6TH INTERNATIONAL CONFERENCE ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

ASSESSMENT OF RAINFALL-RUNOFF MODELS FOR FLOOD RIVER EXTREME EVENT SIMULATIONS

José Guimarães de C. Neto[1], A. Ribeiro Neto[2] and S. Maria G. L. Montenegro [3]
1. *Doctoring in Civil Engineering at the Federal University of Pernambuco.*
2. *Professor of the Federal University of Pernambuco*
3. *Professor of the Federal University of Pernambuco*

ABSTRACT:. Floods are characterized by a rapid runoff response to the rainfall. In many cases, due to the fast response time, it is difficult to provide alerts and to establish the actions needed to remove the population from risk sites. The objective of this study is to analyze the performance of three hydrological models, HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System), MGB-IPH model (Large Basins Hydrological Model) and MODAHC (the acronym from Portuguese "Self Calibrated Hydrological Model") in order to determine which model has the best performance in the simulation of the extreme flood events in the Una River basin in the State of Pernambuco. The analysis will help choosing the hydrological model more adequate to be used in the operation of a flood warning system in the State. The selection of the hydrological models pursuit to take into account the distinct characteristics and the different ways of parameterization. This will provide an accurate analysis of the extreme events simulation performance. MODHAC is a rainfall-runoff lumped model. The HEC-HMS is distributed by sub-basins developed in HEC-USACE. The MGB-IPH is distributed by cell and it has been widely applied in large basins in Brazil. The simulations have been accomplished at five streamgauges for extreme events occurred in 2000, 2004 and 2005. The models analysis were performed using graphs and statistical criteria such as relative peak discharge error, volume error, standard deviation, mean absolute error, root mean square error, Nash-Sutcliffe coefficient and coefficient of determination. MODHAC had more difficulty to represent the streamflow in the study area, hence the MGB-IPH and HEC-HMS achieved good results and similar performance. One factor in favor of the HEC-HMS model is the facility of implementation and integration with the hydrodynamic model HEC-RAS.

Key Words: Rainfall-Runoff Models, Extreme Events, Una River

1. INTRODUCTION

In the last 13 years, until 2013, many brazilian cities have been suffered with the ocurrence of flood river that causes material loss and, in some cases, loss of human life (Senado Federal, 2000; Ministério da Saúde, 2009; Dias, 2011; Collaço, 2012; Malagodi, 2012; Refosco, 2013). Those events are characterized by a fast response of the river basin from the begining of the storm to the discharge in the river. In many cases, owing to the short response time, it is difficult to take the needed actions to remove the population from the risk areas.

The flood warn systems may help in the removal of population using rain forecasting, river stage monitoring and hydrological simulation using as input rain forecasting. For the river basins with short time of concentration, the better tool is the use of hydrological simulation once the time available for decision making is limited.

The hydrological simulation corresponds to two processes: planning and operation. In the flood planning, the hydrological model application should promote, among others, the determination of flood mapping and flood risk mapping. In the operation, the hydrological simulation should be robust and precise in order to predict the peak flow, making possible to steps, for example, the storage reservoir and warn for removal of riverine population. The planning involve the project of management for disasters and calibration of the hydrological model, whilst the operation deal with its application for forecasting at least in daily time step (Plate, 2009).

The Distributed Model Intercomparison Project (DMIP) (Smith, 2004; Reed, 2004; Smith, 2012a; Smith, 2012b) has been planned for comparison among several distributed models, which run with Geographical Information System (GIS) interface, and lumped models in order to get information about the process of execution of the hydrological models and their output, mainly, in respect of the peak flow of flood events. In its second phase, the DMIP aggregated the analysis of fourteen distributed models and two lumped models. Thus, the Project intends to contribute with the system of streamflow forecasting operation in the United States, driving the study of several models and their effectiveness in the applicability of a system of flood warn operation.

On the other hand, the European Flood Alert System (EFAS) has defined the LISFLOOD (de Roo, 2000) as its hydrological model. The LISFLOOD is a platform based on GIS and it exhibits hybrid characteristics of conceptual models and phisicaly based models with routines for land cover, surface flow, groundwater flow and routing flow in the main channel (Thielen, 2009). The LISFLOOD has been applied in Europe for 188 streamgauges in several river basins with satisfactort values of Nash-Sutcliffe coefficient.

The objective of this paper is to analyze the performance of three hydrological models, HEC-HMS, MGB-IPH and MODAHC, in order to evaluate which presents the best performance in the representation of flood events in the Una river basin located in the Pernambuco State-Brazil

2. STUDY AREA AND DATA

2.1 Study Area

The Una river basin (6.704,0 km^2) is located in the south of Pernambuco State and North of Alagoas state, between the latitudes 8º17'14"S and 8º55'28"S and between the longitudes 35º07'48"W and 36º42'10"W. There are 42 municipalities completely or partially inside the basin and 19 urban seats of municipalities in the interior of the basin (Pernambuco, 2006). The population is about 553,3 thousands inhabitants (Pernambuco, 2011). The Una river is 255 km long and it is intermittent in the upper reach due to low precipitations rates (Pernambuco, 2006). The Figure 1 shows the study área with the streamgauges used in the model simulations.

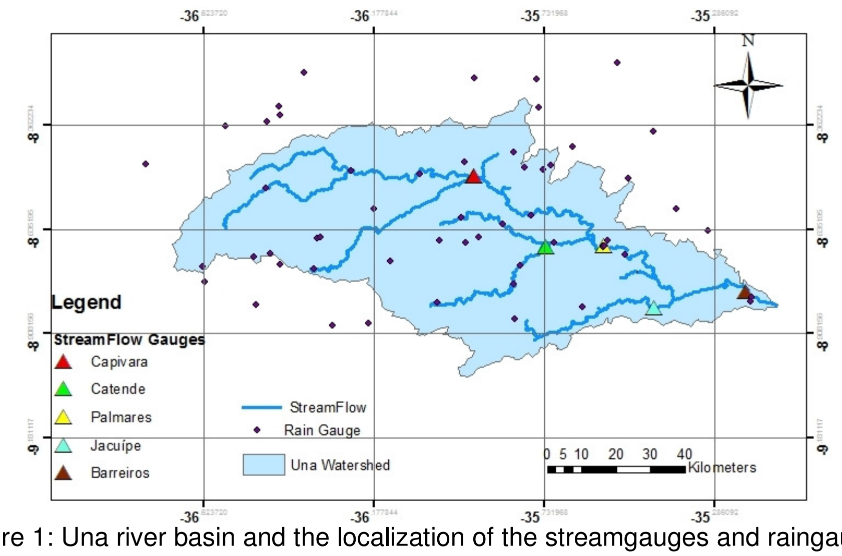

Figure 1: Una river basin and the localization of the streamgauges and raingauges.

The Una river basin has two climatic regions, semiarid and warm wet. The total annual rainfall is 500-800 mm and 1,000 mm, respectivilly, in the semiarid and warm wet regions. The land cover is adapted to the climate with presence of Caatinga vegetation (thornscrub, cactus, and bunch grasses) in the semiarid and Atlantic Forest in the warm wet region, which includes some Environmental Protection Areas in the basin (Pernambuco, 2006).

Cristaline rock is prodominant in the basin, whilst the sedimentary rock is present near the coast. The soil depth varies from moderately deep to shallow, with low permeability and low retention capacity (Pernambuco, 2006).

The main land uses are urban, industry, sugar-cane monoculture, livestock and areas with native vegetation. There are in the bain ten reservoirs with storage capacity greater than 500 thousand m^3 for water demand supply. They are reservoirs located in the upper portion and in tributaries of the Una River. In the recent historic, it was registered severe floods in the Una River basin. The events more severe are the years 2000, 2004, 2005, 2010 e 2011.

2.2 Precipitation and streamflow data

There are 56 rain gauges from Institute of Technology of Pernambuco (ITEP), Water and Climate Agency of Pernambuco (APAC) and National Water Agency (ANA) as shown in Figure 1. Streamflow data is available on the Hidroweb, hydrometeorological dataset from ANA. Five stream gauges have been used in the simulations: Capivara, Palmares, Catende, Jacuípe and Barreiros (Figure 1). These data were used in the simulation of flood events of 2000, 2004 and 2005.

3. HYDROLOGICAL MODELS

The flood events were simulated by the models MODHAC (Lanna, 1999), MGB-IPH (Collischon, 2007) and HEC-HMS (Scharffenberg, 2010). The three models run with continuous data and HEC-HMS may also run event based simulations. Three events have been used for parameter calibration (aug/2000, jan/2004 and jun/2000) and jun/2005 for verification of the parameters.

3.1 Self Calibrated Hydrological Model – MODHAC

MODHAC (the Portuguese acronym for “Self Calibrated Hydrological Model”) is a rainfall-runoff lumped model, whose input variables are mean rainfall, potential evapotranspiration and streamflow (Lanna, 1997). Three reservoirs represent the main processes responsible for rainfall-runoff transformation: interception, evapotranspiration and runoff generation, i.e., determination of the volume of water that will either be infiltrated into the soil or flow on the surface. The model has 14 parameters that can be calibrated automatically using four options of objective functions. MODHAC has performed hydrological simulations well in several basins located in the semiarid lands in Northeast Brazil (Lanna, 1997). In addition, MODHAC can run either monthly or daily time step simulations and it needs few input data (rainfall, PET and observed streamflow).

The MODHAC is similar to other models widely used for synthetic runoff generation such as Soil Moisture Accounting (SMA) present in HEC-HMS model (HEC-HMS, 2000), SMAP present in the MIKE 11 model (MIKE 11, 2009) and Tank model (Sugawara, 2012). All these models, including MODHAC, use reservoirs which represent the main processes responsible for rainfall–runoff transformation.

3.2 Hydrologic Engineering Center Model – HEC-HMS

The HEC-HMS (Hydrologic Modeling System) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It was developed by the Hydrologic Engineering Center of the US Army Corps of Engineers. The model has been applied in the solution of a number of problems in a wide range of basins with different characteristics.

The HEC-HMS is able to either accomplish event-based simulation (few hours to days) or continuous simulation encompassing rain and drought seasons. This is possible due to a set of models, fomulations and equations that may be chosen to represent each part of the continental phase of the hydrological cycle (HEC-HMS, 2000): i) soil-plant interface water balance; ii) run-off routing; iii) baseflow routing; iv) channel routing in rivers and reservoirs. The scheme of simulation of the hydrological processes in the HEC-HMS is showed in Figure 2.

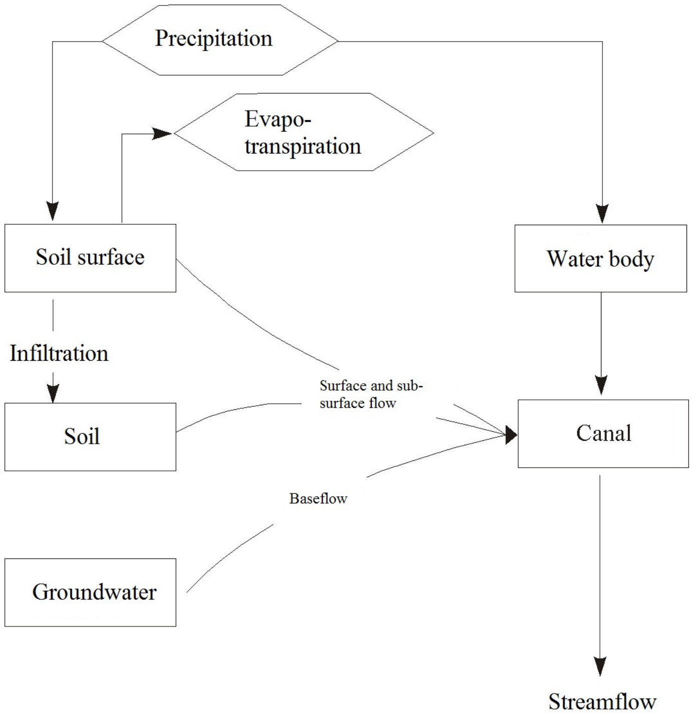

Figure 2: Representation of the hydrological simulation in the HEC-HMS (HEC-HMS, 2000).

3.3 MGB-IPH Model

Alarge scale hydrological model called MGB-IPH, from the Portuguese “Modelo de Grandes Bacias” which means “Large Basins Model”, and “Instituto de Pesquisas Hidráulicas” according to the institution in Brazil where this model was developed (Collischonn et al., 2007) was also used for simulation. Very similar to LARSIM (Bremicker, 1998) and VIC (Liang et al., 1994) models, MGB-IPH is distributed by cells and runs on daily or hourly time steps. Each cell is divided into blocks, patches, which are formed by the combination of land use, vegetation, and soil type. Each block has a uniform hydrological response to meteorological forcing, in the same way as in the case of Hydrologic Response Units (HRU’s) (Pietroniro & Soulis, 2003).

MGB-IPH uses the Xinanjiang model formulation to calculate the soil water balance (Zhao et al., 1980). Three linear reservoirs are used to represent independent routing of surface, subsurface and groundwater flow through the cell. Flow propagation in the rivers is based on the Muskingum-Cunge method. The potential evapotranspiration is calculated by the Penman-Monteith equation.

The soil in the Una River basin was defined according to the SCS-CN hydrologic soil groups. The land cover was defined using five classes. The combination of soil and land cover ended up in nine HRU classes, as can be seen in Table 2 and Figure 3.

Table 2 HRUs for simulation in the MGB-IPH.

Code	Description of the HRU
1	Agriculture/Pasture + hydrologic group A
2	Agriculture/Pasture + hydrologic group C
3	Agriculture/Pasture + hydrologic group D
4	Bare soil
5	Open forest + hydrologic group C
6	Open forest + hydrologic group D
7	Dense forest + hydrologic group A
8	Dense forest + hydrologic group C
9	Open water

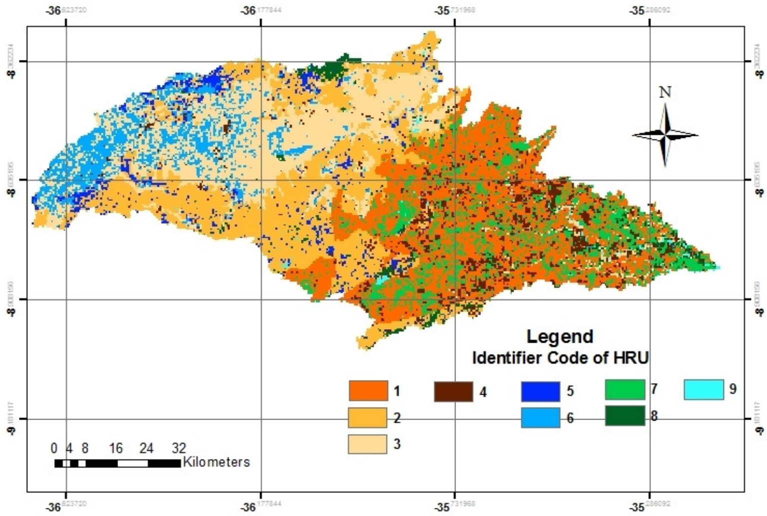

Figure 3: Una river basim map with HRUs.

4. CRITERIA OF MODEL EVALUATION

The evaluation of the results used four events that caused flood disasters. The model parameters were calibrated considering statistical criteria used in other works that analysed the performance of hydrological models (Gupta, 1999; Collischonn, 2001; Smith, 2004; Moriasi, 2007; Koutrolis, 2010; Midiero, 2011; Amiry, 2012;): standart deviation (SD), percent bias (PBias), percent absolute peak error, mean absolute error (MAE), root mean squared error (RMSE), coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE).

The standard deviation is used as a reference to MAE and RMSE. When they are lower than the half of standard deviation of observed discharge, MAE and RMSE are considered satisfactory (Moriasi, 2007). MAE and RMSE describe the difference between observed and simulated values. The perfect fit is indicated by the value zero for both coefficients and the greater their values the worst the performance of the model.

The peak error considers a single value in the evaluation. PBias measures the average tendency of each simulated value be higher or lower than the observed value (Moriasi, 2007). The optimum value is 0.0, the negative values denote tendency to overestimate and the positive values tendency to underestimate (Gupta, 1999). Values between ±25 may be considered satisfatory (Moriasi, 2007).

The coefficient of determination, R^2, varies from 0 to 1, where as the highest values indicate higher linearity between observed and simulated data. Values higher to 0.5 are considered acceptable, describing a proportion of observed data that are captured by the model (Moriasi, 2007). The Nash-Sutcliffe efficiency is a dimentionless statistical criteria that denote how much the simulation is a better predictor than the average of the observed values (Midiero, 2011). Values of Nash-Sutcliffe lower or equal to zero denote that the average of the observed values is better predictor than the model. According to Moriasi (2007), values higher than 0.5 mean that the model performance is satisfactory.

5. RESULTS AND DISCUSSION

The stream gauge of Palmares was chosen to show some results due to its location and importance. Figures 4 to 7 show observed and simulated streamflow at Palmares, respectively, for aug/2000, jan/2004, jun/2004 and jun/2005. In general, MODHAC has underestimated the observed discharge of the events. On the other hand, the HEC-HMS exhibited a time peak error in aug/2000 and jul/2004 and MGB-IPH also showed time peak error in both events of 2004.

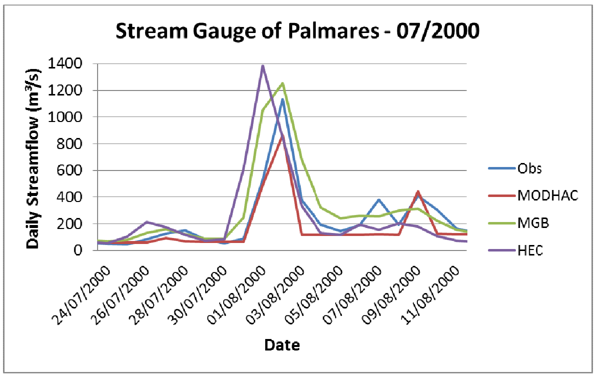

Figure 4: Observed and simulated streamflow for aug/2000.

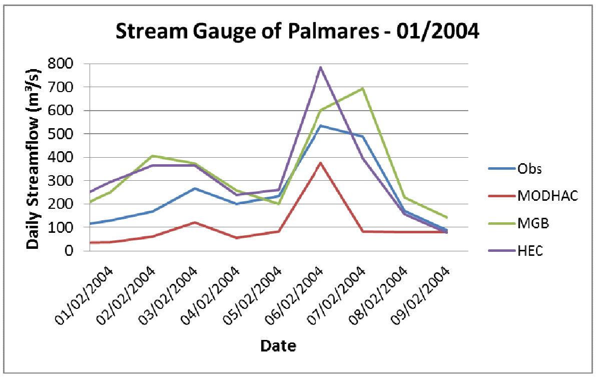

Figure 5: Observed and simulated streamflow for jan/2004.

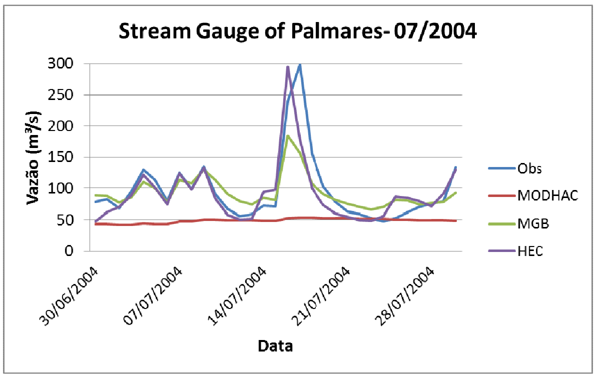

Figure 6: Observed and simulated streamflow for jul/2004.

The validation of the parameters has been done using the event occurred in 2005. In this case, all models underestimated the peak flow. The MGB-IPH model presented the best results in the validation, despite the bad fit in the recession of the discharge. Table 3 exhibits the observed and simuated peak flow.

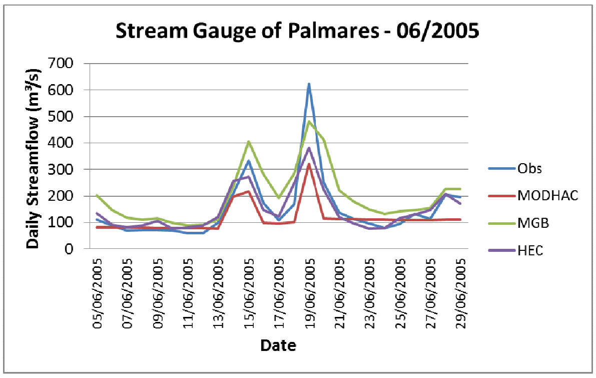

Figure 7: Observed and simulated streamflow for jun/2005.

Table 3: Observed and simulated peak flow at Palmares.

Year	Streamflow (m^3/s)			
	Observed	MODHAC	HEC	MGB
jul/00	1134.09	863.80	847.90	1251.82
jan/04	535.26	377.12	785.10	599.85
jun/04	298.28	53.76	177.70	156.72
jun/05	624.50	320.11	382.7	479.89

Table 4 exhibits the values of the calculated criteria of model evaluation. The Pbias values of MODHAC show the tendency of underestimate the discharge calculated by the model. HEC-HMS and MGB-IPH did not exhibit a clear tendendy of under or overestimate. Analysing the values of MAE it is possible to verify bad results for MODHAC and HEC-HMS in all periods registering daily average errors higher than 18 m^3/s. The MGB-IPH was the only model that presented satisfactory results for all periods. It is possible to verify that the MGB-IPH had the best values for the coefficients RMSE and Nash. Only in the validation event, the HEC-HMS had better performance than the orthers. The MGB-IPH presented values of RMSE always below the standard deviation and Nash coefficient above 0.6. The MODHAC presented serious problem to simulate adequately the discharge in Una River according to the values of Nash coefficient. Finally, the analysis of the coefficient R^2 confirms the best performance of the MGB-IPH model.

Table 4: Criteria of model evaluation for the simulations at Palmares.

Event	Model	Pbias (%)	Standard deviation of observed data (m³/s)	MAE (m³/s)	RMSE (m³/s)	Nash	R^2
Jul/2000	MODHAC	25.95	211.51	47.38	95.32	0.80	0.87
	MGB-IPH	-27.3		73.66	125.93	0.64	0.83
	HEC-HMS	-6.19		101.8	203.01	0.08	0.46
Jan/2004	MODHAC	56.81	147.85	90.26	131.54	0.21	0.64
	MGB-IPH	-40.37		68.10	93.14	0.60	0.90
	HEC-HMS	-45.36		86.24	107.75	0.47	0.79
Jul2004	MODHAC	49.2	53.43	47.68	70.97	-1.36	0.05
	MGB-IPH	3.44		19.81	32.41	0.80	0.82
	HEC-HMS	5.95		18.02	29.52	0.80	0.71
Jun/2005	MODHAC	23.3	117.22	36.87	70.80	0.57	0.85
	MGB-IPH	-32.57		48.61	64.38	0.65	0.80
	HEC-HMS	1.73		26.09	50.73	0.76	0.84

6. CONCLUSION

According to the results obtained, the main conclusions are:

- The MGB-IPH showed the best results, coherent with the average discharge and good fit to the peak flow;
- The MODHAC model presented limitations for representation of streamflow in extreme events;
- The results of HEC-HMS were satisfactory for flood simulation ends. The possibility of integration with the hydrodynamic model HEC-RAS is another advantage of the HEC-HMS;
- There is a need for new simulations of other events or the inclusion of other models in the analysis. This will increase the reliability of the flood simulation of the river system.

7. ACKNOWLEDGEMENTS

We gratefully acknowledge to Rede Clima project, “Centro Nacional de Monitoramento e Alerta de Desastres Naturais” (CEMADEN) and Federal University of Pernambuco for make this work possible.

8. REFERENCES

COLLAÇO, F. M. A.; MELLO-THERY, N. A, 2012. Planejamento e políticas públicas: entendendo o problema das enchentes na cidade de Atibaia nos anos de 2009, 2010 e 2011. In: VI Encontro Nacional de Pesquisadores em Gestão Social. São Paulo/SP, 2012.

COLLISCHON, W.; ALLASIA, D.; SILVA, B. C.; TUCCI, C. E. M., 2007. The MGB-IPH model for large-scale rainfall–runoff modelling. *Hydrological Sciences Journal* 52:5, 878-895.

COMISSÃO EXTERNA ENCHENTES DO NORDESTE, 2004. AVALIAR O ESTADO DE CALAMIDADE PÚBLICA PROVOCADO PELAS ENCHENTES EM VÁRIOS ESTADOS DA REGIÃO NORDESTE. Disponível em: http://www.camara.gov.br/sileg/integras/210633.pdf. Acessado em 20 de Julho de 2013.

DE ROO, A.P.J.; WESSELING, C.G.; VAN DEURSEN, W.P.A., 2000. Physically based river basin modelling within a GIS: The LISFLOOD model. *Hydrological Processes* 14. 1981–1992.

DIAS, N. W.; BATISTA, G. T.; CATELANI, 2011. A enchente de São Luis do Paraitinga: evidências de sua dimen-são obtidas a partir de dados orbitais. In: XV Simpósio Brasileiro de Sensoriamento Remoto. Curitiba/PR, 2011.

FREITAS, C. M.; XIMENES, E. F., 2012. Enchentes e saúde pública – uma questão na literatura científica recente das causas, consequências e respostas para prevenção e mitigação. *Ciência e Saúde Coletiva* 17:6.

HEC-HMS - Hydrologic Modeling System, 2000. Technical Reference Manual. Davis, USA: US Army Corps of Engineers.

MALAGODI, M. S. A.; SIQUEIRA, A. M. M., 2012. Enchentes, Vulnerabilidade e Remoção em Campos do Goyta-cazes (RJ). In: VI Encontro Nacional da Anppas. Belém/PA, 2012.

MINISTÉRIO DA SAÚDE, 2009. Enchentes no Norte e Nordeste do Brasil 2009. Disponível em: http://portal.saude.gov.br/portal/arquivos/pdf/informe_enchentes_norte_nordeste_2009.pdf. Acessado em 02 de Julho de 2013.

MORIASI, D. N.; ARNOLD, J. G.; VAN LIEW, M. W.; BINGNER, R. L.; HARMEL, R. D.; VEITH, T. L., 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simula-tions. *American Society of Agricultural and Bio-logical Engineers* 50:3, 885-900.

PLATE, E. J., 2009. Classification of Hydrological Models for Flood Management. *Hydrology and Earth System Sciences* 13, 1939-1951.

REED, S.; KOREN, V.; SMITH, M.; ZHANG, Z.; MOREDA, F.; SEO, D-J., 2004. Overall distributed model inter-comparison project results. *Journal of Hydrology* 298, 27-60.

REFOSCO, J. C.; SILVA, G. S.; ESKELSEN, C. R.; NICOLE-TI, A. L.; CORDERO, A.; SALVADOR, D. F., 2013. Mapas de inundação a partir de geoprocessamento e ge-orreferenciamento – o caso de Blumenau (SC). In: XVI Simpósio Brasileiro de Sensoriamento Remoto. Foz de Iguaçu/PR, 2013.

RENNÓ, C. D., 2004. Construção de um sistema de análise e simulação hidrológica: aplicação a bacias hidro-gráficas. Tese, Doutorado. INPE, São José dos Capos.

SENADO FEDERAL. COMISSÃO ESPECIAL EXTERNA, CRIADA POR INTERMÉDIO DO REQUERIMENTO Nº 426, DE 2000-SF “DESTINADA A ACOMPANHAR O DRAMA DAS ENCHENTES NOS ESTADOS DE PERNAMBUCO E ALAGOAS, QUE JÁ OCASIO-NARAM MORTE DE VÍTIMAS”. 2000. Disponível em: http://www.senado.gov.br/atividade/materia/getPDF.asp?t=56458&tp=1. Acessado em 20 de Julho de 2013.

SMITH, M. B.; SEO, D.; KOREN, V. I.; REED, S. M.; ZHANG, Z.; DUAN, Q.; MOREDA, F.; CONG, S., 2004. The distributed model intercomparison project (DMIP): motivation and experiment design. *Journal of Hydrology* 298, 4-26.

SMITH, M. B.; KOREN, V.; REED, S.; ZHANG, Z.; ZHANG, Y.; MOREDA, F.; CUI, Z.; MIZUKAMI, N.; ANDER-SON, E. A.; COSGROVE, B. A., 2012a. The Distributed model intercomparison project – Phase 2: Moti-vation and design of the Oklahoma experiments. *Journal of Hydrology* 418, 3 – 16.

SMITH, M. B.; KOREN, V.; REED, S.; ZHANG, Z.; ZHANG, Y.; MOREDA, F.; CUI, Z.; MIZUKAMI, N.; ANDERSON, E. A.; COSGROVE, B. A., 2012b. Results of the Okla-homa experiments. *Journal of Hydrology* 418, 17 – 48.

THIELEN, J.; BARTHOLMES, J.; RAMOS, M-H.; ROO, A., 2009. The European Flood Alert System – Part 1: Concept and Development. *Hydrology and Earth System Sciences* 13, 125-140.