RICE IRRIGATION AT VACACAÍ RIVER BASIN: IMPACT AND REFLEX ON THE RECORDED SERIES OF FLOWS FROM THE FLUVIOMETRIC STATION

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INTRODUCTION

In southern Brazil, especially in Rio Grande do Sul and Santa Catarina states it is very common the cultivation of rice in the floodplain system, [Azambuja et al., (2004 apud AMARAL et al., 2005)].This cultivation is one of the larger users of water, but the total amount of water used at the irrigation is not an easy task to calculate because several variables may change the crops demand. The true amount of water needed for this cultivation is the one used by plants at the growing season. However, some of this water is lost by the soil-water surface evaporation, lateral flow (lateral movement of the underground water), percolation (vertical movement of the water beyond the root zone in its way to the water table), runoff over the dam as well as the loss from the irrigation channels, which may be minimized by the adequate use of the irrigation, but cannot be eliminated.

According to Embrapa (2005), in general, the water consume may achieve 2 l/s/ha during the irrigation season (80 - 100 days), representing from 13800 to 17000 m³/ha. However, there is not a unique value admitted as correct attributed to the water used in the rice irrigation. The utilization of systematic techniques reduces the use of the water resources by the rice crops.

This way, for the control process and decision regarding the water resources, the knowledge of the demand flows by users and the availability of water at rivers is very important.

This study aimed to demonstrate the effects the withdrawal of water causes in the recorded flows at fluviometric stations, utilizing statistics analysis and establishing a relationship between flow and precipitation through the use of a generalized linear model and the use of the method developed by Paiva et al. (2006 b) for the natural flow determination.

AREA OF STUDY

The study area is the Vacacaí Basin (Fig.1), which is located in Rio Grande do Sul State at the coordinates 29º 45'and 30º 45' South and 54º 30' and 53º 15' West, covering a total area of approximately 11,616 Km². Data of the basin soil use are in Table 1.

Figure 1 – Basin location

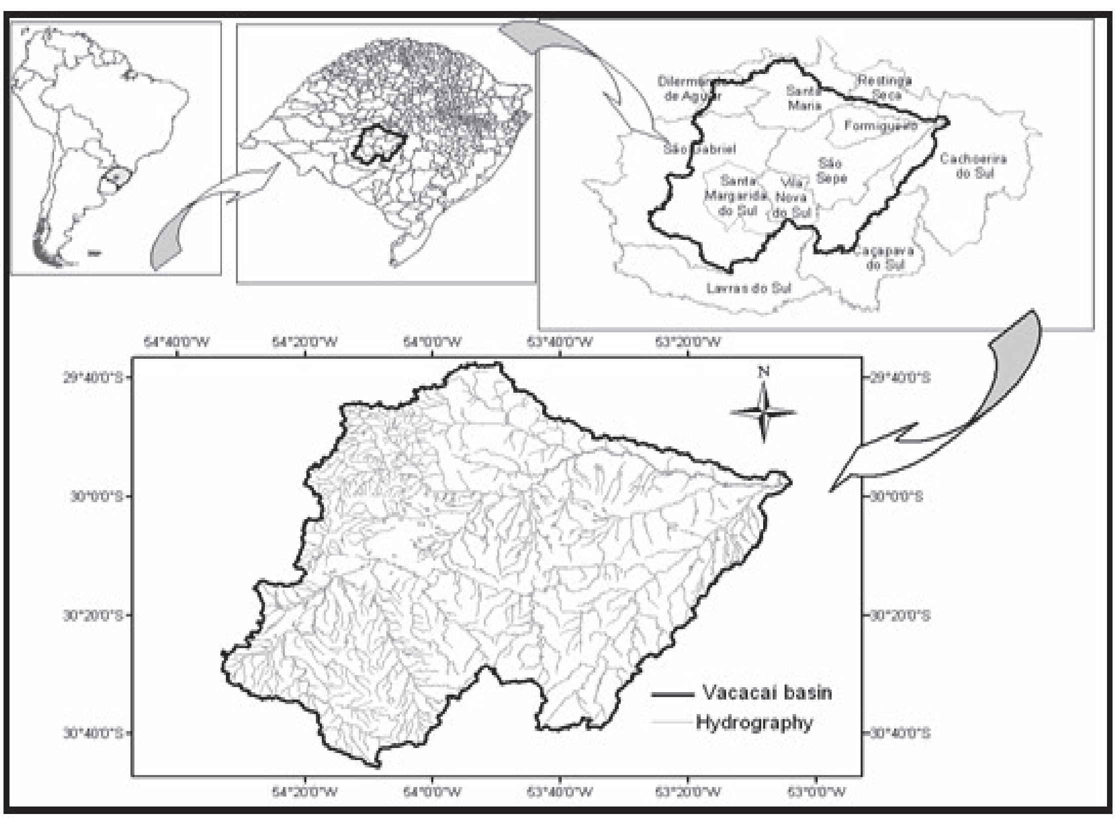


Table 1- Area and percentage of basin soil use

CLASS	AREA Km²	%
Water	151.74	1.31%
Developing Crops	828.8	7.13%
Developed Rive	936.4	8.06%
Vegetation	2597.3	22.36%
Field	6410.5	55.18%
Urban area	60.1	0.52%
Exposed soil	205.6	1.77%
Cultivation Soil	426.3	3.67%
Total	11616.7	

METHODOLOGY

Firstly, a generalized linear model was applied to verify if the water use for the rice irrigation showed reflex on the recorded flows at the fluviometric stations inside the basin. Then, the methodology developed by Paiva et al (2006 b) was applied to determine the natural flow.

Generalized Linear Model

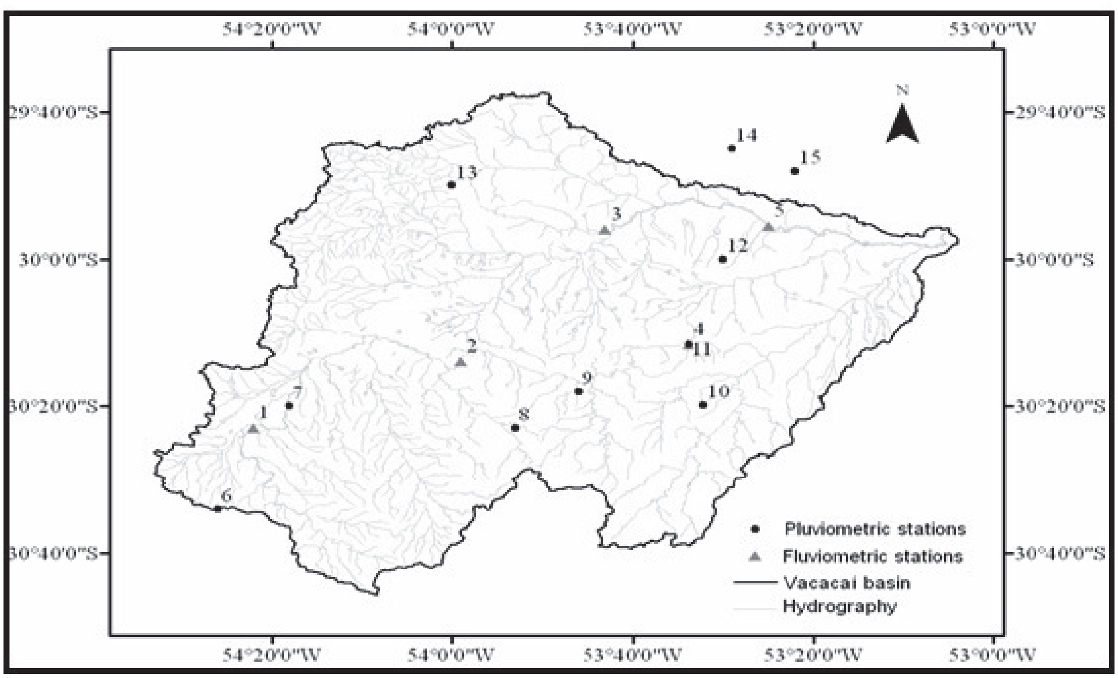
Historical series of rainfall and flow from the station obtained from website of the National Water Agency (Agência Nacional de Águas - ANA) were used. The series used are of the monthly flow average and total monthly precipitation. Analyses were made considered more than one precipitation station related to a flow station, so the arithmetic average of the total monthly rainfall of the rainfall station was used. Table 2 presents a summary identifying the stations and periods considered, and Figure 2 shows their location.

In order to make the regression and establishment of a relationship between the flow and precipitation, the generalized linear model was used because according to Paiva et al. (1999) just one type of a simple regression model is not adequate since (i) the changes in flow are much bigger when the rain increases, and (ii) the flow has always to be positive. Thus, data of the monthly flow versus the monthly precipitation were plotted and we observed that there was little relationship between flow and precipitation, as reported by Paiva et al (1999).

Tabela 2 - Stations used

Fluviometric Station				Pluviometric Station		Coincidence Period
N.	DNAEE Code	Rice Area Km²	% rice land use	N.	DNAEE Code	
1	85460000	47.4	6.4	6	3054006	1960 -1971
				7	3054010	
2	85480000	235.6	7.3	8	3053008	1971 -1979
				9	3053009	
3	85580000	493.6	8.2	13	2954002	1967 -1978
				12	3053005	
4	85623000	12.4	1.5	11	3053020	1986 - 2005
				10	3053022	
5	85600000	594.5	8.9	14	2953012	1957 -1977
				15	2953015	
				12	3053005	

Figure 2- Location of the stations in the Vacacaí Basin



For this reason, data were divided into two groups: i) data from the season without irrigation, April-October, and ii) data from the irrigation season November-March. Clearly, a strong evidence of a relation between the monthly flow and the monthly precipitation was observed when flow and precipitations are plotted in the months without irrigation. The next step was to analyze the two groups separated in order to try to adjust a statistic model that relates precipitation and flow. Then, regressions were made using the generalized linear model and the distribution combination and link function were tested in order to find out which one would give the best adjust.

The distributions analyzed were normal, Gamma and Poisson, as well as the logarithmic and identity link function. The combinations accomplished between the distribution and link function were, respectively (i) normal, logarithmic, (ii) normal, identity, which represents a simple linear regression, (iii) gamma, identity, (iv) Poisson, logarithmic, and (v) poisson, identity. When the models were adjusted to each of these groups separated, the coefficients b0 and b1 were found for the months with and without irrigation.

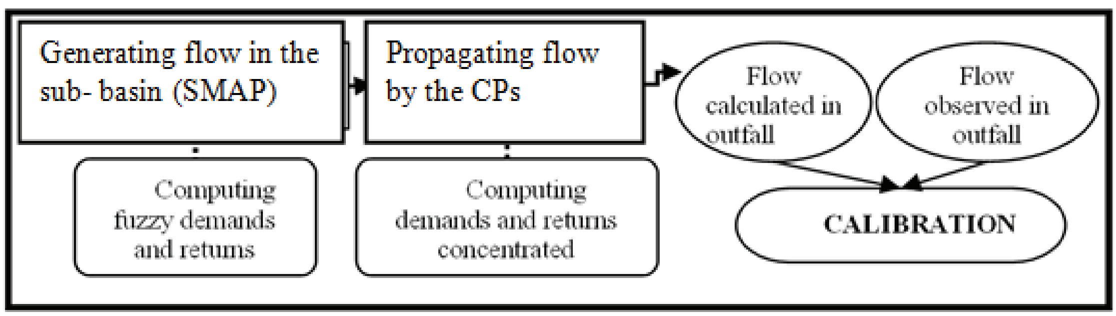
Then, the values of the coefficients found for the period of April-October were put into the model that estimated the values of the flow of the irrigation months aiming to verify if the estimated flows are bigger than the observed ones. According to Paiva et al. (1999), if that happens one reason may be related to the portion of water that is being withdrawn, in this case, by the specific use on rice irrigation and consequently the observed flows are underestimated real flow. Chi-square (X^2) test with 0.1% of probability was applied to verify if this is happening randomly or if there is any other factor leading to its occurrence.

Calculation of the Natural Flows

Calculations of the natural flows were made by the methodology proposed by Paiva et al (2006 b). In the model, the basin is simulated as a hydrological system composed of several sub-basins and characteristic points (CPs), which represent in a segmented manner, the drainage network. The CP location is chosen by the user, however, the choice of the place should consider the points which represent significant demands, reservoir outfalls and sub-basin outfall. (UFRGS,1998).

Figure3 shows schematically the general concept in which the sub-basins process the transformation from rain to flow using the SMAP model and at the outfall of each sub-basin, the demands and diffuse returns are discounted. The flow propagation and the discount of concentrated fuzzy demands and returns occur in the CPs.

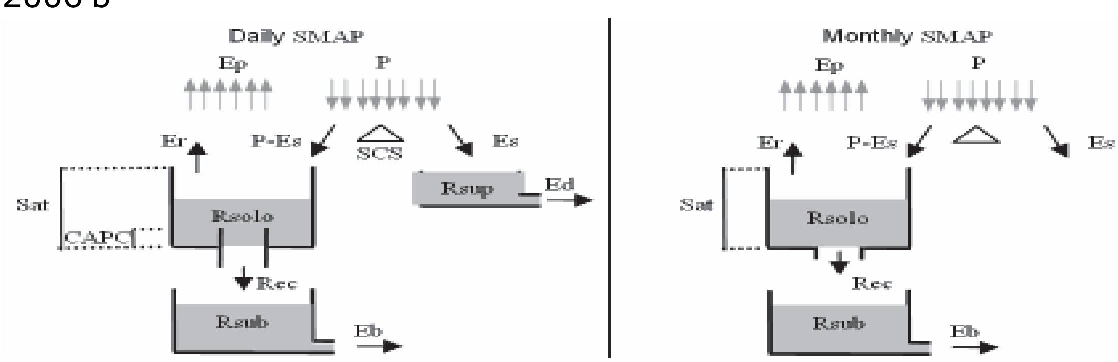
Figure 3- Layout of the proposed model. Font: Paiva et al. (2006 b)



Hydrological model SMAP (“Soil Moisture Accounting Procedure”)

The SMAP model proposed by Lopes et al. (1981) is a deterministic, conceptual, concentrated, rain-flow type hydrologic model, which has been widely used in Brazil due to its relative simplicity as showed in Figure 4. To apply this model it is not necessary to have large data series, and the few parameters are needed to calibrate it.

Figure 4 – SMAP Model structure. Source: Modified by Paiva et al 2006 b



In this paper the simulations are done in three different time intervals: flow generation at month level through SMAP monthly version and monthly propagation; generation of mean flows for 7 days through modifications to the SMAP monthly version to adequate it; and generation of daily flows through the daily version of SMAP and 7 day mean flow propagation.

The description of the model SMAP from the daily and monthly versions is based on the paper by Lopes (1999), Oliveira et al. (2006) and Paiva et al. (2006 b). The daily version of SMAP model uses the basin area (Ab), daily series of precipitations and potential evapotranspiration as input data, being that the adjustable parameters are: Sat, Ai, Capc, Crec, Kkt and K2t. The variables Tuin and Ebin describe the initial conditions of the basin and the coefficients Pcoef and Epcoef are utilized to adjust the precipitation and potential evapotranspiration, respectively.

To start the simulation with SMPA daily version the initial volumes for the reservoirs were:

$$\mathrm{Rsolo}_1 = \mathrm{Tuin} \bullet \mathrm{Sat} \quad (1)$$

$$\mathrm{R\,sup}_1 = 0 \quad (2)$$

$$\mathrm{Rsub}_1 = \frac{\mathrm{Ebin} \bullet 86{,}4}{\mathrm{Ad} \bullet (1 - \mathrm{Kk})} \quad (3)$$

Rsolo is the storage volume in the soil reservoir (mm), Tuin is the initial moisture content ($mm.mm^{-1}$), Sat is maximum storage volume at the soil reservoir (mm), Rsup is the storage volume in the superficial reservoir (mm), Ebin is the initial basis flow ($m^3.s^{-1}$), Ab is the basin area (Km^2) and Kk is the constant of recession from the basic flow.

The hydrological balance for the three hypothetical reservoirs are updated in each time window, according the equations 4 to 6

$$Rsolo_{i+1} = Rsolo_i + P_{i+1} - Es_{i+1} - Er_{i+1} - Rec_{i+1} \quad (4)$$

$$R\,sup_{i+1} = R\,sup_i + Es_{i+1} - Ed_{i+1} \quad (5)$$

$$Rsub_{i+1} = Rsub_i + Rec_{i+1} - Eb_{i+1} \quad (6)$$

Rsub is the storage volume in the underground reservoir (mm), P is the precipitation (mm), Er is the real evapotrasnpiration (mm), Es ,Ed and Eb are runoff, direct and basic, respectively (mm), Rec is the underground recharge (mm) and i is the time window, being all the variable in mm.

The transfer functions are described as:

1. The runoff separation is based on the SCS method (Soil Conservation Service of U.S. Dept. Agr.).

If P > Ai, then

$$S = Sat - Rsolo \quad (7)$$

$$Es = \frac{(P - Ai)^2}{(P - Ai + S)} \quad (8)$$

If not,

$$Es = 0 \quad (9)$$

Ai is the initial abstraction (mm) and S the potential abstraction (mm)

2. Real evapotranspiration

If P - Es > Ep, then

$$Er = Ep \quad (10)$$

If not,

$$Er = (P - Es) + (Ep - (P - Es)) \cdot Tu \quad (11)$$

Tu is the soil moisture rate (dimensionless) and Ep is the evapotranspiration.

3. Underground reservoir recharge

If Rsolo > $(Capc \cdot Sat)$, then

$$Tu = \frac{Rsolo}{Sat} \qquad (12)$$

$$Rec = Crec \cdot Tu \cdot (Rsolo - (Capc \cdot Sat)) \qquad (13)$$

If not,

$$Rec = 0 \qquad (14)$$

Crec is the recharge coefficient and Capc is the soil field capacity (dimensionless).

4. Direct runoff

$$Ed = Rsup \cdot (1 - k2) \qquad (15)$$

5. Basic runoff

$$Eb = Rsub \cdot (1 - kk) \qquad (16)$$

And

$$k2 = 0.5^{\frac{1}{k2t}} \qquad (17)$$

$$kk = 0.5^{\frac{1}{kkt}} \qquad (18)$$

K2 and Kk are the constant of recession from the direct and basic runoff, respectively, and K2t and Kkt represent the number of days that values of the direct and basic flows drop to half.

The total runoff is the sum of the direct and basic runoff

$$Q = \frac{(Ed + Eb) \cdot Ad}{86{,}4} \qquad (19)$$

For the monthly discretization of SMAP there is only the underground reservoir and the soil reservoir. The superficial reservoir is suppressed by the fact that its damping occurs in time intervals smaller than the month and the concept of soil field capacity is also suppressed, according to Lopes (1999). The input data of this version are: area Ab, monthly series of precipitations and potential evapotranspiration; Tuin and Ebin, variables which describe the initial conditions of the basin; the parameters Sat, Crec, and Kkt; and the coefficients of adjust of the precipitation and potential evapotranspiration Pcoef and Epcoef.

Next, only the main differences of the daily version are showed since the monthly version is quite similar. For the initialization of the model the initial moisture content and the basic flow at the beginning of the simulation are given by the equation 1 and 20

$$Rsub_i = \frac{Ebin \cdot 2630}{Ad \cdot (1 - kk)} \qquad (20)$$

The hydrological balance in the two hypothetical reservoirs is utilized in each time window according to the equations 4 to 6. The transfer functions are described as

$$Es = P \cdot Tu^{Pes} \qquad (21)$$

$$Er = Ep \cdot Tu \qquad (22)$$

$$Rec = Crec \cdot Tu^4 \cdot Rsolo \qquad (23)$$

$$Eb = Rsub \cdot (1 - kk) \qquad (24)$$

Tu is given by the equation 12, Kk by the equation 18, and Pes is a parameter of runoff (dimensionless).

The total flow is the sum of the superficial and basic runoff

$$Q = \frac{(Es + Eb) \cdot Ad}{2630} \qquad (25)$$

Methodology proposed by Paiva et al. (2006)

The model developed by Paiva et al. (2006 b) was based on the PROPAGAR system, which is one of core-applications from SAGBAH (Support system to watershed management) described by Viegas Filho & Lanna (2003).

In the model developed by Paiva et al. (2006 b), the SMAP model parameters for the sub-basins are calibrated from a series of flow in the basin outfall by a global optimization algorithm SCE-UA.

The relationship between the sub-basins and the CPs is given by the contribution matrix $MC_{nB \times nP}$ and the relation between the CPs, which indicates the river flow direction is given by the propagation matrix $MP_{nP \times nP}$, being nB and nP the total number of sub-basins and CPs. The matrixes $MC_{j,k}$ and $MP_{k,m}$ are composed of values of 0 or 1, being 1 attributed when the sub-basin j drains to the characteristic point k or when the characteristic point k contributes to the characteristic point m, if not the value assumed is 0.

Utilizing the flow series generated by SMAP, for each time window i, the flow for each sub-basin j is calculated by the equation 26, which represents the hydrological balance.

$$Qsub_{i,j} = Qsubnat_{i,j} - DD_{r,j} + DD_{r,j} \cdot RD_{r,j} \qquad (26)$$

where, Qsubnat is the natural flow effluent generated by SMAP ($m^3.s^{-1}$), Qsub is the flow effluent ($m^3.s^{-1}$), DD is the diffuse demand ($m^3.s^{-1}$), RD is dimensionless correspondent to the percentage of the diffuse demand and r is a relative index to the year period simulated, which in this case it was either a week or a month.

The calculation of the flow in the CPs to each time window initiates with the computation of the contributions for the sub-basins, utilizing the equation 27. Right after that, the propagation of flow is done through the characteristic points, as showed by the equation 28. When there is no reservoir at the CPs, the hydrological balance is made according to the equation 29.

$$Qpc_{i,k} = Qpc_{i,k} + MC_{j,k} \bullet Qsub_{i,j} \qquad (27)$$

$$Qpc_{i,k} = Qpc_{i,k} + MP_{m,k} \bullet Qpc_{i,m} \qquad (28)$$

$$Qpc_{i,k} = Qpc_{i,k} - DP_{r,k} + DP_{r,k} \bullet RP_{r,k} \qquad (29)$$

Qcp is the flow in the CP ($m^3.s^{-1}$), PD is the punctual demand ($m^3.s^{-1}$), RP is and dimensionless corresponded to the percentage of the punctual demand, and r is an index related to the fraction of the year simulated, which in this study was either a week or a month.

When there is a reservoir in the CPs, the equation 29 is replaced by the equation 30 and the storage volume is updated.

$$S_{i,k} = S_{i-1,k} + (Qpc_{i,k} - DP_{r,k} + DP_{r,k} \bullet RP_{r,k}) \bullet \Delta t - 1000 \bullet (Ep_{i,k} - P_{i,k}) \bullet A_{i,k} \qquad (30)$$

where

$$A_{i,k} = a \bullet \left(\frac{S_{i,k} + S_{i-1,k}}{2}\right)^{b} \qquad (31)$$

and if $S_{i,k} > S\max$

$$Qpc'_{i,k} = \frac{(S_{i,k} - S\max)}{\Delta t} \qquad (32)$$

where, S is the storage volume in the reservoir at the end of the time intervals (m^3), Ep is the potential evapotranspiration (mm), P is the precipitation (mm), “t is the time period of simulation (s), A is the area of a water reservoir, Smax is the reservoir maximum storage volume (m^3), and a and b are the relation constants between S and A.

The hydrological balance is done regardless the effects of the storage and attenuation of the flood waves in the rivers. Paiva et al. (2006 b) alert about the importance that the simulation time intervals used must be higher than the values where the adopted simplifications begin to generate significant errors in the results.

Data utilized

Due to the discontinuous of the hydrological data, it was not possible to use the same data series utilized when the generalized linear model was applied. Thus, for the calculation of the natural flow in the calibration and the model validation, data of precipitation from five pluviometric stations were used, being that, none of them presented a period larger than two days of flaw. Since the flaws were not in the same period, they were filled by the data from the stations that did not have flaws. The average precipitation of the basin was estimated through the Thiessen polygon method.

Data of potential evapotranspiration were obtained from Paiva et al. (2006 b). Both precipitation and potential evapotraspiration data were anticipated in a day since there was a difference in the time reading of these data and the flow data. The historical series of flows utilized were from the fluviometric stations: Ponte São Gabriel, Passo do Rocha, and São Sepé Montante. The hydrological information of the flows and precipitations as well as their period of utilization were obtained from the website of National Water Agency (Agência Nacional de Águas - ANA) and are showed in Table 3.

Table 3 – Stations

Name	Code	Kind	Utilized Period	Oparator
Granja Umbu	3054016	Pluviometric	Jan/96 – Dez/04	ANA
Ponte São Gabriel	3054018	Pluviometric	Jan/96 – Dez/04	ANA
Caçapava do Sul	3053022	Pluviometric	Jan/96 – Dez/04	ANA
São Sepé Montante	3053020	Pluviometric	Jan/96 – Dez/04	ANA
Passo dos Freires	3053017	Pluviometric	Jan/96 – Dez/04	ANA
Ponte São Gabriel	85470000	Fluviometric	Jan/96 – Dez/04	ANA
Passo do Rocha	85480000	Fluviometric	Jan/96 – Dez/04	ANA
São Sepé Montante	85623000	Fluviometric	Jan/98 – Dez/04	ANA

To apply the methodology developed by Paiva et al. (2006 b) it is necessary to determine the amount of water consumed by the water resources users. The demand for the rice crop irrigation was the only demand used. This methodology was applied by the fact that the rice crop demand is superior to other types of demands.

The demand was calculated indirectly through images from satellites, where the geographic location of the pumping stations, irrigated area of the crop and an average of consume per hectare were determinate. The determination of this consume comes from the attempts of adjustment with a change in the demand, reaching the value of 1000m³/ha of water consume.

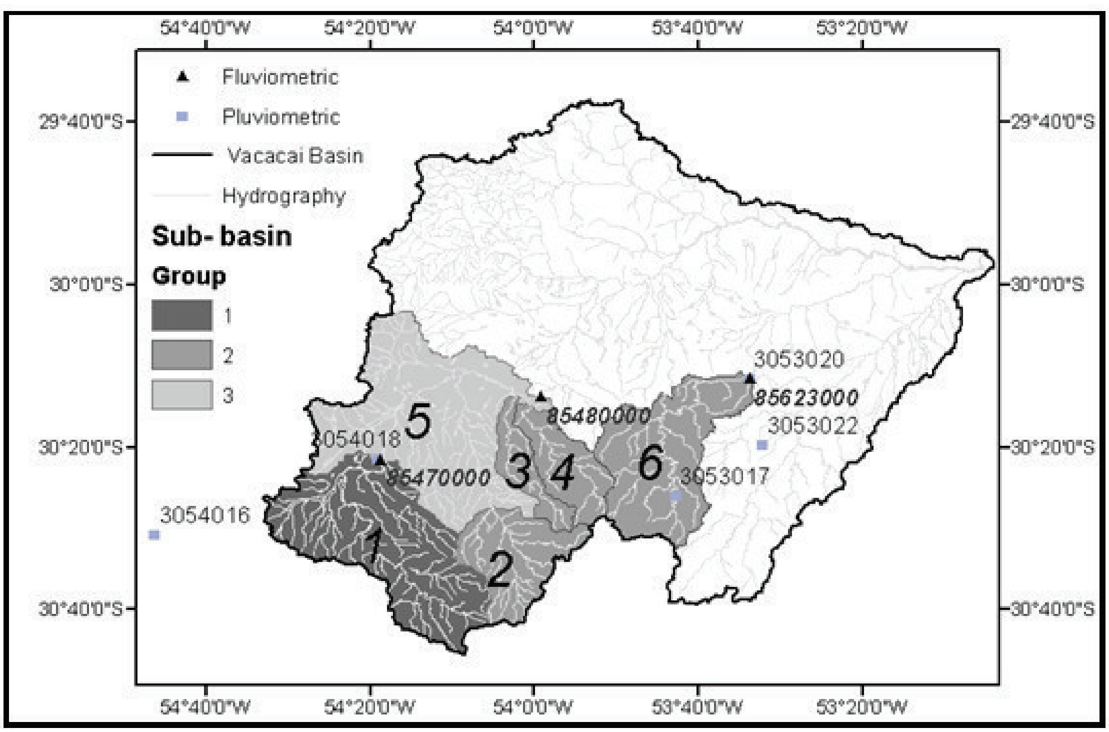
Due to the uncertainty on the daily variability of the water withdrawal, characteristic values for the demand in each time interval of the year are considered and those are repeated annually. However, for this study the returns for diffuse as well as for concentrated demands are nulls.

Model SMAP parameter calibration

The model SMAP parameter calibration in the sub-basins was performed through the global optimization algorithm SCE-UA from an observed flow series in the outfall of the basin. Although there were flow stations in the intermediate sub-basins their data were not computed at the objective function. The objective function utilized for calibration was Nash and Sutcliffe (E_{NS}). For the quality evaluation on the model adjustment the coefficients of determination (R^2) and the errors in the total volume ("V) were calculated.

The idea was to simulate the model utilizing the strategy of grouping the sub-basins in groups with similar characteristics (type of soil, land use and altimetry). This way, all the sub-basins in the same group would assume the same values to calibrate the parameters. Group 1 has predominately Argisols, field followed by vegetation and developed rice, totalizing 5% of the sub-basins area. In Group 2, predominately Neosols, field followed by vegetation and with developed rice, totalizing 1% to 2.9% of the sub-basin area, and Group 3 predominately Argisols, field followed by vegetation and with developed rice, totalizing 7% to 8.5% of the sub-basin area. Figure 5 shows the sub-basins and the hydrological stations utilized in the simulations.

Figure 5 - Sub-basins and hydrological stations



RESULTS

Generalized Linear Model

The distribution combinations and link function of the type Normal, logarithm and Poisson, were the ones who presented the worst results for both considered periods (fact observed for all the stations). One explanation may be that the logarithm link function is not appropriate for this data configuration. Also, it was possible to note that when a simple regression (Normal, identity) was used, the calculated flow assumed negative values to some of the stations, as observed by Paiva et al. (1999). So, it is possible to affirm that the combinations gamma, identity and Poisson were the ones who assumed the best results. To identify if the water abstraction in the crops reflects in the series of observed flows in the fluviometric posts, a test Chi-Square was applied.

For that, it was necessary to use a real value interval, which in this case is the number of times that the calculated flow for the months of November to March, obtained through the coefficients found in the regression for the months of April to October, was bigger than the observed flow in the fluviometric stations. The utilization of expected values is also needed in order to have these flows overcame. In the study, the probability of occurrence of bigger flows or smaller ones was assumed as the same, that is, the expected values were considered as half of the total number of months. Table 4 shows the obtained results through this test.

The admitted probability to compare the calculated values was 0.1%. Thus, all values obtained with the Chi-Square test for the regressions, which presented probability inferior than 0.1%, can be considered not occurring randomly. Table 4 shows that the probability calculated by the Chi-Square test is higher than 0.1% in the stations 3 and 4. This result suggests that the underestimated values of the observed flows in the fluviometric posts occur randomly, i.e., they do not suffer influence of the water withdrawal.

Table 4 - Chi-Square test values

Chi-Square test probability of 0,1%									
N°	Code DNAEE	N°	Code DNAEE	Distribution, Link function	N° Months of the serie	N° months with bigger flow	N° months with bigger flow if p= 50%	X²	pcal
1	85460000	6	3054006	Normal,logarithmic	57	29	28,5	0,02	8,95E-01
				Normal, identity		47		24,02	9,55E-07
		7	3054010	Gama, identity		48		26,68	2,40E-07
				Poisson,logarithmic		29		0,02	8,95E-01
				Poisson, identity		52		38,75	4,81E-10
2	85480000	8	3053008	Normal,logarithmic	45	6	22,5	24,20	8,68E-07
				Normal, identity		39		24,20	8,68E-07
		9	3053009	Gama, identity		40		27,22	1,81E-07
				Poisson,logarithmic		6		24,20	8,68E-07
				Poisson, identity		40		27,22	1,81E-07
3	85580000	13	2954002	Normal,logarithmic	76	6	38	53,90	2,12E-13
				Normal ,identity		***49***		***6,37***	***1,16E-02***
		12	3053005	***Gama,identity***		***50***		***7,58***	***5,91E-03***
				Poisson,logarithmic		6		53,90	2,12E-13
				Poisson, identity		***50***		***7,58***	***5,91E-03***
4	85623000	11	3053020	Normal,logarithmic	135	8	67,5	104,90	1,29E-24
				Normal, identity		***81***		***5,40***	***2,01E-02***
		10	3053022	***Gama, identity***		***85***		***9,07***	***2,59E-03***
				Poisson,logarithmic		7		108,45	2,14E-25
				Poisson, identity		***83***		***7,12***	***7,63E-03***
5	85600000	14	2953012	Normal logarithmic	104	13	52	58,50	2,03E-14
				Normal, identity		86		44,46	2,59E-11
		15	2953015	Gama, identity		88		49,85	1,66E-12
		12	3053005	Poisson,logarithmic		13		58,50	2,03E-14
				Poisson, identity		88		49,85	1,66E-12

The explanation for the station 4 is that there are very few rice crops in the sub-basin area that contribute to this station (Table 4). However, for the station 3, as the hydrological data period is not the same as the land use study period of the basin, there are no clear data that explain this fact. The stations 1, 2 and 5 present the calculated probability by Chi-Square test lower than 0.1% in the Gama, identity and Poisson, identity indicating that the recorded flows in the fluviometric posts are underestimated not randomly, that is, they suffer influence of the water abstraction.

Natural Flows

The intermediate sub-basins that have a fluviometric station in their outfall were calibrated. In this context, the sub-basin 1 was calibrated utilizing data from Jan/96-Dez/04 of the Ponte São Gabriel. Table 5 shows the evaluation of the adjustment quality and Figures 10, 11 and 12 present the calculated and observed hydrograph for the three simulated intervals.

Although the daily simulation represents in more details the hydrological cycle, the simulation with the monthly generation and propagation of the average flows had the best parameter calibration result for the model SMAP.

Table 5 – Evaluation tack calculated and observed hydrograph - Station Ponte São Gabriel

Discrimination	Calibration Jan/1996 - Apr/2004		
	R^2	E_{NS}	ΔV
Daily/ 7days	0.47	0.47	-6.47%
7 days	0.53	0.52	7.51%
Monthly	0.68	0.67	5.42%

It is possible to observe that when Figures 10, 11 and 12 are compared, the monthly simulations damp the maximum flows, fact that may be the cause for the best values in the index that evaluate the model. It is important to note that the model did not manage to represent the high flow very well, mainly the peak flow that occurred in December 1997.

Figure 10 – Observed and calculated flow in the fluviometric station Ponte São Gabriel. (85470000) – interval of simulation daily/7days – period 01/01/1996 to 19/04/2004.

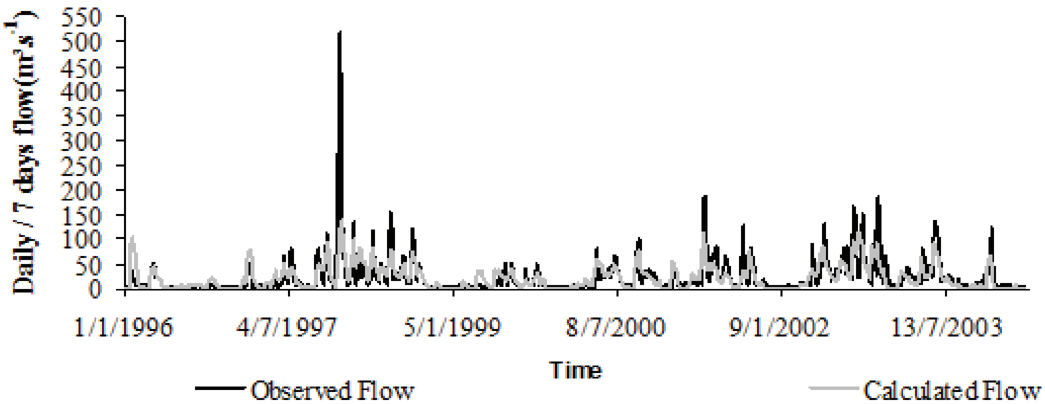


Figure 11 – Observed and calculated flow in the fluviometric station São Gabriel Bridge. (85470000) – interval of simulation 7days – period of 01/01/1996 to 19/04/2004.

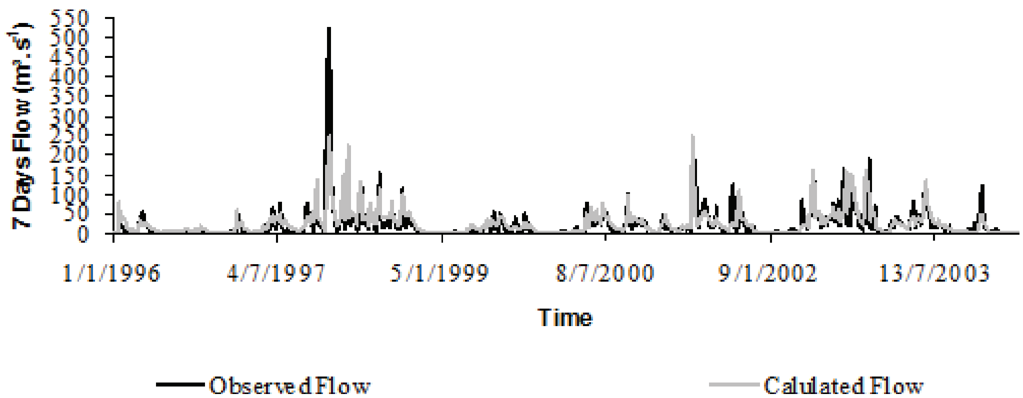
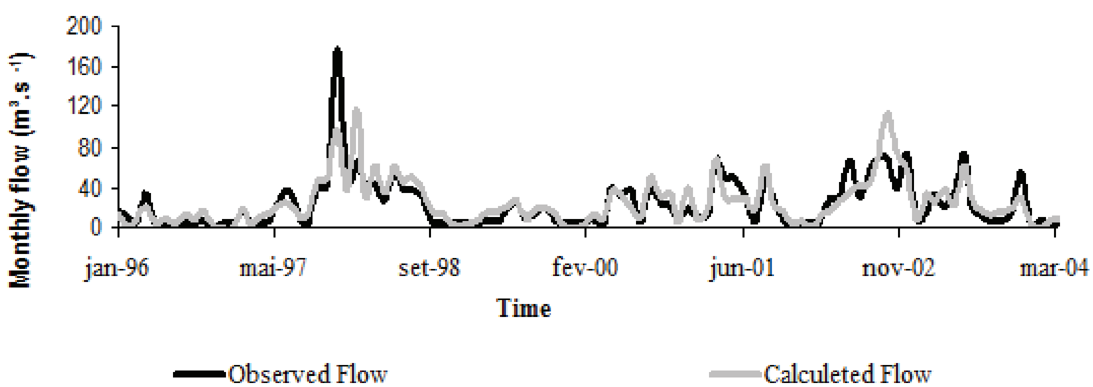


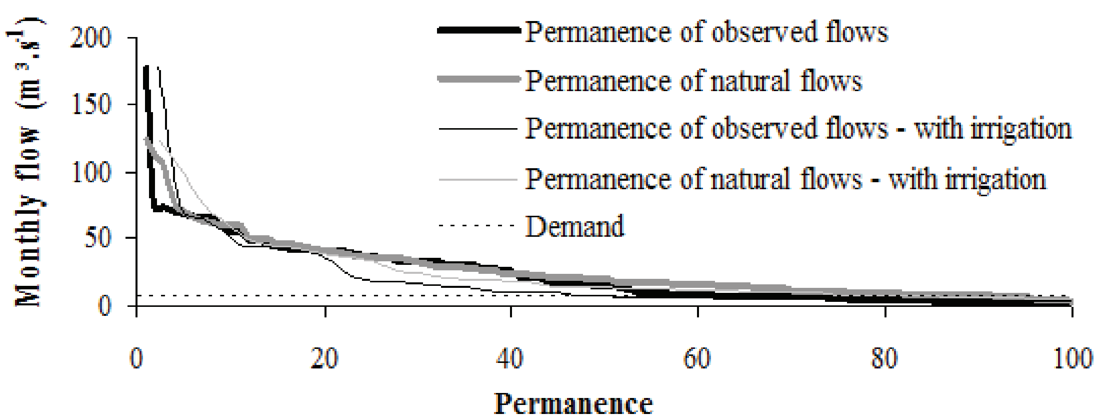
Figure 12 – Observed and calculated flow in the fluviometric station São Gabriel Bridge. (85470000) – interval of simulation daily/7dias – period 01/01/1996 to 19/04/2004



As the monthly simulation presented the best results for the determination coefficients as well as for Nash and Sutcliffe efficiency indexes, the permanence curves showed in Figure 13 are related to this simulation.

It is possible to note that the permanence curve of the natural flows in the irrigation period is under the permanence curve of the natural flows considering the whole year, that is, the natural flows in the summer are really inferior to the ones in the rest of the year.

Figure 13 – Permanence curves for the observed and natural flows in the fluviometric station Ponte São Gabriel. (85470000) – interval of simulation monthly– period Jan/1996 to April/2004



The values of the calibrated parameters for the sub-basins 1 were attributed to simulate the model until the sub-basin 5. Table 6 shows the values of the index that evaluate the model's performance when data from the Passo do Rocha station (85480000) were used for the calibration and validation.

Table 6 – Evaluation of calculated and observed hydrograph– Passo do Rocha

Discrimination	Calibration Jan/1996 - Apr/2004		
	R^2	E_{NS}	ΔV
Daily/ 7days	0.47	0.47	-6.47%
7 days	0.53	0.52	7.51%
Monthly	0.68	0.67	5.42%

As observed on the simulation of the basin 1, the model presented better results for the daily/7days and monthly simulations, both calibration or validation stage. Figures 14, 15, 16 and 17 are related to the calculated and observed hydrographs for these simulation intervals.

Figure 14 – Observed and calculated flows in the Passo do Rocha station (85480000) – simulation interval daily/7days– period 01/01/1996 to 17/12/2001.

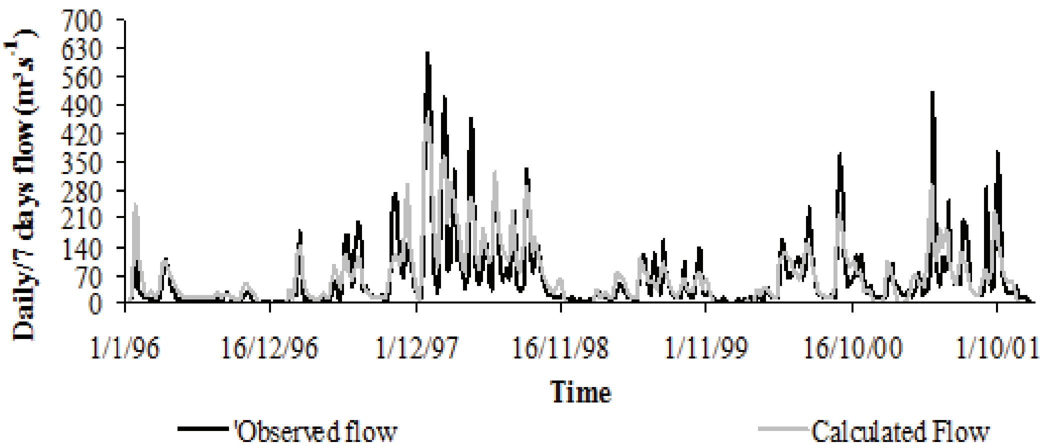


Figure 15 – Observed and calculated flows in the Passo do Rocha station (85480000) – simulation interval daily/7days – period 01/01/2002 to 12/04/2004.

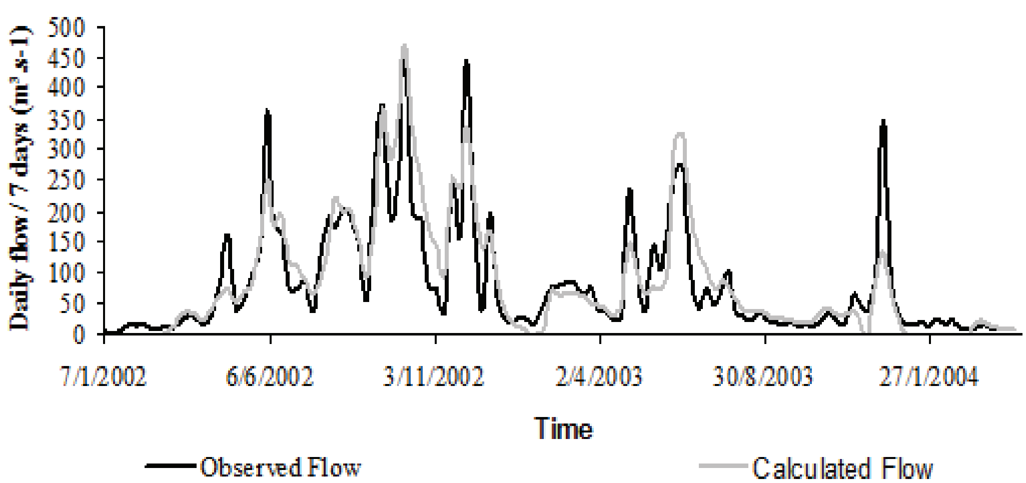


Figure 16 – Observed and calculated flows in the Passo do Rocha station (85480000) – simulation interval monthly – period 01/01/1996 to 17/12/2001.

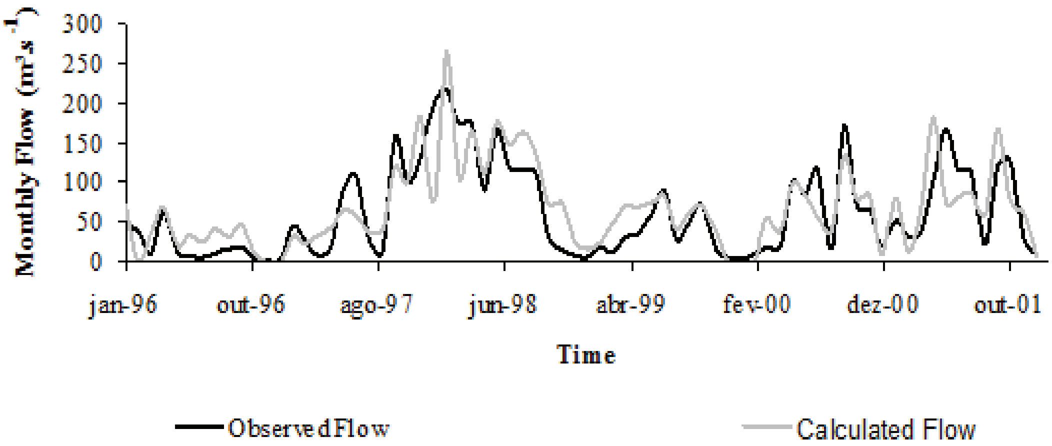
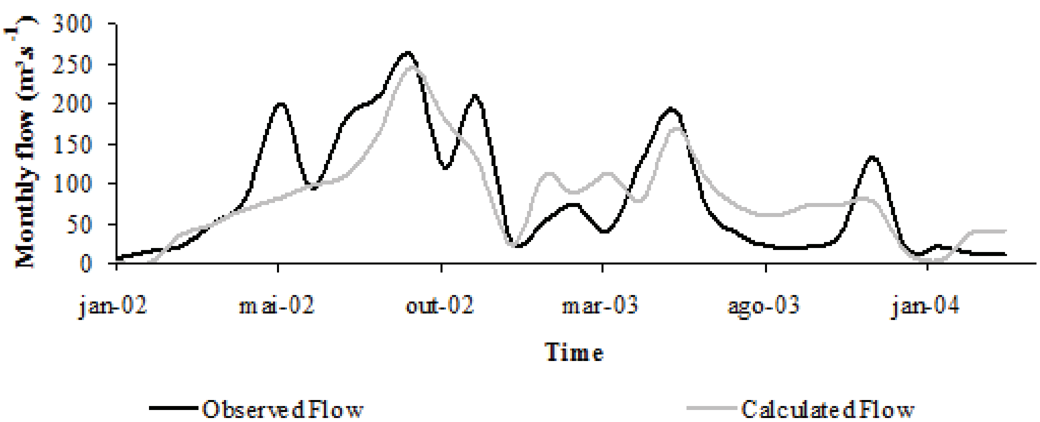


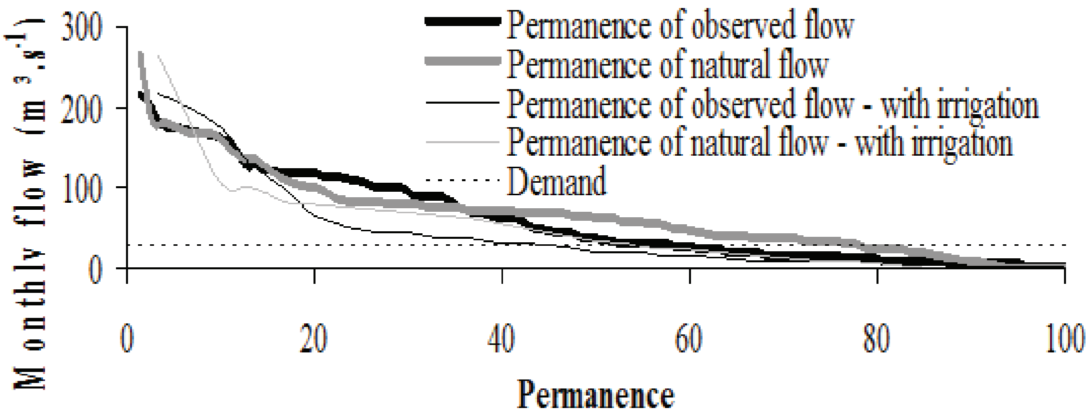
Figure 17 – Observed and calculated flows in the Passo do Rocha station (85480000) – simulation interval monthly – period 01/01/2002 to 12/04/2004.



Again, it was verified that the high flows were underestimated for the daily/7days simulation and the simulations with generation and propagation of monthly flows and generation of daily flows and propagation of 7 days average flows presented better results. It is believed that the reason why the simulation that generates and propagates 7 day flows did not present better results is related to the suppression of the superficial reservoir on the SMAP model, i.e., there is no attenuation of this reservoir in intervals smaller than 7 days.

Figure 18 is related to the permanence curves of observed flow and natural.

Figure 18 – Permanence curves of observed flow and natural from the station fluviometric Passo do Rocha (85480000) – monthly simulation interval– period Jan/1996 to Dec/2001.



The permanence curve resulting of the flows and the withdrawal estimative for the irrigation showed strong interference of the irrigation consume on the recorded flow on the fluviometric posts. This is confirmed when the intersection of the demand curve with the permanence curve of observed and natural flows is analyzed on the irrigation season.

Analyzing Figure 18, the intersection of the demand curve with the permanence curve of the observed flows in the irrigation season occurred approximately in 44% differently from what happens on the intersection of the demand curve with the permanence curve of natural flows, which is 54%, proving that the rice crop irrigation causes an enormous impact on the recorded flows.

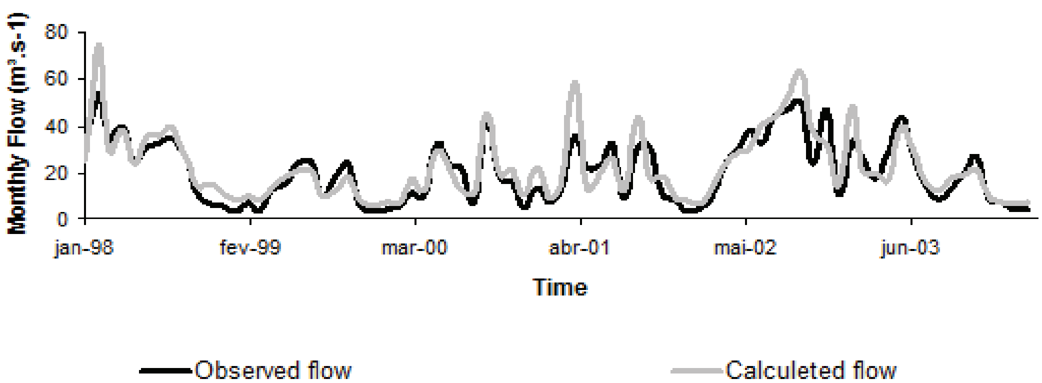
The parameter values of the groups found during the model calibration for the three versions daily/7days, 7days and monthly were utilized to validate the model with the data from the São Sepé Montante station (85623000), which is found at the outfall of the sub-basin 6.

Table 7 exposes the performance evaluation of the model. It is possible to note that the monthly discrimination presented the best values; for this reason it is presented in Figure 19.

Table 7 - Evaluation of calculated and observed hydrograph - Sao Sepe Montante

Discrimination	Validation Jan/1998 - Apr/2004		
	R^2	E_{NS}	ΔV
Daily/7 days	0.43	0.32	-14.01%
7 days	0.16	0.12	13.69%
Monthly	0.79	0.74	7.79%

Figure 19 - Observed and calculated flows at the fluviometric station of Sepé Montante (85623000) - monthly simulation interval - period Jan/1998 to April/2004.



FINAL CONSIDARATIONS

The rice crops totalize a significant share of the River Vacacaí Basin and as this cultivation consumes a lot of water, consequently, water resource management needs the knowledge of the natural flows.

When Paiva et al. (2006 b) methodology was applied, it was possible to verify that among the discretization intervals of the model the ones which presented the best results were those with the generation and propagation of monthly flows and generation of the daily flows and propagation of the 7 day average flows, emphasizing the monthly flow due to the attenuation of the maximum flows, which were not well represented by the model. It is believed that the simulation which generates and propagates the 7 day flows did not present the best results due to the suppression of the superficial reservoir on the SMAP model, that is, there is no attenuation of this reservoir in intervals smaller than 7 days.

It must be also considered that the adjustment results obtained here were similar to those found by Paiva et al. (2006 b), although, in their study the information used was more precise, once they were obtained from the user registration made by Paiva et al. (2006 a).

In this sense, developing and testing methodologies for estimating the natural flow becomes increasingly important, since the changes that man makes on the environment end up reflecting on the records of river flows. However, it is important and necessary to realize that in basins with limited hydrological data, as in this case, simplified methodologies as the one developed by Paiva et al. (2006 b) may be used, since they have showed good results in the determination of natural flow.

BIBLIOGRAPHY

AMARAL, L. G. H, do. *et al.* Vazão retirada e consumo efetivo de água em diferentes sistemas de irrigação do arroz. **Engenharia na Agricultura**, Viçosa, v.13, n. 3, p. 178-192, 2005.

AGÊNCIA NACIONAL DAS ÁGUAS (ANA). Sistemas de informações hidrológicas-Hidroweb. Disponível em: <http://www.ana.gov.br>. Acessado em: 20 de out.de 2007.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (EMBRAPA). **Eficiência do uso da água na cultura do arroz irrigado**. Santo Antônio de Goiás, GO, 2005.

LOPES, J. E. G.; BRAGA JÚNIOR, B. P. F.; CONEJO, J. G. L. Simulação hidrológica: Aplicações de um modelo simplificado. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 3., 1981, Fortaleza. Anais... Fortaleza, 1981.

LOPES, J. E.G. Manual do programa de simulação hidrológica SMAP. 1999.

OLIVEIRA, C. de. P. M. et al. Sistema de Suporte a Decisão para Modelagem e Previsão de Vazões de Cheias para a Bacia do Alto Tietê Utilizando o Modelo Smap Diário. In: SIMPÓSIO DE RECURSOS HÍDRICOS DO SUL-SUDESTE, 1., 2006, Curitiba. Anais... Curitiba, 2006.

PAIVA, J. B. D. de.; PAIVA, E. M. C. D. de.; CLARKE, R. T. Caracterização das Vazões do Rio Ibicuí (RS). In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 13., 1999, Belo Horizonte. Anais... Belo Horizonte, 1999.

PAIVA, J. B. de. D. et al. Demandas de água na bacia do rio Vacacaí Mirim. In: SIMPÓSIO DE RECURSOS HÍDRICOS DO SUL-SUDESTE, 1., 2006 a, Curitiba. Anais... Curitiba, 2006 a.

PAIVA, R. C. D. ; PAIVA, E. M. C. D. ; PAIVA, J. B. D. . Estimativa das vazões naturais nas sub-bacias do Vacacaí Mirim através de modelo simplificado.. In: I SIMPÓSIO DE RECURSOS HÍDRICOS DO SUL-SUDESTE, 1 2006 b, Curitiba. Anais... Curitiba, 2006 b.

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL (UFRGS). MAG 1- MODHAC - Modelo Hidrológico Auto-Calibrável -versão 97. Porto Alegre,1997.

VIEGAS FILHO, J. S.; LANNA, A. E. L. O paradigma da modelagem orientada a objetos aplicado a sistemas de recursos hídricos (II) Modelo de objetos aplicado ao planejamento de uso da água Propagar MMO. RBRH - Revista Brasileira de Recursos Hídricos, v.8, n.3, p. 91.

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