation of the database that will generate the climate (WGEN_user) [13,14]. The information was obtained from the IDEAM, of the climatological and pluviographic station El Túnel with code 19850101 and Las Cintas with code 35190010 respectively.

The only parameter that was supplied and read from file was the precipitation, for being the most important variable in the calculation of flow, the others were generated by the model using the WGEN_user climate generator.

- The filling of the missing data of the precipitation series was done with the SWAT model, assigning the number -99 for this data. SWAT recognizes this number as missing data, generating precipitation for that day [13].
- Climate generator database WGEN_user. Because this generator is configured for the USA it was necessary to modify it, for which the creation of a climatological station with monthly multi-year data measured at the Las Cintas and El Tunel stations was made. The station was located within the subbasin Los Pozos in order to perform the climate simulation and complete the missing rainfall data.

2.1.5. Flow data

The monthly data of flow rates measured in the limnimetric station Criadero was used, because it is located geographically at the exit of the subbasin. The information was provided by the IDEAM, for a period of time from 1985 to 2014.

2.2. Implementation the model

In this phase, with the data organized and debugged the SWAT model implementation process is initiated, by means of the ArcSWAT extension in the ArcGis. Once the entire process was completed, the SWAT simulation was "run", to then perform the parametric sensitivity analysis, the calibration, validation and the creation of scenarios of change in vegetation cover.

2.3. Sensitivity parametric analysis

The aim of the sensitivity analysis is to select the key parameters, to which the results of the model are more sensitive. This was done manually to 21 parameters using the tool of the SWAT software called "Manual Calibration Helper".To assess the degree of sensitivity it was calculated the sensitivity index, S, eq. (1) [15], which provides a quantitative measure about sensitivity of model results to the variation of input data. An index S equal to one indicates that the rate of variation of a given parameter causes the same rate of variation in the model outputs; if it has a negative sign it indicates that inputs and outputs vary in opposite directions.

$$\boldsymbol{S} = \left[\frac{(O_2 - O_1)/O_{12}}{(I_2 - I_1)/I_{12}}\right] \tag{1}$$

Where I2 is the maximum value of the parameter to analyze; I1 is the minimum value of said parameter; and I12 is the average of I1 and I2; O2 is the maximum value of the output variable to be evaluated; O1 is its minimum value; and O12 is the average value of the two outputs. In this case the evaluated variable was the flow. Representing, "I" the parameter and "O" the flow. The larger the value of S, the greater the sensitivity of the output value to the input parameter.

2.4. Calibration

Calibration is the process by which the simulated and observed values are optimally adjusted, focusing on minimizing the differences between these data [16]. It was made manually through the analysis "Error Test" to the parameters that were most sensitive, with the purpose of obtaining a good or very good statistical performance according to Moriasi, D. N., et al (2007) [17], for Nash-Sutcliffe (very good $0.75 \leq NSE \leq 1.00$, good $0.65 \leq NSE \leq 0.75$, satisfactory $0.50 \leq NSE \leq 0.65$ and unsatisfactory $NSE \leq 0.50$) and PBIAS (very good $PBIAS \leq \pm 10$, good $\pm 10 \leq PBIAS \leq \pm 15$, satisfactory $\pm 15 \leq PBIAS \leq \pm 25$ and unsatisfactory $PBIAS \geq \pm 25$), in addition, the coefficient of determination R2 was calculated.

2.5. Validation

Validation is the process that allows establishing the prediction reliability of the model. It consisted in performing the simulation using the parameters determined in the calibration, with precipitation and flow data for a different period. Once the simulation is carried out the simulated and observed hydrographs are compared, again applying the statistical performance coefficients mentioned above. If the tests show results similar to those obtained in the calibration, then this is considered validated and the model is ready to be used [18].

2.6. Years used for the calibration and validation

Due to the climatic variability it was not possible to calibrate and validate the model using the whole time period of simulated and observed flows (1985-2015), so it was necessary to exclude the years that presented climatological phenomena boy and girl (Table 1).

Table 1.
Years that were not taken into account for calibration and validation

Years	Justification
1985	The first year is not taken into account, because a time must be left for the recharge of aquifers to take place [10].
1997-1998-2015	Years strong child [19, 20].
1986-1987-1992-2002-2003	Years moderate child. [19, 20].
1989-2010-2011	Years strong girl [19].
2000-2012	Years moderate girl [19, 20].
2004-2005	There is no data on observed flows to be able to perform the validation.
2013	Doubtful data (reviewing precipitation series).

Source: The authors.

Years used for the calibration and validations were:

Years for calibration: 1988-1990-1991-1993-1994-1995-1996-1999. (8 years)

Years for validation: 2001-2006-2007-2008-2009-2014. (6 years)

Futhermore, taking into account that the land use map was elaborated in 2014, it was necesary to include as many years as possible in order to evaluate whether the model hydrologically represents the behavior of the subbasin throughout the period of the study (1985-2015).

2.7. *Scenarios*

Nine scenarios are proposed which were articulated with the territorial planning instruments such as El Esquema de Ordenamiento Territorial of the municipality of Aquitania (EOT), CONPES (National Council of Economic and Social Policy) and El Plan de Ordenación y Manejo de la Cuenca (POMCA) from Lago Tota.

2.8. *Investigation area*

The study was conducted in the sub-basin Los Pozos, located in the Lago de Tota basin, municipality of Aquitania, Boyacá's department, Fig. 2. With a drainage area of 601.74 ha (according to study), its main channel is the Quebrada Los Pozos.

The precipitation in the subbasin Los Pozos presents a behavior of monomodal type with maximum between the months of June and August, with values of 183.4 mm / month, while the dry months are December, January and February, with rainfall ranging from 22.9 to 40.7 mm / month. An average annual precipitation of 1194.7mm is observed in 30 years. The multi-year average temperature (1971-2012) observed in the El Tunel station is 11.40 ° C, the average relative humidity of the air is equal to 83.0%, the cumulative annual evaporation average is 1213.3 millimeters and brightness solar of 1878.1 hours / year.

In terms of soils, the micro-basin has the following classes:

- Aeric Endoaquepts: moderately deep, with limited use due to the poor drainage, very low fertility and little useful depth; drainage Internal slow, external slow, natural imperfect has poorly drained.
- Typic Dystrudepts: very superficial and drainage: internal medium, external fast, natural well drained; with limitations of use due to extremely acid reaction, superficial stoniness and susceptibility to frost.
- Oxic Dystrudepts: very superficial; drainage: Internal slow, external fast, natural moderately well drained, with limitations of use by very shallow effective depth, low fertility and occurrence of frost, 73% aluminum level.

3. Results and discussions

3.1. *Sensitivity parametrics analysis*

Within the results it was identified that of the 21 parameters analyzed the most sensitive corresponds to the Curve Number CN2 that is part of the runoff processes, followed by the re-evaporation coefficient - Gw_Revap. It is also observed that 3 parameters do not cause change to the output of the model, such as the threshold depth of water in the shallow aquifer to produce Revap - Revapmn, the delay time of surface runoff - Surlag and the temperature gradient - Tlaps, with S values equal to zero.

The results obtained are consistent with some studies conducted on the subject, where it is reported that the parameters that generate greater sensitivity to the model correspond to CN2 according to Caro (2005) [5]. In the same way, Oñate, V. et al (2016) [21], determined that they are the curve number (CN2), the soil moisture content (SOL_AWC), the base flow recession constant (ALPHA_BF) and the coefficient of compensation of soil evaporation (ESCO) and, Torres, B. et al (2004) [22], the CN2, Sol_Awc and Esco.

Table 2 shows the eight parameters to which the model is most sensitive, as well as its degree of sensitivity, ordered from most to least importance:

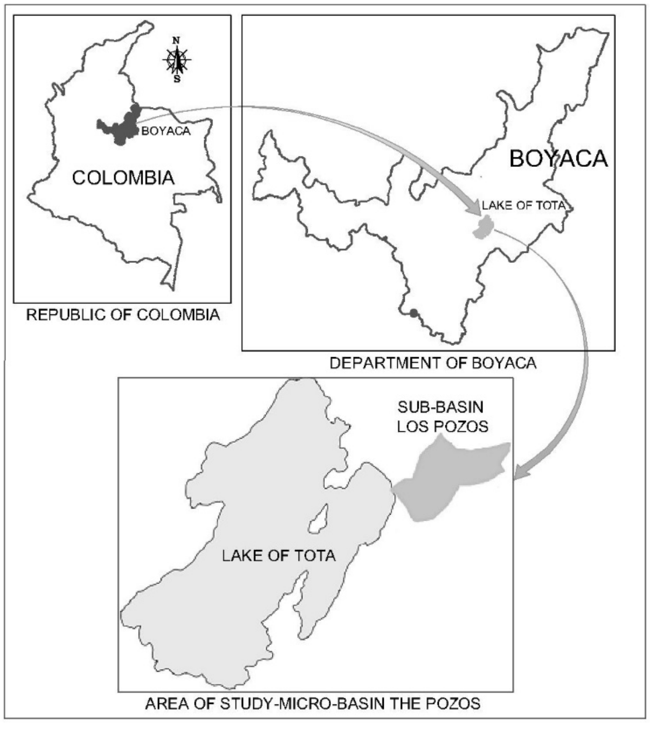

Figure 2. Location the study area
Source: The authors.

Table 2.
Results of the sensitivity analysis for the flow parameters.

Parameter	Description - SWAT Geodatabase	Sensitivity coefficient (*S*)
CN2	Curve number – Humidity condition 2. - (.mgt).	0.18503978
Gw_Revap	Re-evaporation coefficient (GW_REVAP) ground waters, it to decrease wáter soil. - (.gw)	-0.16352952
Alpha_Bf	Direct index from ground wáter flow inside recharge change answer. (Days). - (.gw)	-0.16340400
Sol_Awc	Available wáter capacity of the first soil profile (mm H20/mm suelo). - (.sol)	-0.13656145
Esco	Water evaporation compensation soil factor (.hru).	0.12194472
Gw_Delay	Groundwater delay. (Days). - (.gw)	0.08817376
RCHRG_DP	Aquifer percolating factor - (.gw)	0.06285978
GWQMN	Threshold of wáter depth in the Surface aquifer for the return flow to occur. (mm). - (.gw)	-0.03818785

Source: The authors.

Table 3.
Calibrated parameters (cal) and statistical performance.

	Calibrated parameters				R2	NSE	PBIAS
	CN2	Esco	Gw_ Delay	GWQMN			
Initial Sim	According HRU	0.95	31	1000	0.65	0.60	11.96
Cal.	15%	1	1	1	0.87	0.86	5.81

Source: The authors.

Table 4.
Model Validation and comparison of performance with calibration

	Calibration			Validation		
	R2	NSE	PBIAS	R2	NSE	PBIAS
Performance	0.88	0.86	5.81	0.87	0.79	16.32

Source: The authors.

3.2. Calibration

The model presented a satisfactory performance for the R2 and NSE statistics, and good for PBIAS without making any adjustments to the parameters. Calibration was performed to improve the prediction, obtaining a very good performance for the three statistics analyzed (Table 3).

3.3. Validation

In Table 4 it can be seen that in the validation an adjustment was obtained between the observed and simulated flow rates less satisfactory than that obtained in the calibration. But according to the statistical performance for the coefficients R2 and NSE is very good, and for PBIAS it is reduced to satisfactory.

In Fig. 3 is presented graphically the comparison of the results of observed flows with those obtained in the initial simulation, calibration and validation. Concluding that the model was calibrated for the entire selected time period (1985-2015).

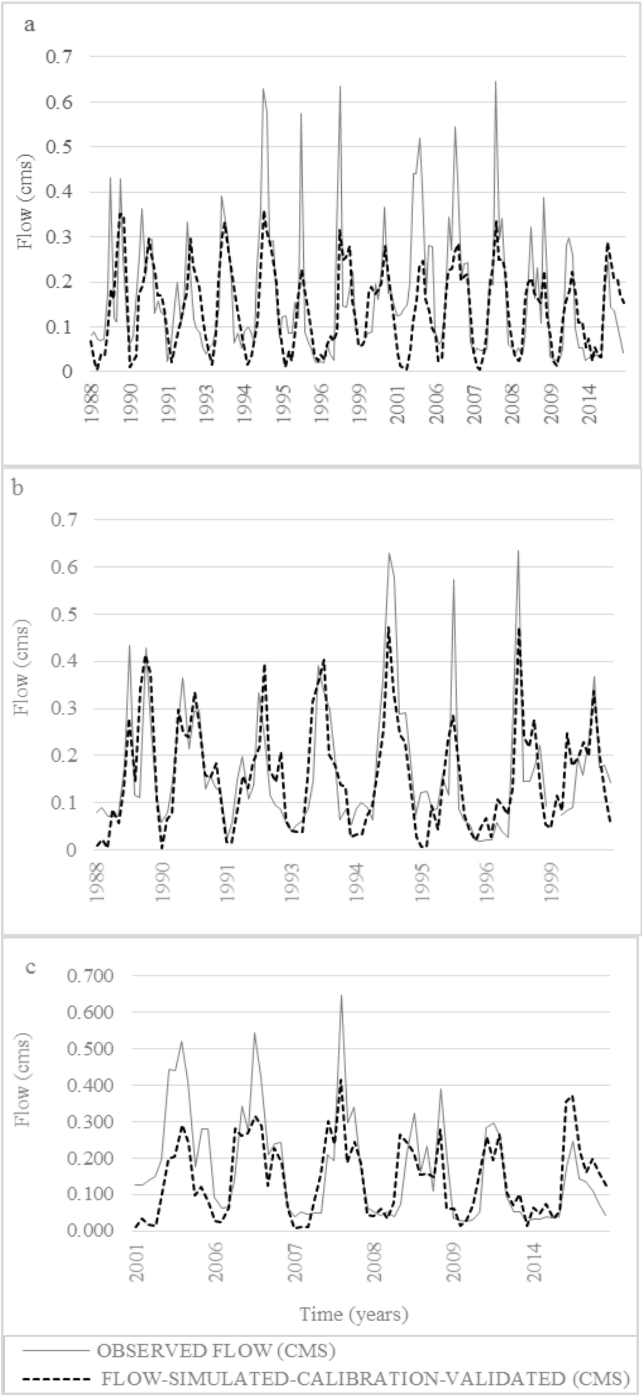

Figure 3. a. Flow observed v/s simulated initially. b. Monthly flow observed v/s calibrated flow. c. Monthly flow observed v/s validated flow.
Source: The authors.

Likewise, Torres, et al, (2005) [23], conclude that the SWAT model is a valuable tool for simulating the impact of soil and vegetation management on water and sediment production in the Laja River basin, located in Guanajuato, Mexico, since they obtained in their research values of R2 equal to 0.82 in the first simulation, without having changed the parameters of the model, however, after the calibration a better adjustment was obtained with values of 0.97 and for the validation of 0.95. Aguayo, et al,

(2016) [24] in its study carried out in the basin of the río Vergara, located in the southern scepter of Chile, to evaluate the hydrological effect of future scenarios of forest expansion in a mesoscale basin (4,340 km2) with the SWAT model, found that the main problem detected was the underestimation of peak flows for the three stations used in the validation process. However, according to the Nash-Sutcliff efficiency index (NSE), the coefficient of determination (R2) and the percentage of deviation (PBIAS), the model satisfactorily reproduces the hydrological regime of the three sub-basins associated with each Renaico station (R2=0.99, PBIAS=4.07 and NSE=0.91), Mininco (R2=0.80, PBIAS=7.95 and NSE=0.87) and Malleco (R2=0.78, PBIAS=663 and NSE=0.85), affirming that the results of the validation show that the SWAT model was able to reproduce the hydrology of the basin satisfactorily and, consequently, it is appropriate to evaluate the hydrological response of future scenarios of forest expansion. Obando, M. et al. 2013 [25], in its study carried out in the sub-basin Peñas Blancas, located in the Nariño's department, Colombia, with an extension of 1934 hectares, obtained in the first instance a regular performance of the SWAT model of R2=0.52, NSE=0.24 and PBias=-14.6%, so it was necessary to perform a calibration to the most sensitive parameters, achieving adjusted values of R2=0.74, PBias=-9.13% and NSE=0.65. In the same way for the validation period of the model, they obtained a very good performance of R2=0.80, NSE=0.70 and PBias=-10.3%.

With the findings obtained in the calibration and validation of the present study, as well as the bibliographic review carried out, it was evidenced that the SWAT model although it was designed to be implemented in large and complex watersheds, It is also applicable in small basins like the subbasin Los Pozos, where represents with a very good level of performance the physical processes that occur with respect to the behavior of water, concluding that the performance of the model in basins of different sizes depends on the veracity and quality of the input data, as well as the level of detail of the system.

Near the subbasin Los Pozos are El Túnel, Las Cintas, Iza, Toquilla and Potrerito weather stations, which have rainfall data. Of these, the Tunnel station is the only one that presents series of temperature, evaporation, relative humidity, solar brightness, among others. To construct the model, it was determined in advance by means of the Thiessen polygons method that the subbasin is within the area of influence of Las Cintas station, and because it does not have all the required information it was necessary to use the data of the other parameters measured in the Tunel, because it is located geographically close to the study area, which is why only these two stations were selected (Las Cintas and El Tunel). Therefore, calibration and validation with the two stations used and the selected time period are considered reliable, since the behavior of the precipitation time series was analyzed in advance, as well as the climatic variability caused by the phenomena of the boy and girl, trying to include as many years as possible, which allowed to evaluate that the model represents hydrologically the behavior of the subbasin Los Pozos.

3.5. Scenarios and quantification of the effect of changing the vegetation cover in the hydrological response of the subbasin

The scenarios proposed are the following:

1. Water rounds of 30 meters: According to the norm of superior hierarchy (Article 83 of Decree-Law 2811 of 1974: "d. - A strip parallel to the maximum tide line or to the permanent channel of rivers and lakes, up to thirty meters wide ").
2. Water rounds of 5 meters: According EOT Aquitania municipality.
3. Agroecological restoration: Conformation of living barriers (bushes and / or trees) inside crops, located in the flat areas and on the slopes. The vegetation strips were located perpendicular to the slope and 100 meters away from each other. Established in POMCA of lago de Tota.
4. Combination of scenario 1 and 3. Rounds of 30 meters and agro-ecological restoration: According to Norma de superior hierarchy and POMCA of Lago de Tota.
5. Recommended use in the Esquema de Ordenamiento Territorial de Aquitania (EOT): Scenario proposed according to the zoning of recommended uses of rural land, establecido en el EOT, which presents the following regime of uses: Natural Reserve Area, Damping Area, Sub-páramos and High Andean Forests, Fruit and Livestock Production Area, Semi-Mechanized or Semi-Intensive agricultural and livestock area, Silvo-pastoral areas and rounds of streams.
6. Pessimistic scenario, agricultural sub-basin, 100% coverage onion branch crops.
7. Optimistic scenario, made up of protective forest and reserve area (páramo vegetation).
8. Combination of scenario 2 and 3. Rounds of 5 meters and agro-ecological restoration: Established in the EOT of the municipality of Aquitania and POMCA of the lago de Tota.
9. Expansion of agricultural borders with onion crops

3.4.1. Analysis of the scenarios

Below is analyzed the behavior of the variables SURQ (surface runoff), LATQ (subsurface runoff), PERC (percolation), GWQ (return flow or base flow) and ET (real evapotranspiration) obtained in the calibration (cal) and in the nine proposed scenarios (Sce) of change of vegetation cover in the multi-year monthly period of 1985-2015.

3.4.1.1. Flow (m3/s)

In Fig.4 the comparison between flows obtained in the calibration with those obtained in the different scenarios is made, observing that there are only variations in scenario 6 and 9, which correspond to a pessimistic situation where land use is completely changed to onion crops and the agricultural frontiers are extended to the buffer zone respectively. When performing the analysis it is observed that it is due to the fact that surface runoff increases considerably, decreasing evapotranspiration, percolation and subsurface runoff.

The behavior of the flow in scenarios 6 and 9 is closely related to the real evapotranspiration variable, since this is lower than that obtained in the other scenarios in the months of January to July, increasing from August to December, as can be seen in Fig. 5, with more rainfall available in the soil to contribute to the flow in the first semester of the year and lower in the second semester.

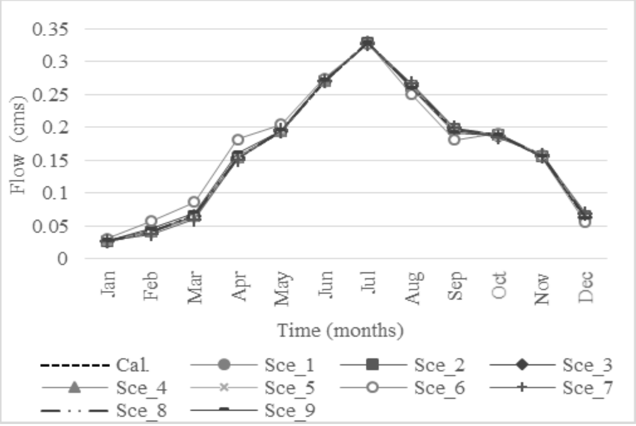

Figure 4. Calibrated flow versus the simulated flows in the scenarios.
Source: The authors.

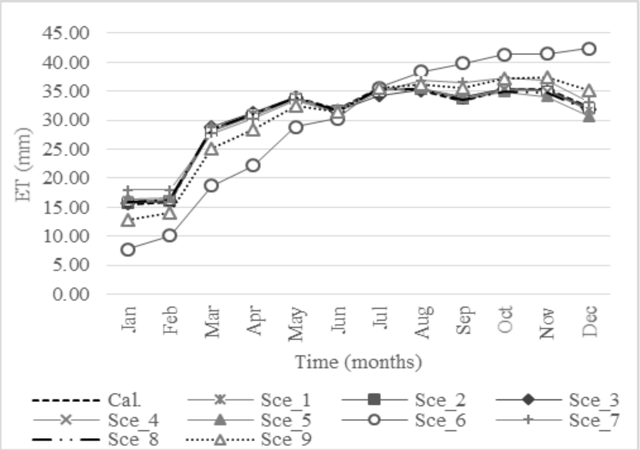

Figure 5. Comparison between actual evapotranspiration obtained in the calibration and in the scenarios.
Source: The authors.

3.4.1.2. Real Evapotranspiration – ET mm

For this study an equal behavior is presented in most of the scenarios, except in the 6 (subbasin covered with onion) and 9 (agricultural frontiers extension), starts with lower values increasing as the year progresses, with an annual average of 356.96 mm and 361.18 mm that is equivalent to 29% and 29.3 of the rainfall respectively, scenario 7 due to the coverage of native vegetation generates the highest real evapotranspiration of 374.29 mm (30.4%), Fig. 5.

3.4.1.3. Superficial runoff - SURQ_mm

The Fig. 6 confirms the increase in surface runoff in Scenarios 6 and 9, which represents 64.06% (789.16 mm) and 49.46% (609.38 mm) of the total precipitation of the sub-basin. The optimistic scenario 7 with native vegetation presents the lowest surface runoff of 34.83% (429.09 mm) which corresponds approximately half of that generated by scenario 6 with onion cover, followed by scenarios 5 (41.1% equal to 506.35 mm) , 4 (42.16 corresponding to 519.4 mm) and 8 (42.50% that is to say 523.6 mm). Observing that the type of vegetation cover existing in the subbasin influences the increase or decrease of surface runoff, in the results obtained the tree species generate a reduction and onion crops a considerable increase.

3.4.1.4. Subsuperficial runoff - LATQ_mm

In scenario 7 this hydrological variable presented the highest percentage with respect to precipitation of 8.4% (103.66 mm), followed by scenario 5 that corresponds to the land use recommended by the EOT of Aquitania with 88.98 mm (7.2%). The lowest subsurface runoff occurred in scenarios 6 an 9 of 33.86 mm (2.7%) and 66.72 mm (5.4%) respectively, the others show a similar behavior ranging between 71.31 mm (5.8%) and 76.25 mm (6.2%), Fig. 7.

3.4.1.5. Return flow - GW_Q mm

Scenario 7 shows the highest average annual return flow of 309.1 mm, which corresponds to 25.1% of total precipitation, this is due to the fact that the basin is totally covered by protect forest and paramo vegetation, which causes a greater infiltration and recharging surface aquifer increasing base flow, being very important the evaluation of this hydrological variable since it is the contribution of the aquifer to rivers levels during periods of low water.

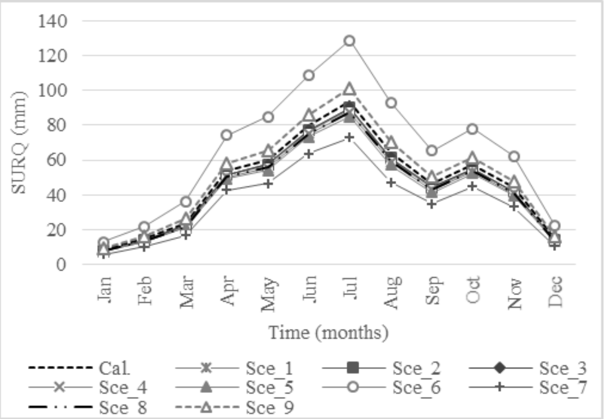

Figure 6. Comparison between surface runoff obtained in the calibration and in the scenarios.
Source: The authors.

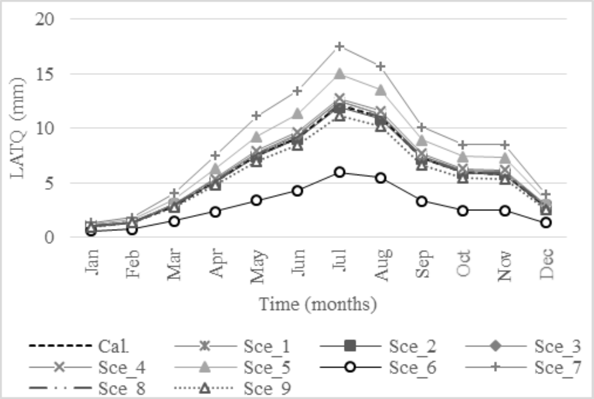

Figura 7. Comparison between subsurface runoff obtained in the calibration and at the scenarios. (1985-2015).
Source: The authors.

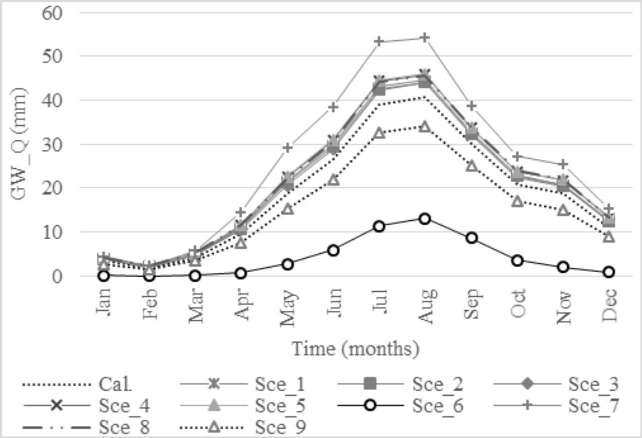

Figure 8. Comparison between return flow obtained in the calibration and scenarios. (1985-2015).
Source: The authors.

Table 5.
Summary hydrological behavior obtained in the sub-basin Los Pozos in annual percentage of total precipitation.

	Annual percentage of total precipitation					
	SURQ	LATQ	GWQ	ET	Recharge	% total
Cal.	45.4	5.9	18.3	29.5	0.95	100
Sce_1	43.1	6	20.3	29.5	1.06	100
Sce_2	43.6	5.8	20.1	29.5	1.05	100
Sce_3	43.6	6	19.9	29.5	1.04	100
Sce_4	42.2	6.2	21.1	29.5	1.1	100
Sce_5	41.1	7.2	21.2	29.4	1.1	100
Sce_6	64.1	2.7	4.1	29	0.21	100
Sce_7	34.8	8.4	25.1	30.4	1.31	100
Sce_8	42.5	5.9	21.1	29.4	1.1	100
Sce_9	49.46	5.4	15.1	29.3	1	100

Source: The authors.

In scenarios 6 and 9 in which the basin is completely covered by onions and where the agricultural frontier was extended generated a less return flow of 4.1% (50 mm) and 15.1% (185.46 mm) of the total precipitation. In the scenarios 4 and 8, where combined the protection of the water round of 30m and 5m respectively, with agroforestry arrangements in the area where there are crops and pastures, as well as scenario 5 that complies with the established in the use soil recommended in the EOT of the municipality of Aquitania, have the same behavior in terms of this hydrological variable, with 21.1% (259.5 mm, scenarios 4 and 8) and 21.2% (260.7 mm, scenario 5) of base flow, Fig. 8.

3.5. *Handling that can be implemented to favor the water regulation of sub-basin Los Pozos*

The Table 5 presents the summary of hydrological behavior obtained in subbasin Los Pozos, further indicating the recharge to the deep aquifer, which corresponds to the amount of water that passes through the confinement layer and contributes to the level of groundwater.

Of the results obtained and taking into account that optimistic and pessimistic scenarios were formulated that can not be developed, they were only taken to observe the behavior of the basin, it is concluded that in order to improve the water regulation of the sub-basin recommended to implement the scenario 8 (Combination of scenario 2 and 3. Rounds of 5 meters and agro-ecological restoration) (Table 6), for the following reasons:

It complies with the established in the planning instruments such as 5 meter water rounds established in the EOT and the program proposed in the Plan de Ordenación y Manejo de la Cuenca del Lago de Tota (POMCA) for agroecological restoration.

The hydrological behavior of scenario 8 compared to scenarios 4 (Combination of scenario 1 and 3. Rounds of 30 meters and agro-ecological restoration) and 5 (Use of rural land established in the EOT of the Aquitania municipality) is similar. Therefore implementing the 5 meter water round, there would be more area to be cultivated, which would cause less social conflict than when establishing rounds of 30 meters. Selecting scenario 5 (recommended land use) would create a conflict in the use of the land, since in the sub-basin the current vocation is mainly the cultivation of onion and not the production of fruit trees and livestock as established in the EOT.

From Table 6 it is concluded that when implementing scenario 8 compared to the current situation, the hydrological behavior of the sub-basin would be:

- The surface runoff will decrease a multiannual average of 36.25 mm per year, which is equivalent to 218130.75 m3 in the year in all the subbasin or a flow rate of 6.91 l.p.s.
- The subsurface runoff will increase 0.63 mm per year, which is equivalent to 3790.96 m3 in the year in all the subbasin or a flow of 0.12 l.p.s.
- The return flow will increase 34.3 mm per year, which is equivalent to 206396.82 m3 in the year in all the subbasin or a flow rate of 6.54 l.p.s.
- The real evapotranspiration will decrease a annual average 0.49 mm in the year, this means an increase in precipitation that drains, infiltrates, percolates, returns and is stored in the deep aquifer, equivalent to having 2933.4 m3 in the year in all the sub-basin or 0.093 lps that can be distributed in these hydrological variables.
- The recharge to the deep aquifer will increase on average 1.78 mm per year, which is equivalent to 10712.76 m3 stored in the year in all the sub-basin or a recharge rate of 0.339 l.p.s.

4. Conclusions

The simulation obtained from the SWAT model allowed us to understand the hydrological behavior of subbasin Los

Table 6.
Comparison current hydrological behavior of the subbasin with selected scenario.

	% and mm Annual total rainfall			
	Calibrated		Scenario 8	
	%/year	mm/year	%/year	mm/year
SURQ	45.4	559.85	42.5	523.6
LATQ	5.9	72.2	5.9	72.83
GW_Q	18.3	225.3	21.1	259.6
ET	29.5	363.21	29.4	362.72
RECHARGE	0.95	11.75	1.10	13.53
Total % and mm precipitation	100.0	1232	100.0	1232

Source: The authors.

Pozos against different changes in vegetation cover, generating a quantification of the water resource with variables such as surface runoff (SURQ) and subsurface (LATQ), percolation (PERC)), return flow (GWQ) and real evapotranspiration (ET).

With the results obtained in the calibration and validation it is concluded that the model represents well the hydrological processes of the sub- basin Los Pozos, predicting with a very good level of statistical performance of Nash Sutcliffe (NSE) the flows at the exit of basin. Therefore, it is considered that the model can be used as a support tool for decision making in the area regarding the handling of land uses, in order to improve water regulation.

The sensitivity analysis allowed us to identify the parameters that influence the result of the model, so when performing it before calibration, it facilitated the process of adjusting the simulated flows to those observed.

In the sensitivity analysis it was identified that of the 21 parameters that influence the flows generated by the model, the most sensitive corresponds to the Curve Number (CN2) that is part of the runoff processes, with a value of the sensitivity index , S, equal to 0.1850, followed by the coefficient of re-evaporation (Gw_Revap) with an S of -0.1635 and the direct index of groundwater flow in response to changes in recharge (Alpha_Bf) with an S of -0.1634, immediately other parameters that are showing lower sensitivity, it was also observed that 3 parameters do not cause change at the exit of the model such as the water depth threshold in the shallow aquifer to produce Revap (Revapmn), the delay time of the surface runoff (Surlag) and the temperature gradient (Tlaps), with sensitivity indexes, S, equal to zero.

The modeling of the hydrological response of the subbasin Los Pozos under different scenarios of change in vegetation cover, allowed to determine that the protection of 5-meter water rounds and the agro-ecological restoration improves the water regulation, decreasing in the year the superficial runoff in average 36.25 mm and the real evapotranspiration 0.49 mm, and increasing the subsurface runoff 0.63 mm, the return flow 34.3 mm and the recharge to the deep aquifer 1.78 mm, activities that are articulated with the instruments of territorial planning.

Should not be expand The agricultural frontiers in subbasin Los Pozos , since from the results obtained in the scenarios it could be observed that when the subbasin was totally covered by onion crops, the water balance was affected with a bad regulation because the 65.17% from total precipitation became surface runoff and only 4.03% is contribution to groundwater, instead when the subbasin was covered by protective forest and vegetation of paramo the 36.15% of the total precipitation was presented as surface runoff and 27.18% it becomes percolation, which is divided into a higher percentage for the return flow that feeds the rivers in times of low water and, to a lesser extent in recharge deep aquifer.

References

[1] Baribbi, A. y Spijkers, P., Asistencia técnica internacional del tercer laboratorio de paz, Bogotá, [en líena]. 2011. Disponible en: http://eeas.europa.eu/archives/delegations/colombia/documents/projects/cartilla_tierra_y_desarrollo_lab_paz_iii_es.pdf

[2] Noriega, J., Castillo, D., Vásquez, A. y Monroy, J., Estudio preliminar del estado de la microcuenca Los Pozos y su posible efecto en un sector de la laguna de Tota, Boyacá-Colombia. Revista de Tecnología, 9(2), pp. 145-163, 2010.

[3] Documento Conpes 3801, Manejo ambiental integral de la cuenca hidrográfica del Lago de Tota. Consejo Nacional de Política Económica y Social, Departamento Nacional de Planeación. Bogotá, Colombia, 2014.

[4] Chaparro, J., Cambios institucionales para preservar la cantidad y la calidad del agua en la cuenca del Lago de Tota, Tesis MSc., Facultad de Estudios Ambientales y Rurales, Universidad Javeriana, Bogotá, D.C. Colombia, 2013.

[5] Caro, C.A., Modelación y cuantificación del efecto de la vegetación en la respuesta hidrológica de cuencas. Revista de Ingeniería de la Universidad de Los Andes, 2005.

[6] Chow, V.T., Maidment, D.R. y Mays, L.W., Hidrología Aplicada. México: Mc GrawHill, 1994.

[7] Hernández, D., Estimación de los parámetros morfométricos y las unidades de respuesta hidrológica de la cuenca del Rió Ráquira departamento de Boyacá a través del programa SWAT. Tesis de Especialización. Universidad Católica de Colombia, Bogotá, 2015.

[8] Fattorelli, S. y Fernández, P., Diseño Hidrológico, [en líena]. 2011. Disponible en: http://www.ina.gov.ar/pdf/Libro_diseno_hidrologico_edicion_digital.pdf

[9] Centro Agronómico Tropical de Investigación y Enseñanza- CATIE. II Curso internacional. Uso del modelo SWAT como una herramienta para el manejo de cuencas hidrográficas. [en línea]. Disponible en: http://www.catie.ac.cr/attachments/article/426/2014_Modelo%20SWAT.pdf

[10] Uribe, N. y Valencia, J., Impacto del uso de la tierra en la generación de caudales y sedimentos: caso cuenca del Rio Tunjuelo – Cundinamarca, [en línea]. 2010. Disponible en: http://oab2.ambientebogota.gov.co/es/documentacion-e-investigaciones/resultado-busqueda/impacto-del-uso-de-la-tierra-en-la-generacion-de-caudales-y-sedimentos-caso-cuenca-del-rio-tunjuelo-cundinamarca

[11] Uribe, N., Estrada R.D. y Jarvis, A., Impacto del uso de la tierra en la generación de caudales y sedimentos: el caso de las cuencas Tuluá-Morales, Guabas, Sabaletas, Amaime, Nima, Bolo, Fraile, Desbaratado y Palo. [en línea]. 2009. Disponible en: http://www.asocana.org/documentos/6122011-7521004a-00ff00,000a000,878787,c3c3c3,0f0f0f,b4b4b4,ff00ff,ffffff,2d2d2d,b9b9b9,d2d2d2.pdf

[12] Uribe, N., Quintero, M. y Valencia, J., Aplicación del modelo hidrológico SWAT (Soil and Water Assessment Tool) a la cuenca del Río Cañete (SWAT). [en línea]. 2013. Disponible en: https://es.scribd.com/document/188349117/Modelo-Hidrologico-Swat

[13] Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B. and Neitsch, S.L., Soil & Water Assessment Tool. INPUT/OUTPUT File Documentation, version 2012. Texas Water Resouces Instiute. [online]. Available at: https://swat.tamu.edu/media/69296/swat-io-documentation-2012.pdf

[14] Uribe, N. SWAT (Soil and Water Assessment Tool), conceptos básicos y guía rápida para el usuario, Versión SWAT2005, [en línea]. 2010. Disponible en: https://swat.tamu.edu/media/46967/swat2005-tutorial-spanish.pdf

[15] Nearing, M.A., Deer-Ascough, L. and Laflen, J.M., Sensitivity analysis of the WEPP hillslope profile erosion model. Transactions of the ASAE, 33(3), pp. 839-849, 1990.

[16] Cabrera, J., Calibración de modelos hidrológicos, [en línea]. 2012. http://www.imefen.uni.edu.pe/Temas_interes/modhidro_2.pdf

[17] Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), pp. 885-900, 2007.

[18] Eterovic, J., Aplicación de modelos hidrológicos con fines de prevención de desastres en cuencas de Venezuela, Tesis MSc., Universidad de Los Andes, Mérida, Venezuela, 2008.

[19] Instituto de Hidrología, Meteorología y Estudios Ambientales - IDEAM. Actualización del componente meteorológico del modelo institucional del IDEAM sobre el efecto climático de los fenómenos El Niño y La Niña en Colombia, como insumo para el Atlas Climatológico. [en línea]. 2014. Disponible en: http://www.ideam.gov.co/documents/21021/440517/Actualizacion+Modelo+Institucional+El+Ni%C3%B1o+-+La+Ni%C3%B1a.pdf/02f5e53b-0349-41f1-87e0-5513286d1d1d

[20] Azcárate, R. y Mejía, A., Meteorología, socioeconomía y gestión del riesgo de desastres del evento El Niño oscilación del sur en Colombia. Revista electrónica editada por la Facultad de Ciencias Naturales e Ingeniería de la UJTL [en línea]. 6(2), pp. 95-109, 2016. DOI: 10.21789/22561498.1154

[21] Oñate, V.F., Bosque, S.J., Sastre, M.A. and Ponce, V.M., Calibration, validation and evaluation of a lumped hydrologic model in a mountain area in southern Ecuador. Texcoco, México. Agrociencia, 50(8), pp. 945-963, 2016.

[22] Torres, B.E., Fernández R.D., Oropeza, M.J. y Mejía, S.E., Calibración del modelo hidrológico SWAT en la cuenca “El Tejocote”, Atlacomulco, estado de México. Chapingo, México. Terra Latinoamericana, 22(4), pp. 437-444, 2004.

[23] Torres, E., Mejía, E., Cortés, J., Palacios, E. y Exebio, A., Adaptación de un modelo de simulación hidrológica a la cuenca del río Laja, Guanajuato, México. Agrociencia, 39(5), pp. 481-490, 2005.

[24] Aguayo, M., Stehr, A. y Link, O., Respuesta hidrológica de una cuenca de meso escala frente a futuros escenarios de expansión forestal, Santiago, Chile. Revista de Geografía Norte Grande, (65), pp. 197-214, 2016.

[25] Obando, M., Morán, M. y Solarte, G., Modelación del recurso hídrico en la microcuenca Peñas Blancas, municipio de Tangua, Departamento de Nariño. Tesis pregrado, Universidad de Nariño, Pasto, Colombia, 2013.

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