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Zoning of infiltration areas using Schosinsky's Soil Water Balance in La Balsa River Basin, Costa Rica

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Key words: *Central America, Costa Rica, rainfall, infiltration, watershed*.

Abstract. In Central America there is little information of water infiltration at the basin level, despite its importance for the design of appropriate conservation and restoration strategies. Thus, the aim of this study is to develop an example for how to use Schosinsky´s Soil Water Balance (SSWB) model -along with other variables-as a more viable way to determine water infiltration zones at the basin level. Zones, in La Balsa River Basin (LBRB), were determined by overlaying information of basin slopes, existing land use, land cover and spatial distributed rainfall. Hydrophysical soil properties in each zone were obtained through field tests measurements and laboratory analyses of soil samples. Once the values of each zone were determined, SSWB model was applied to obtain a map of infiltration zones. Results indicate that rainfall is the most influential component in calculating SSWB, and its distribution and deposition on the ground as effective rainfall is related to soil exposure and land use characteristics. Soil properties control the behavior of water that enters the soil and replenishes groundwater. Infiltration values, obtained using the model are highly correlated to rainfall dynamics. It is concluded that SSWB model is an important tool for obtaining water infiltration estimates at the basin level, useful in those basins for which little information is available.

Апстракт. У Централној Америци нема довољно података о инфилтрацији воде на нивоу слива, упркос њеном значају за креирање одговарајућих стратегија очувања и обнављања. Стога је циљ овог истраживања да се развије пример за коришћење Шосинскијевог модела баланса воде у земљишту (SSWB) - заједно са другим променљивима - као практичнији начин за одређивање зона инфилтрације воде на нивоу слива. Зоне у сливу реке Ла Балса (LBRB) одређене су преклапањем података о нагибу басена, тренутном коришћењу земљишта, покривачу земљишта и просторним распоредом падавина. Хидрофизичка својства земљишта у свакој зони добијена су мерењима приликом теренских испитивања и лабораторијским анализама узорака земљишта. Када су вредности сваке зоне одређене, примењен је модел SSWB, да би се добила мапа зона инфилтрације. Резултати показују да су кишне падавине најважнији фактор за израчунавање SSWB-а, а њихова дистрибуција и сакупљање на површини је у зависности од експозиције тла и коришћења земљишта. Својства земљишта контролишу понашање

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воде која улази у земљу и обнавља подземне воде. Вредности инфилтрације добијене коришћењем модела су у корелацији са динамиком падавина. Закључује се да је модел SSWB важан алат за добијање процене инфилтрације воде у басенима за које постоји мало података.

Introduction

In absence or shortage of surface water groundwater becomes an essential resource for direct human consumption and the development of productive activities such as agriculture and livestock farming. In recent years there has been greater awareness of its importance because of the imbalance between water supply and demand due to increased consumption by humans and irrigation systems, decreasing water yield in deforested basins, increased contamination of water sources caused by human activities, and increased degradation of hydrographic basins.

Quantifying the natural rate of infiltration is necessary for better management of a basin's water resources, allowing the comparison of this rate to output flows through rivers, and with water use from springs and wells.

Several methods are available for quantifying infiltration within a basin; however, at the regional level, methods are scarce, therefore the water balance method becomes more popular given its applicability at large spatial scales (Healy, 2010). The method proposed by Schosinsky (2006) has been widely used (Noriega, 2005; Montoya, 2009; Zuleta, 2011; Ramírez, 2013; Sánchez et al., 2013; Morales, 2014; Servicio Geológico Colombiano, 2015; Alvarado & Barahona, 2016; Haar & Izaguirre, 2016; Paz, 2016; Delgado & Flores, 2017). This method is used to determine water infiltration values at a specific location, based on hydrophysical properties of the soil, rainfall, topography, and land use. Using this information, specific areas or infiltration units are established, for which the soil water balance is applied to obtain the amount of water input into the soil, which in turns is used to determine infiltration zones within a basin or region.

A water infiltration zone is a geographically defined area with similar recharge rates, determined using values of a set of variables such as topography, soil hydrophysical properties, climatic conditions, and land use, among others (Selvam et al., 2015) using a specific analytical method (Agarwal & Garg, 2016) such as SSWB (Schosinsky, 2006). For hydrogeological studies at a regional level, the determination of such zones is an important tool in decision making related to water resource management.

This is particularly important in the case of LBRB due to small number of water sources that supply to the populations living within and outside the basins, especially in its upper part. In this region, groundwater is highly demanded for human consumption, farming irrigation and hydroelectric generation. Moreover, in recent years, there have been changes of land use in the basin which have caused soil degradation, alterations of the discharge responses to rainfall events, causing increases in storm flow and decreases in base flows.

This paper aims at presenting the results of a study on the zoning of water infiltration areas in the LBRB, based on the determination of SSWB model. Results will contribute to the definition of strategic conservation/restoration areas in the basin, a model that may be applied to other river basins in the region.

Methodology

Study site

The LBRB is located within the counties of San Ramón, San Carlos, Alfaro Ruíz and Naranjo in Central Costa Rica (Fig. 1), between coordinates 471500 – 499400 m east and 236800 – 261950 m north, using the Lambert Conical Projection system for Northern Costa Rica. The main villages in the basin are: Bajo Rodríguez, San Lorenzo, Zarcero, Alto Villegas, Los Ángeles Norte and Palmira. It in-

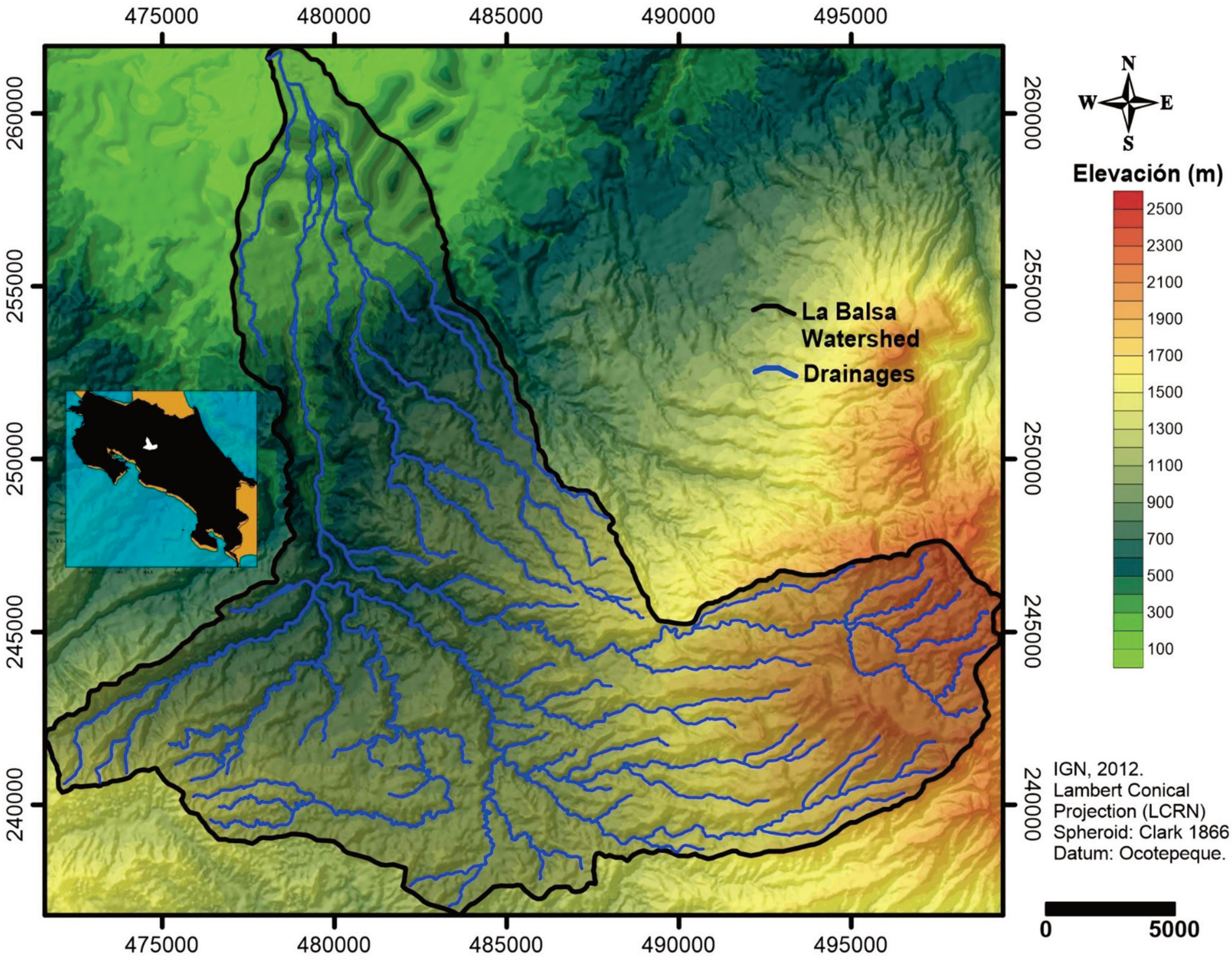

Fig. 1. *Location of LBRB in Costa Rica, Central America.*

cludes the districts of Los Angeles, Florencia, Buenavista, Zapote, Brisas, Palmira, Zarcero, Laguna, Tapezco, Guadalupe and Volio and has a perimeter of 99.63 km and an area of 287.6 km^2.

Schosinsky's Soil Water Balance (SSWB)

To estimate water infiltration in the basin, we employed the methodology developed by Schosinsky (2006) and Schosinsky & Losilla (2000). This approach involves quantifying the soil water balance by utilizing monthly data on rainfall infiltration collected over the course of a hydrological year. This methodology is most suitable for hydrographic basins with well-defined natural boundaries.

Climatic values were collected from meteorological stations installed within and near the basin, such as: Agroverde, Zarcero 1, Zarcero 2 with rainfall data, and Palmira, Finca Junquillal, Daniel Gutiérrez, Hermanos Rodríguez, Santa Clara, Coopelesca and Peñas Blancas with rainfall and temperature data. The data used corresponded to a historical period of 8 years from 2000 to 2008, from January to December, this is what was defined as the hydrological year. The basin experiences a dry period in February, March, and April, and a rainy period from May to December. The year in which the work was conducted was 2009, which was a year with a neutral to dry climatic period, according to the data of National Weather Service of NOAA of United States of America.

(https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php)

Spatial distribution of rainfall in the basin was determined using Thiessen polygons. The choice of this method was due to its ability to construct infiltration zones.

To quantify the amount of water that reaches the ground and will infiltrate the soil, it is necessary to obtain a foliage coefficient (*Cfo*), which can then be used to derive the retention of rain (*Ret*) and it is defined as following equation:

$$Ret = \begin{cases} P, ifP \leq 5 \\ P \cdot Cfo, ifP \cdot Cfo > 5 \\ 5, ifP > 5 \ and \ P \cdot Cfo < 5 \end{cases} \quad (1)$$

where *Ret* is in mm and *P* is rainfall (mm). The value of 5 was determined from a rainfall analysis, where rainfall amounts lower than 5 mm do not infiltrate or drain but are rather directly intercepted by the foliage (Schosinsky & Losilla, 2000). *Cfo* is taken from photo interpretation of aerial images (Carta, 2005). Land uses were classified into three categories: forests, pastures, and crops. A database was associated with the polygonal vector which contained information on the type of land use, the foliage coefficient (*Cfo*), and the infiltration coefficient for land use (*Kv*). The last two of these characteristics were obtained from Schosinsky & Losilla (2000). During fieldwork, exposed soil profiles by roads and rivers were examined to determine the length roots (*pr*) associated with each type of use, and an average value of root distribution was calculated for each of these use types.

A water infiltration coefficient (*Ci*) is then computed, incorporating three components: the fraction of water that infiltrates due to the slope (*Kp*), the fraction influenced by vegetation (*Kv*), and the fraction affected by soil texture (*Kfc*). This computation is described by the following equation:

$$Ci=Kp+Kv+Kfc, \quad 0 \leq Ci \leq 1 \quad (2)$$

where *Kfc* can take the following values:

$$Kfc=\begin{cases} 0{,}267 \cdot \ln(fc) - 0.000154 \cdot fc - 0.723, if 16 < fc < 1568 \\ (0{,}0148 \cdot fc)/16, if fc \leq 16 \\ 1, if fc \leq 1568 \end{cases} \quad (3)$$

Kp was obtained from a 1:50,000 DEM provided by the Costa Rican Geographical Institute. The value of soil hydraulic conductivity (*fc*), in mm/d, was determined from undisturbed soil samples collected in the field, with rings measuring 7,5 × 7,5 cm. The analysis was conducted using the constant head core method (Reynolds, 2008) and corresponds to the first 30 cm of saturated soil.

The values of *R*, *Ret* and *Ci* are used to calculate monthly rainfall infiltration:

$$Pi = Ci \cdot (P - Ret) \quad (4)$$

where *Pi* is the infiltrating rainfall (mm).

Surface runoff, *Esc*, (mm) is determined for the entire basin according to:

$$Esc = P - Ret - Pi \quad (5)$$

Quantifying the water balance requires not only the value of monthly soil infiltration but also the preceding values for maximum and minimum soil moisture–namely, the field capacity (*FC*) and the wilting point (*WP*). *FC* and *WP* were determined for various soils using undisturbed soil samples collected with steel rings measuring 5,0 ´ 1,0 cm. The analysis was conducted through the pressure plate method (Reynolds & Topp, 2008). For soil bulk density (ρ_a), undisturbed soil samples were collected using steel rings with dimensions of 5,0 ´ 5,9 cm, and the analysis was conducted using the core method (Hao et al., 2008). All samples were analyzed at the National Institute for Innovation in Agricultural Technology and Transfer of Costa Rica. It is also necessary to know the extent of depth to which soil water balance will be reached, which is generally given by the *pr*.

At the beginning of any month the soil has an initial moisture (*Hsi*). Likewise, at the beginning of a month, evapotranspiration is zero. Therefore, the moisture condition at the beginning of the month is given by:

$$C_1 = (Hsi - WP + Pi)/(FC - WP) \quad (6)$$

The Hargreaves equation (Hargreaves & Allen, 2003) was used to calculate potential evapotranspiration (*Etp*).

Once evapotranspiration is determined at the end of the month, a new moisture condition will be obtained, which is given by:

$$C_2 = [Hsi - WP + Pi\ (C_1 \times Etp)]/(FC - WP) \quad (7)$$

The available moisture (*Hd*) for plants is defined as the moisture that can be used by plant roots in the evapotranspiration process, and can be described as follows:

$$Hd = Hsi + Pi - WP \quad (8)$$

If *Hd* (mm) is lower than the average of the moisture coefficients (C_1 and C_2) multiplied by evapotranspiration, then a plant can only use the moisture that is available in the soil in the transpiration process, because there is not enough moisture to carry out the entire process to its greatest possible extent. But if *Hd* is greater than the amount of water indicated, then we applied:

$$Etr = \begin{cases} (C_1 + C_2)/2 \cdot Etp, if\ (C_1 + C_2)/2 \cdot Etp \leq Hd \\ Hd, if/2(C_1 + C_2) \cdot Etp > Hd \end{cases} \quad (9)$$

Where *Etr* is the actual evapotranspiration (mm). Just as there is a soil moisture at the beginning of the month (*Hsi*), there is also a value at its end (*Hsf*):

$$Hsf = \begin{cases} Hd + PM - Etr,\ ifHd + PM - Etr < FC \\ FC, ifHd + PM - Etr \geq FC \end{cases} \quad (10)$$

The initial soil moisture, *Hsi* (mm), is determined by the following equation:

$$Hsi = \begin{cases} Hsi \\ Hsf \end{cases} \quad (11)$$

The *Hsf* value is related to its value for the previous month, while the *Hsi* value is related to the maximum moisture value, i.e., *FC*, in the month in which the soil water balance begins, which is the month when *Etp* is greater than *Pi*, following a period of months during which this relationship is reversed, which generally coincides with the rainy season.

Finally, the surface infiltration value is defined as:

$$Rp = Pi + His - Hsf - Etr \quad (12)$$

where the value of *Rp* (mm) will be the amount of infiltrated water once *FC* and *Etr* are satisfied.

From the previously determined variables, homogeneous zones were identified. To identify the infiltration zones, maps were prepared according to 1) The spatial distribution of rainfall, 2) the distribution of the slope and 3) the land use type. For each one, the soil water balance was calculated. Once the balance areas were obtained, each one of the variables of SSWB was calculated.

Results and discussion

A zoning map of infiltration areas in the basin was generated by overlaying distribution maps of zonal rainfall, slope distribution and land use (Fig. 2).

A total of 10 zones were generated. As in other hydrographic basins in Costa Rica and Central America, the La Balsa River basin lacks sufficient hydrological information to discuss the results of this study. Much of this is attributed, in part, to the fact that a significant portion of the basin is in forest protection zones and is distant from major population centers.

The greatest infiltration in LBRB occurs in the highest part of the basin (Zone 1). This could be due to the hydrological properties of the soils of this area and the type of forest cover found here (Blanco, 2010). Annual rainfall in this zone exceeds 5000 mm, of which more than 2700 mm is converted to infiltration, over 50% of annual rainfall. Losses due to evapotranspiration and retention of vegetation cover are more than 2400 mm/year, which is to be expected given that this is a protected natural forest (Calvo et al., 2012; Santos et al., 2018). There are two monthly rainfall peaks during the analysis period, one in the months of June and July, and the highest in the month of November, of more than 600 mm. During the months of February, March and April, there is a significant rainfall decrease, with values lower than 250 mm. During August, September and October, there is a rainfall decrease with respect to the peak periods, to between 500 and 450 mm.

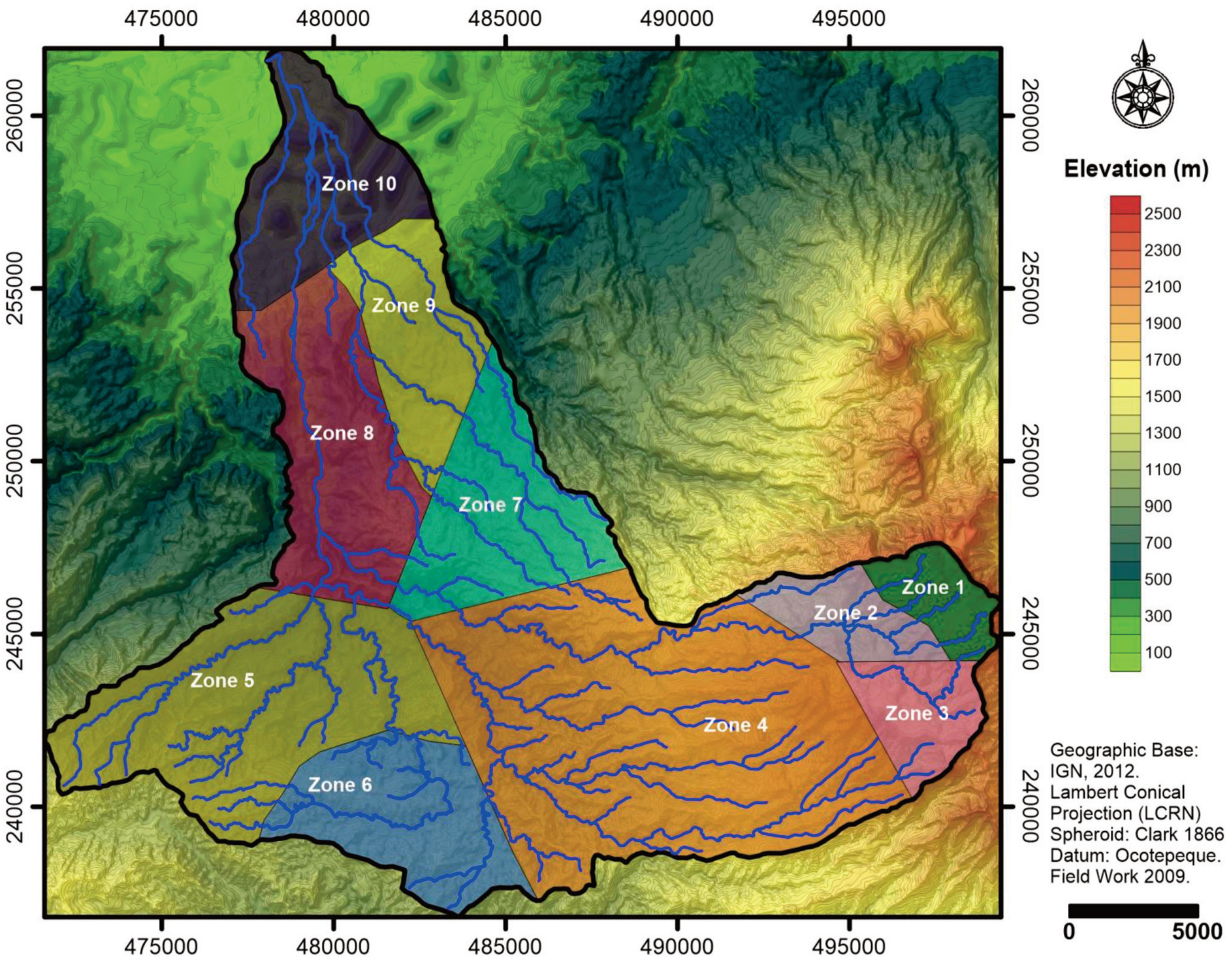

Fig. 2. *Zoning map of infiltration areas of La Balsa basin.*

There are 2 months (March and April) with infiltration values lower than 20 mm.

Infiltration in the upper middle basin in the sector of Palmira and Zarcero ranges between 552 and 804 mm. These low values may be due to several factors, such as steep slopes in the zones (Ríos et al., 2006) and land use primarily consisting of grasslands and croplands (Masís & Vargas, 2014); however, the main contributing factor is that this is the area with the lowest rainfall in the basin, with an average of 2330 mm. The average infiltration value is 592 mm representing approximately 25% of total annual rainfall. Retention and evapotranspiration losses are clearly observable during the zero-infiltration period (January to April). Infiltration peaks in the basin occur in two periods, one in the month of June and another in the months of September and October (Zone 4). In July, November, and December there is a significant infiltration decrease.

In the western sector of the basin, infiltration increases, and this coincides with a greater forest cover than is found in zones (Vargas, 1996; Betanzos et al., 2021). Average rainfall values are above 3240±425 mm/year. Zones, 5, 6 and 8 show very similar behavior, with infiltrations ranging between 978 and 1218 mm (between 30 and 35% of total rainfall). Hydrological behavior throughout the year is very similar between zones 5 and 6. There is a marked rainy season, with three rainfall peaks (May, August, and October). The dry season in zones 5 and 6 is characterized by a rainfall decrease in

December, with minimum values in December, January, February, March, and April – the last three of these months have zero infiltration values. Potential infiltration values are variable during the year and show the same trends as rainfall.

In zone 8, there are 3 months with low infiltration – March, April, and October – while there is no infiltration in March and April. In October, a lower infiltration is associated with decreased rainfall in the rainy season. Rainfall in zone 8 shows two peaks: one in July and another in November. The periods of decreased rainfall occur during the months of February to April, with a slight decrease in October, which has the lowest rainfall in the rainy season and significantly affects infiltration.

In the eastern middle basin, corresponding to zones 7 and 9, infiltration values range from 1218 to 1687 mm. Rainfall varies significantly between these zones: in zone 7, hydrological behavior is very similar to that of zone 8 (with rainfall greater than 3800 mm), while in zone 9, two peaks in rainfall are observed, one in July and another in November. There are two periods when rainfall decreases: one during March and April, in the dry season, and another in October. The potential infiltration in Zone 9 includes two periods of zero infiltration (March and April) and a decrease in October. In these zones the infiltration percentage with respect to rainfall is between 38 and 41%, the second highest after Zone 1. The average infiltration value is 922±23 mm.

Hydrological behavior in the lower basin (Zone 10) shows two clearly defined periods, with a maximum rainfall peak during the month of July and minimum rainfall in the month of April. The dry season extends from February to April, while the rainy season extends from May to January. Potential infiltration is lowest from January to May, with three months of zero infiltration (February, March, and April). The average infiltration value for the whole area is 67±50 mm.

Using the maps of each of the zones, an infiltration zone map was created (Fig. 3) for the entire basin, in which infiltration ranges were established based on the SSWB model.

The zonal rainfall in the La Balsa River basin indicates a variation of approximately 2000 mm between the upper and lower regions of the basin. The lowest rainfall values found in the basin are concentrated in the upper basin, towards the south, which contrasts with the highest values, which are towards the east in the upper basin. Annual rainfall values at the Agroverde station, at 2162 m in the upper basin, are above 5100 mm. Further to the east, the Palmira station at 1974 m recorded rainfall values of 2300 mm. The lowest rainfall values correspond to the Zarcero 1 and 2 stations, the first at 1990 m and second one at 1746 m, with 2170 mm and 1830 mm of rainfall respectively.

Rainfall in the La Balsa River basin decreases between the months of February and April at all stations within the basin. It then increases in May, except in the Zarcero 2 and Finca Hermanos Rodríguez stations, where it increases in June and July, respectively. In some stations (Junquillal, Zarcero 2, Palmira and Zarcero 1) a slight decrease in rainfall is observed in July after this increase. Rainfall peaks recorded in the La Balsa River basin stations occur during the months of October and November, and then decrease in December and January as the dry season begins.

Agroverde station in the upper basin to the southeast has the highest rainfall values, with an average annual accumulation of 5128 mm, and an average elevation of 2160m. The average values of slopes range between 0° and 20°, and the slopes are oriented primarily towards the southeast, south, southwest, and west, except in the canyons of the riverbed, where they are oriented primarily towards the north and northwest. The Zarcero 2, Zarcero1 and Palmira stations, with rainfall values ranging between 1836 and 2305 mm, which are the lowest in the entire basin, have average elevations of between 1750 m and 1975 m, with south-southwest facing slopes of between 0° and 14°. The Finca Junquillal station, with 3199 mm of rain, has an average elevation of 1140 m with slope values between 0° and 10° and mostly flat slopes in the upper north basin. At the Daniel Gutiérrez station, in the middle of the basin, average annual rainfall values reach 3828 mm, with average elevation values of 530 me and slopes between 5° and 20°, primarily oriented towards the east and northeast. In the case of the lower basin, the Hermanos Rodríguez station has an annual rainfall of 4083 mm

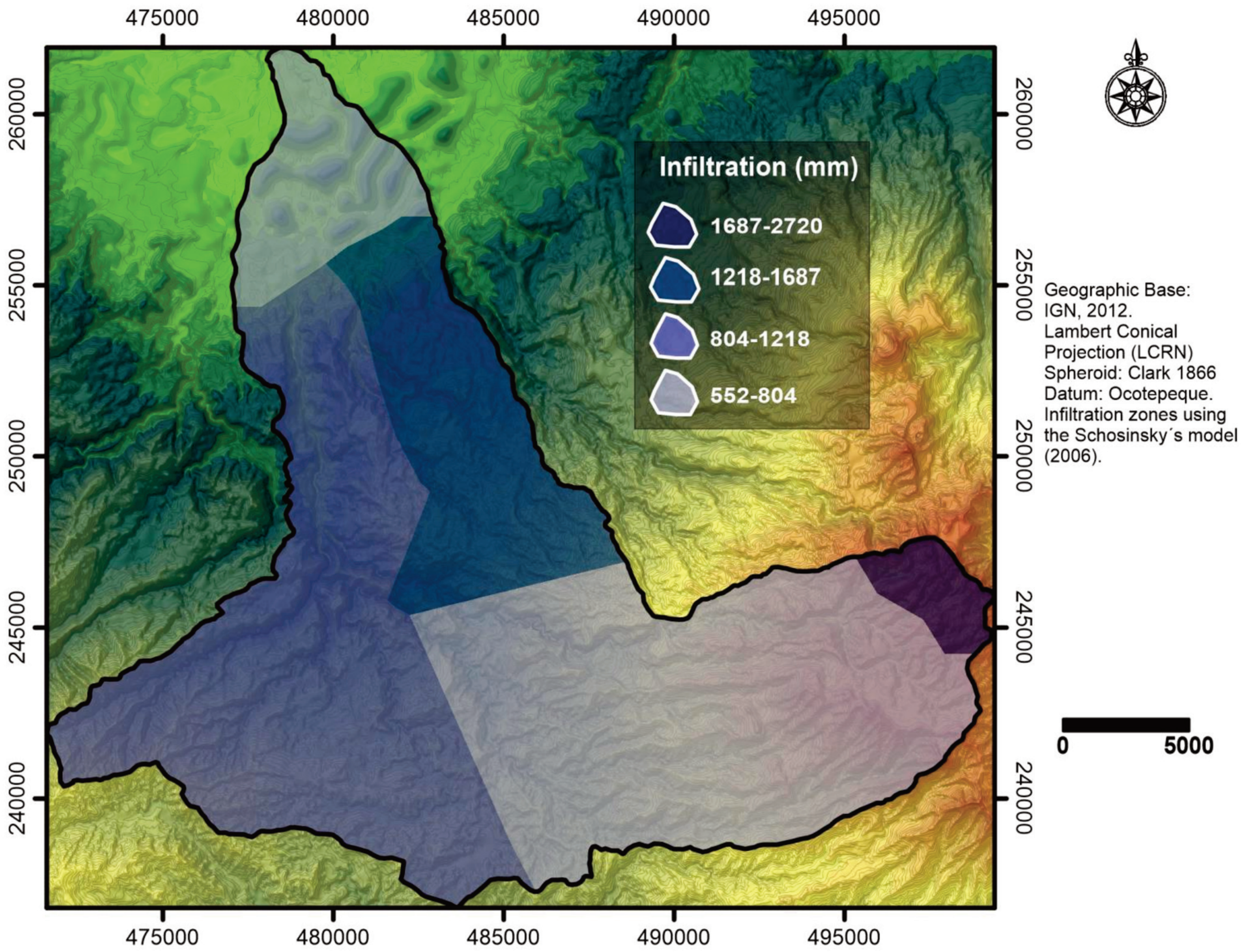

Fig. 3. *Infiltration zones map of LBRB.*

and an average elevation of 350 m, with slopes oriented primarily to the west and sometimes to the northwest. Finally, the Santa Clara station in the northern part of the basin, with an average annual rainfall value of 3377 mm, has an average elevation of 190 m, and slopes that are mostly between 0° to 3°, with no dominant orientation.

There are three primary uses of land in the La Balsa River basin: forest cover, crops, and pastures. The forest cover category includes primary natural forests, riparian forests, secondary forests and forest plantations (Feoli, 2009; Ortega & Vílchez, 2013). In turn, crops are subdivided into annual crops, vegetable crops, ornamental plants, and permanent crops. Finally, pastures include grasslands and pastures with scattered trees (León, 2019). Other minor uses such as bare soils and quarries were included in the pasture category due to their small areas and, in the case of quarries, because after being abandoned they revert to pasture lands. Areas with urban use were very difficult to classify, since their spatial distribution is highly variable and discrete, making it difficult to represent them spatially, and the population centers in this area include mixtures of pastures and wooded pastures.

In the Balsa River basin, there is a notable tendency for forest cover to occur in the western sector of the basin, grasslands, or pastures in the east, and patchy crops in the upper and lower basins. Areas with forest cover tend to coincide with the location of the protected areas in the basin.

The soils of the La Balsa River basin are mostly derived from volcanic deposits; deposits of lava, lahars and ash are especially notable (Báez, 2010), in accordance with the fieldwork conducted. Other colluvial and alluvial deposits also occur, products of the fluvial dynamics of the La Balsa River and its tributaries. This information aligns with that which exists in the areas surrounding the basin (Quesada, 2016).

The *fc* is characterized by relatively low values, which reflects significant degradation of the basin. The sector of the upper basin has relatively low *fc* in most cases, although they increase towards the Palmira and Zarcero sectors. Changes in the values of *fc* in some areas in the middle basin are significant, possibly caused by changes in soil structure or by local changes in land use.*fc*has low average values throughout the basin. The values of *fc* are relatively low in the upper basin while the highest are found in the middle basin and the lower basin.

In the case of water retention, variations in retention values show that the lowest water content in the soil is found in the upper and middle basin, specifically in the east.

Infiltration values for Zone 1 are the highest in the entire basin (2720,63 mm), due mainly to the fact that the highest rainfall of the entire basin (5128,4 mm) is concentrated in this area, as well as the fact that land cover consists of forests and grasslands, which implies an *Cfo* = 0,12, short root lengths and lower evapotranspiration rates. As a protected area, it may be expected that in the future forest cover will increase (*Cfo* = 0,20 and *Kv* = 0,20) and recharge will decrease. One of the most influential factors affecting the recharge level in this area is maintaining moisture retention levels, which would lead to values of *Hsi* and *Hsf* at *fc* throughout the year.

Results of the model show that Zones 2, 3 and 4 have the lowest infiltration values (0 during the 4 months from January to April) in the entire LBRB, caused mainly by a decrease in zonal rainfall compared to Zone 1 (from 5128,4 to 2329,57 mm). Zones 2, 3 and 4 have an average infiltration value of 592,02 mm, which is closely related to the decrease in *Hsi* values (from March to May for Zones 2 and 3, and from February to May for Zone 4), and *Hsf* (February to April for all zones) and therefore lower *Hd*. The effect of decreased rainfall is decisive in these areas despite *fc* values of 1758.92 m/day, also influenced by an increase in moisture retention (84.27 mm) compared to Zone 1.

For Zones 5 and 6, the infiltration value, 1005,57 mm, is higher than that of Zones 2, 3 and 4, although it is not as high as that of Zone 1. Rainfall value is also higher from 2329.57 to 3109.10 mm which may explain the higher infiltration value. Forest cover in these areas is substantially higher, which translates into greater moisture retention to *fc*,116.59 mm. The values of hydraulic conductivity are lower than those of Zones 1, 2, 3 and 4, 466.06 mm/day, and moisture retention values at *fc* are higher than that for those other zones, 116.59 mm, this is probably caused by differences in the basin's lithologies and thus in granulometry, with higher clay content (30 to 44%) and less sand content (16 to 30%).

Marked differences can be seen in the lower middle basin, in which Zones 7, 8 and 9 are located. In Zone 7, the infiltration value is higher, 1467.5 mm, than those of Zones 5 and 6. The rainfall value, 3828.9 mm, is also higher than those of Zones 5 and 6, favoring higher infiltration. Maximum available moisture decreases in Zone 7 for two months, coinciding with two months of 0 infiltration. Zone 8 shows the same amount of rainfall, but retention is higher due to the forest cover effect, from 459.47 to 765.8 mm, which generates a slightly lower infiltration value, from 1467.5 to 1218.12 mm. Zone 9 has a higher rainfall value,from 3828.9 to 4084.1 mm, and a higher recharge value than that of Zones 7 and 8, 1687.54 mm.

Finally, in Zone 10, the infiltration value is lower than those of Zones 7, 8 and 9, which have some of the lowest infiltration values in the Balsa River basin, 804.92 mm, together with Zones 2, 3 and 4. Several factors contribute to this lower value in Zone 10, including a lower rainfall level, 4084.1 to 3 377.9 mm.

The differences between infiltration zones depend on many factors, especially rainfall. When changes in infiltration due to rainfall do not explain the infiltration variations between zones, aspects such as vegetation cover may be responsible. Zhang & Hiscock (2010) indicate that the conversion of agricultural land to forests can reduce groundwater recharge due to a demand for additional water by trees, a conclusion which is also supported by other authors (Natkhin et al., 2012). However, authors such as Haghighi et al. (2010) note that changes in land use negatively affect soil properties; it may therefore be expected that forest increases improve infiltration (Krishnaswamy et al., 2013), because of preferential flow due to plant roots (Shougrakpam et al., 2010). Han et al. (2017) claim that increased recharge values due to the clearing of vegetation can lead to greater water exploitation and increased salinization.

In most of the balance areas defined, there is a clear relationship between foliage retention values and infiltration values, which indicates a strong association between land use and infiltration. However, this relationship is not found in Zones 5, 8 and 10, probably due to the hydrophysical properties of soils in these zones.

Application of regional water infiltration balances at the level of river basins has been a widely used tool in the management of water resources in Costa Rica and Central America. Many Costa Rican and Central American river basins are not systematically measured and hydrometeorological records or hydrogeological data do not exist; this means that much hydrological information must be inferred.

The infiltration approach based on the SSWB model, which was developed for Costa Rican conditions and adapted to several countries in Central America, is an initial tool to establish the areas of highest water infiltration in a basin,thus assisting with critical information the management plans to improve hydrophysical conditions under different types of land use.

Conclusions

The generation of a hydrographic basin water infiltration map using SSWB model demonstrates the integration of geographical and hydrological variables for the definition of water infiltration zones.

The differences in infiltration values between zones of the basin are caused by differences in specific components of SSWB model. However, the component that has the greatest influence on infiltration is the amount of rainfall that reaches each zone.

In the SSWB, one of the factors exhibiting significant spatial variability is the physical and hydraulic properties of soils. These properties can be influenced not only by land use but also by slope and very specific site conditions at the sampling location prior to sample collection. However, in areas lacking prior studies, particularly at the watershed or country-specific territorial unit scale, the application of the method allows for an initial assessment of the amount infiltrating and, consequently, an approximate estimate of aquifer recharge. In this way, preliminary water resource management plans at a spatial scale can be developed, serving as the foundation for more targeted studies.

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Резиме

Зонирање подручја инфилтрације методом Шосинског у сливу реке Ла Балса, Костарика

У недостатку површинских вода, подземне воде постају суштински ресурс за директну људску потрошњу и развој производних делатности као што су пољопривреда и сточарство. Последњих година све је већа свест о њеном значају због неравнотеже између снабдевања и потражње воде услед повећане потрошње људи и система за наводњавање, смањења приноса воде у искрченим сливовима, повећане контаминације изворишта изазване људским активностима и повећане деградације хидрографских басена. Слив реке Ла Балса обухвата округе: Сан Рамон, Сан Карлос, Алфаро Руиз и Наранхо у централној Костарики. Постоје три примарне намене земљишта у сливу реке Ла Балса: као земљиште под шумом, усеви и пашњаци. Да бисмо проценили инфилтрацију воде у речном сливу, користили смо методологију коју је развио Шосински. Овај приступ укључује квантификацију биланса воде у земљишту коришћењем месечних података о инфилтрацији падавина прикупљених током једне хидролошке

године. Ова методологија је најпогоднија за хидрографске басене са добро дефинисаним природним границама. Генерисање хидрографске карте инфилтрације вода у басену коришћењем овог модела показује интеграцију географских и хидролошких варијабли за дефинисање зона инфилтрације воде.

Разлике у вредностима инфилтрације између зона у сливу узроковане су разликама у специфичним компонентама методе Шосинског. Међутим, компонента која има највећи утицај на инфилтрацију је количина падавина која доспева у сваку зону. Један од фактора који показује значајну просторну варијабилност су физичка и хидрауличка својства земљишта која су условљена начином коришћења и нагибом земљишта. У областима у којима нису вршена ранија истраживања, примена ове методе омогућава почетну процену количине воде која се инфилтрира, као и приближну процену пуњења колектора. На овај начин се могу израдити прелиминарни планови управљања водним ресурсима који служе као основа за даље студије.

Примена регионалних биланса инфилтрације воде на нивоу речних сливова била је широко коришћено средство у управљању водним ресурсима у Костарики и Централној Америци. Многи речни сливови Костарике и Централне Америке се не мере систематски и не постоје хидрометеоролошки записи или хидрогеолошки подаци. Приступ заснован на моделу Шосинског, који је развијен за услове Костарике и прилагођен за неколико земаља Централне Америке, представља почетни алат за утврђивање подручја највеће водне инфилтрације у речном сливу, што је неопходно за потребе планирања управљања земљишним ресурсима.

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