ESTIMATION OF THE ANNUAL WATER BALANCE OF THE CUBATÃO-SUL WATERSHED (SANTA CATARINA STATE, BRAZIL) WITH A MATHEMATICAL MODEL - HYCYMODEL

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Abstract - The Cubatão-Sul watershed (738 km^2) characterized by Cubatão river is located near Florianópolis city, Santa Catarina State, Brazil. The objective of the present study was to estimate its annual water balance with a mathematical model HYCYMODEL. The study area is only 403.83 km^2 on account of the locality of the hydro-meteorological station. The discharge and precipitation data observed at the station for the period 1974-1984 were used for analysis. The results obtained through the simulation of the 11-years hydrograph permitted to estimate the annual water balance. The total value of discharge is 56.74% of annual rainfall and the evapotranspiration is 42.45%. The soil-water storage change is +0.81% and could be negligible. Among the total discharge, the direct runoff and the base flow are 29.34 and 70.66%, respectively. In this study, the evapotranspiration consists of three components: the transpiration, the evaporation by interception and the evaporation from the river whose percentage are calculated 60.92, 35.17 and 3.91%, respectively. The mean discharge of the Cubatão river was calculated 12.49 m^3/s.

1 - INTRODUCTION

The Cubatão-Sul watershed characterized by Cubatão river is located near Florianópolis, the capital city of Santa Catarina State, Brazil. The water resources in the watershed is utilized for irrigation in horticulture in the area and
for drinking-water supply to the Great Florianópolis Region. Because of the increasing demand of water use accompanied with population increase, the necessity of hydrological studies has been recently rising for the adequate water-resources management of this watershed.

The objective of the present study was, therefore, to estimate the annual water balance of this watershed with a mathematical model HYCYMODEL proposed by FUKUSHIMA (1988).

2 - MATERIAL AND METHODS

2.1 - Study area

The Cubatão-Sul watershed has the total area of 738 km^2. The Poço Fundo hydro-meteorological station (latitude 27°40'S and longitude 48°47'W) is located at the midway of the Cubatão river. The works at the station has been managed by the *Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina S.A.* (EPAGRI).

The upper stream area from the station within this watershed is here named Cubatão-Sul catchment. The catchment with area only 403.83 km^2 lies approximately between latitudes 27°35'S and 27°54'S and between longitudes 48°47'W and 49°03'W, having the altitude from 100 to 1150 m (Figure 1).

According to the Köppen classification, the climate type of the region is Cfa (humid subtropical with hot summer). The mean annual precipitation is 1712 mm.

The natural vegetation is a Mata Atlântica dominated by canela-preta (*Octea catharinensis*), canela sassafrás (*Octea pretiosa*), perola vermelha (*Aspidosperma olivaceum*), and so on (SANTA CATARINA, 1986). The bedrock in the region is granite, gneiss and sedimentary rock (SILVA & BORTOLUZZI, 1987).

The data of the daily discharge and rainfall observed at the Poço Fundo station for the period 1974-1984 were provided from the EPAGRI and used for the water budget analysis.

2.2 - Theory of HYCYMODEL

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The HYCYMODEL is a kind of conceptual and storage model. The model consists of 5 tanks that express river and hillslope systems (Figure 2). As it is in detail explained by FUKUSHIMA (1988), the model is described briefly here.

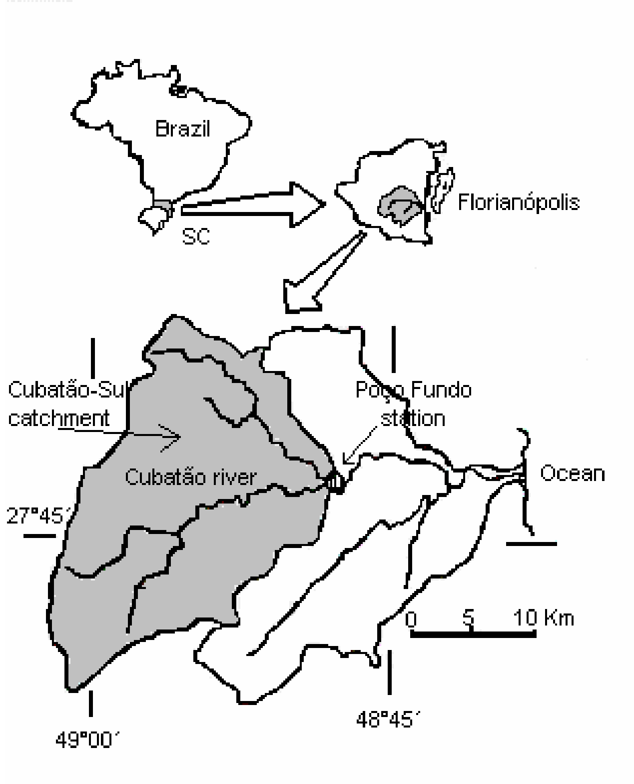

Figure 1 - Cubatão-Sul watershed

Using the ratio of impermeable area, C, rainfall is divided into the channel rainfall $R_c(t)$ and the gross rainfall $R_g(t)$ where t is the time. Tank I shows the interception process which is defined as:

$$R_n(t) = AG \times R_g(t) - AI$$

where $R_n(t)$ is the net rainfall and AG and AI are the interception parameters. The interception $E_i(t)$ is the difference between $R_n(t)$ and $R_g(t)$.

The effective rainfall $R_n(t)$ can be determined with the storage $S_u(t\text{-}1)$ in Tank II and the net rainfall. D_{16} and D_{50} are defined as the effective top-soil depths in which the ratios of the contributing area are equivalent to 16% and 50%, respectively. Then, the standard deviation is:

$$s = \log(D_{50}/D_{16})$$

The variable x is:

$$x = \log\{[S_u(t-1)+R_n(t)]/D_{50}\}/s$$

The ratio of the contribution area, m, is:

$$m = \int_{-\infty}^{x} \frac{1}{\sqrt{2p}} \exp\left(-\frac{x^2}{2}\right) dx$$

Finally, $R_e(t) = m \times R_n(t)$

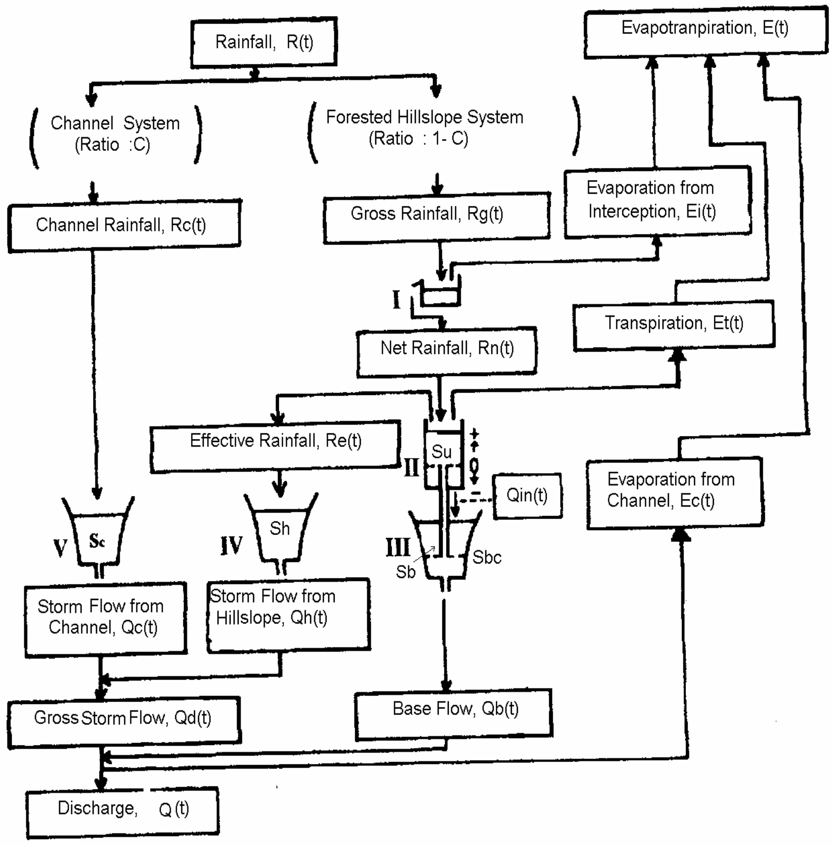

Figure 2 - Flowchart of HYCYMODEL

Tank III, IV and V represent the groundwater system, the subsurface water system and the channel system which determine the base flow $Q_b(t)$, the subsurface flow on hillslope $Q_h(t)$ and the direct runoff in channel $Q_c(t)$, respectively. In Tank II, III, IV and V, the relation between the storage S and the discharge Q is expressed with the storage function, i.e.

$$S = KQ^P$$

where K and P are the storage function parameters. For Tanks II, III, IV and V, K and P are defined K_u and P_u, K_b and P_b, K_h and P_h and K_c and P_c, respectively. As Tanks IV and V form the direct runoff, the values of P_h and P_c are 0.6. As Tank II has the linear phenomenon, the value of P_u is 1.0. Following the suggestion of FUKUSHIMA (1988), the value of P_b is 0.1.

The transpiration ratio is:

$$E_t(t) = Delta\{P_{ta} + P_{tb} \cdot \sin[30^o - (I - IG)]\}$$

where $Delta$, P_{ta}, P_{tb} and IG are the parameters and I is the monthly number (1 to 12) corresponding to January to December. Transpiration during a drought decreases when the storage of Tank II smaller than S_{bc}. The critical discharge for transpiration Q_{bc} corresponds to S_{bc}. The evapotranspiration $E(t)$ is the sum of $E_i(t)$, $E_t(t)$ and the channel evaporation $E_c(t)$.

2.3 - Water balance analysis

KOBIYAMA & DUARTE (1997) confirmed the applicability of the model to hydrological processes of the Cubatão-Sul catchment and proposed the values of the model parameters listed in Table 1. The results obtained through the simulation of the 11-years hydrograph with these values permitted to analyze the mean annual water balance for the period 1974-1984.

Parameter	Value	Parameter	Value	Parameter	Value
C	0.030	K_h	28	AI	1.872
D_{16}	10	K_c	2	P_{ta}	39
D_{50}	66	P_b	0.1	P_{tb}	15
K_u	20.1	Q_{bc}	1.30	IG	10
K_b	4294	AG	0.964	$Delta$	1

(From KOBIYAMA & DUARTE (1997))

Table 1 - Values of the model parameters for the Cubatão-Sul catchment.

In this study, the water balance is expressed as $R = E + Q + ds$
where R is the rainfall, E is the evapotranspiration, Q is the discharge and dS is the change of soil-water storage. By the nature of the HYCYMODEL, E consists of evaporation due to interception E_i, transpiration E_t and the evaporation from the channel E_c and Q of the base flow QB, the direct runoff from hillslope QH and the direct runoff from channel QC.

3 - RESULTS AND DISCUSSION

Figure 3 shows the components of the total discharge. Among the total discharge, the mean value of the direct runoff for the period 1974-1984 is 29.34% with the channel flow 5.29% and the runoff from the hillslope 24.05%. On the other hand, the mean value of the base flow is 70.66%, which agrees with HEWLETT (1982) in which about 70% of the total discharge is usually base flow in mountainous regions.

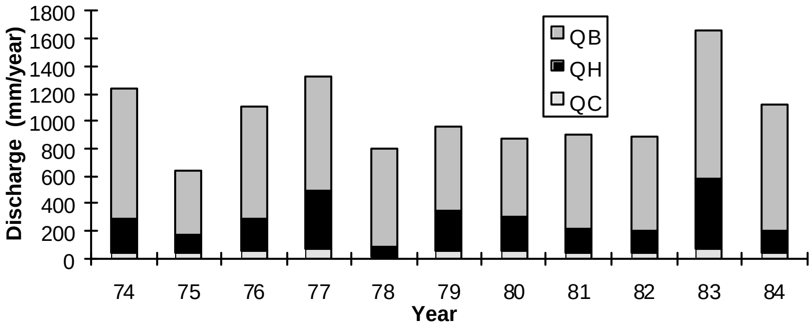

Figure 3 - Components variation of discharge.

The values of ratios of the transpiration, the evaporation by interception and the evaporation from the river to the total evapotranspiration are 60.92, 35.17 and 3.91%, respectively (Figure 4).

According to FUJIEDA et al. (1997), the annual mean value of the transpiration is equal to that of the evaporation by interception in the Serra do Mar, São Paulo State. Compared with this, the ratio of transpiration in the Cubatão-Sul watershed is larger. It means that, when forest area is reduced, the discharge would increase.

From the data of Figures 3 and 4, the ratios of the total discharge and the total evapotranspiration on the annual rainfall are 56.74% and 42.45%, respectively (Table 2). The soil-water storage change is +0.81% and could be negligible. The mean discharge of the Cubatão river was calculated 12.49 m^3/s.

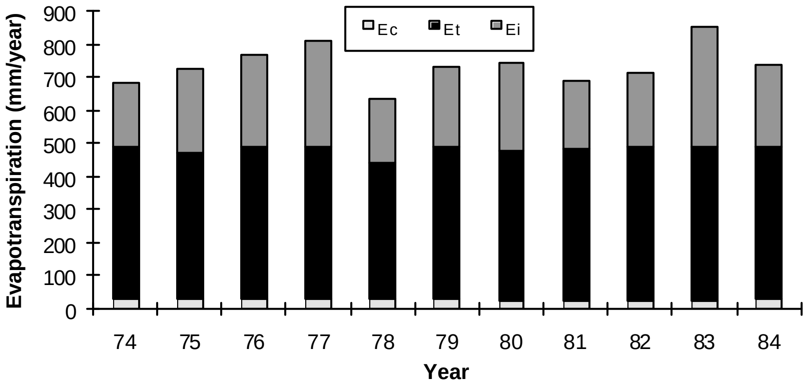

Figure 4 - Components variation of evapotranspiration

Component	**(mm)**	**(%)**
Rainfall, *R*	1712.69	100.0
Total discharge, *Q*	971.8	56.74
Direct runoff, QD	265.12	16.65
Direct runoff from hillslope, *QH*	51.38	3.00
Direct runoff from channel, *QC*	233.74	13.65
Base flow, *QB*	686.68	40.09
Evapotranspiration, *E*	726.91	42.45
Evaporation of interception, E_i,	255.59	14.93
Transpiration, E_t	442.91	25.86
Evaporation from the channel, E_c.	28.41	1.66
Change of the soil-water storage, *dS*	+13.9	+0.81

Table 2 - Mean annual water balance

Figure 5 demonstrates the relations of the discharge *Q* and the evapotranspiration *E* to the rainfall *P*. When the rainfall increases, the increasing rate of *Q* is larger than that of *E*. In the case that *P* is larger than 1300 mm/year, $Q > E$ and, in the other case, *E* could be larger than *Q*. As the transpiration is high and about 60% of the evapotranspiration, the deforestation in the Cubatão-Sul watershed could make the rainfall value, where two lines cross in Figure 5, smaller than 1300 mm/year.

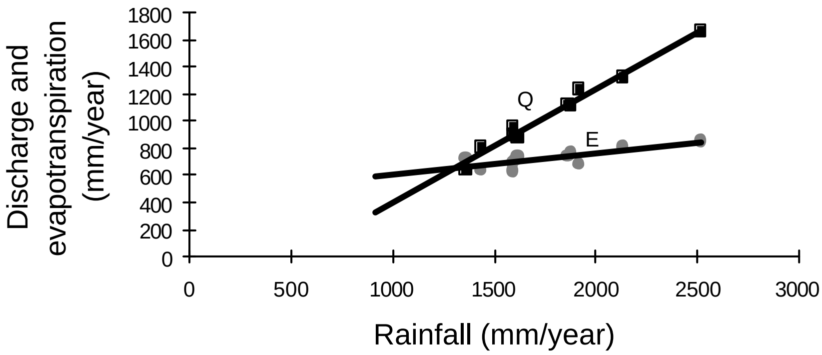

Figure 5 - Relation of discharge and evapotranspiration with rainfall.

4 - CONCLUSION

The annual water balance of the Cubatão-Sul watershed was estimated with the HYCYMODEL and the data observed at the hydro-meteorological station for the period 1974-1984. The annual discharge and the evapotranspiration are approximately 57% and 43%, respectively.

The base flow is about 71% of the total discharge, which agrees with the data of HEWLETT (1982). The high ratio of transpiration to the evapotranspiration implies that, if forested area decreases, the discharge will increase.

The increasing rate of the discharge is larger than that of the evapotranspiration when the rainfall increases. When the annual rainfall is more than 1300 mm, the discharge is always larger than the evapotranspiration.

These results will be useful for establishment of the water resources management and land use manual for the Cubatão-Sul watershed.

5 - ACKNOWLEDGMENT

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