Journal of Urban and Environmental Engineering
E-ISSN: 1982-3932
celso@journal-uee.org
Universidade Federal da Paraíba
Brasil

Santos Oliveira, Jean Maikon; Ricardo Salla, Márcio
MODELLING THE IMPACTS OF WILDFIRE ON SURFACE RUNOFF IN THE UPPER UBERABINHA RIVER WATERSHED USING HEC-HMS
Journal of Urban and Environmental Engineering, vol. 11, núm. 1, 2017, pp. 88-98
Universidade Federal da Paraíba
Paraíba, Brasil

Available in: http://www.redalyc.org/articulo.oa?id=283253419010

- How to cite
- Complete issue
- More information about this article
- Journal's homepage in redalyc.org

redalyc.org
Scientific Information System
Network of Scientific Journals from Latin America, the Caribbean, Spain and Portugal
Non-profit academic project, developed under the open access initiative

JUEE

Journal of Urban and Environmental Engineering, v.11, n.1, p.88-98

ISSN 1982-3932
doi: 10.4090/juee.2017.v11n1.088098

Journal of Urban and Environmental Engineering

www.journal-uee.org

MODELLING THE IMPACTS OF WILDFIRE ON SURFACE RUNOFF IN THE UPPER UBERABINHA RIVER WATERSHED USING HEC-HMS

Jean Maikon Santos Oliveira[1] and Márcio Ricardo Salla*[2]

[1] *Institute of Agricultural Sciences, Federal University of Uberlândia, Brazil*

[2]*Department of Civil Engineering, Federal University of Uberlândia, Brazil*

Received 13 July 2016; received in revised form 02 January 2017; accepted 18 May 2017

Abstract: Fire significantly affects hydrological processes in the watershed because it changes land cover and it creates a double layer of hydrophobic soil covered with ash, increasing the surface runoff and the production of debris flow in the basin. Assessing the impacts of fire on overland flow requires the use of modeling softwares capable of simulating post-fire discharge. Because a total of 760 wildfires were detected in the Upper Uberabinha River subbasin in the last nine years, it is of dire importance to understand the consequential impacts of fire on hydrological processes in this basin. In this study, the HEC-HMS model was used to evaluate post-fire discharge in the Upper Uberabinha River watershed. Model was previously calibrated and validated using two representative storms observed in the wet season. After calibration, the 5-, 10-, 25-, 50-, 100-, and 200-year storms were simulated in scenarios with increasing burn severity. The calibrated model performed well in the prediction of discharge values at a daily basis (0% difference in peak timing; 0% difference in peak flow; 31.8% *BIAS*). Peak flow and discharge volume increased and peak timing shifted to the left as severity of burn increased. The highest increment in peak discharge was 74.7% for the 10-year storm, whereas overall discharge volume raised in up to 31.9% for the 50-year storm, both after simulation in the most fire-impacted scenario. The results reveal that fire highly affects hydrological characteristics, e.g. peak timing and flow and discharge volume, in the Upper Uberabinha River watershed. The authors suggest further investigations concerning the impacts of wildfire on other processes, such as the production of debris flow in the basin.

Keywords: Wildfire; surface runoff; HEC-HMS; modelling; Uberabinha River watershed.

© 2017 Journal of Urban and Environmental Engineering (JUEE). All rights reserved.

* Correspondence to: Marcio R. Salla, Tel.: +55 34 3239 4170 Ext 224; Fax: +55 34 3239 4159.
E-mail: marcio.salla@ufu.br

INTRODUCTION

In Brazil, the use of fire for agricultural purposes is still a common technique. Fire is mainly used in the clearing of soil in preparation for planting of several crops, e.g. soybean and also for the harvesting of sugarcane (Klink *et al.*, 1993; Ronquim, 2010; Mistry, 1998). Additionally, records of accidental and intentional burning close to roads are frequent (Costa *et al.*, 2009), although the practice is outlawed by the Federal Law N. 9.605 (Brasil, 1998).

Wildfire significantly changes soil chemical composition, producing a double layer of water-repellant soil covered with ash. Moreover, vegetation removal exposes soil to erosive processes with consequential impacts to hydrological processes in the watershed, e.g. production of debris flow and increase in overland flow (Jung *et al.*, 2009; Moody *et al.*, 2001). Hence, predicting peak discharge following wildfire is decisive in order to avoid floods in watersheds whose outlet is located near urban areas.

Many models have been used for simulating discharge in watersheds subject to alterations in land cover. A few models previously used for this purpose are the Hydrologic Modeling System (HEC-HMS), the Rowe Countryman and Storey (RCS), the United States Geological Survey (USGS) Linear Regression Equations, the USDA Windows Technical Release 55 (USDA TR-55), the Wildcat5, the Système Hydrologique Européen (MIKE-SHE), and the Simulator for Processes of Landscapes: Surface/Subsurface Hydrology (SPLASH) (Beeson *et al.*, 2001; Kinoshita *et al.*, 2014; Moussoulis *et al.*, 2015).

The Upper Uberabinha River watershed, located in the Triangulo Mineiro Region – Brazil, was strategically chosen for this study for three main reasons: (1) the subbasin is cut by two federal highways, namely the BR-050 (goes from Brasília – Federal District to Santos – State of Sao Paulo) and the BR-452 (goes from Rio Verde – State of Goiás to Araxá – State of Minas Gerais), increasing chances of intentional and accidental fire caused by humans; (2) the large extension of areas planted with crops, such as soybeans, sugarcane, and corn in this basin (Rosolen *et al.*, 2009) increases chances of fire related to the clearing and preparation of soil during the planting and harvesting; and (3) there is a water right to divert and use 3.4 cubic meter per second of water for public supply in the city of Uberlândia – MG near the basin outlet. Predicting peak discharge is essential to the proper management of water resources, e.g. control of the water supply reservoir and channels, as the outlet is located near the urban area of the city.

The aim of this study was to evaluate the impacts of wildfire on surface runoff in the Upper Uberabinha River watershed for the 5-, 10-, 25-, 50-, 100-, and 200-year storm events, comparing pre- and post-fire scenarios from point source fire data obtained from INPE (2016) for the periods of 2007 through 2015. Hydrological simulation was performed using the free modeling software HEC-HMS.

STUDY AREA

The Uberabinha River watershed is a subbasin of the Araguari River watershed and is located in the state of Minas Gerais – Brazil, between coordinates 18º36’05” to 19º26’27” S latitude and 48º38’45” to 47º50’39” W longitude. The selected study area, termed “Upper Uberabinha River subbasin” (787 km^2), is located in the upper reaches of the Uberabinha river watershed, as shown in **Fig. 1**. The Uberabinha river runs from Uberaba to Uberlandia, eventually meeting the Bom Jardim stream.

Elevation varies from 875-1000 m over a 96.3 km watershed length, with an average watershed slope of 0.14%. Shaded elevation bands (25 m intervals) and contours (50 m intervals) are represented in **Fig. 2a**.

The Upper Uberabinha River subbasin is covered with Cerrado vegetation (9.5%), wetlands (20%), bare soil (26%), row crops and pasture (43%), and water bodies (1.5%) (**Fig. 2b**). The land cover map was created in a GIS software using Landsat 8 satellite images at 30 m resolution in natural-color band combination (4R3G2B) (USGS, 2015).

The predominant soil types are red and red-yellow latosols, which belongs to the hydrologic soil group (HSG) A (**Fig. 2c**). HSGs are A, B, C, and D, classified according to their respective infiltration rates. HSG A represents well drained soils with low runoff potential and infiltration rates higher than 0.76 cm/h (USDA, 2007). Yet in **Fig. 2c**, LV4, LV59, LVA5, LVA19, and NV21 are different red latosol, red-yellow latosol, and red nitosol soil types, according to the Brazilian Soil Classification System (EMBRAPA, 1999). Soil data was acquired from IBGE (2016).

METHODS

Hydrologic Data

Daily discharge data from 1991 through 2014 was acquired from the ANA (2015) stream gage named Fazenda Letreiros (#60381000), located near the urban area of Uberlandia, MG, with drainage area equivalent to the Upper Uberabinha River subbasin (see location in **Fig. 1**). Precipitation data for the same period was acquired at 24 h intervals from two nearby rainfall gages operated by INMET (2015), named INMET #83577 (located in the city of Uberaba) and INMET #83527 (located in the city of Uberlandia). The mean

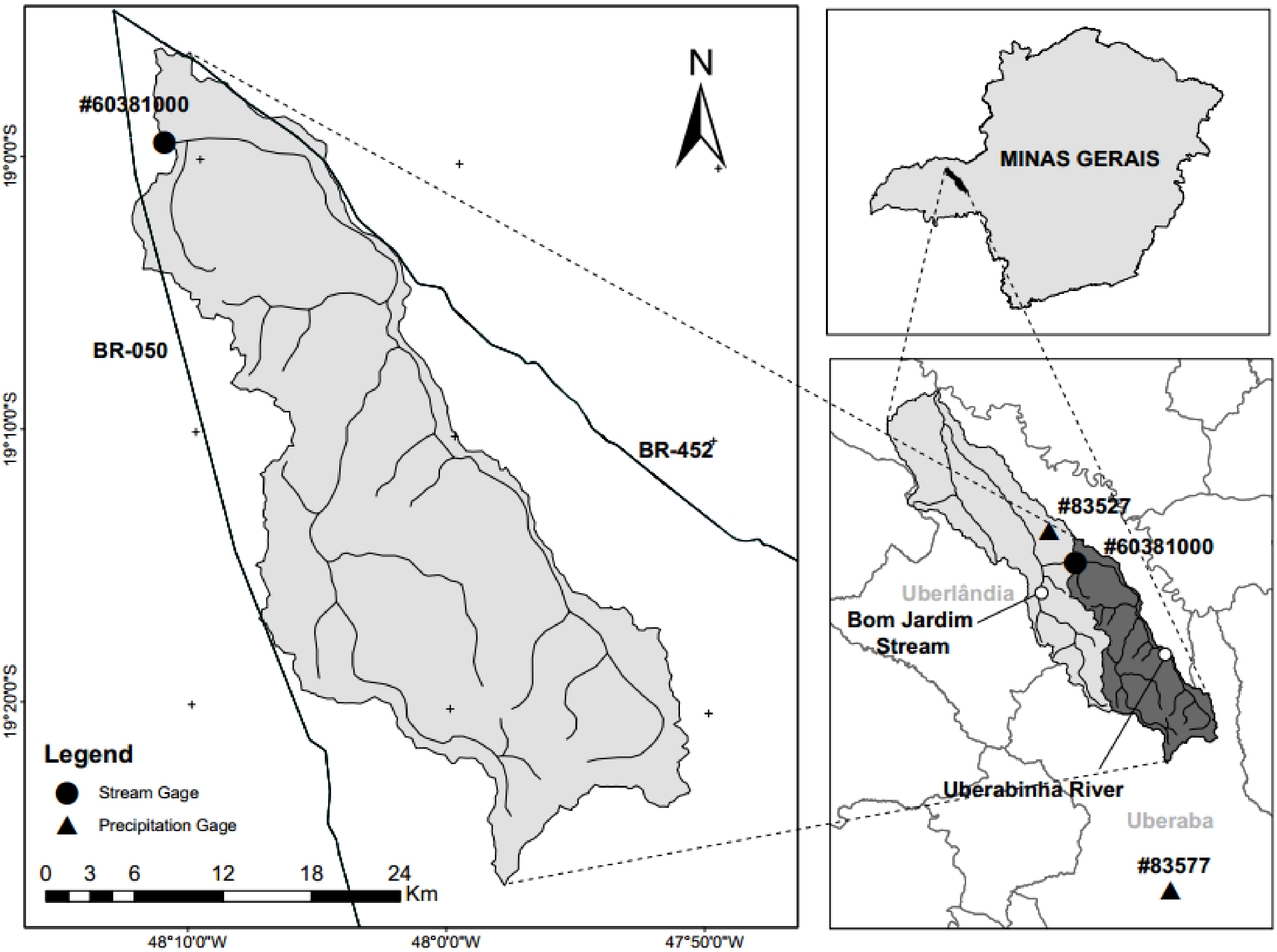
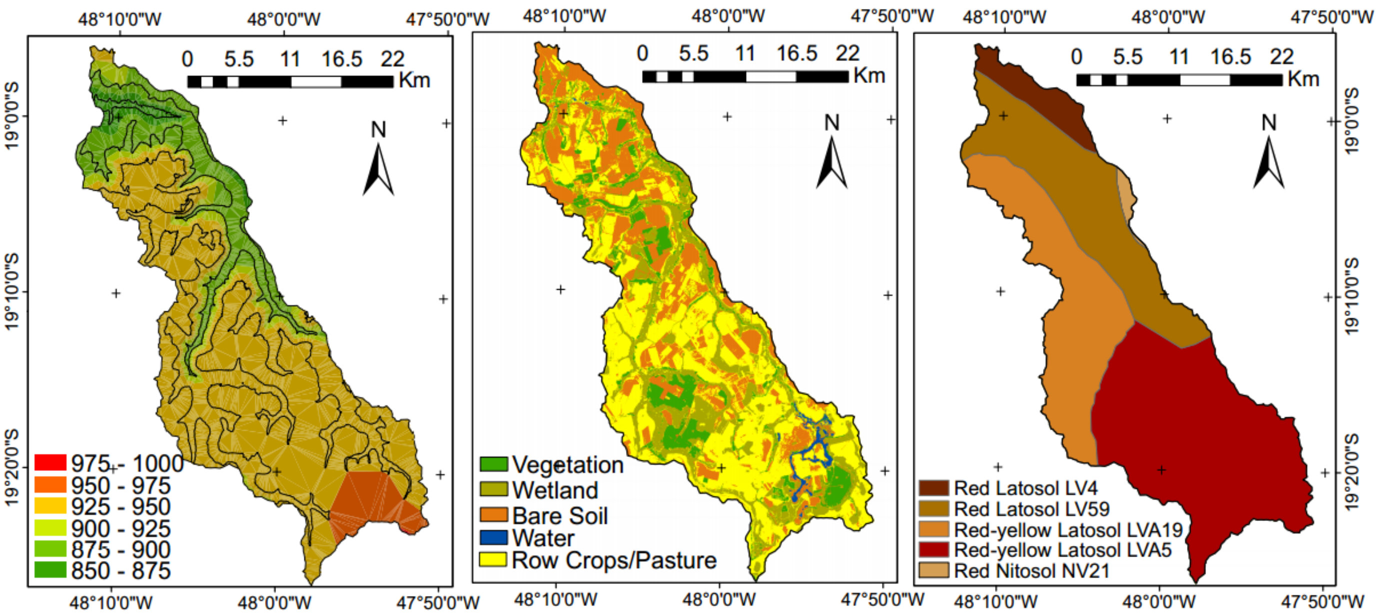


Fig 1. Location of the Upper Uberabinha River subbasin.



(a) (b) (c)

Figure 2. (a) Elevation map; (b) Land cover map; and (c) soil type map in the Upper Uberabinha River watershed.

areal precipitation (MAP) over the watershed was calculated using the Thiessen polygon method. The area of influence around each gage was determined by using a GIS software. The percentage of area influenced by INMET #83577 is 30%, whereas INMET #83527 accounts for 70% of the study area. Representative storms with continuous data were evaluated for use in the model during the calibration and validation procedures. A storm was selected for calibration and validated with another storm in the same period of the year.

Additionally, the 5-, 10-, 25-, 50-, 100-, and 200-year storm values were estimated for use during burn scenario simulations. Calculations were based on peak daily rainfall for both Uberaba and Uberlandia gages during the periods of 1991-2014. Log-Pearson Type 3, Lognormal (3P), Log-Logistic (3P), and Weibull distributions were tested. Predicted values were subject to goodness of fit tests such as Kolmogorov-Smirnov, Anderson Darling, and Chi-Squared, and the best model was selected for each gage by using a distribution fitting software. The MAP was calculated for each recurrence interval.

HEC-HMS Methods

HEC-HMS is a program designed by the US Army Corps of Engineers for simulating precipitation-runoff processes in a watershed. The software provides many different loss methods for predicting infiltration and different transform methods for calculating surface runoff within the subbasin (U.S. Army Corps of Engineers, 2015). The loss method used in this study was the Soil Conservation Service (SCS) Curve Number method, whereas SCS Unit Hydrograph was selected as the transform method. According to the USDA (2007, 2009) the curve number (*CN*) method combines depth of runoff (Q), depth of rainfall (P), maximum potential retention (S), and Initial Abstraction (I_a) in the **Eq. (1)**.

$$Q = (P - I_a)^2/[(P - I_a) - S] \quad (1)$$

In **Eq. (1)**, I_a includes all the losses before runoff begins, such as interception, evaporation and infiltration. Studies from many small agricultural watersheds found it to be related to the maximum potential retention (USDA, 2009). This empirical relationship is expressed in **Eq. (2)**.

$$I_a = 0.2S \quad (2)$$

The maximum potential retention (S), in millimeters, can be estimated for a given *CN* value through the empirical **Eq. (3)**.

$$CN = 1000/(10 + S/25.4) \quad (3)$$

In the **Eq. (3)**, *CN* was estimated based on cover type and hydrologic soil conditions in the basin. Because all the soil types in the region belong to the same hydrologic soil group, *CN* was calculated individually for each cover type. The *CN* for the whole subbasin was considered to be the sum of each individual *CN* value weighted by the respective fraction of area it occupies in the watershed. Although the storm selected for calibration was observed during the wet season, no significant precipitation event occurred in the prior five days, and therefore the antecedent soil moisture conditions was considered to be the average (Type II). The S value was obtained from **Eq. (3)**, and I_a using the formulation represented in **Eq. (2)**. The total impervious area was assumed to be 0% due to the lack of urban areas in this portion of the Upper Uberabinha River watershed.

For the SCS Unit Hydrograph transform method, the main entry is the lag time (T_l), which Mockus (1957) and Simas (1996) found to be a fraction of the time of concentration (T_c), according to **Eq. (4)**.

$$T_l = 0.6\ T_c \quad (4)$$

Mockus (1961) developed an equation that relates T_c to the flow length (L, in feet), average watershed land slope (Y, in percentage), and maximum potential retention (S, in percentage). The formula is demonstrated in **Eq. (5)**.

$$T_c = [L^{0.8} * (S + 1)^{0.7}]/(1140 * Y^{0.5}) \quad (5)$$

L and Y were appropriately measured with the aid of a geoprocessing tool. The digital elevation model (DEM) used in this study is a product of the Shuttle Radar Topography Mission (SRTM) and is available on the Brasil em Relevo database (EMBRAPA, 2015).

The method selected for the routing calculations was the Muskigum-Cunge method, which is based on channel properties and the flow depth (U.S. Army Corps of Engineers, 2015). The inputs considered are shape, length, energy slope, bottom width, side slope, and Manning's n roughness coefficient of the channel. The energy slope was estimated from a DEM, in the same way as the watershed slope. The cross section shape was considered to be trapezoidal with 1H:1V side slope. Bottom width data at stream gage #60381000 was obtained from ANA and was assumed to be uniform along all the extension of the reach. The Manning's roughness value adopted was 0.046 (Salla *et al.*, 2015). Baseflow were inputted on a constant monthly basis and was considered to be the flow that was equaled or exceeded 90% of the time after analyzing historical flow data for each month (1991-2014). Model design included a single basin (Upper Uberabinha River subbasin) connected to its outlet through a single reach (Upper Uberabinha River).

Calibration and Validation Procedures

After model was set up and the parameters were inputted, rainfall data from the calibration storm was run in HEC-HMS and the runoff response at the Upper Uberabinha River watershed outlet was evaluated. The model was optimized by adjusting *CN*, I_a, and T_l values so that simulated flow had similar hydrological response to that observed in the representative hydrograph. Peak discharge and peak volume were the main parameters considered. A different storm was selected in order to validate the model after parameters were optimized. Both the storms picked for this study occurred during the beginning of the wet season, since it is a critical period in which first storms happen after a long dry season, and therefore great floods may happen. Root mean square error (*RMSE*) and percent of bias (*%Bias*) were calculated for the calibrated model and respective storm using **Eq. (6)** and **(7)**.

$$RMSE = \sqrt{[(1/n)\Sigma(Q_{obs(i)} - Q_{model(i)})^2]} \quad (6)$$

$$\%Bias = \{[\Sigma(Q_{model(i)} - Q_{obs(i)}]/[\Sigma(Q_{obs(i)}]\} \quad (7)$$

In **Eq. (6)** and **(7)**, Q_{obs} is the observed flow at time *i*, Q_{model} is the simulated flow at time *i*, and *n* is the number of observations.

Pre- and Post-Fire Simulations

Burn scenarios (BS) were created in order to simulate post-fire conditions in the subbasin, where the burn scenario 1 (see **Fig. 3a**) covers the period from 2007 to 2009, the burn scenario 2 (see **Fig. 3b**) covers the period from 2010 to 2012, and the burn scenario 3 (see **Fig. 3c**) covers the period from 2013 to 2015.

The burn simulations were constructed with the help of fire density maps, which were based on fire data obtained from INPE (2007-2015). The Portal do Monitoramento de Queimadas e Incêndios from INPE registers wildfire occurrence in Brazil in a near real-time basis with the aid of remote sensing. Optical sensors from several polar and geostationary satellites (thermal region, between 3.7 to 4.1 µm) are used to detect fire throughout the country. The satellites used are NOAA-15, NOAA-16, NOAA-18, NOAA-19, NASA, TERRA, AQUA, GOES-12, GOES-13, and MSG-2 (INPE, 2016). Fire less than 30 m wide cannot be detected. Because of the varying spatial resoultion of the many sensors, and additionally due to contraints in pixel resolution, the extension of the burned area is unknown. The burn severities were adopted based on visual inspection of the density maps and also to provide BS with increasing fire-related impacts. Althought point source fire data represents real fire occurrence in the basin, the burned areas created in each scenario, shown in **Fig. 3**, were purely simulated.

The post-fire *CN* value was predicted according to the method described in Higginson and Jarnecke (2007), which has been used by the U.S. Burn Area Emergency

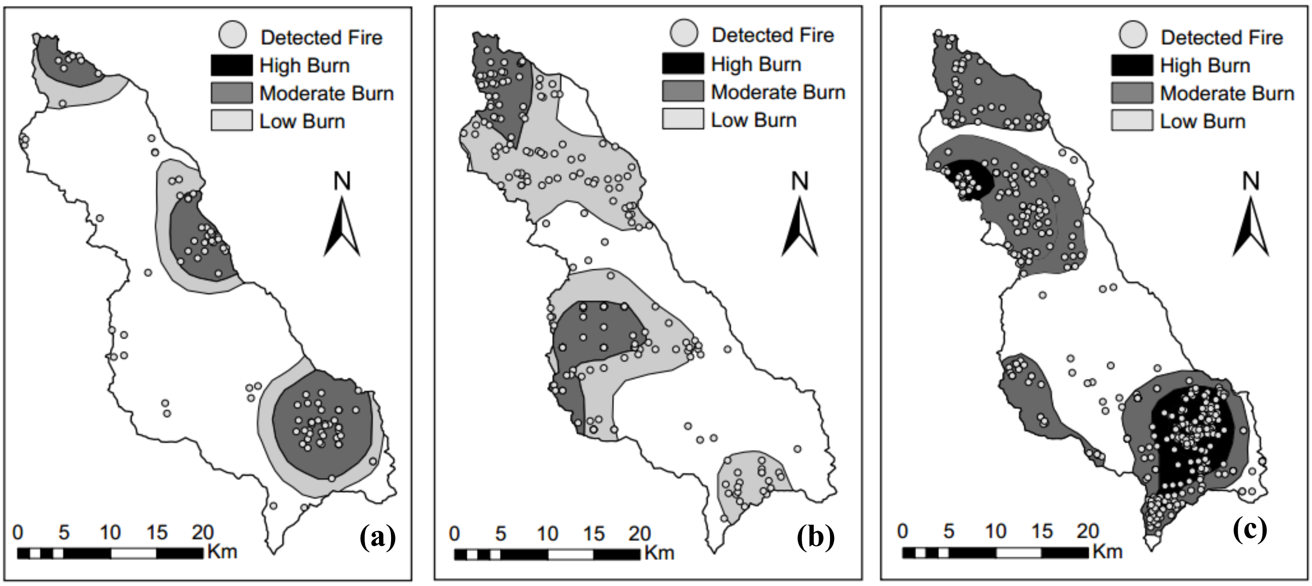


Figure 3. BS simulations based on fire data from INPE (2016), where: (a) BS 1 (2007-2009); (b) BS 2 (2010-2012); and (c) BS 3 (2013-2015).

Response (BAER) team and other authors (Foltz *et al.*, 2009; Kinoshita *et al.*, 2014). The method assumes different burn severities change cover type and soil properties in a different degree, according to **Eq. (8)**, **(9)**, and **(10)**.

High burn severity CN = pre-fire CN + 15 (8)

Moderate burn severity CN = pre-fire CN + 10 (9)

Low burn severity CN = pre-fire CN + 5 (10)

SCS precipitation method was set for the pre-fire baseline and each post-fire scenario. The 5-, 10-, 25-, 50-, 100-, and 200-year storm with 99% confidence interval were tested using the type 2 rainfall distribution, 24 hour. The hydrological response at the Upper Uberabinha River basin outlet was observed during the next 15 days after the storm started.

Fire Risk Analysis

The INPE database provides further information on fire risk based on data provided by satellite sensors. The fire risk (RF) calculation method was developed by the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), and it indicates the likelihood of a vegetation to start burning. The method considers the number of days without rain, vegetation type, maximum temperature, and relative humidity of the air in the calculation (Setzer, 2006). Fire risk data was compared to fire occurrence in the subbasin in order to evaluate the performance of the method in predicting wildfire in the Upper Uberabinha river watershed.

RESULTS AND DISCUSSION

Model Calibration and Validation Results

Input parameters were optimized for use in the model. Predetermined CN, I_a, and T_l values were manually adjusted until peak flow matched calibration storm, with a secondary focus on matching discharge volume. Model calibration results are shown in **Table 1**. The uncalibrated model overpredicted peak discharge in 24% and discharge volume in 109%. Additionally, peak timing was nearly three days delayed. After calibration, surface runoff peaked at the same day with a much lesser difference in peak discharge and volume. The calibrated CN differed from the original estimate in approximately 31%, and T_l was lowered to 59.4% from the initial value. I_a and T_c were readjusted accordingly because both the parameters depend on the CN. The model seems to overestimate peak discharge and T_l, since other authors have also lowered CN and T_l during calibration in order to, respectively, decrease peak flow and make the water route more quickly through the watershed (Kinoshita *et al.*, 2014; Cydzik & Hogue, 2009). The routing parameters were not altered because they are less sensitive in model simulations (Cydzik & Hogue, 2009). The uncalibrated, calibrated, and validated discharge values are shown in **Fig. 4**.

Table 1. Summary of initial and calibrated parameters, optimization statistics, and channel properties for the model. Uncalibrated parameter values were predicted using the SCS CN loss method and SCS Unit Hydrograph method. The values were calibrated with a representative calibration storm picked during the wet season.

Model Parameters				
	CN	T_c (h)	T_l (h)	I_a (cm)
Uncalibrated	61	239	143	3.25
Calibrated	42	388	58.1	7.02
Model Statistics				
	%BIAS	*RMSE* (cms)	%Difference Peak	Difference in Peak Timing (days)
Uncalibrated	109.1	55.1	24	3
Calibrated	31.8	19.6	0	0
Channel Properties				
Shape	Length (km)	Slope (m/m)	Bottom Width (m)	Manning's n
Trapezoid	83	0.0014	15	0.046

[1]Value obtained from ANA at stream gage #60381000 (http://hidroweb.ana.gov.br/)
[2]Salla *et al.* (2015)

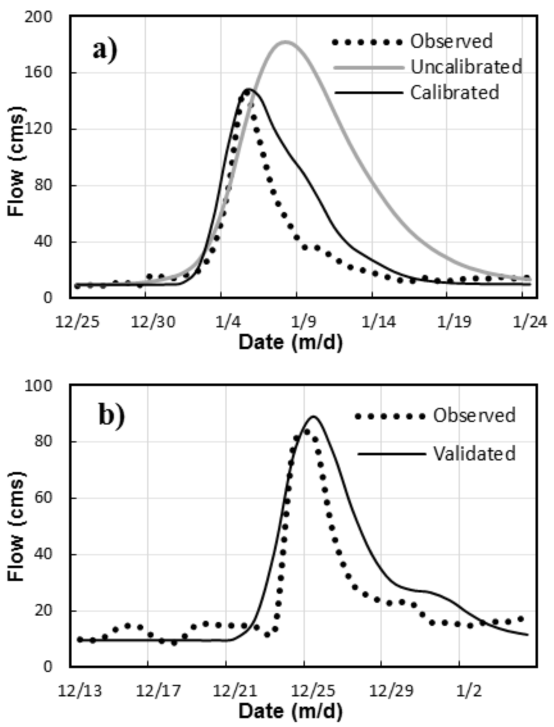


Fig. 4 Calibrated and uncalibrated HEC-HMS hydrographs (a) for a storm observed in the Upper Uberabinha River watershed (Dec-25-1999 to Jan-24-2000). The calibration storm was validated with another independent storm (b) also observed during the wet season (Dez-13-1994 to Jan-05-1995).

The *RMSE* and the percentage bias were used to evaluate the performance of the model. The results show that calibrated HEC-HMS model oversimulated the real hydrological conditions in the watershed (31.8 % BIAS). Modeled data was deviated from the observed discharge data in an average of 19.6 cms. Nevertheless, model was able to keep a percentage difference in peak discharge as low as 0%. The peak discharge is one of the most important parameters used in studies involving flood risk assessment, and therefore matching the peak flow was a priority during calibration. Cydzik & Hogue (2009) obtained a lower error (RMSE = 2.45 cms) after the calibration of a lumped model using HEC-HMS, however with a difference in peak discharge value of 28.1% and a 41.9% BIAS. The more accuracy in results probably lays on the fact that the authors were able to use hourly discharge data in their study. Model was validated using another independent storm observed in the wet season, which performed well with a positive 18.9% BIAS and an error of 11.3 cms (**Fig. 4b**). Percentage difference in peak discharge was 7.2%. The results show that the calibrated HEC-HMS model is suitable for use in simulation of precipitation-runoff processes in watersheds with hydrologic and geomorphologic characteristics similar to those of the Uberabinha river watershed.

Peak Rainfall Probability Distribution Results

The 2-, 5-, 10-, 25-, 50-, 100-, and 200-year storm values were estimated for both INMET #83577 (Uberaba) and #83527 (Uberlandia) precipitation gages by using a distribution fitting software. The quantile estimates were subject to goodness of fit test and the best distribution was selected based on Kolmogorov-Smirnov, Anderson Darling, and Chi-Squared test results. The results for the chosen distribution are summarized in **Table 2**.

Table 2. Summary of the goodness of fit test for peak rainfall at each station and quantile estimates for various return periods.

		Uberlandia	Uberaba	Recurrence Interval	P (mm) Uberlandia	Uberaba	MAP
Best-fit Model		Log-logistic (3P)	Log-logistic (3P)	2	80.62	81.81	80.98
Kolmogorov-Smirnov	Statistic	0.0658	0.0938	5	98.49	99.36	98.75
	Critical value[a]	0.3229	0.3229	10	112.37	113.08	112.58
Anderson Darling	Statistic	0.1461	0.1974	25	133.59	134.16	133.76
	Critical value[a]	3.9074	3.9074	50	152.83	153.37	152.99
Chi-Squared	Statistic	0.1061	0.2798	100	175.64	176.23	175.82
	Critical value[a]	6.6349	6.6349	200	202.83	203.59	203.06

[a] Confidence interval $\alpha=0.01$

Log-Logistic (3P) performed the best for both the precipitation gages evaluated, while Log-Pearson Type 3 performed second best. Other distributions (Lognormal (3P) and Weibull) also had satisfactory results. The results are partially in agreement with a study developed by Olofintoye *et al*. (2009), in which Log-Pearson Type III was the best fit for peak daily rainfall in 50% out of 20 stations studied. However, Log-Logistic (3P) was not tested. The quantile estimates for each return period were used in the calibrated HEC-HMS model for simulation.

Wildfire Frequency and Risk Analysis

Wildfire data from the Upper Uberabinha River subbasin were obtained from INPE in the periods ranging from 2007 through 2015. The database provides information about wildfire occurrence and fire risk, although the size of the burned area cannot be estimated. The fire risk (RF) calculation method was developed by the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), and it indicates the likelihood of a vegetation to start burning. The method considers the number of days without rain, vegetation type, maximum temperature, and relative humidity of the air in the calculation (Setzer, 2006). The results, shown in **Table 3**, demonstrate a strong correlation between fire risk and wildfire occurrence in the watershed. The RF was at a critical level in 76.6% of the days a fire was detected. The number of fires significantly increased in 2015 probably due to the great drought of 2014 and 2015. Wildfire frequency and risk results highlight the relevance of the issue in the region and the urge for studying the impact of fires on the watershed.

Table 3. Wildfire occurrence and relation with fire risk calculated using the CPTEC method (INPE, 2016).

Year	Wildfires	Risk				
		Minimum	Low	Medium	High	Critic
2007	84	12	7	11	18	36
2008	12	6	4	0	0	2
2009	1	1	0	0	0	0
2010	57	3	14	0	0	40
2011	81	3	5	21	4	48
2012	67	0	0	0	0	66
2013	80	3	0	0	12	65
2014	91	0	8	6	7	70
2015	287	32	0	0	0	255
TOTAL	760	60	38	38	41	582

Baseline Design Storm Simulation and Burn Scenario Results

Burn scenarios were created using fire data from the Upper Uberabinha River watershed in the years from 2007 through 2015. The previously calibrated *CN* value was adjusted according to the BAER Team method for each BS. The new parameters for post-fire design storms are shown in **Table 4**. The weighted post-fire *CN* increased in up to 14.5% in the most impacted scenario (BS3). CN in BS1 and BS2 raised in 6.2% and 8.1% after the burn, respectively. I_a and T_l decreased as *CN* rose, resulting in a 21.9% drop in I_a and a 14.8% drop in T_l for the BS3 simulation. A consequential impact on volume and peak discharge is expected, since other authors have emphasized the sensitivity of this model to *CN* (Kinoshita *et al.*, 2014). The new parameters are inputted in the model and the 5-, 10-, 25-, 50-, 100-, and 200-year design storms are simulated for post-fire parameters. The main results are shown in **Fig. 5** and **Fig. 6**.

Table 4. New parameters for post-fire design storms in three different burn scenarios.

	Soil Burn Type	% Area	Post-fire *CN*	Weight. *CN*	I_a (mm)	T_l (hr)
BS1	Non-Burned	67%	42	44.6	63.1	54.2
	Low Burn	14%	47			
	Moderate Burn	19%	52			
	High Burn	0%	57			
BS2	Non-Burned	47%	42	45.4	61.1	53.1
	Low Burn	38%	47			
	Moderate Burn	15%	52			
	High Burn	0%	57			
BS3	Non-Burned	46%	42	48.1	54.8	49.5
	Low Burn	0%	47			
	Moderate Burn	41%	52			
	High Burn	13%	57			

The hydrographs presented increased values for volume and peak discharge in all post-fire scenarios (**Fig. 5**). In general, hydrographs get flashier and peak flow shifts to the left as burn severity increases. For the 5-yr design storm, peak discharge increased in up to 69.9% (i.e., from 14.6 to 24.8 cms) in BS3. Discharge volume had an increase of 21.5% in the same scenario. The raise in both the parameters was less dramatic in BS2 and BS3 (BS1: 23.3% increase in peak discharge, 8.1% increase in volume; BS2: 30.8% increase in peak discharge, 10.9% increase in volume). For the 100-yr design storm, the increase in peak discharge was greater in terms of value (from 61.2 cms to 101.9 cms), representing a 66.5% raise in the most severely-burned scenario (BS3). The discharge volume had a more significant increase (31.5%) compared to the 5-yr storm under the same conditions. The 10-, 25-, 50-yr, and 200-yr design storms followed similar pattern (i.e., progressive increase in peak discharge and volume for BS1, BS2, and BS3, respectively).

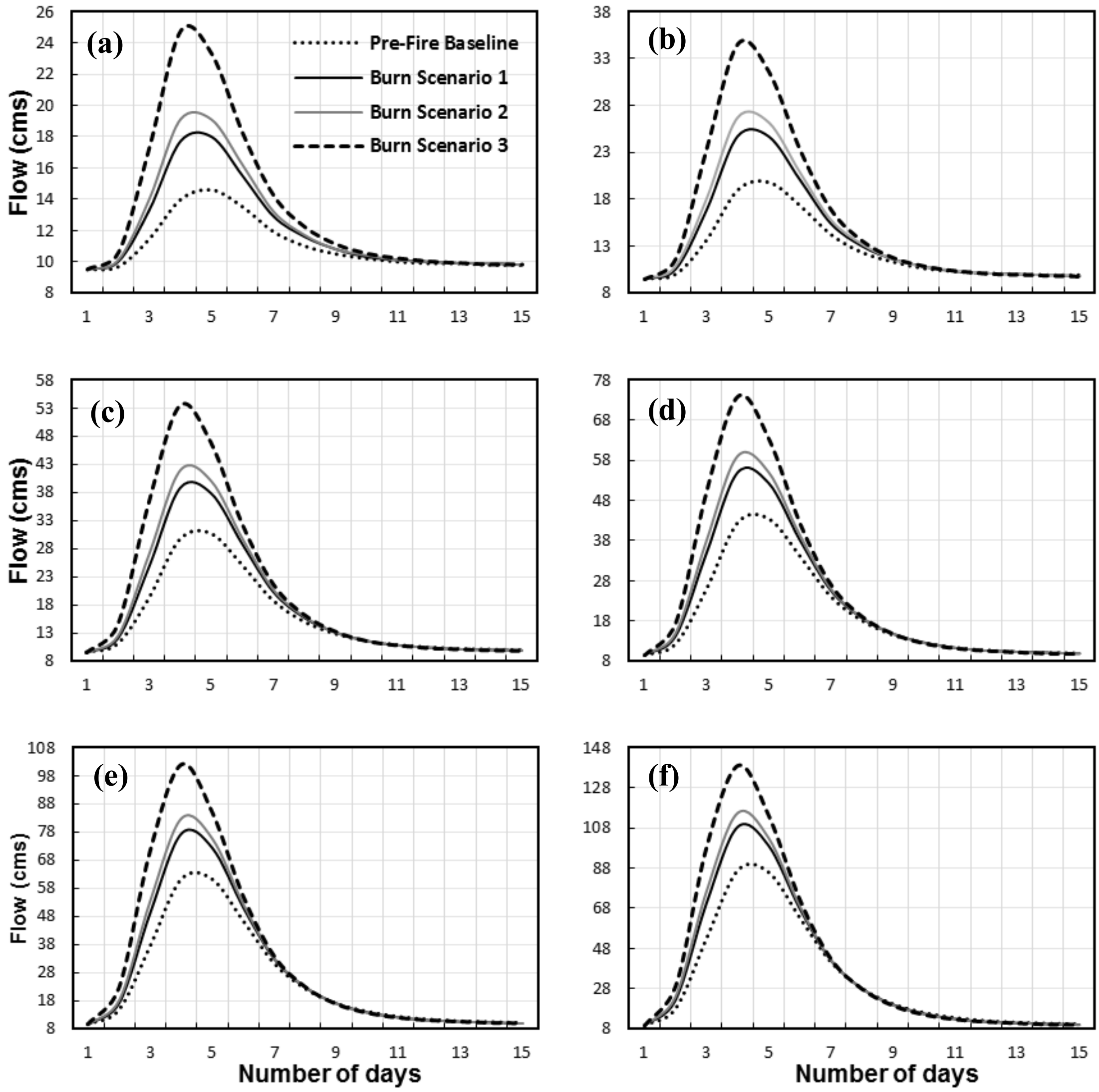


Fig. 5 Hydrographs for the 5-yr (a), 10-yr (b), 25-yr (c), 50-yr (d), and 100-yr (e), and 200-yr (f) design storms. Pre-fire baseline and post-fire (BS1, BS2, and BS3) parameters were tested using the calibrated HEC-HMS model. Precipitation method was the SCS with type 2 rainfall distribution and 24-hr duration storm.

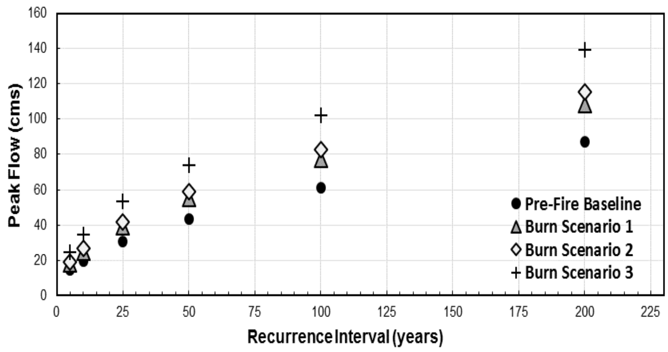


Figure 6. Peak flow values for the 5-, 10-, 25-, 50-, 100-, and 200-yr design storms in three burn scenarios.

The trend in peak discharge for the many return periods analyzed is shown in **Fig. 6**. The increase in surface runoff during first years after a wildfire was reported in other studies which also used a modeling approach for predicting post-fire discharges (Beeson *et al*., 2001; Mossoulis *et al*., 2015; Lebedeva *et al*., 2014). Mossoulis *et al.* (2015) relates an increase in mean surface runoff of 166% for the second year following a wildfire. However, impacts of fire on surface runoff are sometimes not detectable at a daily temporal scale (Lebedeva *et al*., 2014). The findings reveal that stream flow in the Uberabinha watershed is highly affected by wildfire.

CONCLUSION

This study aimed to evaluate the impacts of fire on surface runoff in the Upper Uberabinha River watershed, which is essential for the planning and management of local water resources, noting that was identified a total of 287 fire occurrences in the watershed in 2015.

The model used for predicting post-fire discharge was the HEC-HMS, which performed well in simulations of overland flow in watersheds with distinct hydrologic and geomorphologic characteristics. The Uncalibrated HEC-HMS model overpredicted peak discharge in 24% and discharge volume in 109%. Additionally, peak timing was nearly three days delayed. After calibration, hydrograph peaked in the same day with a 0% difference in peak flow and a 31.8% difference in discharge volume.

The calibrated model was used to assess the variations in overland flow for the 5-, 10-, 25-, 50-, 100-, and 200-year. In general, discharge values increased and peak flow shifted to the left as severity of burn progressed. In all post-fire scenarios, the hydrographs peaked one day earlier compared to the pre-fire baseline storm. The increase in peak flow in the most affected scenario was 69.9% for the 5-yr storm, 74.7% for the 10-yr storm, 73.7% for the 25-yr storm, 70.5% for the 50-yr storm, 66.5% for the 100-yr storm, and 59.7% for the 200-yr storm. Discharge volume increased in up to 31.9% (50-yr storm), with a less dramatic raise for other return periods (5-yr storm: 21.5%; 10-yr storm: 26.5%; 25-yr storm: 30.9%; 100-yr storm: 31.5%; and 200-yr storm: 29.8%). The results reveal that fire highly affects hydrological characteristics, e.g., peak timing and flow and discharge volume, in the Upper Uberabinha River watershed.

Acknowledgements We acknowledge the supports of the following establishments in the course of this research works, such as: Foundation for Support of Research of Minas Gerais State (Fundação de Amparo à Pesquisa de Minas Gerais – FAPEMIG), financing in the Demand Universal form through CRA-APQ 01024/14 process; Faculty of Civil Engineering and Environmental Engineering of University Federal of Uberlandia, Minas Gerais State, Brazil.

REFERENCES

Beeson, P.C., Martens, S.N. & Breshears, D.D. (2001) Simulating overland flow following wildfire: mapping vulnerability to landscape disturbance. *Hydrol. Processes,* **15**, 2917-2930.

BRASIL, Lei 9.605 de 12 de fevereiro de 1998. Dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente, e dá outras providências. Brasília, DF, 1998.

Costa, E. P., Fiedler, N. C., Medeiros, M. B. & Wanderley, F. B. (2009) Incêndios florestais no entorno de unidades de conservação – estudo de caso na estação ecológica de águas emendadas, Distrito Federal. *Ciênc. Flor.*, **19**(2), 195-206.

Cydzik, K. & Hogue, T.S. (2009) Modeling post-fire response and recovery using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). *J. Amer. Water Resour. Assoc.,* **45**(3), 702-714.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. (1999) Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. *Brasília: Embrapa Produção de Informações*, 412p.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. Brasil em Relevo. Available at: <http://www.relevobr.cnpm.embrapa.br/>. Accessed in: Aug. 2015.

Foltz, R.B., Robichaud, P.R., & Rhee, H. (2009). A Synthesis of Post-Fire Road Treatments for BAER Teams: Methods, Treatment Effectiveness, and Decision making Tools for Rehabilitation. *Gen. Tech. Rep. RMRS-GTR-228 Fort* Collins, *CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 152 p.*

Hidroweb: Sistema de Informações Hidrológicas [S.I]: Agência Nacional de Águas, 2015. Available at: <http:hidroweb.ana.gov.br>. Accessed in: Aug. 2015.

Higginson, B. & Jarnecke, J. (2007). Salt Creek BAER-2007 Burned Area Emergency Response. *Prvo, UT: Unit national Forest. Hydrology Specialist Report. 11 p.*

IBGE – Instituto Brasileiro de Geografia e Estatística. (2001) *Mapa de Solos do Brasil*. Rio de Janeiro. Brasil

INMET. Instituto Nacional de Meteorologia. Available at: < http://www.inmet.gov.br/>. Accessed in: Aug. 2015.

INPE. Instituto Nacional de Pesquisas Espaciais. Monitoramento de Queimadas e Incêndios. Available at: < http://www.inpe.br/queimadas/>. Accessed in: Aug. 2015.

Jung, H.Y., Hogue, T.S., Rademacher, L.K., & Meixner, T. (2009) Impact of wildfire on source water contributions in Devil Creek, CA: Evidence from end-member mixing analysis. *Hydrol. Processes,* **23**, 183–200.

Kinoshita, A.M., Hogue, T.S., & Napper, C. (2014) Evaluating pre- and post-fire peak discharge predictions across western U.S. watersheds. *J. Am. Water Resour. Assoc.*, **50**(6), 1540-1557.

Klink, C.A., Moreira, A.G. & Solbrig, O.T. (1993) *Ecological impact of agricultural development in the Brazilian cerrado.* In Young, M.D. and Solbrig, O.T., editors, the world's savannas. Economic driving forces, ecological constraints and policy options for sustainable land use. Man and the Biosphere Vol. 12, Paris: UNESCO, 259±82.

Lebedeva, L.; Semenova, O. & Folton, N. (2014) Estimation of hydrological response of a small Mediterranean watershed to fire by data analysis and a modelling approach. *Proc.* ICWRS2014Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions, Bologna, Italy.

Martin, D.A. & Moody, J.A. (2001) Comparison of soil infiltration rates in burned and unburned mountainous watersheds. *Hydrol. Processes,* **15**, 2893–2903.

Mistry, J. (1998). Fire in the cerrado (savannas) of Brazil: an ecological review. *Prog. in Phys. Geogr.*, **22**(4), 425-448.

Mockus, V. (1961) *Watershed lag.* U.S. Dept. of Agriculture, Soil Conservation Service, ES–1015, Washington, DC.

Mockus, V. (1957) *Use of storm and watershed characteristics in synthetic hydrograph analysis and application.* Paper presented at the annual meeting of AGU Pacific Southwest Region.

Moussoulis, E., Mallinis, G., Koutsias, N. & Zacharias, I. (2015) Modelling surface runoff to evaluate the effects of wildfires in multiple semi-arid, shrubland-dominated catchments. *Hydrol. Processes,* **29**, 4427-4441.

Olofintoye, O.O., Sule, B.F. & Salami, A.W. (2009) Best–fit Probability distribution model for peak daily rainfall of selected Cities in Nigeria. *New York Sci. J.,* **2**(3), 1-12

Ronquim, C.C. (2010) Queimadas na colheita da cana-de-açúcar: impactos ambientais, sociais e econômicos. *Campinas, SP: Embrapa Monitoramento por Satélite. 45p.*

Rosolen, V., Herpin, U., Coelho, N.M.M., Coelho, L.M., Brito, J.L.S., Silva, L.A. & Lima, S.C. (2009) Sediment quality in

Uberabinha river (Uberlândia, MG) and environmental implications. *Braz. J.f Geol.,* **39**(1), 151-159.
Salla, M.R., Magalhães, A.A.B., Alves, L.A., Schmidt, M.A.R. & de Lima, G. (2015) Sensibilidade de características morfológicas no comportamento de parâmetros de qualidade da água em rio de porte médio. *Ciênc. & Eng.,* **24**(2), 29-37.
Setzer, A.W. & Raffi, A.S. (2006) Risco de Fogo – Resumo do Método de Cálculo. Centro de Previsão de Tempo e Estudos Climáticos (CPTEC). *Instituto Nacional de Pesquisas Espaciais.*
Simas, M. (1996) Lag time characteristics in small watersheds in the United States. MSc Thesis, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.
U.S. Army Corps of Engineers. (2015) Hydrologic Modeling System HEC-HMS: User's Manual version 4.1. *Institute for Water.*
U.S. Department of Agriculture, Natural Resources Conservation Service. (2007). Engineering Field Handbook: Chapter 7 – Hydrologic Soil Groups. In: *National Engineering Handbook*, Claudia C. Hoeft (Editor). Soil Conservation Service: Part 650. U.S. Department of Agriculture, Washington, D.C.
U.S. Department of Agriculture, Natural Resources Conservation Service (2009). Small Watershed Hydrology: WinTR-55 User Guide. *Conservation Engineering Division.*
USGS. United States Geological Survey. Earth Explorer. Available at: <http://earthexplorer.usgs.gov/>. Accessed in: Aug. 2015.