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Artículo de Investigación

The relationship between land use change and flood flows, a case study in a transboundary watershed

La relación entre el uso de suelo y los caudales de crecida, un caso de estudio en una cuenca transfronteriza

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Abstract:
Introduction: Introduction: The HEC-HMS model was applied in the transboundary basin of the Zarumilla River (Ecuador – Peru) to simulate the flows that would occur during maximum precipitation events. **Methodology:** The model integrated the precipitation determined by intensity equations, the infiltration defined by the curve number, the rain - runoff transformation by unit hydrographs, the hydrological routing calculated by applying Muskingum - Cunge and was calibrated by a frequency analysis using the hydrometric information available. **Results:** The model was executed satisfactorily and the resulting maximum flows at the outlet of the basin varied between 1.100 m^3/s and 1.670 m^3/s depending on the return period. A land use scenario for the year 2027 was generated using information from 2014 and 2017 that was evaluated with the model. **Discussion:** The transitions with the largest area of influence observed were pasture to crop, forest to crop and crop to pasture. Other classifications do not present a significant change. **Conclusions:** The flows calculated with the coverage of the generated scenario are lower than those calculated for 2017, due to the expansion of crops, which are mostly fruit crops. Despite this, the variation in flow rates was not very significant.

Keywords: flood flows; hydrological model; HMS; land use change scenarios; TerrSet; transboundary basin; rain – runoff; Zarumilla.

Resumen:
Introducción: El modelo HEC-HMS fue aplicado en la cuenca transfronteriza del río Zarumilla (Ecuador – Perú) para simular los caudales que se presentarían ante eventos de precipitación máxima. **Metodología**: El modelo integraba la precipitación determinada mediante ecuaciones de intensidad, la infiltración definida mediante el número de la curva, la transformación lluvia - escorrentía mediante hidrogramas unitarios, el transito hidrológico calculado aplicando Muskingum – Cunge y se calibró mediante un análisis de frecuencias utilizando la información hidrométrica disponible. **Resultados:** El modelo se ejecutó satisfactoriamente y los caudales máximos resultantes en la salida de la cuenca, variaron entre 1.100 m^3/s y 1.670 m^3/s según el período de retorno. Un escenario de uso de suelo para el año 2027 fue generado usando información del 2014 y 2017 que fue evaluado con el modelo. **Discusión**: Las transiciones con mayor área de influencia observadas fueron pasto a cultivo, bosque a cultivo y cultivo a pasto. Otras clasificaciones no presentan un cambio significativo. **Conclusiones**: Los caudales calculados con la cobertura del escenario generado son menores a aquellos calculados para el 2017, debido a la expansión de los cultivos, que en una mayor parte son de tipo frutal. Pese a esto, la variación de caudales no fue muy significativa.

Palabras clave: caudales de crecida; modelo hidrológico; HMS; escenarios de cambio de uso de suelo; TerrSet; cuenca transfronteriza; lluvia – escorerentía; Zarumilla.

1. Introduction

The change in land use in rural basins directly affects the infiltration capacity of the land, which in turn influences the dynamics of flood flows (Sugianto *et al.*, 2022). Infiltration is a key process in the hydrological cycle, as it determines the amount of water that penetrates the soil and recharges aquifers, versus the amount that is converted to surface runoff. The relationship between land use and infiltration is complex and depends on factors such as soil type, topography, vegetation, and soil management practices.

One of the most common problems in rural watersheds is the conversion of forest lands to agricultural lands. Forests, with their dense vegetation cover and soils rich in organic matter, have a high infiltration capacity. When these areas are cleared for agriculture, vegetation cover is significantly reduced, and soil structure is altered. Agricultural soils are usually more compact due to the use of heavy machinery, which reduces pore spaces and, consequently, reduces infiltration (Kurowska *et al.*, 2020). This process increases surface runoff, which not only increases flood flows, but can also cause erosion and loss of fertile soil. The solution to this problem lies in the implementation of sustainable agricultural practices, such as the use of cover crops, crop rotation and conservation agriculture, which can help maintain soil structure and improve its infiltration capacity.

Urbanization in rural areas is another significant change in land use that affects infiltration. The construction of infrastructure such as roads, homes and other buildings creates impermeable surfaces that virtually eliminate infiltration. In these cases, rainwater cannot penetrate the ground and becomes runoff, which can lead to rapid and large floods in nearby streams. Implementing green infrastructure solutions, such as permeable pavements, green roofs, and sustainable drainage systems, can mitigate these effects by allowing a greater proportion of water to infiltrate the soil (Oñate-Valdivieso *et al.*, 2022).

Another problem linked to the change in land use is deforestation for livestock expansion, which particularly affects mountain basins (Silveira, 2022). Deforestation reduces evapotranspiration and increases runoff, which can lead to greater frequency of floods in lower-lying areas of the basin. In addition, the loss of forest cover causes direct exposure of the soil to rain, which intensifies erosion and can reduce the quality of water in water bodies (DeFries, 2010). The solution to this problem includes reforestation with native species and the creation of biological corridors that maintain landscape connectivity, which can improve infiltration and reduce erosion.

In rural watersheds, proper land use management is essential to maintain a healthy hydrological balance. Soil management practices that promote infiltration, such as reforestation, soil conservation, and the use of green infrastructure, are essential to mitigate the negative effects of land use change on flood flows. Furthermore, integrated water resources planning and management, which considers both land uses and hydrological characteristics of the basin, are crucial to prevent problems such as erosion, soil degradation and flooding.

Adequate knowledge of runoff variation in a watershed is used in the design of many hydraulic projects, for the prediction of flows and floods, for the study of rainfall-runoff processes, and for the contribution to watershed management plans. All this is carried out using hydrologic modeling. Hydrologic modeling is a tool that is mainly used to estimate the hydrologic response of a watershed to a precipitation event, and to study the effect of different scenarios like climate, change of coverage, infrastructure construction or others, on the flows of medium and large watersheds. This makes it a very important tool for decision making (Mera-Parra, 2021).

The selection of the model depends on the basin and the objective of the hydrological prediction in the basin (Halwatura, 2013). With the use of GIS tools, hydrological information can be extracted from a DEM (digital elevation model). The estimation of flows and other hydrological parameters is still a difficult task due to the combined effects of climate change (Alcamo, 2007) and land use change due to population growth or economic pressure (DeFries, 2010).

Since hydrologic modeling is a data-demanding process and contains a high degree of uncertainty (Leimer, 2011). In data-scarce areas, predicting the flood hydrograph becomes even more difficult. The limited availability of hydrologic data is a major obstacle to the implementation of detailed hydrologic models. In cases where available data are limited, hydrologic models should be simplified and consider a minimum number of parameters

(Ahmad, 2009). The model should be calibrated and validated for the study watershed and reliable data should be used to verify the suitability of the model (Halwatura, 2013).

The HEC-HMS model has been widely used in different applications satisfactorily. Based on the experience carried out in the Misai and Wanan basins in the Republic of China, Oleyiblo and Li (2010) established that the HEC-HMS model satisfactorily predicts the maximum discharge based on the available historical flood data, with the volume flood and weather quite accurate. The effect of the increase in urban areas over time on flood flows in a basin in the Andes was successfully studied using the HE-HMS (Oñate-Valdivieso *et al.*, 2022) for each timestep using HEC-HMS hydrological model. The complexity of the model structure does not determine its suitability and efficiency (Oleyiblo & Li, 2010). On the other hand, Laouacheria and Mansouri (2015) made a comparison between the HEC-HMS and WBNM models for the generation of runoff hydrographs in an urban basin. Hence it is said that the accuracy of the results of hydrological models depends on the underlying hypothesis and the availability of data. The HEC-HMS model has CN and concentration time as the most sensitive parameters and also shows better performance statistically speaking (Laouacheria & Mansouri, 2015).

The Zarumilla River basin is located in the border area between Ecuador and Peru, a large part of the basin is arid and semi-arid and due to its climatic characteristics, it presents very notable fluctuations in its flows, reaching a minimum monthly flow of 0 m^3. /s in the dry season (June – December) to significantly higher average monthly flows reaching levels of the order of 67,15 m^3/s. Being a basin that crosses urban areas and agricultural productivity, it is essential to know the maximum instantaneous growth levels that can be reached in order to establish an adequate management plan that contributes to protecting the population and productive areas.

The general objective of this project is to develop a methodology for the determination of extreme flows, in addition to generating and analyzing scenarios and studying their effect on the hydrological response of a watershed. Having said this, the specific objectives are: to implement a hydrological model of precipitation event in the Zarumilla river basin to determine the extreme flows in the basin; to generate a land occupation scenario for the year 2027 in the basin and finally to evaluate the effect of this scenario on the hydrology of the basin.

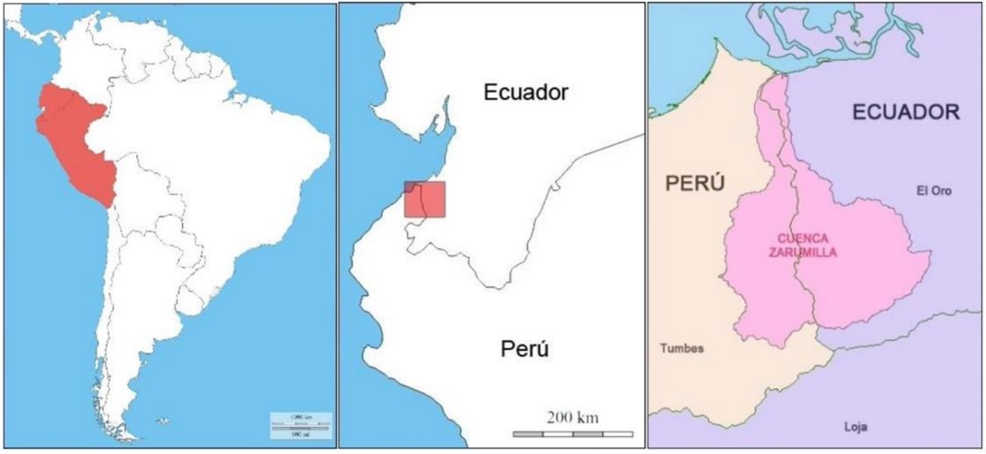
2. Methodology

2.1 Study area

The Zarumilla River basin is located in northwestern South America, shared between Ecuador and Peru. It has an approximate area of 874 km^2 and its area is divided with 55% in Ecuadorian territory and 45% in Peruvian territory. Approximately 280 km^2 of this watershed is occupied by the Tumbes National Reserve, which protects a large area of tropical forest and dry forest. The basin is intermittent, so it has long periods of low water, but during the winter, between March and August, it has large flows, which can even overflow the river, flooding areas and towns located along its banks, with the cities of Huaquillas (Ecuador) and Aguas Verdes (Peru) being the most affected (INAMHI, 2011).

Figure 1.

Location of the Zarumilla watershed



Source: Own elaboration

The basin has a fairly pronounced relief from the point farthest from the basin outlet, with elevations that vary from 1,200 m above sea level to 100 m above sea level in areas located in the middle part of the basin. From this elevation, the terrain gradually varies up to 6 m above sea level as it approaches the basin's outlet. The climate of the basin can be defined as tropical subdesert because it is located in the transition zone between the arid climate of Peru and the humid climate of Ecuador. During the dry season, between June and December, the average temperatures range from 19,0 °C to 25,0 °C. In the rainy season, from December to May, the average temperatures range from 25,9 °C to 26,5 °C. The annual average is around 24,5 °C. The variation of precipitation in the area is wide, so there are periods of drought and heavy rainfall. This is due to the variable movement of the Humboldt and El Niño currents. The rainy season coincides with the presence of the El Niño current, beginning in December. Average annual rainfall is around 150 mm per year in the lower part, 700 mm in the middle part and up to 1.080 mm in the upper part. During the dry season, rainfall is nil (INAMHI, 2011). The location of the watershed is shown in Figure 1.

2.2 Data collection

A 30m resolution digital elevation model from the SRTM project, carried out by the USGS and NASA, was used (USGS, 2019). The hydrological information used for model calibration is obtained from annual instantaneous peak flow data from the La Palma station in the Peruvian zone of the watershed, which is located at coordinates 587602 m E and 9606643 m S (INAMHI, 2011). Land cover and land use information in the watershed was taken from maps available on the geoportal of the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP, 2017) for the Ecuadorian zone, while for the Peruvian zone, land use and soil type information were taken from the land cover map portal of the Peruvian Ministry of Environment (MINAM, 2017).

2.3 Hydrological model

The HEC-HMS model is a tool developed by the United States Army Corps of Engineers to simulate the hydrological cycle in watersheds, it is widely used in hydrological engineering to model and analyze hydrological processes, such as runoff generation, flow traffic and the impact of land use changes. HEC-HMS is particularly useful in flood flow assessment, hydraulic works design, water resources planning and flood risk management.

The HEC-HMS model is based on a modular structure that allows the user to represent in detail the different hydrological processes within a basin. Key components of the model include precipitation, loss, runoff transformation, baseflow, and runoff routing. Each of these components can be modeled using different methods, depending on the specific characteristics of the basin and the available data. The strength of HEC-HMS lies in its ability to integrate all these components into a coherent model that simulates the hydrological behavior of a basin in response to precipitation events.

For the implementation of the hydrological model, a topological model was developed, whose sub-basins coincided with the demarcation of the sub-basins of the Binational Development Plan for the Border Region (Senagua & Ana, 2013) and its main morphometric characteristics were determined. The basin was delimited up to the site called Puente Bolsico (586.211, 9.607.512 UTM 17S) and the La Palma station (587594, 9606643 UTM 17S) was considered for calibration.

Design storms were defined for the different return periods considered: 25, 50 and 100 years, using the maximum rainfall intensity equations (Table 1) provided by INHAMI (2019).

The infiltration characteristics of each of the sub-basins were determined using the NRCS curve number (Chow *et al.*, 1994) for each of the hydrological response units defined by crossing the land use and soil type maps. The rainfall-runoff transformation was performed using the NRCS hydrograph (Chow *et al.*, 1994). The hydrological transit was performed by applying the Muskingum-Cunge (Chow *et al.*, 1994) method, considering the average characteristics of the existing channels in the basin under study. The model was calibrated using the available information on maximum flows at the La Palma station, to which probability distributions were applied, which allowed the adjustment between the calculated and observed flows.

Table 1.

Intensity equations

Zone	Duration	Equation
37	5 min < 51,4 min	$I_{TR} = 49,64\ Id_{TR}\ t^{-0,296}$
	51,4 min < 1440 min	$I_{TR} =370,3\ Id_{TR}\ t^{-0,806}$
50	5 min < 42,98 min	$I_{TR} = 80,137\ Id_{TR}\ t^{-0,455}$
	42,98 min < 1440 min	$I_{TR} = 235,8\ Id_{TR}\ t^{-0,724}$
54	5 min < 72,71 min	$I_{TR} = 71,544\ Id_{TR}{}^{-\wedge 0,406}$
	72,71 min < 1440 min	$I_{TR} = 448,05\ Id_{TR}\ t^{-0,834}$

Source: INAMHI (2019).

2.4 Land use change model

The multi-temporal study of land use was performed employing the Land Change Modeler (LCM) of TerrSet. The LCM is an advanced tool for analyzing and modeling land use and land cover changes. It allows the detection of changes through bitemporal comparisons and transition matrices, models change using influencing factors such as socioeconomic and environmental variables, and projects future scenarios based on specific probabilities.

The changes occurred in the coverage of the study area between the years 2014 and 2017 were analyzed. The original land maps were reclassified into 8 general land cover groups of the study area: forest, population center, shrub vegetation, mangrove, water body, pasture, wasteland and crops (Oñate-Valdivieso *et al.*, 2016).

Using neural networks (Oñate-Valdivieso *et al.*, 2010) and land topography and distance to roads and towns as explanatory variables, transition models for each category were calculated and a transition probability matrix was generated using neural networks. Using the land use map entered with the most recent date (2017) and the transition probability matrix calculated previously using neural networks, to determine the areas that will experience a transition from the end date of the period analyzed (2017) to the date of the horizon year (2027) (Eastman, 2016).

Using the calibrated hydrological model and the land use scenario to 2027, the effect that this scenario would have on the flows of the basin was analyzed.

3. Analysis and discussion of results

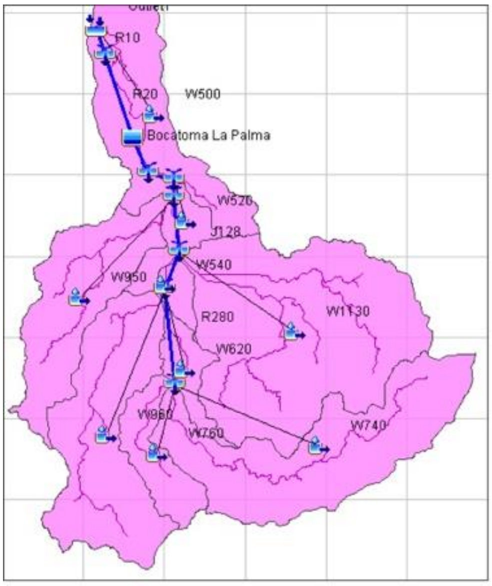
3.1 Hydrologic Model

The topological model used is shown in Figure 2, which includes the dendritic network, the junctions, the reservoir and the outlet located at the Bolsico Bridge, and the calibration station at the La Palma.

The characteristics of the basin are presented in the Table 2. The values of the curve number range between 57 and 78. The higher values, above 60, are evidence of greater surface runoff due to low vegetation cover and considerable mendientes. It should be noted that sub-basins W760, W620 and W950 are part of the Tumbes National Reserve, which includes a large area of tropical forest and dry forest. For this reason, the estimated CN values are around 60, which indicates that there is a greater degree of infiltration than runoff.

Figure 2.

HMS Zarumilla basin schematic



Source: Own elaboration.

Table 2.

Characteristics of the basin

Code	Area (km)	Concentration time (min)	CN
W500 (Puente Bolsico)	127,7	236,2	73
W500 (La Palma Station)	45,1	118,2	68
W520	25,2	171,0	66
W540	12,5	73,9	67
W620	24,4	217,2	61
W740	162,5	325,8	78
W760	38,7	167,2	64
W950	100,3	218,9	57
W960	139,3	281,7	61
W1130	250,1	277,4	70

Source: Own elaboration.

The time of concentration used for the model was that calculated by Kirpich, which presented values of medium order, compared to those obtained by the other methods. The largest value in minutes of time of concentration is the one corresponding to interbasin W740, which is in accordance with the fact that the longest stretch of channel of all the basins is the one located in this interbasin, considering Kirpich as calculation parameters the length and average slope of the channel. For this same reason, inter-basin W540 has the shortest time of concentration, since it is the smallest of the sub-basins.

The Zarumilla riverbed has 7 inflows from the upper zone of the basin to the exit point at the Bolsico bridge. The characteristics of the reaches between the inflows are detailed in Table 3.

Table 3.

Parameters of the river reaches between inflows.

River	Length (m)	Slope (m)	n	Bottom Width (m)
R280	9.714	0,0010	0,053	35
R150	3.509	0,0026	0,053	14
R90	5.111	0,0006	0,042	38
R60	1.614	0,0012	0,038	36
R40	2.378	0,0034	0,038	46
R30	5.732	0,0020	0,034	84
R20	7.524	0,0010	0,034	105
R10	4.770	0,0010	0,030	105

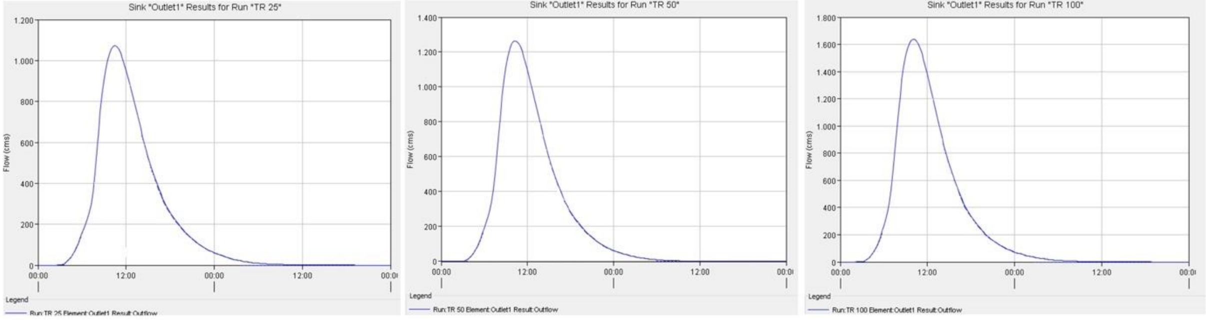
Source: Own elaboration.

Manning's coefficient n goes from a value of 0.053 in the section of the riverbed located in the upper part of the basin, to a value of 0.03 in the section closest to the basin outlet, this is due to the fact that the upper part of the basin has characteristics of a mountain river, with bed and boulder banks and trees and bushes along the upper part, while in the last section before the Bolsico Bridge outlet, there are dykes on both banks of the riverbed.

The hydrographs generated up to the La Palma station for each return period (25, 50 and 100 years) are shown in Figures 3, which are in accordance with the maximum flow values obtained through frequency distribution (the GEV distribution) applied to the historical data recorded at the station.

Figure 3.

Hydrographs generated for 25-, 50- and 100-year return periods at La Palma station.

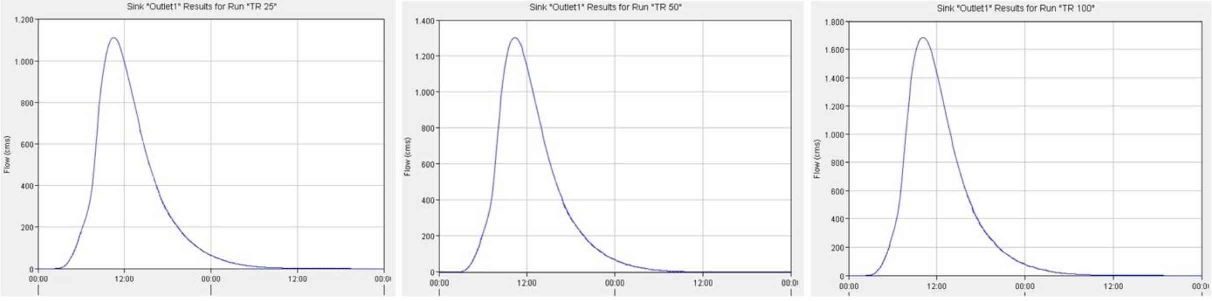


Source: Own elaboration.

The adjustment of the parameters involved in the model was carried out for the calibration of the flow values for the return periods of 25 and 50 years, taking as validation values the flows corresponding to the TR of 100 years. When comparing the values obtained by probabilities and those obtained by the HEC-HMS model, it can be observed that the range of variability between the probabilistic value and that of the model is in the order of +27% for a 25-year return period, +7% for a 50-year return period and +1% for a 100-year return period. Since the flows obtained by the model are higher than those generated by the frequency distribution, these values can be accepted as valid and the model as calibrated, since they also provide a safety margin.

Figure 4.

Hydrographs generated for 25-, 50- and 100-year return periods at Puente Bolsico station.



Source: Own elaboration.

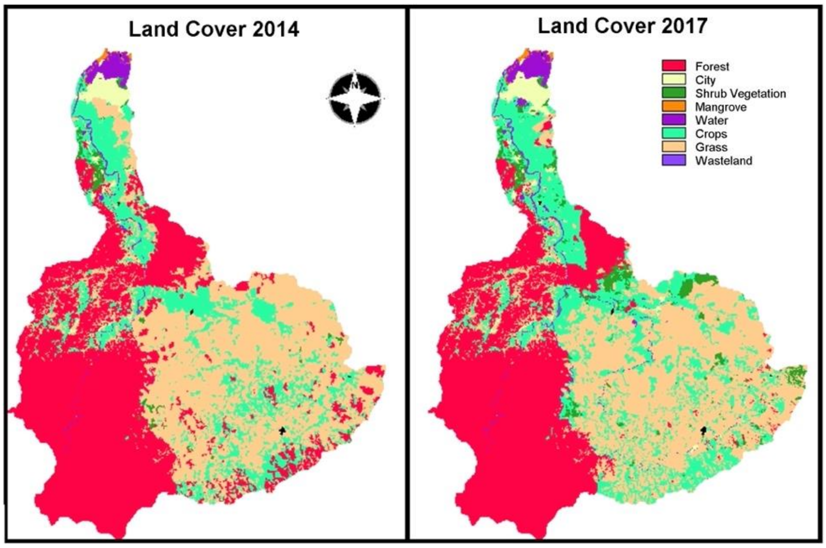
The Puente Bolsico is located approximately 12.300 m downstream of the La Palma station, and has a larger catchment area than that considered for the calculation of flows at the intake; therefore, the maximum flows are higher at this point. However, the variation in flow is in the order of 3% (Figure 4). The peak time for the maximum flood hydrographs at the La Palma intake is 9.75 hours, while the peak time at the Bolsico bridge is 10.5 hours. This is due to the transit of flows between the two points mentioned above, which due to the distance between them, the peak time is out of phase.

3.2 Change in land use

The land use at the two base dates is presented in Figure 5. The maps were reclassified into general categories that encompass the multiple coverages existing in the watershed under study. The predominant coverages are grasslands, followed by forest and crops.

Figure 5.

Land use in 2014 and 2017

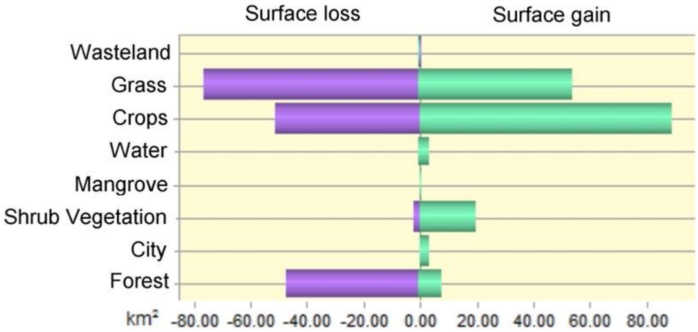


Source: Own elaboration.

With the soil maps corresponding to the years 2014 and 2017, the change in land use between both years is obtained. The gain and loss of area for each type of watershed cover in km² is presented in Figure 6. the three most important transitions taking into account the area of change are: Pasture to crop, forest to crop, and crop to pasture.

Figure 6.

Profit and loss between 2014 and 2017

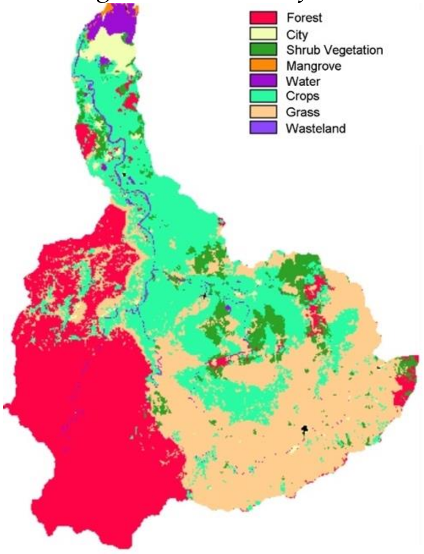


Source: Own elaboration.

As can be seen in Figure 6, pasture has an area loss greater than its expansion, while crops have a gain greater than its area loss, as does shrub vegetation. On the other hand, the forest has a drastic loss of surface area, much greater than its gain in area.

Figure 7.

Land use change scenario generated using Markov chains for the horizon year 2027



Source: Own elaboration.

The land use change scenario generated using Markov chains for the horizon year 2027 is shown in Figure 7. As shown in Figure 7, the area with the greatest potential for change for the 2027 scenario is the area of sub-basins: W520, W540, W620, W740 and W1130 while sub-basins W950, W960, W760 do not present a significant transition potential as they are ecological reserves. The generated map considers only a land use change scenario, whose results could be validated with the use of an additional map to those used for the generation of the scenario to the horizon year, so that a scenario can be generated to the year of the additional available map (Cadavid & Rong, 2016).

Table 4 shows the change in the areas of the different coverages in the basin.

Table 4.

Areas of the different coverages

LandUse	2014 (km²)	2017 (km²)	2027 (km²)
Forest	360,2	320,6	286,5
City	13,1	16,6	16,7
Shrub Vegetation	8,1	25,2	50
Mangrove	1,5	1,5	1,5
Water	13,3	17,2	17,2
Crops	148,4	185,9	222,6
Grass	329,3	306,4	278,9
Wasteland	1,1	1,2	1,2
Total	875	875	875

Source: Own elaboration.

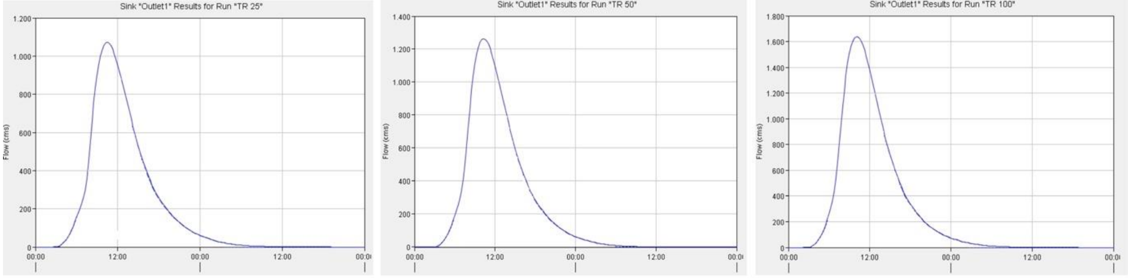
As shown in Table 4, the forest area is progressively decreasing, as is the pasture area, which is being replaced by crops. This is due to the expansion of agricultural activities in the watershed. Despite this, there is also a growth of shrub vegetation, and the replacement of crops by pasture. This behavior may be due to the abandonment of agricultural land and crop rotation (Oñate-Valdivieso *et al.*, 2024). Classifications such as mangrove, wasteland and water bodies do not show a significant change.

3.3. Maximum flood flows corresponding to the 2027 land use change scenario

With the coverage estimated using TerrSet, the curve number for each sub-basin, flood hydrographs and peak flows for the entire basin were again obtained. Comparing the NC results in Table 2 for the 2027 coverage scenario and the current coverage (2017) included in Table 5, the W500, W520, W540 and W620 have the largest change in the curve number, decreasing by up to 7 units. On the other hand, sub-basins W740, W760, W950, W960 and W1130 do not present a significant change in the curve number, this may be due to the fact that three of the five basins mentioned are part of the Tumbes National Reserve. The decrease in the curve number in the aforementioned watersheds means greater infiltration, and a lower flood flow, as can be seen in Figure 8, which shows the maximum flood hydrographs for the 2027 land use change scenario.

Figure 8.

Maximum flood hydrographs for the 2027 land use change scenario



Source: Own elaboration.

Table 5.

Characteristics of the basin for the 2027 scenario

Code	Area (km)	Concentration time (min)	CN
W500 (Puente Bolsico)	127,7	236,2	65
W520	25,2	171	60
W540	12,5	73,9	60
W620	24,4	217,2	64
W740	162,5	325,8	77
W760	38,7	167,2	64
W950	100,3	218,9	57
W960	139,3	281,7	61
W1130	250,1	277,4	69

Source: Own elaboration.

The peak time of the maximum flood hydrographs for the 2027 land use change scenario have as peak time 10,5 hr, the same time as those determined for 2017, due to the fact that they correspond to the same outlet point in the watershed. As mentioned above, the flood flows are slightly lower than those calculated for 2017, due to their direct relationship with the curve number.

4. Conclusions

The modeling of the Zarumilla River basin was carried out satisfactorily, as was its calibration, which achieved an appropriate correlation between the maximum flow values calculated by the model and those obtained probabilistically. It was also possible to generate the land use change scenario for the year 2027 and determine its effect on the extreme flows in the study area.

The maximum flood flow at the La Palma station, for a return period of 25 years, is 1.089 m^3/s. For a 50-year return period it is 1.265 m^3/s and for a 100-year return period it is 1.618 m^3/s.

The maximum flood flow at the Puente Bolsico, the point established as the outlet of the Zarumilla basin, for a 25-year return period is 1.100 m^3/s. For a 50-year return period, it is 1.290 m^3/s and for a 100-year return period it is 1.670 m^3/s.

When comparing the flows obtained by the model and those calculated probabilistically by the GEV distribution adjustment with the series of annual maxima recorded at the La Palma station, no significant differences were observed. Therefore, the calibration was satisfactory.

Since about 280 km^2 of the total 874 km^2 of the watershed belong to the Tumbes National Reserve, the coverage of this area does not change in the generated land use scenario. The area with the greatest potential for land use transition are the following watersheds: Interbasin W520, W540, W620, W740 and Palmales.

Between 2014 and 2017 and the scenario with 2027 as the horizon year, the transitions with the largest area and therefore the most important are: pasture to crop, forest to crop and crop to pasture. There is a decrease in forest and pasture and an increase in crops and shrub vegetation. The other coverages have minimal changes in area. The transition from forest and pasture to crop is due to the expansion of agricultural activities in the study area. On the other hand, the change from cultivation to pasture may be due to the abandonment of the land by farmers or to the crop rotation they carry out to mitigate soil erosion.

The coverage of the populated center does not present a significant change in area in the scenario generated, which is due to the fact that the Land Change Modeler tool is not the most appropriate for modeling this type of changes, which require more explanatory variables and other modeling alternatives such as cellular automata. As the populated area is quite low in the basin, it is not a very relevant coverage.

The curve number calculated with the 2027 land use scenario does not change for the watersheds that comprise the Tumbes National Reserve, while for the inter-basins W500, W50, W540 and W620 there is a decrease of up to 7 units, which implies greater infiltration and less runoff. This is mainly due to the change of cover from forest and pasture to crops, since most of the crops in the study area are fruit crops, which allows for greater water retention in the soil.

The flows calculated with the coverage of the scenario generated for 2027 are lower than those calculated for 2017. This is due to the expansion of fruit crops shown in the scenario. However, the flow variation is not very significant, with flows of 1.072 m^3/s for a 25-year return period, 1.263 m^3/s for a 50-year return period and 1.637 m^3/s for a 100-year return period.

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