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HIDROLOGIA DE UMA MICROBACIA COM COBERTURA DE FLORESTA DE EUCALIPTO COM 50 ANOS DE IDADE NA ESTAÇÃO EXPERIMENTAL DE ITATINGA, ESTADO DE SÃO PAULO

The hydrology of a small catchment covered with 50-year old eucaliptus plantation in the Itatinga forest experimental station, State of São Paulo

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RESUMO: O presente estudo consistiu da análise dos 3 anos iniciais de dados hidrológicos obtidos desde abril de 1991 em uma microbacia localizada na Estação Experimental de Ciências Florestais da ESALQ/USP, em Itatinga, São Paulo. A área da microbacia é de 68,2 ha, a qual foi reflorestada com *Eucalyptus saligna* por volta de 1944. A precipitação média anual é de 1635 mm, e a temperatura média anual é de 19,4 ^{0} C. A precipitação foi medida por meio de um pluviógrafo e dois pluviômetros. Para o monitoramento da vazão foi instalada uma calha tipo "H"de 45 cm, na parte final de uma seção de controle construído ao longo de um trecho retilíneo de 2 m do riacho. A variação da altura d'água na calha foi registrada continuamente por meio de um linígrafo modelo Stevens, de rotação semanal. Amostras semanais da água da chuva e do riacho foram coletadas para efeito de análise de parâmetros de qualidade da água, assim como das concentrações de Ca, Mg, K e Na. Os resultados mostraram um balanço hídrico anual, como valor médio para o pe-ríodo, com os seguintes valores de precipitação (P), deflúvio (Q), e evapotranspiração (P - Q): 1635 mm, 551 mm e 1084 mm, respectivamente. As medições realizadas no Tanque Classe A deram como resultado da evapotranspiração potencial para a região o valor médio anual de 1138 mm. Os resultados dos parâmetros físicos de qualidade da água situaram-se dentro de valores normais para águas naturais de boa qualidade. As concentrações de sedimentos em suspensão equivaleram a uma perda média anual de solo de 0,28 ton.ha^{-1}. O balanço geoquímico dos nutrientes estudados foram, respectivamente para entrada via precipitação e saída via deflúvio, em kg.ha^{-1}.ano^{-1}, para Ca, Mg, K e Na: 4,1, 1.3, 3.7, e 1.2; 4.9, 2.4, 1.4,e 1.4. A análise de hidrógrafas selecionadas ao longo do período mostrou um valor médio da relação Escoamento Direto/Precipitação = 0,024.

PALAVRAS-CHAVE: Monitoramento de Microbacia, *Eucalyptus saligna*, Qualidade da água, Balanço hídrico.

ABSTRACT: This study consisted of the analysis of three years of hydrologic data, which began in April 1991, for a small catchment located in the Municipality of Itatinga, State of São Paulo. The catchment has an area of 68.2 ha, and was planted with *Eucalyptus saligna* back in the 1944. Average annual rainfall and temperature are 1635 mm and 19.4^{0} C, respectively. Precipitation was measured with one recording gage and two non-recording

gages. Streamflow was monitored using a "45-cm type "H flume, which was installed in the downstream end of a 2-m long artificial, rectilinear control section, and the stage was continuously monitored with a Stevens stage recorder, with weekly rotation. Weekly samples of precipitation and streamflow were also collected, which were analyzed for Ca, Mg, K and Na, as well as for physical water quality parameters and suspended sediment concentrations. Results showed an average annual water balance for the three-year period as follows: Precipitation (P) = 1635 mm; Streamflow (Q) = 551 mm; Water Loss (P - Q) = 1084 mm. Class A pan evaporation measurements showed an average value of 1138 mm per year. Water quality parameters remained well within the range of variation of natural, good quality, waters. Suspended sediment loads amounted to a total soil loss of about 0.28 ton/ha/year, as average for the three study years. The geochemical balance of nutrients showed the following results, in terms of flux density ($kg.ha^{-1}.yr^{-1}$) of Ca, K, Mg and Na. Precipitation inputs: 4.1, 2.7, 1.3, 1.2; Streamflow outputs: 4.9, 1.4, 2.4, 1.4. The analysis of selected streamflow hydrographs for the study period showed an average catchment response, in terms of direct stormflow runoff / Precipitation, of 0.024.

KEYWORDS: Catchment Monitoring, *Eucalyptus saligna*, Water quality, Water balance.

INTRODUCTION

Eucalyptus plantations are the center of a very debated controversy in many parts of the world, mainly over environmental and ecological effects of large-scale industrial plantations.

Within this controversy, water consumption is by far the most polemical aspect, and there is a general belief that eucalypts dry up the soil, leading, in the long run, to the destabilization of the water cycle.

A comprehensive review about the environmental impacts of the eucalypts has been published recently by Lima (1993), and recent results of a very broad cooperative programme of field studies about the growth and water use of eucalypt plantations can be found in Calder et al.(1992).

In this paper we examine the results of the first three years of hydrologic measurements of an experimental catchment covered with the regrowth of an old eucalypt forest planted about 50 years ago.

Experimental catchments as a suitable methodology for the study of water and nutrient budgets of forest ecosystems have been proved useful in many studies conducted in different countries since the beginning of this century (Hibbert,1967; Bosch & Hewlett, 1982; Likens et al., 1977; Likens,1985). As an "excellent example of a geomorphological open system" (Gregory & Walling, 1973), the catchment renders itself very adequate for the global evaluation of the land use impacts on water con-sumption, water quality and nutrient budgets. In this context, it is particularly suitable for the long-term monitoring of the influence of forest management on the catchment water balance. This is precisely the case of the preoccupation with water consumption implicit in the eucalypt controversy.

Although there are several catchment results dealing with forest plantations in the literature (Lima et al., 1996), only a few such studies can be found with eucalypt plantations, worldwide. A pioneer study of the effect of eucalypt plantation at the catchment level was conducted in South Africa (Van Lill et al., 1980), in a 26-ha catchment originally covered with savanna. Other similar studies then

followed: (David et al., 1986; Samraj et al., 1988; Sharda et al., 1988; Bosch & Smith, 1989). In general, these studies examined the hydrological effects of the initial 5 to 10 years of the plantation growth, which are characterized by a decrease in the catchment water yield, as has been also encountered in similar studies with different tree species (Lima, 1993).

As stated by Van Lill et al.(1980), their data revealed that the annual rate of water yield decrease began to stabilize after the fifth year of the plantation, in proportion with the stabilization of the rate of tree growth.

Therefore, it is interesting to analyse the hydrological behaviour of a catchment, in terms of water balance, water quality and nutrient cycling, which has been under eucalypt plantation for so long a period.

THE STUDY AREA

The experimental catchment is part of the Itatinga Forest Experimental Station, of the University of São Paulo, which is located in the municipality of Itatinga, in the central part of the State of São Paulo, at latitude of 23^0 02'S, and longitude of 48^0 38'W.

Mean altitude is about 830 m and topography is generally undulating, with slopes of up to 10 - 15 %. Soils of the area are very deep and vary from sandy to clayey, formed from altered sandstones. The catchment is of the 2nd order, and has an area of 68.2 ha, and drains perennially in a general NW direction.

Average annual precipitation is about 1635 mm, and mean annual temperature is around 19.4^0 C. Thornthwaite water balance (Thornthwaite & Matter, 1955) shows annual potential evapotranspiration of 877 mm. June, July and August are the driest months, when there is some soil moisture utilization, but practically no water deficit.

Eucalyptus saligna was planted around 1944. From 1947 to 1957 the area was logged for firewood production, after which the sprouts were left to grow for selective extraction of larger trees for the production of railroad sleepers, which was stopped in 1978. The present condition is characterized by an understocked coppice, with total, surveyed volume of about 135 m^3/ha, and a dense understory of natural, herbaceous vegetation.

MEASUREMENTS

Measurements of precipitation, streamflow, and water quality have been taken since April 1991 as part of a broader and longer research project, with the purpose of attempting to establish a self-calibration procedure for the catchment, which will be followed by the hydrologic monitoring of some prescribed forest treatment (Scardua, 1994).

Precipitation is being measured by one recording rain gage and three non-recording gages. Weekly samples of rain water are collected on a device similar to the one developed by Coutinho (1979). Other climatic measurements include Class A pan evaporation, air temperature, wind and relative humidity.

Streamflow is being monitored in a stream-gaging station which includes a pre-fabricated, 45-cm "H" type flume, installed at the downstream end of a 2-m long artificial control section, and a Stevens water-level recorder. The stream gaging station is serviced weekly, when a grab sample of the stream water is taken at the flume for chemical analysis. The station is also provided with a semi-automated collecting system for sampling stream water in two different levels of the stage hydrograph (Knisel Jr. et al., 1971).

The weekly samples of rain water and stream water were routinely analysed for Ca, Mg, K and Na, turbidity, conductivity and pH, according to standard laboratory procedures (APHA, 1975). Suspended sediments in streamflow were also analysed by filtration through a 0.45 μ membrane.

RESULTS AND DISCUSSION

The average monthly values of precipitation and streamflow for the three-year period are given in table 1, for the water year April-March.

Table 1:
Average monthly values of precipitation (P), and streamflow (Q) for the three-year period.

Médias mensais de precipitação (P), do deflúvio (Q) para o período de 3 anos.

MONTH	P (mm)	Q (mm)
April	138	47
May	91	50
June	49	43
July	22	39
August	37	37
September	138	41
October	135	40
November	111	36
December	161	43
January	279	45
February	273	68
March	201	62
ANNUAL	1635	551

The precipitation data of the study period was found to be consistent, using double-mass analysis, with the regional, historical record.

As given in table 1, the ratio between the annual values of streamflow and rainfall ($\Sigma Q / \Sigma p$) is equal to 0.337, wich is similar to the water balance measured in other catchment experiments (Bosch & Hewlett, 1982; Leopoldo et al., 1992).

Neglecting the change in storage, the simplied water balance equation of the catchment can be written as

$$ET = P - Q$$

wich, for the annual average results shown in table 1 gives the following value for the average annual catchment evapotranspiration: ET = 1084 mm.

As a comparison, the adjusted Class A pan evaporation for the area was found to be 1138 mm, which is practically similar to the mass balance value of the catchment evapotranspiration, and slightly higher than the Thornthwaite estimate of 877 mm.

The arrangement of the water balance data according to the water year minimizes the changes in storage, but part of the difference may still be attributed to this aspect. Nevertheless, the long-term catchment water balance is apparently well within the climatic mean.

Flow duration curve analysis showed that the catchment presented, for the study period, an average daily streamflow of 1.5 mm, equivalent to an average daily discharge of 11.8 l/s, which occurred during 38 % of the time. The median value (50% of the time) was 1.31 mm, equivalent to 10.3 l/s. The minimum daily streamflow was 0.4 mm, equivalent to a minimum daily discharge rate of 3.2. l/s.

Stormflow analysis is also convenient for the evaluation of the hydrologic conditions of a catchment. Table 2 shows the compilation of selected stormflow hydrographs which occurred during the study period, in terms of rainfall characteristics, total volume, duration and peak flow of stormflow, as well as its partition between base flow and direct runoff.

It can be observed in table 2 that the average value of the ratio direct runoff / rainfall is 0.024, that is, in general only 2.4% of the rainfall volume leaves the catchment as direct runoff, implying that most of the rainfall infiltrates in the soil. The range of variation of this ratio in table 2 is from 1.3 to 4.9%.

As reviewed by Lima (1989), the direct runoff of forested catchments is, in general, mostly composed by subsurface processes. Therefore, the occurrence of surface runoff in the study catchment, if any, is practically similar to what can be found in catchments well protected with undisturbed forest cover.

Table 2:
Tabulation of select stormflow hydrographs for the study period, in terms of rainfall depth (P), duration (D), total stormflow volume (STR), duration of storm runoff (D), peak flow (PF), direct runoff (DR) and base flow (BF).

Tabulação da hidrógrafa de algumas chuvas durante o período de estudos em termos do total de chuva (P), duração da chuva (DP), volume total do hidrograma da chuva (STR), duração do hidrograma (DH), pico do hidrograma (PF), escoamento direto (DR) e escoamento base (BF).

DATE	**P (mm)**	**D (min)**	**STR (mm)**	**D (min)**	**PF (l/s)**	**DR (mm)**	**BF (mm)**
24/04/91	61.6	960	2.43	1250	54.35	1.30	1.13
24/06/91	20.4	220	1.29	1320	25.73	0.55	0.74
11/07/91	19.4	600	1.48	1380	33.35	0.51	0.97
08/08/91	18.4	150	1.16	1290	21.13	0.35	0.81
25/09/91	15.6	510	0.87	1290	10.38	0.65	0.22
02/10/91	18.8	810	1.21	1230	16.63	0.35	0.86
17/10/91	41.0	205	1.73	1260	50.22	0.90	0.83
09/11/91	35.6	180	1.31	1115	44.38	0.67	0.64
14/11/91	22.2	390	1.26	1380	19.48	0.39	0.87
22/12/91	13.6	540	1.67	1140	37.26	0.67	1.00
25/01/92	25.8	790	1.44	1580	22.60	0.50	0.94
28/01/92	12.8	30	0.74	1140	8.71	0.13	0.61
30/01/92	13.0	315	0.88	1140	14.23	0.22	0.66
04/03/92	62.1	230	3.36	1200	143.0	2.32	1.03
13/03/92	26.8	55	1.71	1220	65.56	0.81	0.90
24/03/92	43.4	720	2.14	1680	45.89	1.03	1.11
31/03/92	50.0	300	2.25	1260	79.13	1.00	1.25
01/05/92	23.8	420	1.84	1500	33.03	0.48	1.36
13/05/92	35.2	1180	2.31	1240	67.47	0.85	1.46
12/11/92	31.0	180	1.34	1110	35.93	0.42	0.92
20/01/93	25.4	360	1.31	1200	26.27	0.43	0.88
21/04/93	31.3	90	2.79	1215	107.23	1.04	1.75
05/05/93	13.0	120	1.96	1170	31.18	0.25	1.71
04/06/93	26.6	420	3.16	1380	47.44	0.76	2.40
18/06/93	21.0	320	2.54	1390	32.10	0.50	2.04
21/09/93	29.4	300	2.57	1310	44.01	0.74	1.83
23/10/93	34.8	600	2.36	1405	52.26	0.71	1.65
24/11/93	19.8	95	1.76	1165	34.62	0.58	1.18
05/02/94	105.8	800	6.21	1510	155.56	3.16	3.04

Another interesting aspect in connection with this stormflow discussion is related to the results of water quality parameters shown in figure 1, which were measured in two different levels of the rising limb of the stormflow hydrograph. As can be observed in these selected parameters, nutrient concentrations, turbidity, color and suspended sediments tend to increase during the stormflow, particularly due to surface runoff leaching. Therefore, the observed small values of direct runoff are also related to small nutrient and soil losses from the study catchment.

The average concentrations of the studied nutrients in the streamflow was generally greater than those found in precipitation, with the exception of potassium, which showed similar values for both precipitation and streamflow.

Table 3:

Precipitation inputs and streamflow outputs of the studied nutrients as annual average values for the three-year period

Entradas pela precipitação e saídas pelo deflúvio dos nutrientes estudados (médias anuais para o período de 3 anos).

NUTRIENT	INPUTS	OUTPUTS	BALANCE
	——— ($kg.ha^{-1}.yr^{-1}$) ———		
Ca	4.1	4.9	- 0.8
K	3.7	1.4	+ 2.3
Mg	1.3	2.4	- 1.1
Na	1.2	1.4	- 0.2

The results of turbidity and color were highly variable along the weekly samples, but pH and conductivity values were very consistent throughout the period.

Average values of suspended sediment concentrations for the three-year period amounted to a total soil loss of 0.28 ton per hectare per year.

Similarly, in terms of catchment geochemical budget, the calculation of nutrient inputs and outputs gave the results shown in table 3, which are very similar to results obtained in other catchment studies (Lima, 1993).

CONCLUSIONS

The present study consisted of a three-year period of monitoring of water balance, water quality, and nutrients geochemical budget of a small catchment covered with a 50-year old Eucalyptus plantation.

The overall analysis of the results showed that the catchment is in a very stable condition, presenting an annual water balance which is well within the climatic mean, as well as a very conservative storm runoff response.

Streamflow water quality parameters presented a seasonal pattern of variation, but the range were within the expected variation for natural, good quality waters.

The geochemical budget of the studied nutrients was very similar to the results obtained in other catchment studies, with a balance characteristic of stable catchments.

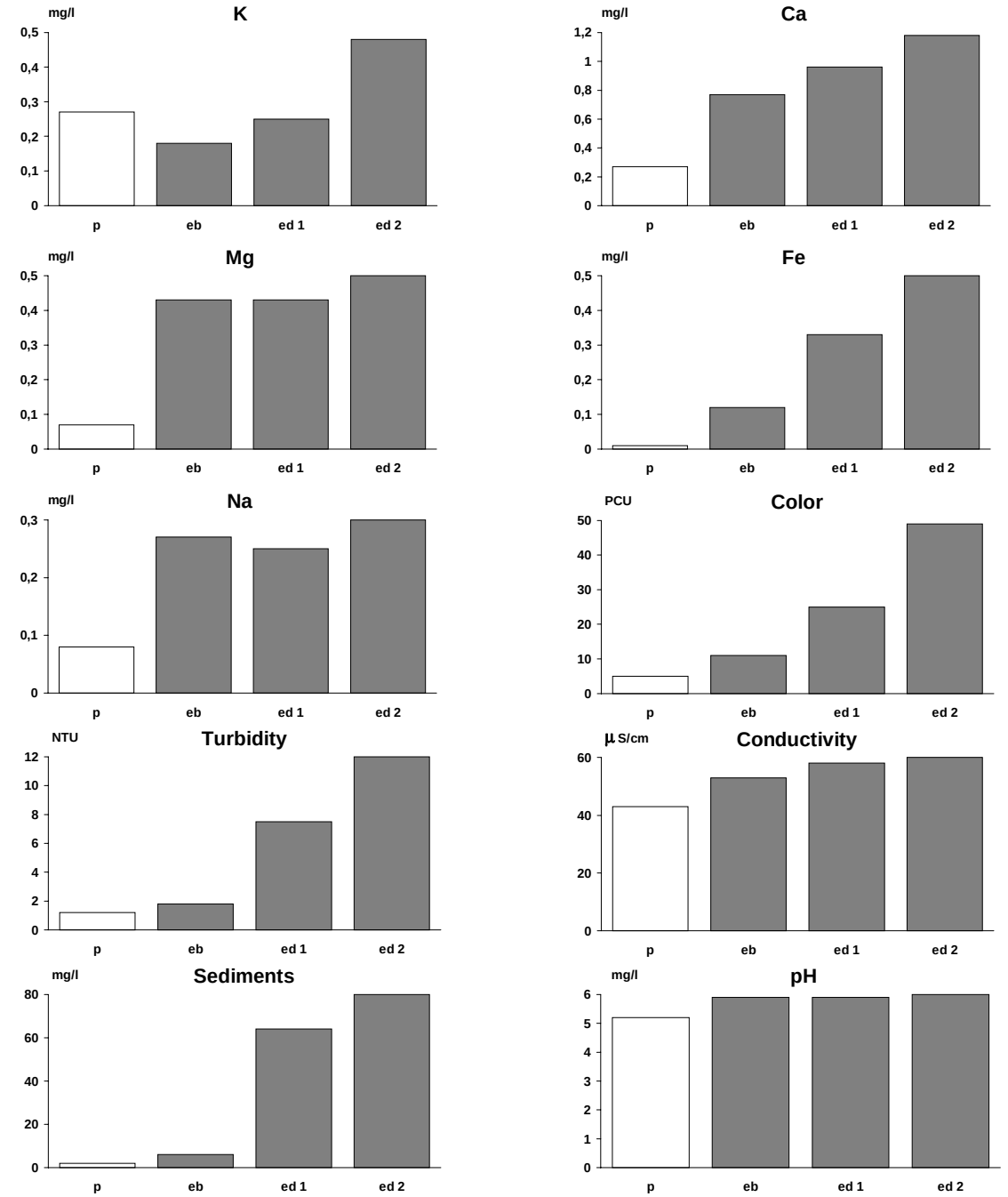

Figure 1:

Average annual concentrations of K, Ca, Mg , Na and suspended sediments, as well as values of turbidity, color, conductivity and pH, in samples of rain water (p) and stream water, in both base flow (eb) and direct runoff (two levels of the rising limb(ed1, ed2)). Annual values are average for the three years of the study period.

Concentrações médias anuais de K, Ca, Mg, Na e sedimentos em suspensão, e valores médios anuais de turbidez, cor, condutividade e pH para amostras de água da chuva (p), do escoamento base (eb), e escoamento direto em dois níveis do braço de ascensão da hidrógrafa (ed1 e ed2)

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