water

MDPI

Supplementary Material

Simulating discharge in a non-dammed river of Southeastern South America using SWAT model

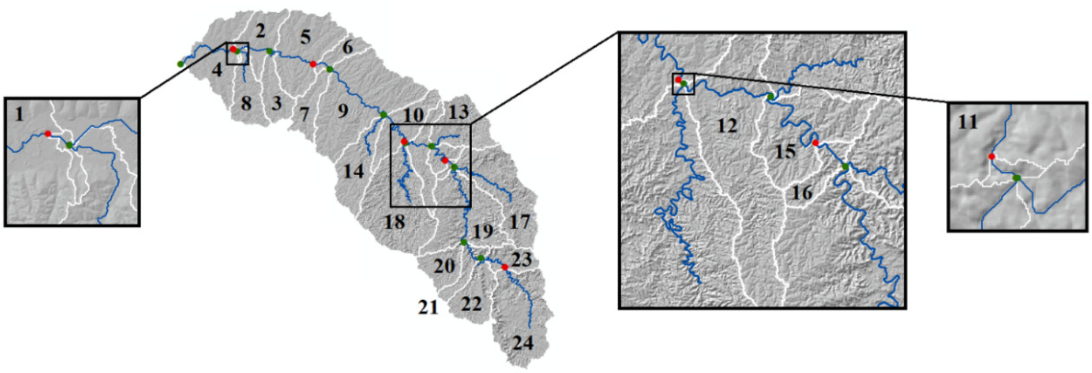

Figure S1: Identification of delineated subbasins of Ivaí River Basin.

Table S1: Detailing of the Ivaí Rivers subbasins with number and name of the main tributary. Area, altitude, number of Hydrologic Response Unit per subbasin are also identified.

Subbasin	Tributary	Area (km²)	Altitude			HRU
			Mean	Minimum	Maximum	
1	Ivaí River	24.08	283.43	232	380	25
2	Bonito River	1,228.31	344.46	232	524	21
3	Tapiracuí River	932.78	393.70	235	540	18
4	Ribeirão Tamanduá and Córrego do 215	2,188.17	320.31	187	497	22
5	Ribeirão Paixão and Ribeirão Paranavaí	2,597.81	371.80	230	546	25
6	Ribeirão Inhuma	598.27	404.73	239	586	24
7	Rio dos Índios	906.13	448.67	253	624	27
8	Ribeirão das Antas	1,217.29	361.98	230	517	22
9	Ribeirão Paranhos, Ligeiro River and Claro River	4,416.82	433.86	236	681	18
10	Ribeirão Keller, Arurão River and Ribeirão Barbacena	1,400.62	429.57	268	808	19
11	Ivaí River	2.48	326.28	279	377	11
12	Ribeirão Cambará and Rio da Bulha	1,042.88	508.95	273	881	22
13	Bom River	1,631.44	621.94	324	1,192	19
14	Mourão River	1,648.85	582.70	284	853	10
15	Ivaí River	436.85	484.54	323	723	32

Subbasin	Tributary	Area (km^2)	Altitude			HRU
			Mean	Minimum	Maximum	
16	Ivaí River	111.65	528.92	357	687	31
17	Alonzo River	2,823.10	667.25	373	1,278	38
18	Curumbataí River	3,615.99	600.71	292	1,158	31
19	Rio do Peixe, Branco River, Maria Flora River and Borboleta River	2,991.96	680.58	366	1,109	43
20	Pitanga River	912.65	899.13	453	1,252	35
21	Bonito River	618.20	849.61	450	1,205	45
22	Marrecas River	1,294.49	959.80	466	1,335	45
23	Ribeirão dos Índios	767.30	715.40	469	1,145	24
24	Rio dos Patos and São João	3,181.46	801.90	480	1,331	46

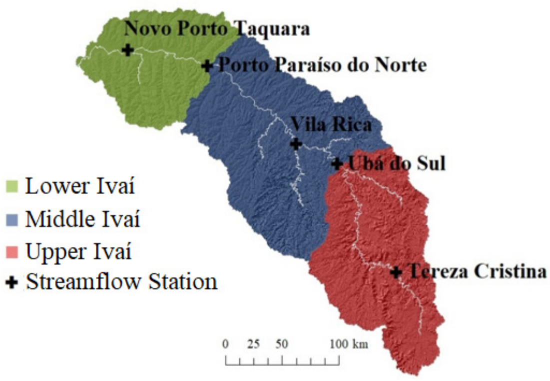

Figure S2: Ivaí River main areas used to regionalize parameters during calibration. Upper Ivaí River in red drains Tereza Cristina and Ubá do Sul streamflow stations; Middle Ivaí in blue drains Vila Rica and Porto Paraíso do Norte and Lower Ivaí in green draining Novo Porto Taquara and subbasin 4.

Table S2: Summary statistics for calibration and validation (inside brackets) periods of the SWAT modeling for the five fluviometric stations of IRB model.

	Drainage Area (km^2)	95PPU		Best Simulation (Calibration n = 129, Validation n = 18)				
		P-factor	R-factor	NSE	RSR	PBIAS	Simulated (Standard Deviation) [m^3/s]	Observed [m^3/s]
Tereza Cristina	3,572	0.70 (0.88)	0.72 (1.05)	0.89 (0.86)	0.33 (0.37)	6.70 (10.20)	80.18 ± 69.42 (43.93 ± 40.12)	85.94 ± 75.31 (48.91 ± 42.48)
Ubá do Sul	12,701	0.73 (0.92)	0.83 (1.30)	0.86 (0.81)	0.37 (0.43)	6.00 (12.20)	286.41 ± 245.06 (155.00 ± 143.13)	304.77 ± 233.59 (176.60 ± 125.93)

Vila Rica	19,300	0.67 (0.92)	0.49 (0.92)	0.70 (0.83)	0.55 (0.42)	16.0 (2.40)	448.14 ± 306.84 (278.70 ± 188.05)	533.64 ± 504.30 (285.45 ± 230.06)
Porto Paraíso do Norte	28,427	0.92 (0.96)	1.00 (1.45)	0.88 (0.85)	0.35 (0.39)	-3.90 (-3.00)	625.01 ± 383.60 (399.08 ± 251.76)	601.39 ± 393.23 (387.47 ± 238.07)
Novo Porto Taquara	34,432	0.83 (0.88)	0.91 (1.25)	0.87 (0.83)	0.36 (0.42)	8.80 (11.20)	655.04 ± 422.62 (427.90 ± 280.05)	717.88 ± 439.61 (481.87 ± 276.99)

Parameter Assessment:

Sensitivity analysis performed within SWAT-CUP indicated that simulations were sensitive to 11 of 15 parameters listed in Table 2, which are related to groundwater, runoff, and evaporation processes, as well as soil and vegetation interactions. The parameters selection was based on parameterization of the three main portions of IRB; 29 parameters were selected from 54 possibilities (see Table 2, every parameter was discretized per basin's section apart from the determination of four land use classes to CANMX parameters – maximum canopy storage), and details from calibrated parameters are shown in Table 3.

From the best iteration, Global Sensitivity analysis was performed so parameters could be ranked based on the regression coefficients measured by SWAT-CUP module. Results from the second iteration showed that the groundwater delay time (GW_DELAY) from the Upper Ivaí is the most sensitive parameter and presented values up to 92.5 days to water move from the lowest depth of the soil profile before becoming shallow aquifer recharge. In agreement with the investigated area, Hu et al. [1] found out that the influences of granular rocks on the Guarani aquifer produce a faster response to rainfall, with lag ranging up to one to three months. For the other portions of the basin, according to the same study, the lag was also for three months. During calibration, the modification ranges were 33 to 112 days, in the Middle Ivaí, and 0 to 100 days, in the Lower Ivaí.

The second most sensitive parameter is CN2, specified for the Middle Ivaí, as well as the fourth most sensitive to the upstream portion. CN2.mgt belongs to the management files that summarize HRU practices of land and water management within the HRU. The CN2 parameter is defined as the initial Soil Conservation Service runoff number for moisture condition II (SCS; [2]), which ranges from 35 to 98 and it is associated to the land use, treatment or practice of the cover, hydrologic condition, and soil group. As this parameter is distributed, the proposed alteration shall respect the HRU characteristics individually. Thus, the initial multiplying value was ±20%. Initial modifying ranges were reduced to 66%, 98% and 56.5% for the Upper, Middle and Lower portions respectively as identified in the Remaining Modification Interval percentages (RMI; the ratio between the final calibrated range from the best iteration and the modification range allowed by the model). The average curve number found for the IRB was 61.2.

The deep aquifer percolation fraction from the root zone (RCHRG_DP) is the third most sensitive parameter for the Middle portion of IRB. The final calibrated range was 0.29 – 0.88 and for the best simulation (n = 129), the fraction of 0.30 portrays only 2% of the incoming precipitation going to deep aquifer recharge. Other studies on SWAT applications inside Upper Paraná River Basin (UPRB) also relied on the maximum interval admitted by the model (0 – 1; [3-5]). For upstream and downstream, maximum values of modification after the iteration were 0.54 and 0.60, respectively, and the minimum value for both areas was zero since only positive values are acceptable for RCHRG_DP.

The initial value set for GWQMN was 1000 (in millimeters); meaning that to the return flow from the shallow aquifer occurs, the threshold of one meter must be achieved. For the Upper Ivaí, the GWQMN was the fifth sensitive parameter, and the final modification threshold was between 910.1 and 2,731.8 mm. For the Middle Ivaí, the minimum value was zero and 859 mm for the lower portion. Bressiani [6] established GWQMN ranging from 3,000 to 4,000 mm in an application within the UPRB, as well as in Monteiro et al. [3] that allowed a modification range between 0 to 3,000 mm thresholds. The last application presented the same initial range as this study, as shown in Table 2, where the initial value is 1000 mm with change being the addition of -1000 to 2000 mm.

The compensation factor for soil evaporation (ESCO) ranges between 0.1 and 1.0. In a general analysis, this parameter was sensitive to the entire basin since it was rated as the 6th, 8th and 9th position for the Upper, Middle and Lower Ivaí. During calibration, the initial value (0.95) was adjusted to reduce the evapotranspiration. For the modification ranges, possible values were kept inside the 0.55 and 0.76 intervals, aligned with results found in others UPRB applications [7-9]. However, other applications [10, 3, 11] found smaller values for the best simulation (0.1; 0.16 and 0.44; 0.5, respectively). ESCO is a calibration parameter and not a property that can be directly measured [12].

Surface runoff lag coefficient (SURLAG) was sensitive to only one portion of the IRB. This parameter is a model feature to lag the surface runoff release to the main channel. It measures the time of concentration in hours and the smallest possible value is 0.5 reaching up to 24. The initial value entered for the Middle Ivaí was 2, as smaller values of SURLAG smooth streamflow hydrograph simulated in the reach [13]. For the other portions, the parameter was set equal to 4 (default). UPRB applications showed a great variability of SURLAG. For the best simulation, Eduardo et al. [9] found 2.26 in the Mortes River in Minas Gerais State and the highest value was 23.05 in Sarapuí River, a Tietê tributary in São Paulo State [8].

The available water capacity of the soil layer (SOL_AWC) was calibrated to the whole basin as a relative parameter. The initial multiplication allowed a variation of ±20% attributed to the input data previously defined as soil properties during the model construction. In an overall interpretation, the Upper and Middle segments had SOL_AWC values reduced, as the final modification interval are predominantly negative, unlike the Lower Ivaí where modifications were mostly increments.

The parameter that governs the water that is removed from the capillary fringe or deep-rooted plants is the GW_REVAP. Such removed water is replaced by the underlying aquifer. Values should be between 0.02 and 0.20. During calibration, the entire basin parameters were modified by replacement modification with a minimum value of 0.02 and a maximum of 0.083. Hernandes et al. [14] and Eduardo et al. [80] found GW_REVAP within this interval, with values for their best simulation of 0.2 and 0.8 for the first application and 0.48 for the second.

Baseflow and groundwater recharge were previously treated with a baseflow filter developed by Arnold and Allen [15] available in SWAT website (https://swat.tamu.edu/media/70817/baseflow2006-06.zip). This filter allows the estimation of baseflow and groundwater recharge from streamflow records and limits the dependence of the model results on rainfall [16]. Streamflow data were computed in a daily time step to each year of the calibration period and the average value was attributed as an initial parameter setting (ALPHA_BF). This procedure was applied for the five fluviometric stations of IRB. Since Upper and Middle Ivaí includes two stations and Lower Ivaí only one, the calibration was arranged to attend this particular feature. Modification ranges were identical, but initial values were distinct. The final modification interval proposed up to 31.7% addition for the Upper Ivaí. For the best simulation, the final aggregated value was 28.8%, resulting in an ALPHA_BF of 0.12 for subbasin 24 and 0.08 for the remaining area of Upper Ivaí. Theoretical documentation indicates that values ranging from 0.1 to 0.3 concerns to land with slow response to recharge [13].

The maximum canopy storage parameter (CANMX) belongs to the land cover characteristics at an HRU level. It complements the surface runoff calculation by limiting the maximum amount of water trapped in a fully developed canopy (mm H20). It plays an important role in the rainfall abstraction control, and its values can be assigned between 0 and 100. For the best iteration, the minimum value was 3.50 and the maximum 18.06. Other applications within UPRB found the maximum limit modification of 25 [6], 30 [7, 17], 40 [3] and 100 [18].

The plant uptake compensation factor, EPCO, allows lower layers of the soil to compensate the amount of water available in the upper layer to meet the potential water uptake required to plant transpiration. EPCO can range from 0.01 to 1.00, where higher values allow more water uptake demand. The initial modification range used the whole interval accepted by the model, thus this parameter was not regionalized. During calibration, the model used the 0.44 to 1.0 and 0.41 to 1.0 to the Lower and Middle Ivaí, respectively, and for the Upper, the interval was between 0 and 0.62. For the best simulation, the Upper received value of the 0.4, and the remainder basin received 1. When it concerns other studies, the smaller value found within the UPRB was 0.1 attributed to Mortes River (Minas Gerais State [9]), and the highest was 1 in the Santa Maria/Torto basin (Federal District [10]). The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be carefully reviewed, and key publications cited. Please highlight controversial and diverging hypotheses when necessary.

Table S3: Flow threshold indices.

Simulated (Observed)	Q_{10}	Q_{50}	Q_{90}	Q_{95}	Q_{10}/Q_{50}	Q_{90}/Q_{50}	Q_{10}/Q_{90}
Tereza Cristina	173.05 (192.52)	63.55 (61.44)	7.09 (18.51)	2.31 (14.45)	2.723 (3.133)	0.111 (0.301)	24.407 (10.400)
Ubá do Sul	640.76 (600.57)	222.12 (235.25)	23.96 (83.05)	7.94 (69.64)	2.884 (2.552)	0.107 (0.353)	26.742 (7.231)
Vila Rica	886.72 (1,098.65)	361.77 (339.42)	123.64 (121.89)	94.94 (88.38)	2.451 (3.236)	0.341 (0.359)	7.171 (9.013)
Porto Paraíso do Norte	1,167.70 (1,096.03)	545.33 (482.32)	221.67 (209.38)	188.69 (196.96)	2.141 (2.272)	0.406 (0.434)	5.267 (5.234)
Novo Porto Taquara	1,218.86 (1,301.06)	557.45 (594.03)	220.61 (280.29)	184.79 (264.02)	2.186 (2.190)	0.395 (0.471)	5.524 (4.641)

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