Revista
Torreón Universitario
www.faremcarazo.unan.edu.ni / ISSN 2410-5708 / e-ISSN 2313-7215
Year 10 | No. 27 | February - May 2021

Surface runoff and participatory actions for environmental management in Sub-basin III of the South Basin of Lake Managua, Nicaragua

Ingrid Úbeda Trujillo
Professor of the Geography Department
Universidad Nacional Autónoma de Nicaragua, Managua
https://orcid.org/0000-0002-1349-4682
ingrid.ubeda@unan.edu.ni / ingrideut@gmail.com

Lester Rocha
Professor of the Zootechnics Department
Universidad Nacional Agraria (UNA)
https://orcid.org/0000-0002-0622-9733
lester.rocha@ci.una.edu.ni

Submitted on January 25, 2020 / Accepted on July 13, 2020
https://doi.org/10.5377/torreon.v10i27.10844

Keywords: Curve Number, land cover, Hydrological Response Units, public and private sector.

ABSTRACT

In Sub-basin III of the South Basin of Lake Managua, Nicaragua, there is an increase in surface runoff caused by the increase in urban coverage, agriculture, and the fluctuating trend of forest cover. In this study, the surface runoff was evaluated based on the land cover of the years 2003, 2010, 2016, and the projected the year 2025. Methodologically, the area under study was delimited in 23 Hydrological Response Units (URH) to identify the areas where the greatest runoff occurs. In each URH, the Curve Number (NC) method of the Soil Conservation Service (SCS) was applied, and to discretize the method, a hietogram, the hydrological type of soil, and the antecedent humidity condition were used. The hyetogram was generated based on the calculation of the Curves of Intensity, Duration, Frequency. Furthermore, the hydrological number was estimated based on the type of soil and the preparation of land cover maps for each year evaluated. The results indicate that the URH associated with agriculture and urban coverage generate the greatest runoff (47 $m^3.s^{-1}$, 36 $m^3.s^{-1}$, 25 $m^3.s^{-1}$, 13 $m^3.s^{-1}$, and 10 $m^3.s^{-1}$). Therefore, in these URH´s it is recommended the implementation of participatory actions of a regulatory, economic, educational, and organizational nature for the environmental management of the area under study.

INTRODUCTION

The Curve Number (CN) method is widely used to approximate to calculate the rainfall-runoff relationship (Chow, Maidment, & Mays, 1994; Satheeshkumar, Venkateswaran, & Kannan, 2017), and to provide input data for hydrological modeling (Adham, M. I; Shirazi, S. M; Othman, F; Rahman, S; Yusop, Z; Ismail, Z, 2014). Recently, for the execution of participative actions derived from an environmental management program, it is interesting to examine the impacts in the basin (Guo, Huo, & Jiang, 2008; Satheeshkumar, *et al.*, 2017), according to the temporal and spatial scale. , and based on the integration of hydrological models and models for prediction of land cover (Verburg, Rousenvell, & Veldkamp, 2006; Miranda, 2008; (Hernández Guzmán, Ruiz, Berlanga-Robles, & Zoltán Vekerdy, 2009; Sundarakumar, K; Harika, M; Begum, S; Aspiya, K; Yamini, S; Balakrishna, K, 2012; Cano, Andreoli, Arumi, & Rivera, 2014, Adham, *et al.*, 2014; Ndulue, L; Mbajiorgu, CC; Ugwu, SN; Ogwo, V; Ogbu, KN, 2015; Mwathi, 2016).

The change in land cover and its interaction with water and soil modifies the hydrological balance of a basin and consequently significantly influences the runoff volume (Notter, MacMillan, Viviroli, Weingartner, & Liniger, 2007; Guo, Huo, & Jiang, 2008; Mango, Melesse, Mcclain, & Gann, 2011; Satheeshkumar, *et al,* 2017). Agricultural coverage has adversely degraded the proper functioning of the environment, producing surface variability of runoff and decreased water yields (Villarreal Hernández, Martínez Valdés, & Belmonte Jiménez, 2013; Alemayehu, 2015; Ndulue *et al.*, 2015). Simultaneously, urban coverage has four stages that affect the environment. In the first stage during the removal of natural vegetation, soil erosion is caused. In the second stage, with the construction of houses, streets, and channels, infiltration into the aquifers is reduced. In the third stage, when there is already urban coverage, the impermeability increases, the concentration-time of the runoff is reduced, and the discharge peaks increase after the rain begins in a basin. Finally, when the sewers and drainage channels are consolidated in the city, floods occur in the lower part of the basin (Villarreal, *et al.*, 2013).

The Hydrological Response Units (URH) approach with areas of approximately 10 km^2 makes it effective to quantify the impacts of land cover on surface runoff (FAO, 2002), allowing the identification of critical URHs (Espíritu and Hernández, 2013) and also implement management actions in a basin. Since the division of a large basin into small physiographic or hydrologically similar units facilitates and makes economic development of environmental management programs (Hernández, *et al.*, 2009; Leonel, Aguilar Robledo, & Medellín, 2013).

METHODOLOGY

Study area

Figure 1 shows the geographical location of Sub-basin III of Managua, of the South Basin of Managua, Nicaragua. It has an area of 17, 337 ha, and extends from the El Crucero Plateau (940 masl) coinciding with the upper part (south of the map) to the shores of Lake Managua (40 masl) coinciding with the lower part (at the north of the map). The municipalities that are part of the study area are El Crucero, La Concepción, Ticuantepe, Nindirí, and districts V and VI of Managua. 90% of rainfall occurs in the rainy period (May-October) and 10% of rainfall during the dry period (ALMA, 2008). The slopes in the upper part are 15° and 49°, in the middle part 0° and 49°, and the lower part 0° and 3.6°, and the mainland covers are: forest, agriculture, urban, scrub and water in a smaller area.

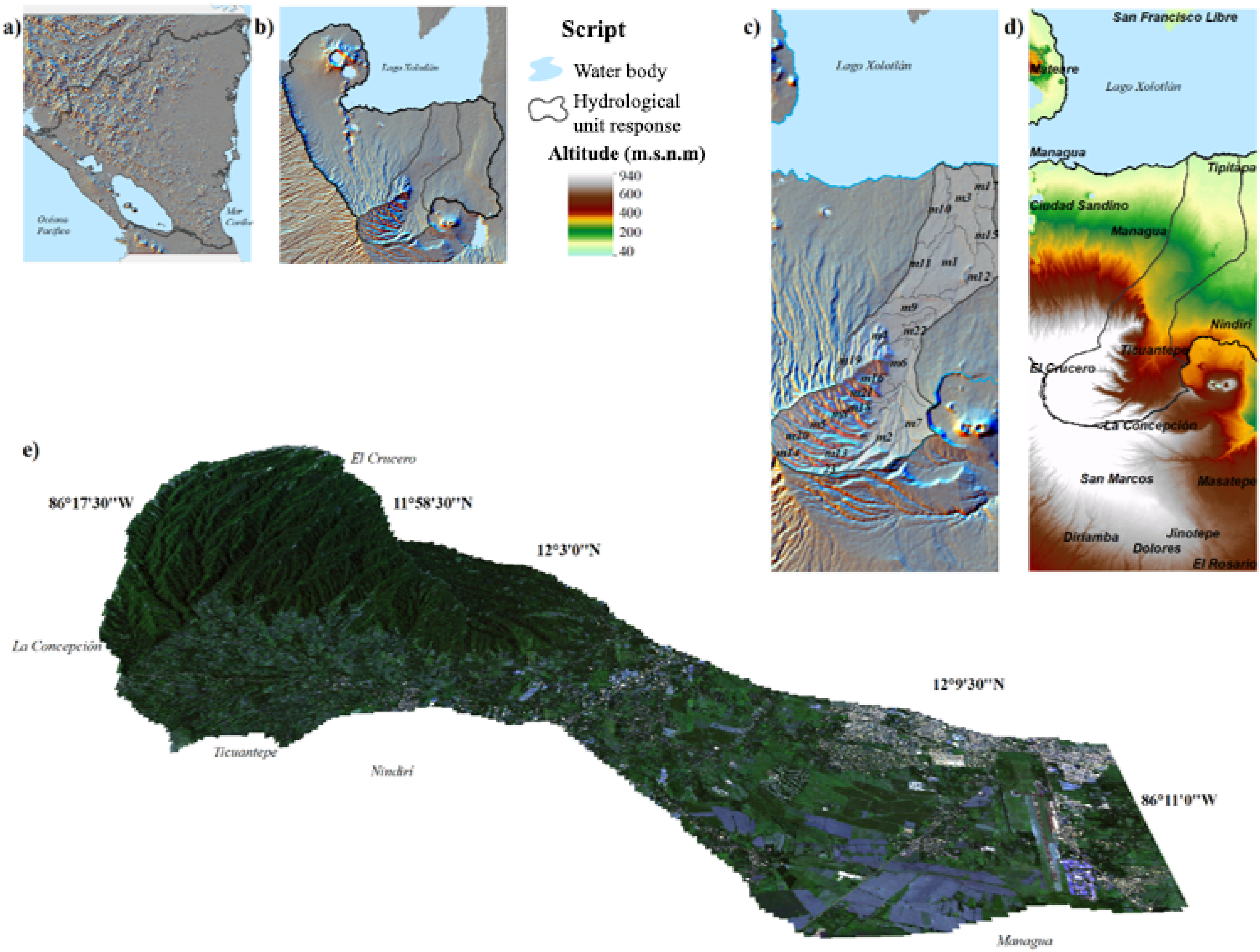

Figure 1. Location of Sub-basin III of Managua a) Map of Nicaragua, b) Map of the southern Basin of Lake Managua, c) Map of Hydrological Response Units d) Map of Altitudes of Sub-basin III of Managua e) Map 2D of the study area.

Methods

Surface runoff was estimated for the years 1997, 2003, 2010, 2016 and was simulated to the year 2025 using the Curve Number (CN) method of the US Soil Conservation Service (SCS) (Satheeshkumar., *et al.* 2017) and based on the land cover maps generated for each year evaluated (unpublished data).

The CN method was executed in the HEC-HMS (Hydrologic Engineering Center) Software and the input data generated were: the hietogram, the hydrological type of soil, and the antecedent humidity condition.

For the calculation of the hyetogram, the annual records of 10 years of precipitation of the meteorological station (code 69027) of the Managua International Airport, located in the lower part of Sub-basin III (location coordinates 12° 08' 36" N, 86° 09' 49" O). Next, the maximum probable precipitation in 24 hours was estimated by adjusting a Gumbel probability distribution (Equation 1), and correction by fixed interval 1.13 was established (Hershfield, 1961).

Due to the scarcity of one-hour rainfall records, the maximum values of precipitation in one day were related to the coefficients of precipitation of one hour (Campos, 1992). From the maximum daily rainfall according to its duration and frequency, as well as the application of the alternate block method (Chow *et al.*, 1994) the intensity of the precipitation (mm / hr) was estimated and design precipitation of 113 mm in 24 hours (Equation 2).

Equation 1. Distribution of probability density

$$F_{(x)} = \alpha\, e^{\left(-\alpha(x-\beta)-e^{\alpha(x-\beta)}\right)}$$

where: *N* samples, contains n events. α y β are the function parameters.

$$I = \frac{K.\, T^{m}}{t^{n}}$$

Equation 2. Rain intensities from Pd, according to Duration of precipitation and Frequency of the same where P = Daily precipitation in mm, t = duration in hours, *k* = constant regression term, *t* = return period, *m* = coefficient regression, *t* = duration time of precipitation in mm, *n* = adjustment parameter. *K, m, n* was calculated by applying logarithms to each variable to obtain a mathematical expression that represents the variation in the intensity of precipitation as a function of its duration (Campos, 1992).

The hydrological soil type and therefore the Curve Number with a normal antecedent humidity (ACM II) was obtained by spatially superimposing the soil type (INETER, 2015) and the land cover of the years 1997, 2003, 2016 and the projected year 2025. The coverage categories were: agriculture, forest, urban, scrub, and water.

When considering an antecedent humidity III (AMC III) at the five days before the event (design precipitation), the Curve Number III (Chow *et al.*, 1994) was calculated using Equation 3.

Equation 3. Calculation of NC III

$$CN\ (III) = \frac{23\ .\ CN\ (II)}{10 +\ 0.13\ CN\ (II)}$$

Additionally, the study area was delimited in 23 Hydrological Response Units with areas of 3 to 14 km^2 (FAO, 2002) to identify the areas that are critical due to the production of the largest runoff generated according to their area and coverage of the earth. For the delimitation, an 80 m Digital Elevation Model, the accumulation of the flow and the drainage network were used. Subsequently, to contribute to the environmental management of Managua Sub-basin III, participatory actions of a regulatory, economic, educational, and organizational nature were proposed in critical URH´s.

RESULTS AND DISCUSSION

Net surface runoff

The net surface runoff was 352.8 $m^3.s^{-1}$ (cubic meters per second), 449.2 $m^3.s^{-1}$, 396.4, 407.5 $m^3.s^{-1}$, and 383.6 $m^3.s^{-1}$ during the years 1997, 2003, 2010, 2016 and the projected year 2025, which meant an increase of 12%, 6% and 3% during the time periods: 1997-2003, 2003-2010, 2010-2016 and a decrease of 3% for the projected period 20016-2025 (Figure 2).

The increase in net surface runoff coincides with the increase in urban coverage (1,658 ha), scrub (1,519 ha), agriculture (712 ha), and forest (847 ha) during 1997-2016. On the other hand, the decrease in a net surface runoff for the projected period (2016-2025) coincides mainly with the increase in the forest (1,566 ha) and urban coverage (446 ha).

By increasing urban coverage, agriculture, scrub, and forest (in a smaller area), and considering an antecedent humidity of 5 days, total runoff also increases. The conversion of the forest area to crops or pastures increases the annual surface runoff causing floods and decreased flows (Guo, *et al.*, 2008, Notter *et al.*, 2007; Ndulue *et al.*, 2015; Satheeshkumar *et al,*. 2017).

Contrary to previous years, for the projected year 2025, the surface runoff will decrease. One of the causes of this decrease is probably due to the high storage capacity of the soil hydrological groups (Adham, *et al.*, 2014) on which the coverings have changed. Since both the urban coverage that is highly impermeable, as well as the forest cover with high water storage capacity will increase its surface. However, whether or not forests increase runoff could depend on its age, the extent of the vegetation cover, the root system, light, regeneration, and its effect on the organic matter content of the soil. In this matter, Álvarez (2010) observed that the secondary forest generates less runoff since it has a higher water consumption due to its growth phase. On the other hand, Ndulue *et al.*, (2015) observed that if the canopy coverage is reduced to 20% and 70% of the area, greater runoff occurs in the basin (Hernández, *et al.*, 2009, Notter *et al.* , 2007).

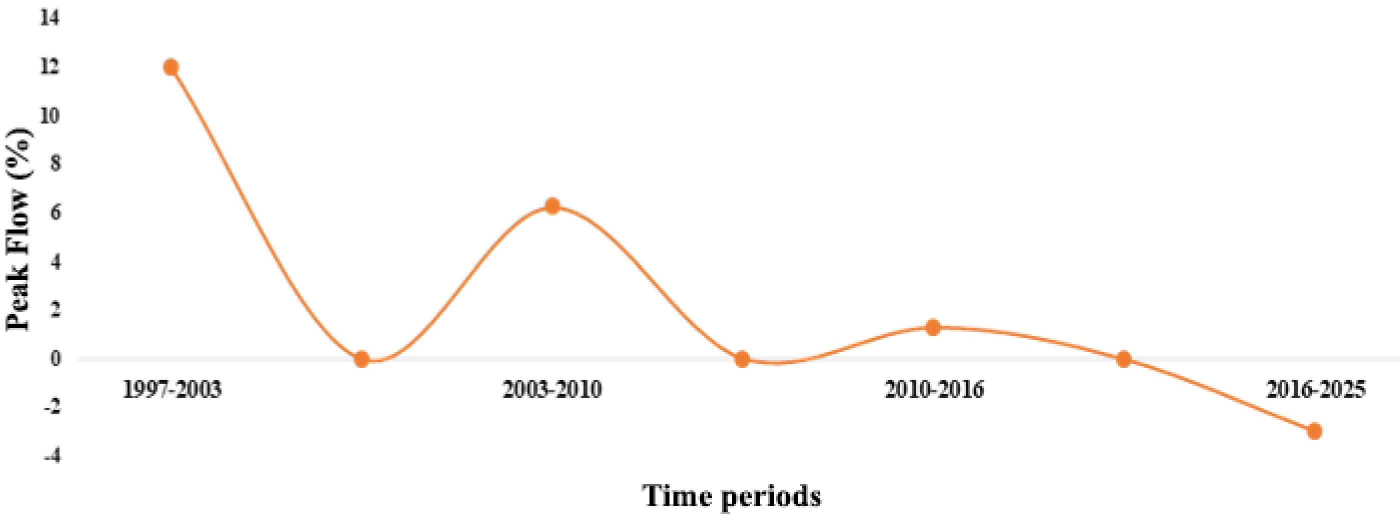

Figure 2. Flow peaks rates in percentages by periods

Surface runoff depending on the area of the Hydrological Response Units (URH)

For the year 2016 and the projected year 2025, the greatest runoff was 47 $m^3.s^{-1}$, 36 $m^3.s^{-1}$, 25 $m^3.s^{-1}$, 13 $m^3.s^{-1}$, and 10 $m^3.s^{-1}$ (Figure 3) in the URH where 90% of agriculture and urban coverage predominate (Figure 4). The runoff in these URH is not proportional to the area of the same and they are also located on Sierra's aquifer (Figure 5), which is why they are considered critical URH; like in the case of URH 5, 13, and 14 located in the upper part of the study area, and URH 2, 5, 6, and 13 coinciding with the areas of greatest infiltration (ALMA 2008). On the other hand, in the critical URH, there is a predominance of urban and agricultural coverage.

In critical URHs with a predominance of urban coverage (impervious surfaces), the net runoff increases and it is not ruled out that they are areas more prone to water erosion (Mango, *et al.*, 2011) and floods (Guo, *et al.* , 2008, Villarreal, *et al.*, 2014, Ndulue *et al.*, 2015) because the potential storage of water and soil infiltration decreases on impervious surfaces (Adham, *et al.*, 2014). Likewise, Vammen, Katherine; Flores, Selvia; Picado, Francisco; Hurtado, Iris; Jiménez, Mario; Sequeira, Gustavo; Flores, Yelba (2015), explained that for every square kilometer waterproofed, the Managua aquifer ceases to receive 240,000 $m^3.year^{-1}$. This means that probably during 2016 the aquifer stopped receiving 9,120,000 $m^3.year^{-1}$ and in 2025 it is expected to stop receiving 10,357,250.4 $m^3.year^{-1}$.

In URH's with agricultural cover, runoff increased probably due to the transition from coffee cultivation (ALMA, 2008) to pineapple and pitahaya cultivation located on the slopes of the upper part of the study area. In this sense, Hernández, *et al.*, (2009), Notter *et al.*, (2007) suggest that the change towards urban coverage in the upper parts of the basin will negatively affect runoff patterns and erosion of the slopes (Mango, *et al.*, 2011), even if the cover is forested with a canopy less than 50%, the runoff will increase (Ndulue *et al.*, 2015). On the other hand, Mango, *et al.*, (2011) and Alemayehu, (2015) showed a greater runoff caused by the change in land cover than by the increase in precipitation and temperature.

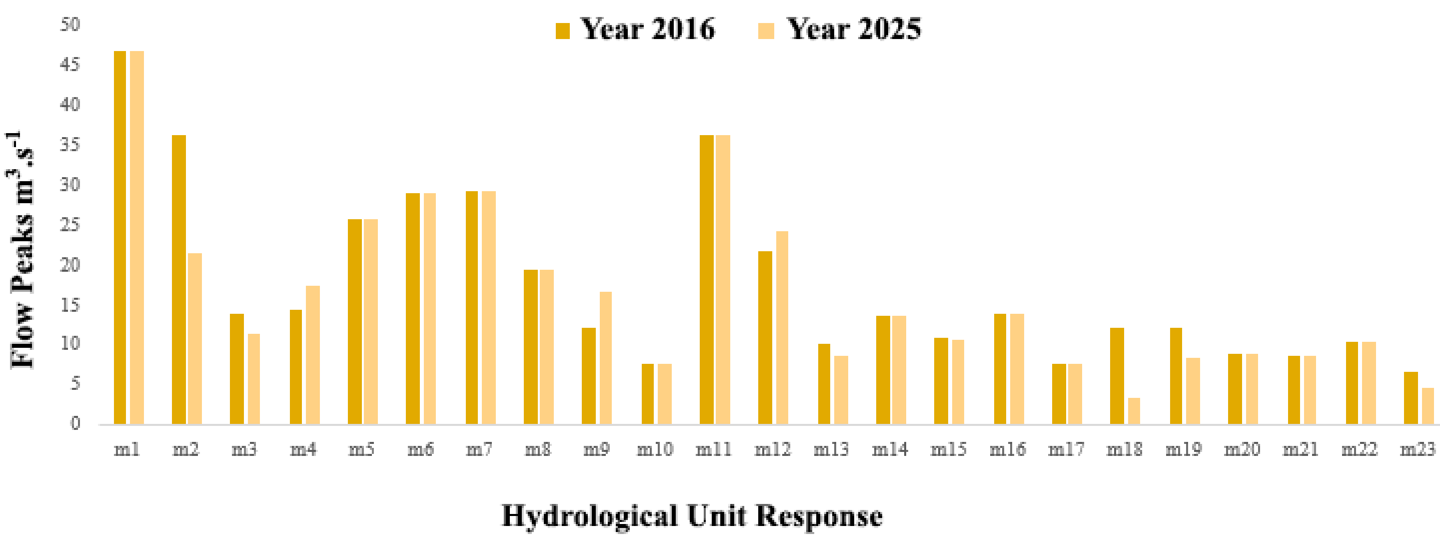

Figure 3. Peak flows in $m^3.s^{-1}$ depending on the area of each URH for the year 2016 and the projected year 2025.

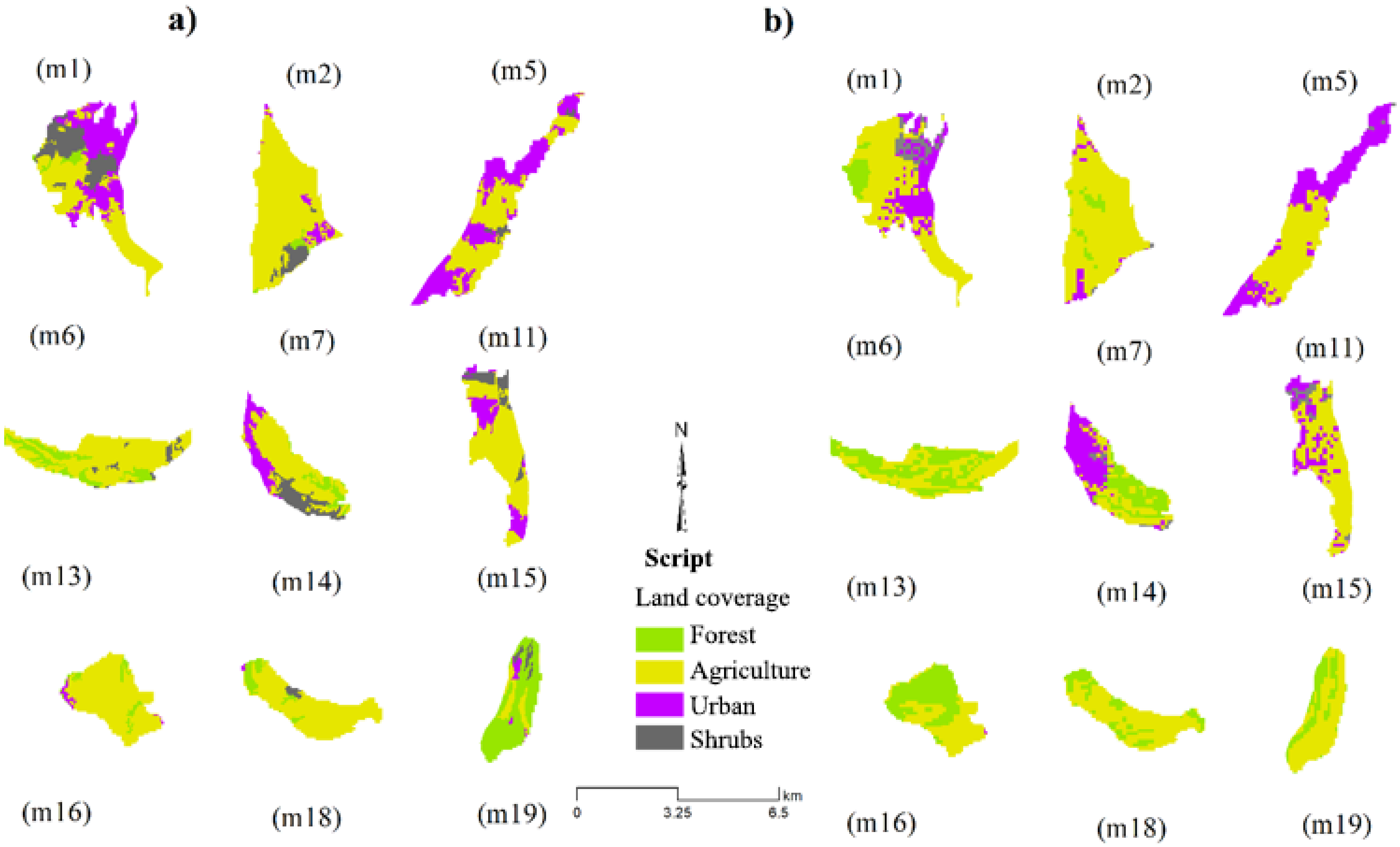

Figure 4 Land cover for the years: (a) 2016 (b) 2025 in the URH with the highest flow peaks in Sub-basin III of Managua.

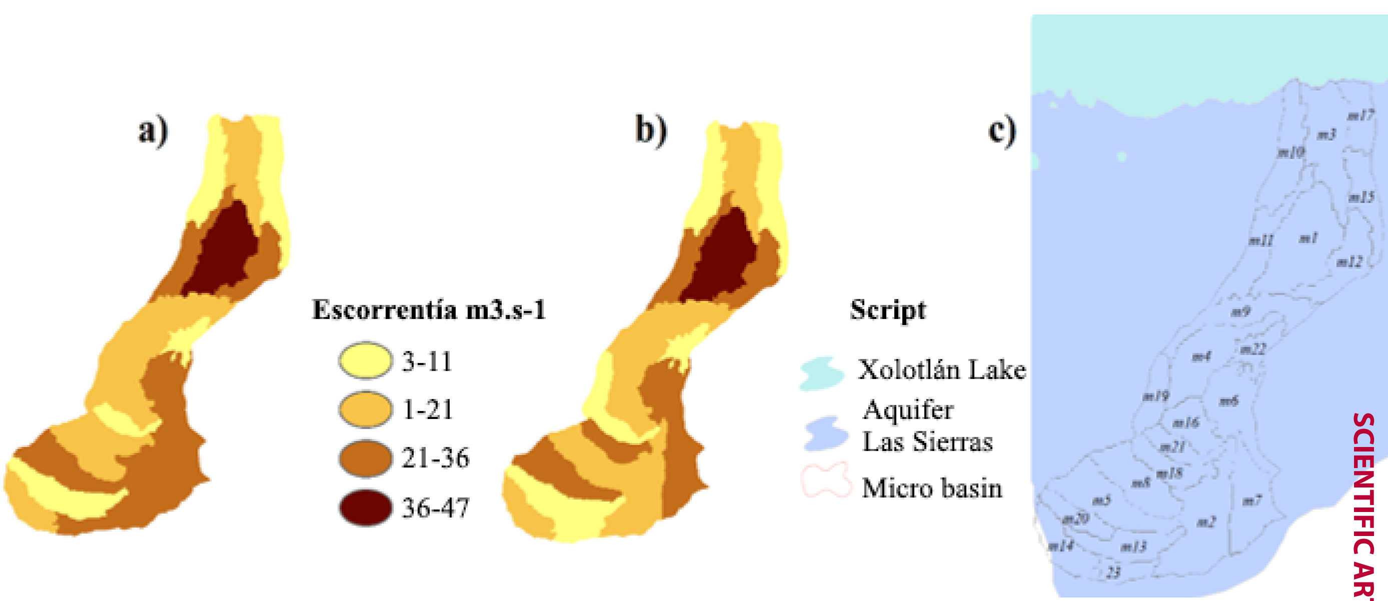

Figure 5 Flow peaks $m^3.s^{-1}$ in Managua Sub-basin III (a) Map year 2016 (b) Map projected for the year 2025 (c) Map of the URH of the study area.

Participatory actions for environmental management of Managua Sub-basin III

The interaction between land cover and surface runoff found in critical Hydrological Response Units (URH) necessitates a local assessment to develop appropriate actions for environmental management (FAO, 2002). The participatory actions proposed below are of a regulatory, economic, educational, and organizational nature (FAO, 2002; Mociño, 2015) and for their operation, the participation of the public and private sectors is required (Table 1).

Regulatory actions

In Managua Sub-basin III there is an important role of urban coverage and agriculture in administrative and economic terms, which causes an increase in surface runoff and the pressure that is probably causing the aquifer. Recently, the public sector recommends creating instruments for regulating land uses that generate incentives for land users (Leonel *et al.*, 2013; Lambin, EF; Meyfroidt, P; Rueda, X; Blackman, A; Borner, J; Cerutti, PO; Dietsch, T; Jungmann, L; Lamarque, P; Lister, J; Walker, NF; Wunder, S, 2014). Therefore, it is suggested that the Mayors and the private sector develop policy instruments such as ecological certification, geographical indications, round tables on basic products, moratoriums, and Payments for Environmental Services (Lambin *et al.*, 2014), mainly in the URH which are critical.

Economic

Institutions linked to agricultural production such as MAG (Ministry of Agriculture), INTA (Nicaraguan Institute of Agricultural Technology) and MEFCA (Ministry of Family, Community, and Associative Economy) are recommended to implement direct and indirect subsidies that aim to compensate farmers who simply extend their land in the upper parts of the study area.

The direct subsidy can be managed from the funds generated by the application of regulatory instruments. The indirect subsidy can be obtained from the water harvest made by those farmers who simply extend their agricultural land to the highlands. Up to a 90% reduction in the payment of agricultural property taxes is also important if they prepare a forest management plan and commit themselves to carry it out over a period of 10 years (FAO, 2002; Lambin *et al.*, 2014). In this sense, Hargrave and Kis-Katos (2013) explain that the success of stopping deforestation in the Brazilian Amazon was achieved mainly through a combination of law enforcement on the ground, including the on-site seizure of assets along with administrative measures to conditionality, such as conditional access to credit and trade embargoes as part of the soy moratorium.

One mechanism to improve cooperation between the actors involved is to support markets. INTA, restaurants, markets, and merchants must commit to buying products from farmers participating in soil conservation programs (FAO, 2002) as does the Netherlands and the United Kingdom. Another of the public and private participatory actions is outsourcing and the signing of memoranda of understanding, such as the case of China where local governments signed with Walmart to promote sustainability through their supply chains (Lambin *et al.*, 2014).

Another possibility of implementing a runoff reduction program in critical URHs is that urban developers must contribute to the costs of future projects focused on soil conservation (FAO, 2002). Soil conservation may contemplate the ecological management of crops, conservation tillage, cultivation in contour lines, crops for cover and green manure, planting in the most exposed areas, use of crop residues, delay in soil preparation of cultivation, filter strips and delimitation of farms, grassy watercourses, cultivation in strips, construction of terraces (Mociño, 2015).

Education

The Nicaraguan Institute of Agricultural Technology (INTA) and the Ministry of the Environment and Natural Resources (MARENA) can organize farmers who are located in critical URHs to participate in the environmental audit of their farms. The audit includes the identification of potentially eroded soils. Likewise, the exchange of knowledge between farmers could be managed from INTA, which would consist of farmers visiting farms that prepare runoff and soil erosion prevention evaluations.

Organizational

Establish the relationship between the land users located in the upper part and the water users located in the lower part of the basin. This relationship consists of long-term planning of the sub-basin management and implementation of the instruments. The relationship between users could be started through a forum where the municipalities, INTA, MARENA, MAG, among others, participate. (FAO, 2002; Hernández, *et al.*, 2009; Leonel, *et al.*, 2013).

Table 1. Actors identified with a direct incidence in Sub-Basin III

Characteristics	Identified actors		
	High lands	**Middle lands**	**bottom lands**
Critical URH´s	5,13,14	2, 7, 16, 18, 19	6, 11, 15, 18
Communities	Las Nubes y San Ignacio	Cebadilla, Los Ríos, El Edén, Las Enramadas, Denis Larios, La Francia, Las Dispersas	Managua Distritos V y VI (Sabana Grande)
Business and Organizations unions	ASOCAM, Cooperativa de Pitahayeros de La Concepción	Café El Mejor, Procesadores de materiales de construcción, granjas avícolas, Tricotextil, Pinturas Sur ASOCAM, Unión de Productores de Ticuantepe	Airport A C Sandino, Factory Industrial Las Mercedes, Hotel Las Mercedes, Hotel Camino Real Cooperativa Juan Ramón Robles

Source: ALMA 2008 updated with data from this research.

CONCLUSIONS

The effects of the dynamics of land cover on surface runoff indicate that 12 of the 23 URH generated the greatest runoff due to agriculture and urban coverage. These 12 URH´s are considered critical and are also located in areas of greater infiltration, so the application of participatory actions for environmental management is recommended.

The application of participatory actions for environmental management is often achieved through complementary interactions between the private and public sectors. This means that if governments provide technologies to enforce regulations related to monitoring surface runoff and land cover dynamics, such as the case of the soybean moratorium in Brazil (Lambin *et al.*, 2014), then the private company must support the enforcement of regulations.

For subsequent studies, it is recommended to have information from Remote Sensors that provide climatic data in each part of a hydrological unit to understand in this way the behavior of other components of the hydrological cycle.

WORKS CITED

Adham, M., Shirazi, S., Othman, F., Rahman, S., Yusop, Z., & Ismail, Z. (2014). Runoff Potentiality of a Watershed through SCS. *The Scientific World Journal*, 1-15. doi:10.1155/2014/379763

Alemayehu, K. T. (2015). Land use land cover change and its implication on surface runoff: a case study of baro river basin in southwestern Ethiopia. *Journal of Environment and Earth Science,* V(8), 2224-3216. http://www.iiste.org/Journals/index.php/JEES/article/view/22025/22064

ALMA. (2008). *Actualización del estudio de drenaje pluvial de la Subcuenca III de la cuenca sur del lago de Managua*. Informe final para la municipalidad de Managua, Alcaldía de Managua, Managua, Nicaragua.

Campos, A. (1992). *Proceso del Ciclo Hidrológico* (Segunda ed., Vol. I).

Cano, C., Andreoli, A., Arumi, J., & Rivera, D. (2014). Uso de imágenes de satélite para evaluar los efectos de cambio de cobertura de suelo en la escorrentía directa de una Cuenca Andina. *Tecnología y Ciencias del Agua*, V(4), 145-151. http://www.redalyc.org/articulo.oa?id=353532522009

Chow, V. T., Maidment, D., & Mays, L. (1994). *Hidrología aplicada* (Vol. I). NOMOS S.A.

FAO (Food and Agriculture Organization of the United Nations). (2002). *Relaciones tierra-agua en cuencas hidrográficas rurales*. http://www.fao.org/3/y3618s/y3618s00.htm

Guo, H., Huo, Q., & Jiang, T. (2008). Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang lake basin, china. *Journal of hydrology,* CCCLV, 106-122. doi:10.1016/j.jhydrol.2008.03.020

Hargrave, J., & Kis-Katos, K. (2013). Economic Causes of Deforestation in the Brazilian Amazon: A Panel Data Analysis for the 2000s. *Environmental and Resource Economics*, LIV(4), 441-494. doi:10.1007/s10640-012-9610-2

Hernández Guzmán , R., Ruiz , L. A., Berlanga-Robles, C., & Zoltán Vekerdy. (2009). Evaluation of total runoff for the Rio San Pedro sub-basin (Nayarit, Mexico). *Journal of Spatial Hydrology,* IX(2), 72-85. http://www.spatialhydrology.net/index.php/JOSH/index

Hershfield, D. M. (1961). R*ainfall frecuencu atlas of U.S for duration from 30' to 24 h and return periods from 1-100 years*. Washington, DC,: U.S. Weather Bureau. ttps://www.lm.doe.gov/cercla/documents/fernald_docs/CAT/109669.pdf

Lambin, E F; Meyfroidt, P; Rueda, X; Blackman, A; Borner, J; Cerutti, P O; Dietsch, T; Jungmann, L; Lamarque, P; Lister, J; Walker, N F; Wunder, S. (2014). Effectiveness and synergies of policy instruments for land use governance in tropical regions. *Global Environmental Change,* XXVIII(1), 129-140. doi:10.1016/j.gloenvcha.2014.06.007

Leonel, H. F., Aguilar Robledo , M., & Medellín, M. P. (2013). *Gestión participativa en la cuenca del Río Valles*. Morelia, Michocán: Centro de Investigaciones en Geografía Ambiental, Universidad Nacional Autónoma de México. http://www.ciga.unam.mx

Mango, L., Melesse, A., Mcclain, M., & Gann, S. S. (2011). Land use and climate change impacts on the hydrology of the upper mara river basin, Kenya: results of a modeling study to support better resource management. *Hydroly and Earth system Sciences*, XV, 2245-2258. doi:10.5194/hess-15-2245-2011

Miranda, A. L. (2008). *Dinámica de uso y su efecto en el escurrimiento superficial en la cuenc del Rio Grande, Tlalchapa, Guerrero.* Tesis MSc, Estado de México. Obtained from http://www.biblio.colpos.mx:8080/xmlui/handle/10521/1189