Superficial Water Balance of the Watershed at Epitacio Pessoa Dam used Digital Information Terrain

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Abstract—*Currently, there is an urgent need to manage and rationalize the use of water resources worldwide, especially in areas subject to periodic droughts such as the semiarid Northeast of Brazil. One of the first steps of the great task of managing water resources is on the estimate of the supply of water within the basin. To do so, it is necessary to study the interactions between climate, land use and physiographic. Given the importance of proper management of water resources, the aim of this study is to examine the impacts of space-time variability of rainfall, soil depth and plant cover on the production of water from the reservoir basin Epitácio Pessoa, located in semiarid state of Paraiba - Brazil. A program called TOPAZ was used to obtain the physical characteristics of the basin, based on data from digital terrain elevation. The Landsat TM-5 was used to estimate the vegetation cover. Among several scenarios, the fifth was the best represented the overland flow in the reservoir basin Epitácio Pessoa. In general, the model responded well to the space-time variability of rain. Approximately 12% of rainfall was turned into the confluence Epitácio Pessoa. The coefficients of determination and Nash were on average 0.89 and 92% respectively. The results showed that there were changes in the pattern of runoff upstream of the dam. These changes are resulting in delayed and reduced runoff tributary to Epitácio Pessoa, due to the construction of new reservoirs upstream of it.*

Keywords— Water balance model, Digital elevation model, Superficial drainage, Semiarid, Epitácio Pessoa dam, River basin

I. INTRODUCTION

The growing need for management and rational use of water resources, especially in the Northeast of Brazil, which is characterized by long periods of drought and poor spatial-temporal distribution of rainfall requires the necessary understanding of the complex interactions between climate, land use and physiographic. Additionally, these natural interactions are often disturbed by human actions that lead to important consequences on water availability, both quantitatively and qualitatively.

The management of water resources in Brazil and worldwide, the vulnerability hydro-climatologically and alternatives to the drought in Northeast Brazil, with emphasis on semi-arid regions, are controversial issues that have attracted regional expectations, always associated with actions proposed in order to reverse the socio - economic current, when these relate to meeting the water needs of the region.

Planners and managers of water resources, responsible for proposing solutions to match the supply of water to the ever-growing demands must be supplied reliable data describing the regional physiographic, climate, land use, the temporal evolution of this occupation and an account of major hydraulic projects implemented in the region of interest. According to (Palacios-Veles et al., 1998) society's demand for scientific models that improve hydrologic forecasting when there is increased reporting of floods and damages related to them. The development of better models, however, requires ongoing effort to search out and within the academic community. In the application of models is essential that information is available with consistent rainfall, evaporation, runoff, topography and soil.

Currently, Brazil is a clear increase of conflicts between users of water resources. As an example, may be cited the use of water for irrigation and public supply of water catchment Epitácio Pessoa dam. In this basin the projected water demand for irrigation and public water supply have shown concern about the availability of water in years with below average rainfall climatology. The water stored in Epitácio Pessoa dam, located in the Bouqueirão city in the state of Paraiba, are captured by sub-basins of the Upper Paraíba and Taperoá. The total area of these sub-basins is 12 square kilometers - that represents about 20% of the state area. These sub-basins are included in the driest state, the Cariri, part of the semiarid northeastern Brazil. The Epitácio Pessoa dam, popularly known as weir Boqueirão, is responsible for producing water for public supply about half a million people - considering only the inhabitants of the towns along the river and the most populous and important of them: Campina Grande, 45 km away dam.

Due to drought in the region, the utility of Campina Grande was rationed, from October 1998 to April 2000 at around 50% to avoid the collapse of the system. Although late, the choice of rationing was right since the rains of 1999 were not sufficient to recover satisfactorily, the water volume of the reservoir. Moreover, in recent years, demand for water in the city has grown dramatically, not only because of population increase but also due to the growth of productive sectors. Given the above, it is a clear need for improved monitoring of water catchment of the reservoir Epitácio Pessoa. The complexity of demands for water for irrigation, industry and the public supply requires closer attention to the origins and destinations of water. A water balance model helps correct decision for the management and conservation of water in the long term.

The objective is to ascertain the impacts of space-time variability of rainfall, soil depth, vegetation and topography on runoff from the catchment area of Epitacio Pessoa Dam. It is expected that the proposed model, ranges annual, monthly and daily may help to account for water availability in the basin and assist in the management of water resources.

II. MATERIALS AND METHODS

Study region

The watershed of the Epitácio Pessoa dam, more known as dam Boqueirão, geographically is located in the center of a region surrounded for a fragmented mountain range. The water flow for the dam is originated in the sub-basins of the High Paraíba and the Taperoá. The water courses that cut the region in study and that they benefit the farming production are the following ones: river Paraíba, river Bodocongó, stream of the Marinho Velho, stream of the Perna, stream of the Canudos, stream of the Ramada, stream of the Relva and stream of the Feijão. Currently, according to Managing Plan of the State of the Paraíba, the Epitácio Pessoa dam has capacity for 450, 424,550 m3 of water. Figure 1 shows the localization of the watershed of the Epitácio Pessoa dam.

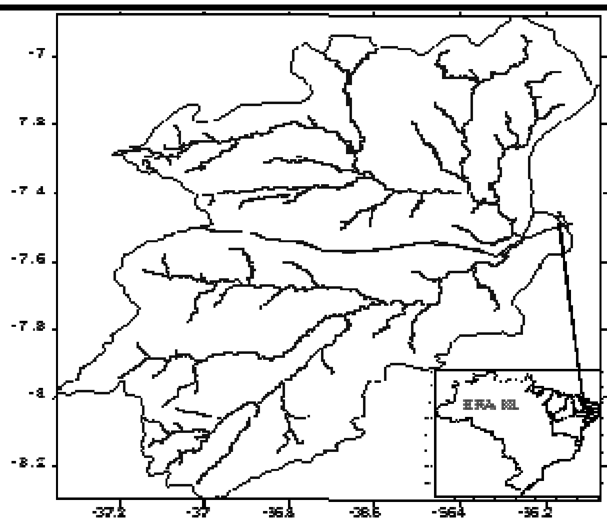

Fig. 1: Localization of the watershed of the Epitácio Pessoa dam

Topography, soil and relief

The basin under study is formed by rocks of the Precambrian period. The predominant soil in the region of sub-basins are the type Bruno non-calcium, low thickness, which covers the entire crystal existing in the area, with the presence of Entisols, Solonetz Solodizado, Regosols and Cambisols. From the taxonomic point of view, the basin presents a combination of Entisols, Solonetz Solodizado, Regosols and Cambisols and outcroppings. The Entisols predominate in relation to other soils, making the sub-basins almost impermeable.

Second (Villela and Matos, 1975) the slope of the land of a watershed largely controls the speed of runoff, affecting therefore the time it takes rainwater to reach the river beds which form the drainage network. The magnitude of peak flood and more or less opportunity for infiltration and susceptibility to soil erosion depends on the speed with which runoff occurs over a bowl.

Climate and hydrology

The average annual rainfall in the semi-arid northeastern Brazil is about 520-660 mm. The same amount occurs in many European cities such as Berlin and Paris, but with a difference: no one speaks of catastrophic droughts in those two cities. Among the reasons for the drought in semi-arid one can cite the high rate of evaporation and spatiotemporal irregularity of rain. This region, located near the equator, has high temperatures throughout the year, strong winds and low humidity. All this contributes to increased rates of potential evaporation. If the dams and water holes are not deep enough, certainly will be empty in a few months after the end of the rains. The portion of rainwater that infiltrates the earth is absorbed by clumps of soil and, in part, is protected from evaporation. After weeks and even months after a heavy rain, the roots of the plants can get the necessary moisture in the deepest portion of the soil.

The hydrographic sub-basin is poor in its broad aspects, so that the water conditions are insufficient to meet the flow of rivers in the long periods of no rain. Rivers and lakes are irregular, intermittent features, where surface water disappears during the dry season. The landscape of temporary rivers and lakes, where the presence of surface water is more constant, presents a seasonal drought well marked.

Some general aspects and importance, which characterize the basins are: low productivity of crops, reduced crop choices, low technology used in seeds, lack of soil conservation and pest control, low utilization of natural resources, limited and irregular availability of reduced water and natural preservation area which implies a loss in biodiversity. These aspects are of fundamental importance to ensure the survival of peasant families in an environment subject to droughts. In semiarid region, dominated by extensive livestock, the owner accumulates large water reserves, where weather conditions are favorable and otherwise transfer the flock to areas of warmer climate.

Software, programs and data

For accomplishment of the tasks of this work The Following had been materials necessary: satellite image of Landsat TM-5 of the 17th day of October of 1999, orbit 215, point 65 Acquired by the INPE and yielded by the research project "Study of the Ambient Degradation and the Agricultural Disasters Vulnerabilities Front to the ENSO in the semiarid Paraiba, "Process CNPq: 480480/01-0, Coordinated for the Professor Marx Prestes Barbosa and digital data of rise of the land with Resolutions of one kilometer and 90 meters. These digital data had been six mosaics and a composite for each one of these mosaics has covered an area of a degree of latitude for the longitude degree. The Superintendence of Northeast Development (SUDENE) and The Extraordinary Secretary of the Environment, of the Water Resources and Minerals (SEMARH) had supplied annual, monthly and daily totals precipitated the ranks of 23, distributed in Sub-Basins in the study, in the 1973 period "of the 1990s. Also, the annual totals evaporated had been gotten next to SEMARH, through the "Program of Monitoring Moisture of the Ground." The data flow had been gotten next to the National Agency of Water (ANA) and the Department of Civil Engineering of the University Federal of Campina Grande (UFCG), for the 1973 period "of the 1990s. Computational program TOPAZ (Topographic Parameterization), writing in FORTRAN-90 language, the land on the basis of digital given (USDA, 1992) and was considered developed by the Department of Agriculture of the United States by shape (Garbrecht and Martz, 2000). It was used to extract the physiography characteristics of the land. To view the results of exit of this program IDRISI 15.0 was used. The TOPAZ has the one of the better STI treatment characteristics of "pits" and "flats", reason is sufficiently which has been used in geoprocessament works. They had been used still ERDAS 8.5 software to effect the calculation of the NDVI. The date of entrance in the annual scale model in series are formed daily from annual precipitations. Annual rain is divided by the number of rainy days of the month. Already in monthly scale, the daily series are formed on the basis of the precipitated monthly totals, divided for the number of rainy days of the month. The scale model in daily works with Observed daily precipitation series. The main steps for the development of this work will be: (1) processing of the rise time, (2) attainment of physical characteristics of the basin, using the TOPAZ, (3) estimate of the fraction of plant covering, using image of satellite Landsat-5, (4) development of the model of water balance for the Sub-Basins of Caraúbas and Well and stones, (5) to calibrate, to verify and to apply the model simulated the outflows of the basin of Epitácio Pessoa dam of the annual, monthly and daily in scales, formed for the Sub-Basins of the High Taperoá and Paraíba.

Vegetation and relief analysis

NDVI and fraction of vegetal cover was estimated to the basin in study, with images Landsat TM-5. Gutman and Ignatov, (1998) the vegetated fraction can be simulated of the following form:

$$Vfrac = \frac{NDVI - NDVI_0}{NDVI_{¥} - NDVI_0} \qquad (1)$$

where $NDVI_0$ it is the minimum value of the vegetation index, $NDVI_{¥}$ it is the maximum value of the index of the used series and $NDVI$ it is the average value of the index of vegetation in each point of grating.

Water balance model

The runoff is influenced by several factors that facilitate or hinder its occurrence. These factors can be such climate-related precipitation and evaporation, or physiographic nature relating to the physical characteristics of the basin. Initially, the variation of precipitation is considered in the model, since it is one of the most important climatic factors for the runoff. Then, the flow is separated into two fundamental parts: surface runoff and subsurface.

Evapotranspiration is divided into the surface evaporation and plant transpiration. Any methodology used to develop the model of water balance in three time scales can be seen below:

Annual scale model and formulation
The model developed here allows you to vary precipitation and evaporation potential in the years following the same methodology used by (Manabe, 1969) (Milly, 1994) and (Jothityangkoon et al., 2001). Initially, the model conceptualizes the response of the sub-basin in terms of a single underground reservoir with storage capacity of finite water. The intent of this choice is to represent the runoff with minimal complexity in order to capture its interannual variability. The observed annual precipitation is divided into evaporation and runoff. It is considered as a loss in canopy interception, evaporation and transpiration extracted by roots of plants of the underground reservoir. It is considered that the runoff is generated when the water storage in underground storage tank exceeds its capacity.
In the first simulation is necessary to specify an initial condition of soil moisture. After several iterations it is assumed that the final value of water storage in soil is equal to the initial value. This is done because the initial value of soil moisture or the volume of water stored underground affect other terms of water balance. The annual scale model is the simplest and the results were evaluated for four general scenarios. The first scenario considers the entire sub-basin as a single reservoir, assuming a homogeneous in terms of climate and soil depth uniform. The second scenario is to represent the sub-basin by multiple independent underground reservoirs. In this case, it is assumed constant depths of the reservoirs, but they vary precipitation and potential evaporation. In the third scenario, we use the model of multiple reservoirs, it is considered the spatial variation of soil depth and neglects to the spatial variation of rainfall and evaporation. Due to limited information about the depth of soil, were initially considered four different depths, 0.3, 0.5, 0.8 and 1.0 m to represent the vertical variability of soil sub-basin. In the fourth scenario, the model of multiple reservoirs is used considering the spatial and temporal variations of rainfall and space-vertical soil depth.

Water balance equations
The simplified equation of water balance per unit area is given by:

$$\frac{ds(t)}{dt} = p(t) - q_{se}(t) - e(t) \qquad (2)$$

where $p(t)$ is the precipitation intensity, $q_{se}(t)$ is the saturation excess runoff rate, $e(t)$ is the evaporation rate, and $\frac{ds(t)}{dt}$ is the volume of soil water storage. The outflows, $q_{se}(t)$ and $e(t)$, appearing in Eq. (2) are described as functions of soil water storage s(t).

$$q_{se} = (s - S_b)/\Delta t \qquad se \qquad s > S_b \quad (3a)$$

$$q_{se} = 0 \qquad se \qquad s \le S_b \quad (3b)$$

$$e = \frac{s}{S_b} e_p \quad (4)$$

Where $S_b = Df$ is the single bucket's storage capacity, with D being the average soil depth, f the average porosity, and Dt is the time step (which in this case is 1 day).
Apply water balance model, described by equations (2), (3a) (3b) and (4), using historical series of total annual precipitation and evaporated and the soil parameters and.
The rate of precipitation for the year is calculated as follows: divide the total annual precipitation of number of days with rain that year and, to obtain the evaporation rate divided by the total evaporated annual number of days of the year . In the scale model all annual rainfall is regarded with the same intensity every day. The interception rate (i) shall be equal to 10% of precipitation in all cases.

Monthly scale model and formulation
Without any change in the number of parameters or the complexity of the model, the different scenarios used in the annual time scale, will also be considered at a monthly scale. The difference is that the data series is formed by total monthly precipitate of each month divided by the number of days with rainfall of that month. This procedure performed because the interest will be to assess the runoff between the months.
Aiming to solve problems of delay and overestimation of the flow, the flow can be separated into two basic types: subsurface and surface runoff. Already evapotranspiration can be separated into the surface evaporation and plant transpiration, as shown by equation (5). This procedure is aimed at refining the physical processes in the basin.

Monthly water balance equation
To refine the estimates of monthly water balance is proposed the following equation:

$$\frac{ds(t)}{dt} = p(t) - q_{ss}(t) - q_{se}(t) - e_b(t) - e_v(t) \quad (5)$$

where q_{ss} is the subsurface runoff, $e_b(t)$ is the tax of evaporation in the ground without vegetation and $e_v(t)$ is the transpiration tax of the plants. The subsurface runoff is described in function of the water storage in the ground:

$$q_{ss} = \frac{s - s_f}{t_c} \quad se \quad s > s_f \qquad (6a)$$

$$q_{ss} = 0 \qquad se \qquad s < s_f \qquad (6b)$$

Where S_f is the water storage in the ground, considering one given field capacity. It is assumed that $S_f = f_c D$. Where fc is the capacity of predominant field of the basin and D is the average depth of the ground. The reason for the use of the field capacity is that, frequently, when the humidity content is lesser of what the field capacity, the capillarity force is bigger of what of gravity, consequently the runoff is delayed. The time of reply of the subsurface runoff t_c is simulated on the basis of the law of Darcy, to represent of triangular form, the water-bearing subterranean in an inclined surface. In the estimate of t_c is assumed that the hydraulically gradient is come close to the angle of the surface of the ground. Thus:

$$t_c = \frac{Lf}{2K_s \tan b} \qquad (7)$$

where L is the average length of the lateral runoff, $\tan b$ is the average declivity of the surface, and is K_s the saturated average hydraulically conductivity. The estimate of the evaporation in the ground without vegetation is given by:

$$e_b = \frac{s}{t_e} \qquad (8a)$$

$$t_e = \frac{S_b}{(1 - M)e_p} \qquad (8b)$$

where t_e is an associated secular scale to the evaporation of the ground without vegetation. *M* is the fraction of the vegetal covering of the sub-basin, and varies of zero to one. On the other hand, the estimate of the perspiration of the plants is given by the equations:

$$e_v = Mk_v e_p \qquad se \qquad s > s_f \quad (9a)$$

$$e_v = \frac{s}{t_g} \qquad se \qquad s < s_f \quad 9b)$$

$$t_g = \frac{s_f}{Mk_v e_p} \qquad (10)$$

where t_g is an associated secular scale to perspiration and k_v is the perspiration efficiency of the plants, second (Eagleson, 1978), k_v generally is equal to one. The M parameter is used to divide the total evaporation in evaporation in the ground without vegetation and perspiration of the plants. The evaporation in the ground without vegetation e_p is a ratio on that it depends on the relation of s and S_b. When s will be bigger of what S_f transpiration will be maximum and equivalent e_p. When s will be lesser of was S_f the transpiration will be given by a fraction of e_p.

Evaporation of the ground vegetated of the one of the ground was broken up to it naked, because in monthly scale the evaporation can very be different of one month for another one.

Model parameters

The parameters of the model in monthly scale is classified as: topographical, D, f, f_c, L, K_s and vegetation M, k_v.

Daily formulation and scale model

Finally, without any change in the number of parameters or the complexity of the model, the different scenarios proposed for the monthly time scale, were also used to estimate the runoff on a daily.

In general, the analysis was performed on scales annual, monthly and daily basis because the interest will be to analyze the intertemporal runoff.

Model Evaluation Criteria

This study used two criteria to choose the best scenario. The first was the Nash coefficient to evaluate the response using the model. The second was the determination coefficient, used to explain the variability between the observed and estimated flows.

Sensibility analysis of the parameters adjust

Sensitivity analysis is a process that evaluates the response of the model to the values of input parameters. Here it is executed when changing the value of a parameter and holds the remaining unaffected. Then compare the output results of the model, resulting from possible changes in the values of parameters. The sensitivity analysis of model parameters: canopy interception, soil depth and porosity and hydraulic conductivity will be performed by comparative difference.

III. RESULTS AND DISCUSSION

With the digital data of rise of the land maps of the topography of the watershed of the Epitácio Pessoa dam had been generated in two and three dimensions, Figure 2. These results had evidenced high degree of consistency when compared with the planialtimétricas letters, in the scale of 1:100.000, of the SUDENE (1982). This comparison served to validate the exits of the applicatory TOPAZ.

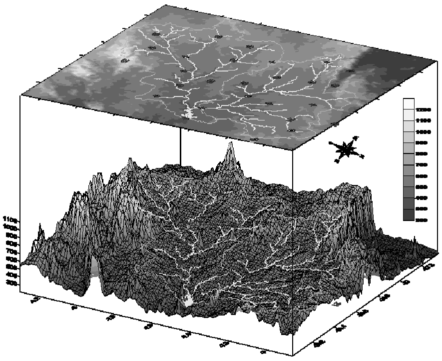

Fig. 2: Three and bi-dimensional maps of the watershed in study

Catchment delimitation, drainage network and vegetal cover

The TOPAZ could define about 92% of the basin area of study. This percentage was obtained when comparing the area obtained by the TOPAZ with that of the Master Plan for Water Resources of the State of Paraíba. This result is superior to that obtained by (Eid and Campana, 1999) for sub-basin of Rio Negro in San Felipe, with the help of GIS tools. Furthermore, studies (Martz and Garbrecht, 1993) obtained results with error less than 5%. These authors argue that the resolution of the data is extremely important so that errors are minimized. (Verdin and Jenson, 1996) by using digital elevation data with a resolution of 90 meters at 10% missed the delimitation of the study area.

The vegetation of the study area displays a predominant vegetation of Caatinga. (Melo, 2003) estimated the value of 0.65 as the fraction of vegetation to savanna. Here the value found was 0.5348 and was used as initial value in the model to differentiate the evaporation of bare soil and vegetated areas.

Water balance to subcatchment Caraúbas

Annual water balance

Initially, we applied the annual scale model (simpler) sub-basins of Caraúbas and Poço de Pedras. On this scale the model was evaluated for four pre-selected scenarios. The first scenario considers the sub-basin Caraúbas with a single underground reservoir, we assume the climatically homogeneous. The second scenario is to represent the sub-basin by several independent underground reservoirs. In this case, it is assumed constant depths of the reservoirs and variable rainfall and potential evaporation. In the third scenario considers the spatial variability of soil depth and disdains to spatial variability of precipitation and evaporation. In the fourth scenario considers the variability of precipitation and soil depth.

Figure 3 shows the probability of surplus of annual runoff observed and estimated by the model in sub-basin Caraubas for four sxenarios mentioned in this text. In Figure 3 Q is the annual runoff and PMA is the annual average rainfall. The average soil depth for the first three scenarios was 0.36 m. In the fourth scenario the variations of soil depth were 0.3 m for Prata, 0.8 m for Sao Sebastiao do Umbuzeiro, 0.3 m to São João do Tigre, 0.3 m for Caraúbas and 0.5 m for Congo. Note that results of fourth scenario are very close to observed values. In this scenario the coefficient of Nash was equal to 0.82 and the determination of 87%. This outcome is similar to that obtained by (Lacroix et al., 2002) when he used a hydrologic model coupled to semi distributed TOPAZ.

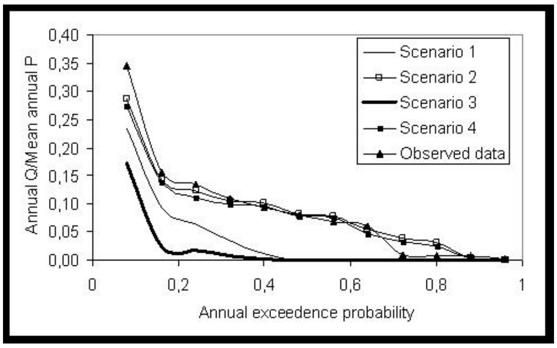

Fig.3: Probability surplus of the observed superficial runoff and estimated by the annual model in Caraúbas

Monthly water balance

The model results in a monthly scale, using the same scenarios and parameters of the model in annual scale can be seen in Figure 4, which displays the probability of surplus of the monthly flow to the surface, observed and estimated by the model in the sub-basin Caraúbas. Note that the model is still responding to the pattern of interannual runoff, checked with the previous result. Also note that the scenarios considered, the room is that most closely approximates the observed pattern. This was due to variations in soil depth and space-time rainfall. When considering only the space-time variability of rain there was overestimation of runoff. Guo et al., (2002) argue in their study that runoff is very sensate to variations in precipitation, especially in semiarid regions. Braga and Figueiredo (2003) studied the effects of rainfall variability on runoff in semiarid regions of Northeast Brazil showed that this variability has a large influence on the peaks of flow. The results obtained here agree with those of Braga and Figueiredo

Figure 5 compares the flow at the surface, observed and estimated by the model at a monthly scale in the sub-basin Caraúbas. In figure QMM is the average monthly runoff and PMA has been previously defined. Note that the values estimated in scenario three, especially to the most significant are those that come closest to observed values. In this scenario the ratio of Nash was equal to 0.91 and the determination of 94%. However, there is a delay in runoff estimated. In other scenarios there was overestimated.

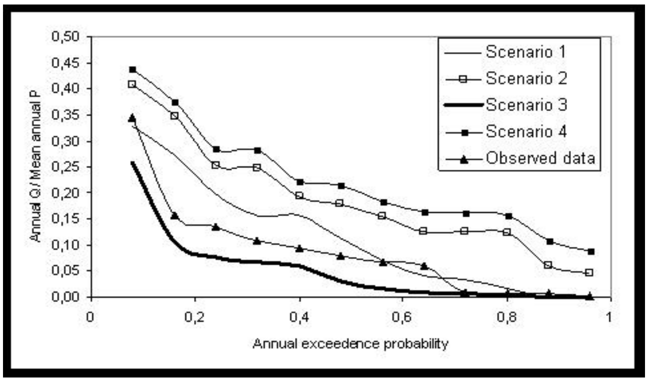

Fig.4: Probability of surplus of runoff estimated by the model and observed monthly in the sub-basin of the river Paraíba, Caraúbas

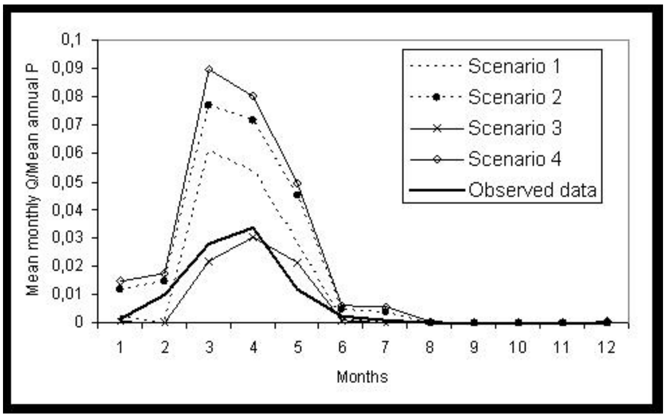

Fig.5: Comparison of surface runoff and observed monthly estimated by the model in the sub-basin of the river Paraíba, Caraúbas

In order to solve the problems of delayed setting and three in overestimate scenarios one, two and four, Figure 5, were refined in the model representations of processes: subsurface flow, transpiration and canopy. This refinement was necessary because, in a monthly scale, the variations in subsurface flow and plant cover were influencing the calculation of water balance. In other words, the subsurface flow and the canopy can be very different from one month to another. The refinement was also added a fifth scenario. In this new scenario varied the precipitation in space and time, soil depth and vegetation cover. Following, will present the results of the refined model (called modref) for the five scenarios. Note in Figure 6 that the modref still represents very well the pattern of annual runoff. In Figure 7, the criterion of change of variables improved, with the exception of scenario three, roughly estimating the runoff. The difference in results between scenarios one and three was due to the average depth of soil. In the first case was 0.3, the second 0.65 m, respectively. The increase of 0.35 m caused damping of 67% in the runoff. Thus, one can say that, even in shallow soils, as is the case of the sub-basin Caraúbas, runoff is sensitive to variation of soil depth.

Figure 8 highlights the modref settings for the two best scenes. In scenario five is visible improvements in the estimation of runoff. In this scenario we considered the variation of vegetation cover. For modref Nash coefficient was 0.93 and the determination of 95%. Results similar to the scenario five was obtained by Jothityangkoon et al., (2001). They said the most important variables in the process of runoff in all scales of time and space are: depth of soil, climate and vegetation cover.

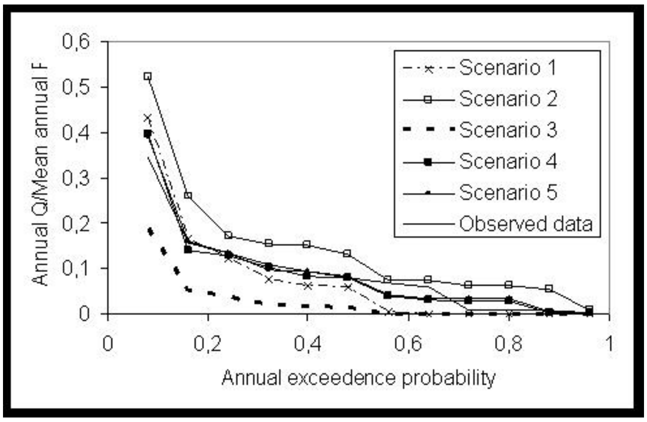

Fig.6: Probability of surplus of runoff observed and estimated monthly by the model refined in sub-basin of the river Paraíba, Caraúbas

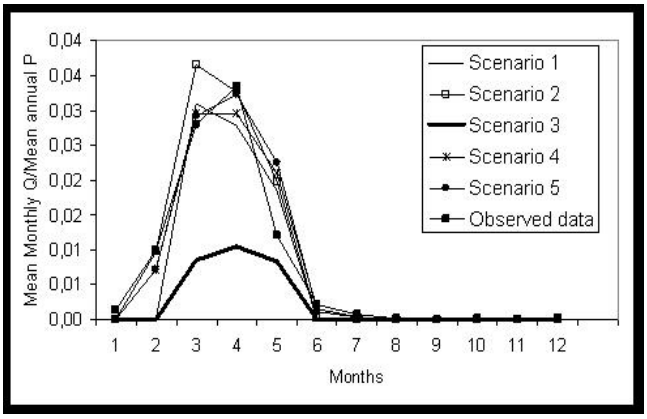

Fig.7:Comparison of monthly surface runoff observed and estimated by model refined in sub-absin of Paraiba river in Caraubas.

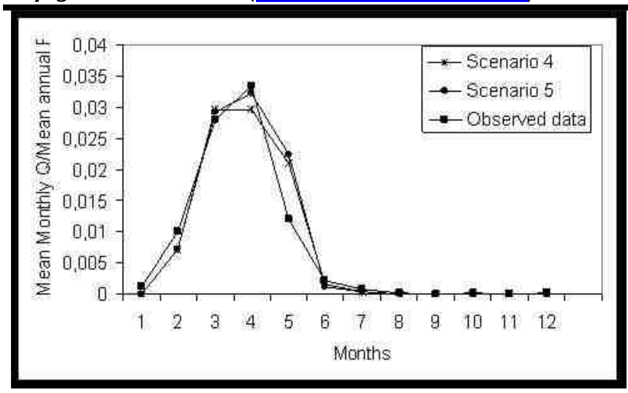

Fig.8: Comparison of monthly surface runoff observed and estimated by model refined in Sub-basin of Paraiba River, in Caraubas.

Daily water balance

Here modref was used on a daily, ie, the daily rainfall data were entered directly into the model. Figure 9 shows the comparison between the daily flow to surface, observed and estimated in Caraubas sub-basin. Note that the model improved the estimation of runoff, changing only the scale, from monthly to daily. The coefficient of Nash was equal to 0.94 and 96% determination.

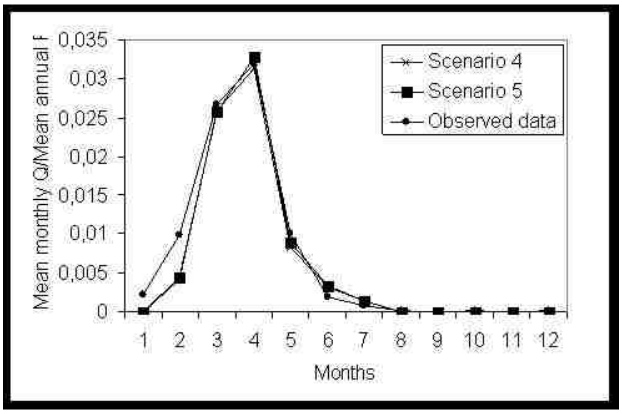

Fig.9:Comparison between daily flow of the surface, observed and estimated by modref in Caraubas sub-basin.

Figure 10 displays the curves of daily flow of stay, observed and estimated by modref in the sub-basin Caraúbas to five scenarios. It was found that the four five scenarios are those that best reproduce the pattern of drainage sub-basin. In scenario four the Nash coefficient was equal to 0.80 and the determination of 90%. Figure 11 highlights the five scenario as the most appropriate to express the daily flow in sub-basin, whereas, during the process of evaluating the scenarios four and five, it was noted that the increment of one more variable, land cover, not add significant improvement in the estimates. In this scenario, the best values for soil depth and vegetation cover are: 0.8 m, 50% for São Sebastião do Umbuzeiro; 0.3, 90% for São João do Tigre, 0.3 and 80% for Caraúbas and 0,3 and 90% in Congo. In scenario five Nash coefficients was equal to 0.81 and the determination of 90%.

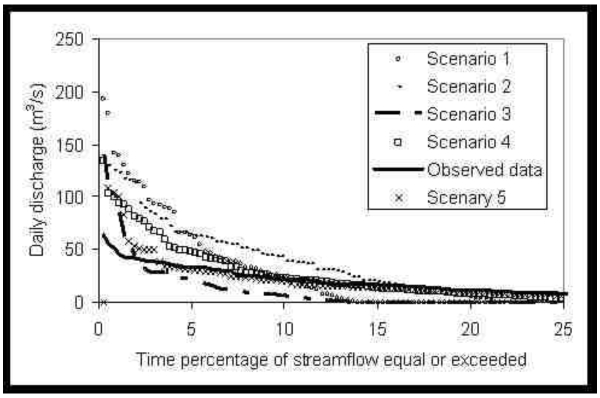

Fig.10:Curves duration of flow observed and estimated by refined model daily, in Paraiba river, Caraubas sub-basin.

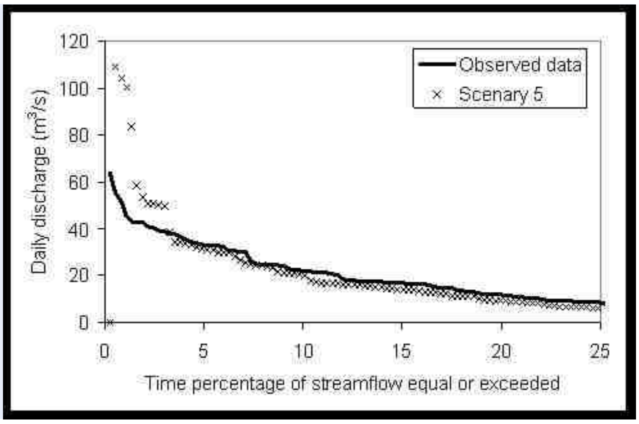

Fig.11:Curves duration of flow observed and estimated by refined model daily, in Paraiba river, Caraubas sub-basin.

Water balance to Poço de Pedras subcatchment

Annual water balance

The procedures adopted here to fit the model were similar to the sub-basin Caraúbas. Figure 12 displays the probability of surplus of the annual flow to the surface, observed and estimated by the model in the sub-basin of stone pit. Scenario four presented the best results. The Nash coefficient between the observed and predicted values was equal to 0.88 and the determination of 84%. Kunkel and Wendland (2002) used the GROW- 98 model, the basin of the Elbe in Germany, obtained 15% difference between estimated and observed. The authors considered their results. Here the result is similar.

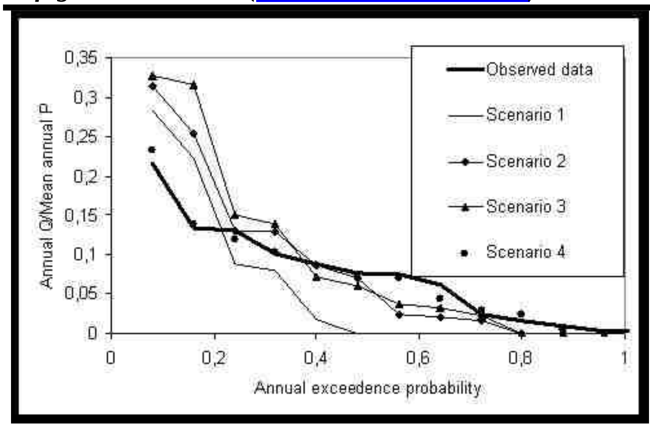

Fig.12: Probability of surpples of runoff observed and estimated by year model, in Taperoa river, Poco de Pedra sub-basin.

Monthly water balance

Because some heterogeneity among the Caraubas and Poco de Pedras sub-basin wer added two scenarios: sixth and seventh. In the sixth scenario vary rainfall, soil depth, vegetation cover and hydraulic conductivity. In the seventh scenario vary rainfall, soil depth, soil porosity and vegetation cover.

Figure 13 displays the probability of surplus of the monthly flow to the surface, observed and estimated by the model in the sub-basin of Poço de Pedras. Again, the results of scenario four that were closest to the observed values. The Nash coefficient between the observed and predicted values was equal to 0.90 and the determination of 83%. (Jothityangkoon et al., 2001) obtained similar results using the same methodology and procedure.

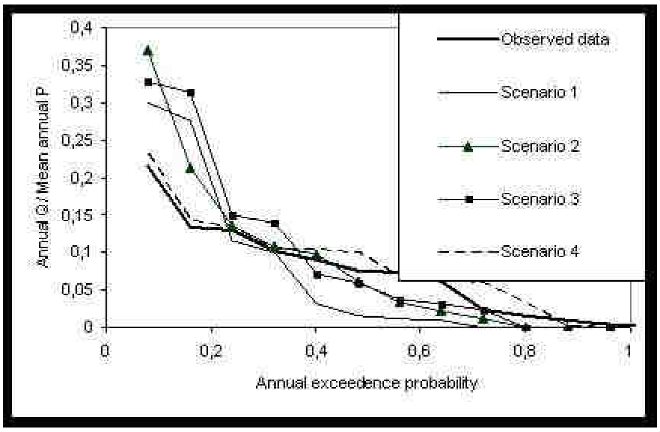

Fig.13: Probability of surplus of runoff observed and estimated by the monthly model, the sub-basin of the river Taperoá in Poço de Pedras

Figure 14 compares the monthly flow to the surface, observed and estimated by the model in the sub-basin of Poço de Pedras. Note that the model also responds to intra-annual variability. However, there is overestimation of peak flow. The Nash coefficient between the estimated and observed was equal to 0.69, similar to that obtained by (Zhang et al., 2002) for the South Creek watershed located in the southeast of Sydney, Australia, and the determination of around 73 %.

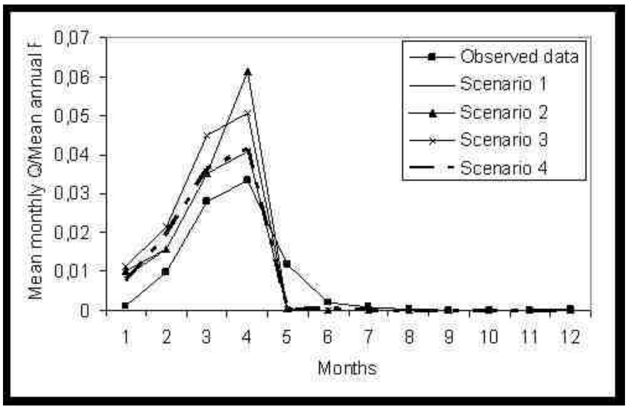

Fig.14: Comparison of monthly surface runoff observed and estimated by model in Taperoa river, Peco de Pedras sub-basin.

Figure 15 displays the probability of surplus of annual flow to surface, observed and estimated by modref in Poco de Pedras sub-basin. Note that the estimates of four five scenarios are the ones that come closest to observed values. Below 10% probability of surplus is overestimate, but nevertheless the model continues to respond to the signal flow. This result was obtained when the flow was separated into two fundamental parts: surface and subsurface, and to separate evapotranspiration into bare soil evaporation and transpiration. This methodology was presented in chapter Material and Methods.

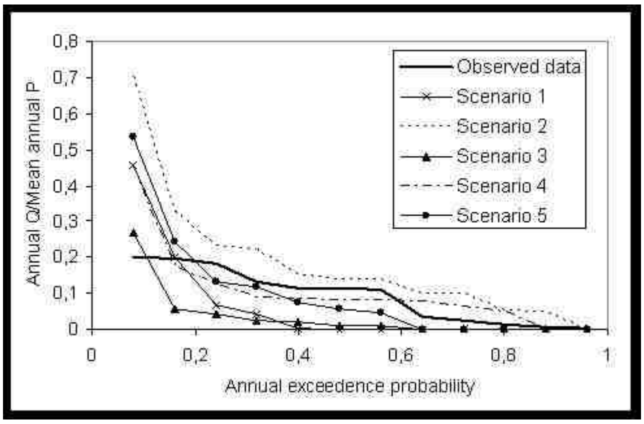

Fig.15: Probability of surplus of runoff observed and estimated monthly by the model refined in Taperoá River, Poço de Pedras sub-basin.

Figure 16 compares the monthly flow, observed and estimated by modref the sub-basin of Poço de Pedras. For scenarios one to four land cover was considered constant and equal to 50%. This value was obtained of the fraction of vegetation cover. In the scenario a soil depth was 0.5 m. This value was defined and first used in the model. In scenario two soil depths continues to be 0.5 m, but varied the precipitation. In scenario three precipitations was considered to be constant and varied soil depth, optimized at 0.65 m. In scenario four is varied soil depth and precipitation. It was taken to depths of 0.7 m for Desterro, 0.33 m Serra Branca and 1.5 m to São José dos Cordeiros. As a result, the scenario presented five small improvements in the estimation of the flow, when compared with the estimate of scenario four. In this step, the best value for vegetation cover was 80%. (Melo, 2003) used land cover 90% when analyzed the effect of vegetation with a model Regional Atmospheric Modeling System (RAMS).

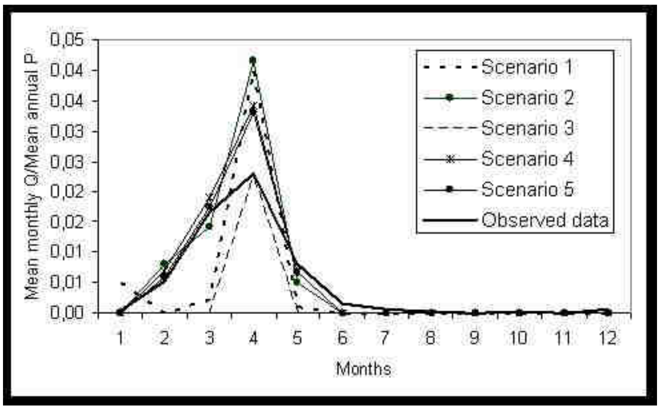

Fig.16: Comparison of monthly surface runoff observed and estimated by model refined in Taperoa river, Poco de Pedras sub-basin.

Figure 17 highlights the monthly flows, observed and estimated by modref for scenario five, the sub-basin of Poço de Pedras. Note that the estimates of this scenario, except the peak, were the closest to the observed values.

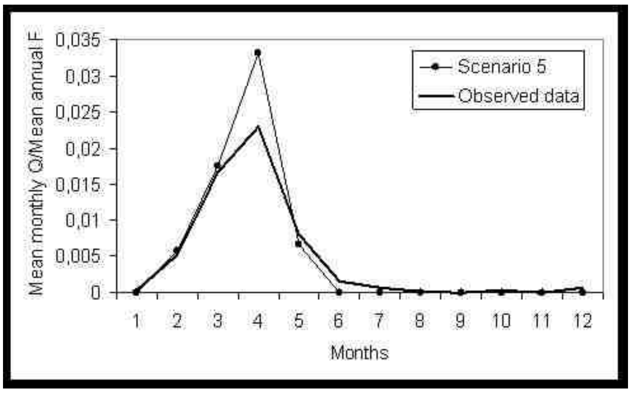

Fig.17:Comparison of monthly surface runoff estimated and observed by model refined in Taperoa river, Poco de Pedras sub-basin.

To solve the problems of under and overestimation of the flow, checked the scene five, in a monthly scale, made up the sixth scenario described earlier in this item. Figure 18 compares the observed and estimated flows at the modref on a monthly scale, for the sixth scenario, the sub-basin of Poço de Pedras. The best value of hydraulic conductivity was 11 m / day. It is noticed significant improvement in representation of runoff in sixth scenario. The coefficient of Nash was equal to 0.92 and the determination of 92.5%. (Melo, 1973) highlights the importance of knowledge of soil physical characteristics for the management of natural resources in a region. In this scenario there is a contribution of hydraulic conductivity in modref.

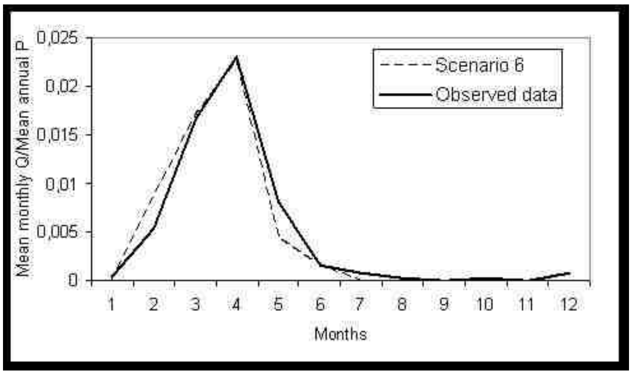

Fig.18:Comparison of monthly surface runoff estimated and observed by refined model in Taperoa river, Poco de Pedras sub-basin.

Figure 19 compares the observed and estimated flows at the modref on a monthly scale, for seventh scenario, Poco de Pedras sub-basin. In this scenario the porosity was enhanced by 50%. The Nash coefficient was 0.92 and the determination of 93%. In the seventh scenario the estimated flow is slightly higher than the sixth. It is noteworthy that any possible change of model fit was performed on the seventh stage.

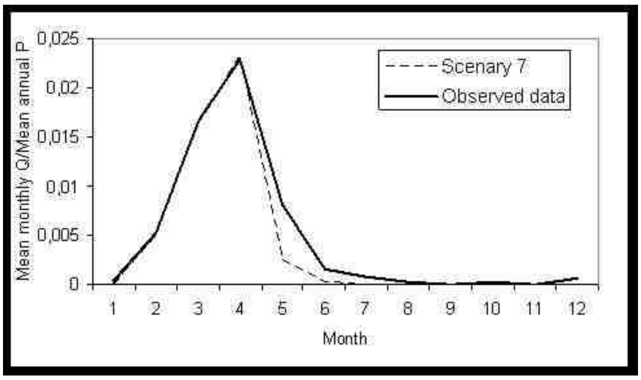

Fig.19: Comparison of observed and estimated monthly surface runoff by refined model in Taperoa river, Poco de Pedras sub-basin.

Daily water balance

Figure 20 compares the flow to the surface, observed and estimated by modref, on a daily for scenario five, the sub-basin of Poço de Pedras. Note to excellent correspondence between the estimated and observed. In this scenario, also varied soil depth, precipitation and vegetation cover. The best values of depth and vegetation cover are: 0.6m, 85% to São José dos Cordeiros, 70%, 0.8 m to Desterro and 0.4 m, 20% to Serra Branca. With these variations was obtained Nash coefficient was equal to 0.97 and coefficient of determination was 96%.

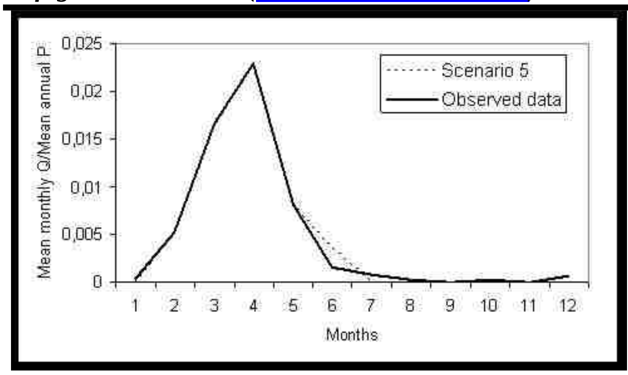

Fig.20: Comparison of observed and estimated daily surface runoff by refined model in Taperoa river, Poco de Pedras sub-basin.

Figure 21 displays the curves of daily flow of stay, observed and estimated by modref for scenario five, the sub-basin of Poço de Pedras. Note that the model corresponds reasonably well to observed values. However, overestimates the throughput for residence times less than 12%. Up this time is small underestimation. The coefficient of Nash was equal to 0.85 and the determination of 88%. Berger and Entekhabi, (2001) studied the hydrological response of ten small watersheds, based on physiography and climatology, obtained value of 89% on average of coefficient of determination.

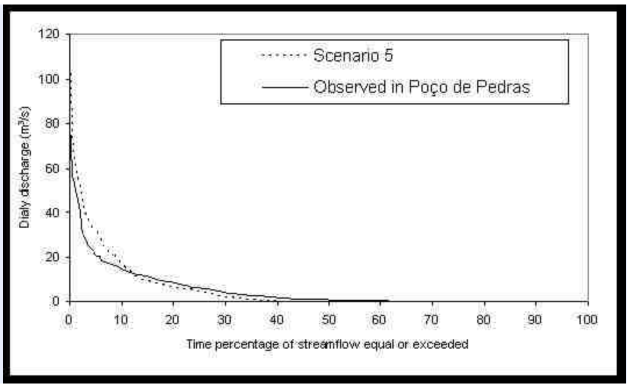

Fig.21: Curves duration of flows daily observed and estimated in Taperoa river, Poco de Pedras sub-basin.

In order to solve problems of under and overestimation of the flow, observed in five scenario (Figure 21), the sixth scenario was proposed. Figure 22 displays the curves of daily flow of stay, observed and estimated by modref for the sixth scenario, the sub-basin of Poço de Pedras. It was found that a small increase in the value of hydraulic conductivity is optimized at 11.0 m / day, significantly improves the estimation of the flow. The Nash coefficient was equal to 0.87 and the determination of 88%.

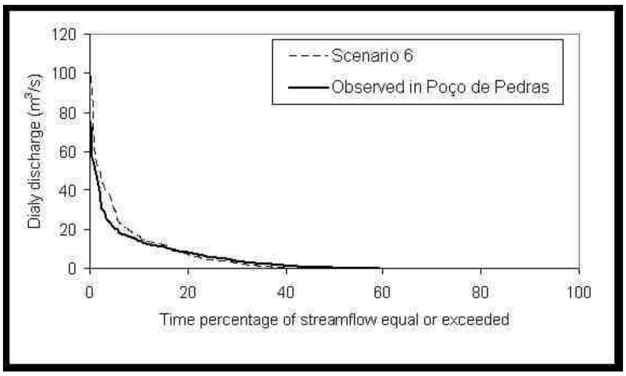

Fig.22: Curves duration of flow daily observed and estimated by refined model in Taperoa river, Poco de Pedras sub-basin.

Table 1 shows the states of 0 variable and parameters for the adopted scenes. It notices that the scenes increase its complexities from top to bottom.

Table 1 - States of 0 variable and parameters for the scenes adopted in the study

Simulated	Soil depth	Precipitation	Vegetation	Hydraulic conductivity	Soil porosity
one	uniform	homogenous	uniform	constant	constant
two	uniform	variance space-temporal	uniform	constant	constant
three	variably	homogenous	uniform	constant	constant

four	variably	variance spatial-temporal	uniform	constant	constant
five	variably	variance spatial-temporal	variance spatial	constant	constant
six	variably	variance space-temporal	variance spatial	variably	constant
seven	variably	variance space-temporal	variance spatial	variably	variably

Application of the model to the watershed of the Epitácio Pessoa dam

The water balance model, called modref, adjusted for sub-basins and Caraúbas and Poço de Pedras, will be applied to the reservoir basin Epitácio Pessoa, composed of the sub-basins of the Upper Paraíba and Taperoá, monthly and daily scales. To perform this task it was necessary to increase the number of rain gauge stations in these sub-basins. The outflows of these sub-basins are close to the water surface of the reservoir Epitácio Pessoa and are downstream of the outfall of the sub-basins and Caraúbas and Poço de Pedras.

Application of the model to the sub-basin of the High Paraíba

Figure 23 compares the monthly flow, observed in Carubas and estimated by modref, Upper Paraiba sub-basin. It is noted excellent correlation between the observed and predicted values. The coefficient of Nash was equal to 0.97 and the determination of 97%. As based on the results obtained can be said that the water behavior of sub-basin Caraúbas is identical to the sub-basin of the Upper Paraíba.

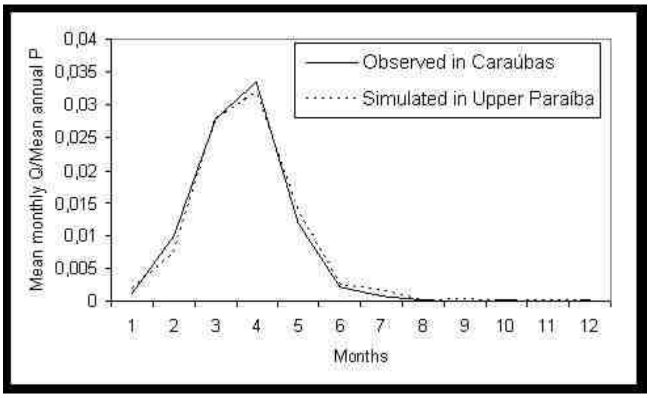

Fig.23: Runoff monthly observed and estimated by refined model in Upper Paraiba, in Caraubas sub-basin.

Figure 24 displays curves of daily flow, observed in Carubas and estimated by modref for Upper Paraiba. Note that the estimated values are very close to observed values.

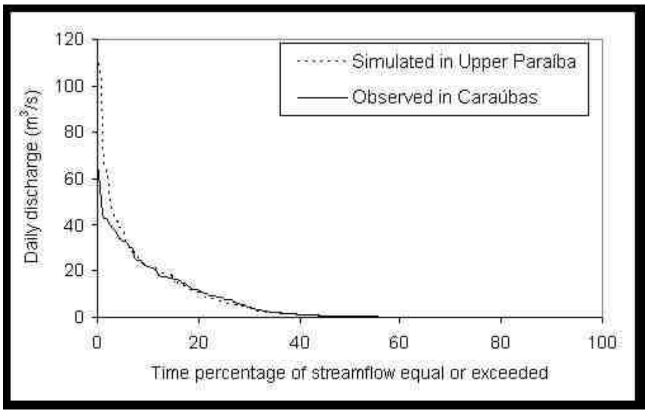

Fig.24: Duration curve of daily flows observed and estimated by refined model in Upper Paraiba, Caraubas sub-basin.

Application of the model to the sub-basin of the Taperoá

Figure 25 compares the monthly flow to the surface, observed in Poço de Pedras and modref estimated by the sub-basin Taperoá. Note also a good fit of the model. The coefficient of Nash was equal to 0.95 and the determination was 95%.

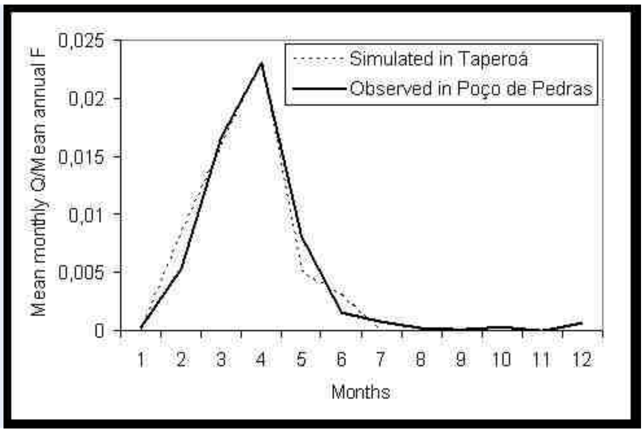

Fig.25: Runoff observed and estimated monthly by refined model in Taperoa Sub-basin.

Figure 26 displays the curves of daily flow, observed in Poco de Pedras and estimated for Taperoa sub-basin by modref. Note that the estimated values correspond to those observed. The percentage of time spent of the most significant flow occurred at about 20% of the year. (Galvão et al., 2001) to analyze the curve of stay in Poço de Pedras obtained the percentage of 22.7% of the year with occurrences of flows above 0.5 m^3 / s.

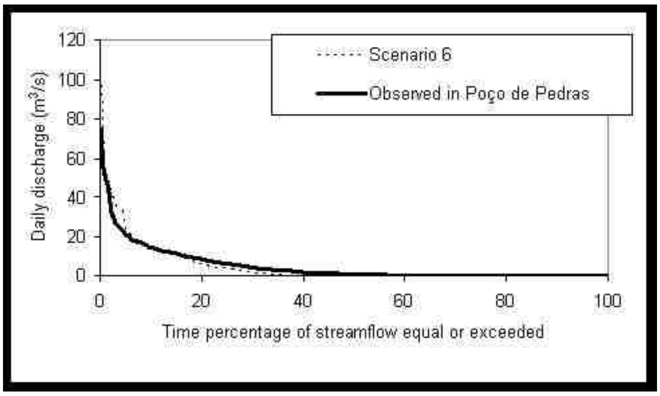

Fig.26: Daily flow duration curve observed and estimated by refined model in Taperoa river.

Monthly inflow of runoff to Epitacio Pessoa dam

The inflow of water into the reservoir was carried out based on a consideration. To this end, we used the areas of sub-basins of the Upper Paraíba and Taperoá. This procedure is similar to that used by Ward, (1993) when he realized the water balance for the state of Texas - USA.

Figure 27 shows the average monthly inflow, observed and estimated by modref in the catchment of the reservoir Epitácio Pessoa. It can be seen that the estimated values fit very well to the observed. The coefficient of Nash was equal to 0.97 and the determination of 97%.

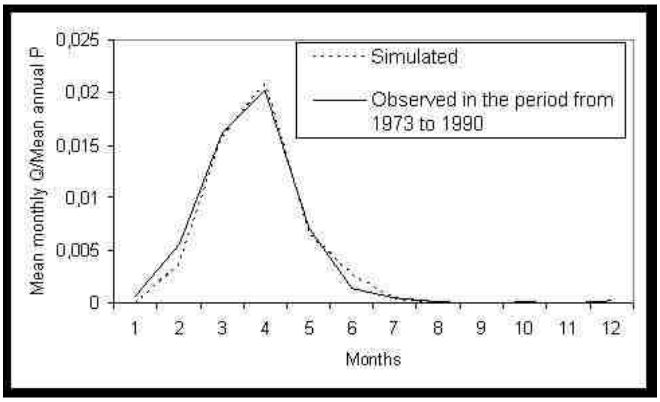

Fig.27: Monthly runoff observed and estimated for refined model in Epitacio Pessoa basin.

Turnout daily runoff to Epitacio Pessoa dam

Figure 28 displays the curves of daily flow of stay, observed and estimated by modref in watershed Epitácio Pessoa dam, in the period studied. The most significant flows occur in only 20% of the year. The coefficient of Nash was equal to 0.93 and the determination of 94%.

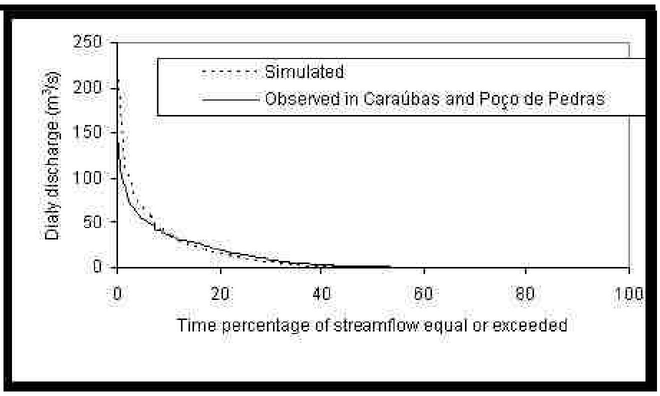

Fig.28: Daily curves duration of flow observed and estimated by refined model in Epitacio Pessoa catchment.

Annual inflow of runoff to the Epitácio Pessoa dam

Figure 29 displays the estimates of annual inflows to Epitacio Pessoa dam.On average, about 12% of the rainfall in the basin is transformed into runoff.

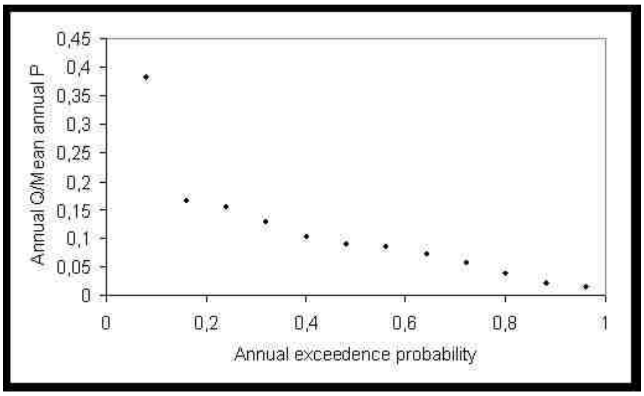

Fig.29: Estimated annual runoff estimated by model for Epitacio Pessoa basin.

IV. CONCLUSIONS AND FUTURE WORK

The water balance developed here and applied, generally responds very well to the variability of runoff from the catchment area of Epitácio Pessoa dam, despite the large spatial and temporal variability in rainfall. Based on the various aspects evaluated in this study, the findings can be grouped in terms of: 1) results obtained with the adjustment and application of model 2) methodology and 3) tools.

Adjustment and application of the model

The model results showed that there were changes in the pattern of runoff upstream of the Epitácio Pessoa dam. These changes are resulting in delayed and reduced runoff tributary to the dam, due to the construction of new reservoirs upstream of it. It was found that about 12% of precipitation is transformed into the crowd Epitácio Pessoa.

The runoff of the sub-basin Caraúbas is influenced by soil depth. On average, this depth is 0.65 m. The soil of the sub-basin Taperoá is more porous, more profound and more variable than that of the sub-basin of the Upper Paraíba. This translates to greater infiltration and less runoff. As a result, the sub-basin of the Upper Paraíba produces more runoff than the sub-basin Taperoá. In other words, the inflow to the Epitácio Pessoa dam, Upper Paraíba, is about 7.5% of average annual precipitation and the Taperoá is around 4.5%. The difference of 3% demonstrated major sub-basin of the Upper Paraíba in the production of water for the dam.

Methodology adopted

The model developed here based on annual scale and progressively refined until the daily scale, was very efficient to quantify the water resources of the basin Epitácio Pessoa. Applying the model allows to check the relative importance of various hydrological processes such as evapotranspiration, surface and subsurface flow and the influences of soil characteristics.

This study was not obtained the hydrograph at the daily level because the interest was to quantify the performance of monthly and annual water tributary to the Epitácio Pessoa dam.

Tools used

GIS TOPAZ and have the following advantages: minimal cost, speed to get the information you need, less work, easy to detect errors more and better features and details of the drainage network. The TOPAZ is very efficient in getting the topographic parameters of the basin for the purpose of hydrologic modeling. In summary, GIS tools - TOPAZ used in watershed Epitácio Pessoa dam is a pioneer and directs the future of studies of water resources in northeastern Brazil. The errors suggest a strong dependence on the size of the basin and the cell (cell area equal to 1.0 km^2). The errors are smaller when working with the entire watershed of the reservoir Epitácio Pessoa.

Finally, it is suggested that henceforth there is better management of water resources within the basin studied, especially with regard to decision making for construction of new reservoirs, since the uncontrolled construction of reservoirs upstream of the Epitácio Pessoa dam, has negative impact on flow of water for this dam.

V. ACKNOWLEDGEMENTS

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