Hydrologic Evaluation for a Small Watershed in Southern Brazil with the Soil and Water Assessment Tool

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ABSTRACT – In Southern Brazil, native forests are being replaced by tobacco crops. These changes are negatively impacting the region's water balance and resource quality. Accurately representing the region's hydrologic processes is essential to obtaining meaningful water and contaminant transport results. The Soil and Water Assessment Tool (SWAT) model was used to evaluate the hydrology of the Arroio Lino watershed, located in Southern Brazil. Measured streamflow data was used in model streamflow parameter sensitivity analysis, calibration and validation. Sensitivity analyses were performed on 27 input variables. Model calibration was performed with a Shuffled Complex Evolution Algorithm (SCE-UA). The parameters that had the most responsive model outputs were: runoff were curve number (CN2), soil evaporation compensation factor (ESCO), and baseflow alpha factor (ALPHA_BF). The predicted monthly streamflow matched well with the observed values, with a Nash–Sutcliffe coefficient of 0.87 and 0.76 for calibration and validation, respectively. Daily simulations were less accurate than monthly predictions. Results indicate that the model is a promising tool to evaluate small watershed hydrology in subtropical areas for long time periods. This model will continue to be used for climate and land use change analyses and to assess the impact of various management scenarios on stream water quality.

Keywords: SWAT model; Hydrologic processes; Agricultural watersheds

1.1 - Introduction

In Southern Brazil, intensively cultivated agricultural lands (i.e. tobacco), have been altering the region's water balance and transforming these areas into sources of environmental contamination. Most of the tobacco in Southern Brazil is produced on small farms with low agricultural potential (Merten and Minella, 2006). Incompatible agricultural practices coupled with the land use capability of these regions and the application of high fertilizer and pesticide rates make tobacco cultivation an activity with a high contamination risk for water resources (Kaiser *et al*., 2010).

In search of solutions for more efficient water resource utilization, an adequate assessment of water quality and quantity is pertinent. A key hydrologic water transport pathway, within the region, is surface runoff which is predominantly responsible for the movement of sediment, nutrient, and other contaminants throughout the watershed.

Computer-based watershed models can save time and money because of their ability to perform long-term simulations of watershed processes and management activities to discern affects on water quality, water quantity, and soil quality (Moriasi *et al*., 2007). The Soil and Water Assessment Tool (SWAT, Arnold et al., 1998), developed by the United States Department of Agriculture's Agricultural Research Service (USDA-ARS) is a continuous time model developed to predict the impact of land management practices in watersheds with varying soils, land use and management conditions (Neitsch *et al*., 2005). A detailed theoretical description of SWAT and its major components is documented in Neitsch *et al*. (2005). An extensive set of SWAT applications can be found in Arnold and Fohrer (2005) and in Gassman *et al*. (2007).

The focus of this study is to assess the ability of the Soil and Water Assessment Tool (SWAT) to simulate streamflow at a small watershed in Southern Brazil. The results obtained from this research can be applied to similar watersheds in this region. Thus, the objectives of this study are to (1) conduct a parameter sensitivity analysis; (2) calibrate and validate the SWAT model for stream flow at an outlet in the Arroio Lino watershed.

1.2 - Materials and Methods

1.2.1 - SWAT model

Components of SWAT model include: weather, hydrology, soil temperature, plant growth, erosion/sedimentation, nutrients, pesticides, and land management. This study focuses on the hydrologic component of the model.

SWAT simulates a watershed by dividing it into multiple subbasins, which are further divided into hydrologic response units (HRU's). These HRU's are the product of overlaying soils, land use and slope classes. The water balance in each HRU is composed by four storage volumes: snow, soil profile, shallow aquifer, and deep aquifer.

Major hydrology components of SWAT include: precipitation, interception, evapotranspiration, infiltration, percolation, and runoff. The SWAT model uses two phases of the hydrologic cycle: a land portion and a channel portion. The land phase of the hydrologic cycle is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (Prec - Surq - Et - Perco - Bf) \tag{1}$$

where SW_t is the final soil water content (mm), SW_0 is the soil water content available for plant uptake (initial water content - permanent wilting point water content), t is the time in days, *Prec* is the amount of precipitation (mm), *Surq* is the amount of surface runoff (mm), *Et* is the amount of evapotranspiration (mm), *Perco* is the amount of percolation (mm), and *Bf* is the amount of baseflow (mm).

The actual plant transpiration and the actual soil evaporation are estimated based on the potential evapotranspiration and additional soil and land use parameters. SWAT offers three methods to estimate the potential evapotranspiration: Priestley-Taylor (Priestley and Taylor, 1972), Hargreaves (Hargreaves and Samani, 1985), and Penman-Monteith (Allen *et al.*, 1989). For this study, the Penman-Monteith method (P-M) was used.

In SWAT, the surface runoff can be estimated from daily or sub-daily rainfall. In this study, the surface runoff was estimated from daily rainfall with the modified Soil Conservation Service curve number II method (CN2; USDA SCS, 1972), which takes into account the land use, soil type, and antecedent moisture condition. Peak runoff rate predictions are made with a modification of the rational method. Channel routing can be simulated using either the variable-storage method or the Muskingum method. The variable-storage method was used in this study.

1.2.2 - Watershed description

The Arroio Lino watershed covers 4.8 km^2 and is located in Agudo County, in the state of Rio Grande do Sul, Brazil (29.1° S, 67.1° E) (Figure 1). The Arroio Lino is a tributary of the Jacuí River, where the drainage area is characterized by intensive land use for agriculture and livestock.

Concerning the geological aspects, the watershed belongs to the “Serra Geral Formation” which contains basaltic hillsides and localized outcrops of Botucatu sandstone (Pellegrini *et al*., 2009). Due to the steep terrain, geologic structures, and rock units, steep slopes commence the headwaters and dictate the drainage patterns. *Chernossolos* (Mollisols) predominate, but *Neossolos* (Entisols) are found on steeper slopes (Dalmolin et al., 2004; Soil Survey Staff, 1999). The vegetation is composed of remnant seasonally deciduous forests in different stages of succession (Pellegrini *et al*., 2009).

Climate in the region is humid subtropical (Cfa type), according to the Köppen classification, with an average temperature of more than 22 °C in the hottest and between -3 and 18 °C in the coldest month. Rains are usually well distributed, ranging from 1,300 to 1,800 mm $year^{-1}$ (Kaiser *et al*., 2010).

Almost 30% of the Arroio Lino watershed area is occupied by annual crops and more than 50% by native forest cover (Table 1). Approximately 90% of the crops areas are devoted to tobacco production (Pellegrini *et al*., 2009). The tobacco crops are cultivated under conventional tillage, with environmental degradation due to intense agricultural exploration.

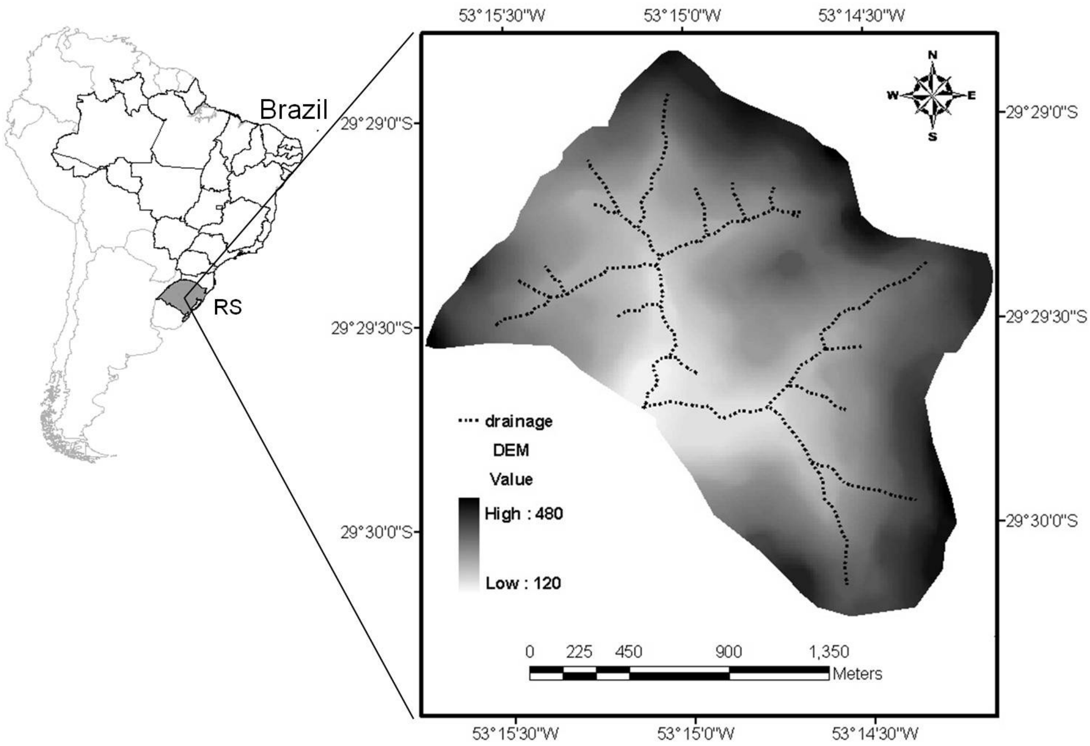

Figure1 – Location of the Arroio Lino Watershed in Rio Grande do Sul (RS) state in Brazil.

Table 1 - Land use classification for the Arroio Lino Watershed

Land Use	Area (ha)	Percent
Tobacco/corn	119.7	24.9
Beans/others	19.2	4.0
Pasture	42.3	8.8
Native forest	259.6	54.1
Exotic forest	25.4	5.3
Urban/roads	13.8	2.9
Watershed	480.0	100.0

1.2.3 - Input data

The SWAT model requires topography, land use, management, soil parameters input, and weather data. The digital maps (topography, land use and soil types) were processed with a GIS preprocessing interface to create the required model input files.

Topographic Data. Topography data were obtained by digitizing contour lines and drainage network from a 1:25,000 scale topographic map. The digitized contour vectors were used to create Triangular Irregular Network (TIN) for generating the Digital Elevation Model (DEM) with spatial pixel resolution of 10 m (Figure 1). The DEM and the digitized drainage network were used to delineate and partition the watershed into 21 subwatersheds and reaches with an average size of 0.15 km^2 (3% of the watershed area). The slope map was divided into five slope classes: 0-5%, 5-15%, 15-30%, 30-45% and >45%. Information extracted and calculated from the DEM includes overland slope, slope length, and elevation corrections for precipitation and evapotranspiration.

Land Use and Agricultural Management Data. Land use was determined by field surveys, assisted by a GPS with GIS software (Pellegrini *et al*., 2009). Principal land uses in the watershed consist of cultivated tobacco fields, forest, pasture and fallow. A detailed list of agricultural management operations carried out in the watershed with dates and type of operation (planting of crop, tillage, and harvest) was included in the SWAT user database. For model purposes, in SWAT, the CN2 is updated for each management operation. The date of operation can vary year to year depending on the cumulative days exceeding the minimum (base) temperature for plant growth. The potential heat units for the crops were calculated and the values were added in the management input file.

Soil Data. The digital soil map (1:15,000) identifies 11 soil types, mainly Entisols and Mollisols (Dalmolin et al., 2004; Soil Survey Staff, 2003). The key soil physical properties such as percentage of sand, silt and clay, bulk density, porosity and water content at different tension values (available water capacity) were analyzed for each soil. Additional soil parameters were taken from previous studies developed in the watershed (Rheinheimer, 2003) and assigned to main soil types. The physical and chemical properties of the soils were added to the SWAT user databases.

Hydrologic response units (HRU's). The number of HRU's is limited by the precision of the input digital maps. The combination of land uses, soil types and slope classes, with 10% of threshold area, resulted in 344 HRU's.

Weather data. Precipitation data were obtained from an automated meteorological station and from five rain gauges installed within the watershed (Kaiser *et al*., 2010; Sequinatto, 2007). Watershed rainfall data were collected from 2001 to 2005. The P-M potential evapotranspiration method requires solar radiation, air temperature, wind speed, and relative humidity as input. Daily maximum and minimum temperature, solar radiation, wind speed and humidity values were also obtained from the automated meteorological station. The gaps in the climate data were completed with information from the Brazilian National Institute of Meteorology (INMET) and National Water Agency (ANA) stations adjacent to the watershed.

Hydrologic Discharge Data. A Parshall flume at the watershed outlet was established in 2004 to collect stage heights in 10-minute intervals using an automatic water level sensor (Gonçalves *et al*., 2005; Sequinatto, 2007). Flow rates were calculated with a stage-discharge relationship that was developed using in-situ manual velocity measurements at the stream cross section where the water level sensor is located (Sequinatto, 2007). The 10-minute flow rates were integrated to obtain daily outflow rates. The daily streamflow data at the watershed outlet were used for model sensitivity analysis, calibration and validation simulations.

1.2.4 - Model evaluation

The performance of SWAT was evaluated using graphical comparison and statistical analysis to determine the quality and reliability of the predictions when compared to observed values. Summary statistics include the mean and standard deviation (SD), where the SD is used to assess data variability. The goodness-of-fit measures were the coefficient of determination (r^2) and the Nash-Sutcliffe efficiency (NSE) value (Nash and Sutcliffe, 1970).

Coefficient of determination (r^2) is calculated as:

$$r^2 = \frac{\left(\sum_{i=1}^{n}(Y_i^{obs} - Y_m^{obs})(Y_i^{sim} - Y_m^{sim})\right)^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_m^{obs})^2 \sum_{i=1}^{n}(Y_i^{sim} - Y_m^{sim})^2} \qquad (2)$$

where *n* is the number of observations during the simulated period, Y_i^{obs} and Y_i^{sim} are the observed and predicted values at each comparison point *i*, and Y_m^{obs} and Y_m^{sim} are the arithmetic mean of the observed values. The r^2 ranges from 0 to 1, with higher values indicating less error variance.

Nash-Sutcliffe efficiency (NSE) is calculated as:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_m^{obs})^2}\right] \qquad (3)$$

NSE ranges between -∞ and 1.0, where a value of 1 indicates a perfect fit. The ENS value describes the amount of variance for the observed values over time that is accounted for by the model.

Further goodness-of-fit was quantified using the percent bias (PBIAS) and the ratio of the root mean square error to the standard deviation of measured data (RSR) (Moriasi *et al*., 2007). PBIAS assesses the average tendency of simulated data to exhibit underestimation (positive PBIAS values) or overestimation (negative PBIAS values) bias (Gupta *et al*. 1999):

$$PBIAS = \frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) * 100}{\sum_{i=1}^{n} Y_i^{obs}} \qquad (4)$$

where PBIAS is the deviation of simulated values (Y^{sim}) relative to measured values (Y^{obs}), expressed as a percentage.

RSR incorporates the benefits of error index statistics and includes a normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR is calculated as the ratio of the root mean square error and standard deviation of measured data, as shown in equation 4 (Moriasi *et al*., 2007):

$$RSR = \frac{RMSE}{SD_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_m^{obs})^2}\right]} \tag{5}$$

where RMSE is the root mean square error and SD_{obs} is the standard deviation of measured values. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR, the lower is the RMSE, and the better is the model simulation performance (Moriasi *et al.*, 2007).

In order to assess how well the model performed Green *et al*. (2006) and Green and van Griensven (2008) used standards of NSE > 0.4 and $r^2 > 0.5$. Moriasi *et al*. (2007) suggested that model simulation can be judged as satisfactory if NSE > 0.50 and RSR ≤ 0.70, and if PBIAS ± 25% for stream flow for a monthly time step. For this study, $r^2 > 0.6$, NSE > 0.50, RSR ≤ 0.70, and PBIAS ± 25% are chosen as standards for acceptable simulations.

- Parameter Sensitivity Analysis.

In order to determine the effect of model parameters on model output directly and on model performance, a parameter sensitivity analysis tool embedded in SWAT was used (van Griensven *et al*., 2006). The errors on the output were evaluated by comparing the model output to corresponding observations. The relative ranking of which parameters most affected the output was determined by error functions that were calculated for the daily flow measured at the watershed outlet gauge.

- Calibration and Validation.

Measured data from the watershed outlet gauge were compared to SWAT output during calibration and validation. Predicted total flow for monthly and daily calibration and validation was calculated for the appropriate subbasin in the main channel output file from SWAT. To calibrate streamflow, an automated digital filter technique (Arnold and Allen, 1999) was used to separate baseflow from the measured streamflow. As SWAT is a complex model with many parameters that will complicate manual model calibration, an auto-calibration procedure tool that is embedded in SWAT was also used. This procedure is based on a multi-objective calibration and incorporates the Shuffled Complex Evolution Method algorithms (SCE-UA). The optimization uses a global optimization criterion through which multiple output parameters can be simultaneously evaluated (van Griensven *et al*., 2002). The calibration procedure followed the steps presented in Green and van Griensven (2008). First, the parameters were manually calibrated until the model simulation results were acceptable as per the NSE, r^2, RSR and PBIAS values. Next, the final parameter values that were manually calibrated were used as the initial values for the autocalibration procedure. Maximum and minimum parameter value limits were used to keep the output values within a reasonable value range. Finally, the autocalibration tool was run with the optimal fit values to provide the best fit between the measured and simulated data as determined by the NSE values and how reasonable the values were. The autocalibrated determined parameter values were then adjusted to ensure that they were reasonable. For the validation the model was run using input parameters determined during the calibration process from another time period.

1.3 - Results and Discussion

1.3.1 - Hydrology parameters sensitivity analysis

A sensitivity analysis was carried out using 27 parameters of SWAT model suggested as being the most sensitive for the simulation of the stream flow (van GRIENSVEN *et al*., 2006). Regarding the effects of the 27 parameters on variable flow, 20 indicated some sensitivity (Table 2). The lack of effect of the other seven parameters lies in the fact that most of them are directly related to the processes of melting snow, which does not occur in this region. The CN2 parameter’s variation had the highest sensitivity; increased values of CN2 result in an increase in the surface runoff. The second parameter with the greatest effect was the soil evaporation compensation factor (ESCO). Kannan *et al*. (2007) noticed that a change in the value of the ESCO affects all of the water balance components. The third most sensitive parameter was the BF alpha factor (ALPHA_BF). Similar analysis made in other watersheds suggested that the parameters CN2 and ALPHA_BF also have great importance in the simulation of water quality (van Griensven *et al*., 2006).

Table 2 - Sensitive model parameters for streamflow.

Parameter	Description	Rank
ALPHA_BF	Baseflow alpha factor (days)	3
BIOMIX	Biological mixing efficiency	20
BLAI	Potential maximum leaf area index for the plant	5
CANMX	Maximum amount of water that can be trapped in the canopy when the canopy is fully developed (mm)	8
CH_K2	Effective hydraulic conductivity (mm h^{-1})	4
CH_N2	Manning's roughness coefficient for the channel	12
CN2	Initial SCS runoff curve number for moisture condition II	1
EPCO	Plant evaporation compensation factor	14
ESCO	Soil evaporation compensation factor	2
GW_DELAY	Groundwater delay time (days)	16
GW_REVAP	Groundwater re-evaporation coefficient	17
GWQMN	Minimum shallow aquifer depth for "revap" to occur (mm)	6
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	15
SLOPE	Average slope steepness (m m^{-1})	9
SLSUBBSN	Average slope length (m)	19
SOL_ALB	Soil albedo	18
SOL_AWC	Available water capacity of the soil (mm H_2O mm $soil^{-1}$)	10
SOL_K	Saturated hydraulic conductivity of the soil (mm h^{-1})	7
SOL_Z	Soil depth (mm)	11
SURLAG	Surface runoff lag coefficient	13

1.3.2 - Calibration and Validation

The entire period of simulation was carried out from January 1, 2001 to December 31, 2005. The period from January 1, 2001 to December 31, 2003 serves as a parameter initialization period for the model. The initialization period was used to establish the appropriate starting conditions for soil water storage. The outlet gauge data from January to December 2005 were used to optimize the calibration parameters and the remaining data for validation.

The uncalibrated SWAT run was unability to describe this watershed's hydrology as determined by comparing the simulation results and the measured streamflow data. Simulation using default values parameters underestimated stream flow in relation to the measured stream flow, particularly during austral spring months (September to December). Both manual and autocalibration procedures were required to correct these simulation errors. To calibrate and validate baseflow and surface runoff, total flow was separated into two components.

The simulated surface flow was increased through calibration of the following parameters: runoff curve number (CN2), daily curve number calculation method (ICN), curve number coefficient (CNCOEF), soil evaporation compensation factor (ESCO), initial soil water content expressed as a fraction of field capacity (FFCB), and available soil water capacity (SOL_AWC). The Soil Conservation Service runoff curve number for moisture condition II (CN2) parameter was originally set to values recommended by the USDA SCS National Engineering Handbook (USDA SCS, 1972) for each hydrologic group. For estimation of CN2 for slopes above 5%, an equation developed by Williams (1995) was used. The final CN2 values were kept within reasonable ranges by limiting the change from the original value to ± 10%. The ICN and curve number coefficient (CNCOEF) parameters are defined in Williams and LaSeuer (1976) and Green *et al*. (2006). The ICN and CNCOEF parameters were used to account for the soil moisture in addition to the SCS runoff curve number (Green *et al*., 2008). The soil evaporation compensation factor (ESCO) is a calibration parameter and not a property that can be directly measured. As ESCO increases, the depth to which soil evaporative demand can be met decreases, which limits soil evaporation and reduces the simulated value for ET (Feyereisen, 2007). The ESCO parameter was adjusted so as to decrease actual evapotranspiration. The FFCB parameter was expressed as a fraction of field capacity

(FFCB=1.0) instead of be expressed as a function of average annual precipitation (FFCB=0.0). The available soil water capacity (SOL_AWC) was reduced which resulted in an increase in surface flow. Storm flow is inversely proportional to SOL_AWC; the two variables exhibit a straight-line relationship throughout the range of values for SOL_AWC. Reducing SOL_AWC results in the soil profile being saturated more quickly, thereby generating more runoff, less ET, and increased baseflow (Feyereisen, 2007).

As the values of baseflow simulated with SWAT was significantly lower in relation to the baseflow estimated from the measured streamflow, the groundwater parameters were adjusted to improve the subsurface response. The threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN) was increased and the time for water leaving the bottom of the root zone to reach the shallow aquifer (GW_Delay) was reduced. Saturated hydraulic conductivity (SOL_K) of the first soil layer was increased which resulted in increased baseflow.

Finally, the temporal distribution of the flow and the shape of the hydrograph were improved through calibration of the storm flow lag time (SURLAG) and the baseflow recession constant (ALPHA_BF).

Table 3 lists the ranges and the calibrated values of the adjusted parameters used for streamflow calibration for the Arroio Lino watershed. All other parameters remained at the SWAT default values.

Table 3 - The SWAT model parameters included in the final calibration and their initial and final ranges.

Parameter	Description	Range	Initial Value	Calibrated Value
ALPHA_BF	Baseflow alpha factor (days)	0.0 to 1.0	0.048	1
CN2	Initial SCS runoff curve number for moisture condition II	± 25%	30 to 100	+10%
CNCOEF	Curve number coefficient	0.5 to 2.0	0	0.5
ESCO	Soil evaporation compensation factor	0.0 to 1.0	0.95	1
FFCB	Initial soil water storage expressed as a fraction of field capacity water content	0.0 to 1.0	0	1
GW_DELAY	Groundwater delay time (days)	0 to 500	31	5
ICN	Daily curve number calculation method	0 or 1	0	1
PHU	Potential heat unit (used for tobacco)	1000 to 2000	1800	1000
	Potential heat unit (used for corn)	1000 to 2000	1800	1450
	Potential heat unit (used for beans)	1000 to 2000	1800	1350
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)	0 to 500	1	300

SOL_AWC	Available water capacity of the soil layer (mm H_2O mm $soil^{-1}$)	± 25%	Default	-5%
SOL_K	Saturated hydraulic conductivity of the soil (mm h^{-1})	± 25%	Default	+5%
SURLAG	Surface runoff lag coefficient (days)	0 to 4	4	1

Monthly observed and simulated streamflow matched well during both the calibration (2005) and validation (2004) periods (Figure 3) at watershed outlet. The streamflow statistics for the calibration and validation periods are listed in Table 4. The monthly calibration and validation r^2 values were 0.90 and 0.86 (> 0.6), respectively. Based on Moriasi *et al*. (2007), model performance was "very good" for the calibration period. This is supported by NSE of 0.87 (> 0.75), the RSR value of 0.35 (≤ 0.50), and PBIAS of -8 % (<±10%). Similarly, for the validation period the model performance was "good" since the NSE was 0.76, the RSR value was 0.49, and PBIAS was -13.3 % (10% < PBIAS < 15%).

Table 4 - Streamflow statistics for the calibration and validation period.

Statistical Measure		Monthly			Daily		
		Calibration	Validation	Average	Calibration	Validation	Average
Measured (mm)	Mean	94.30	57.25	75.78	3.81	2.31	3.06
	SD	65.62	26.56	46.09	10.50	4.25	7.37
Simulated (mm)	Mean	85.12	49.65	67.38	2.80	1.60	2.20
	SD	66.29	22.96	44.63	8.46	2.97	5.71
r^2	(>0.6)	0.90	0.86	0.88	0.78	0.59	0.69
NSE	(>0.5)	0.87	0.76	0.82	0.56	0.20	0.38
RSR	(≤0.70)	0.35	0.49	0.42	0.66	0.97	0.82
PBIAS	(±25%)	-8.4%	-13.3%	-10.9%	14.6%	30.0%	22.3%

At the daily time scale, particular attention was given to the magnitude of peak flows and the shape of recession curves. Figures 3 and 4 represent the daily predicted streamflow compared with the measured data for the calibration and validation periods, respectively. Table 4 lists the daily calibration and validation calculated statistics. For the calibration period the daily r^2 value was 0.78, whereas for the validation period the r^2 value was 0.59. The daily calibration NSE and RSR were 0.56 and 0.66, respectively, while the validation NSE and RSR were 0.20 and 0.97, respectively.

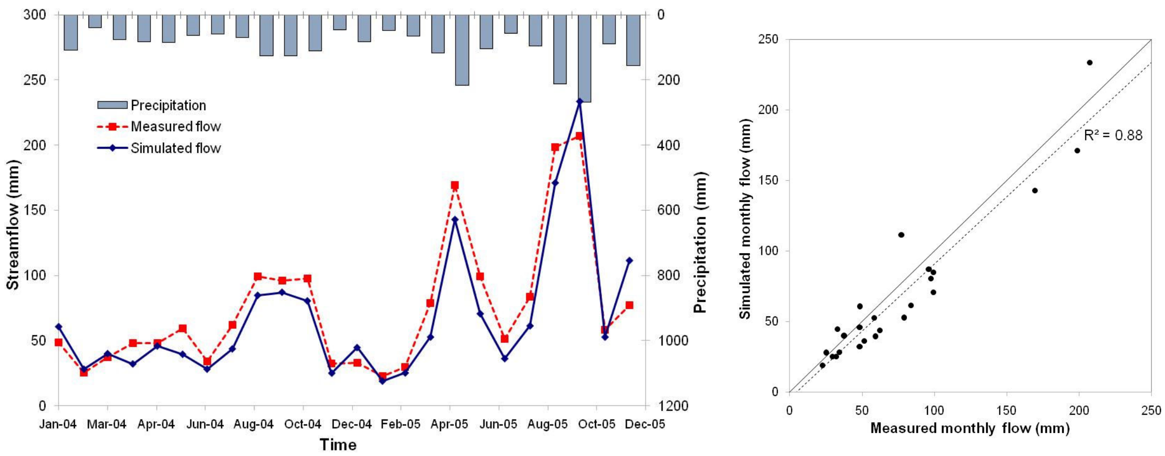

Figure 2 – Monthly flow calibration and validation results.

Model simulations could not capture the runoff peaks well in the daily flow record (Figure 3) may be due to uncertainty in the modified Soil Conservation Service curve number method (Mishra and Singh, 2003) used for estimate surface runoff. In the case where the time of concentration of the watershed is less (smaller) than 1 day, the uncertainty in estimated surface runoff from daily rainfall is even higher. Green *et al*. (2006) argues that as one value represents the range of rainfall intensities that can occur within a day, there can be a considerable amount of uncertainty within that time period.

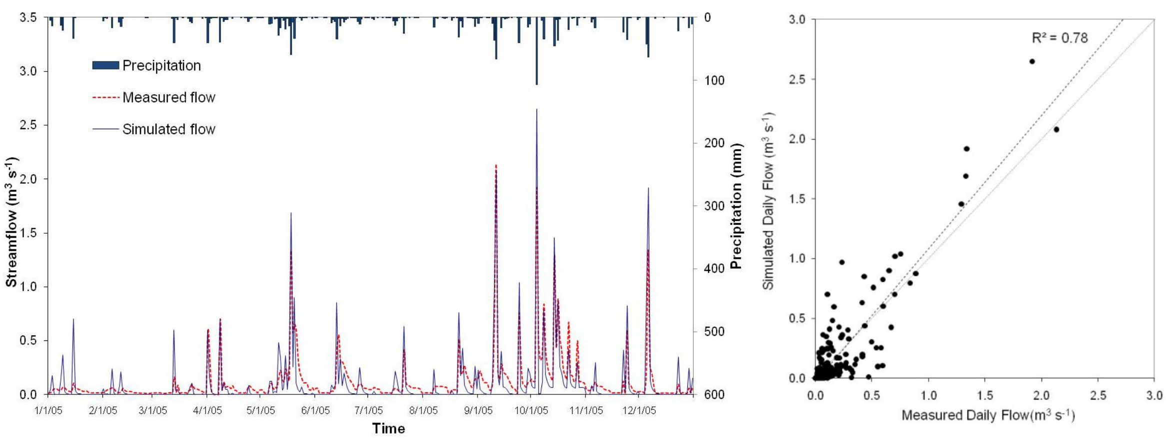

Figure 3 – Daily streamflow calibration results.

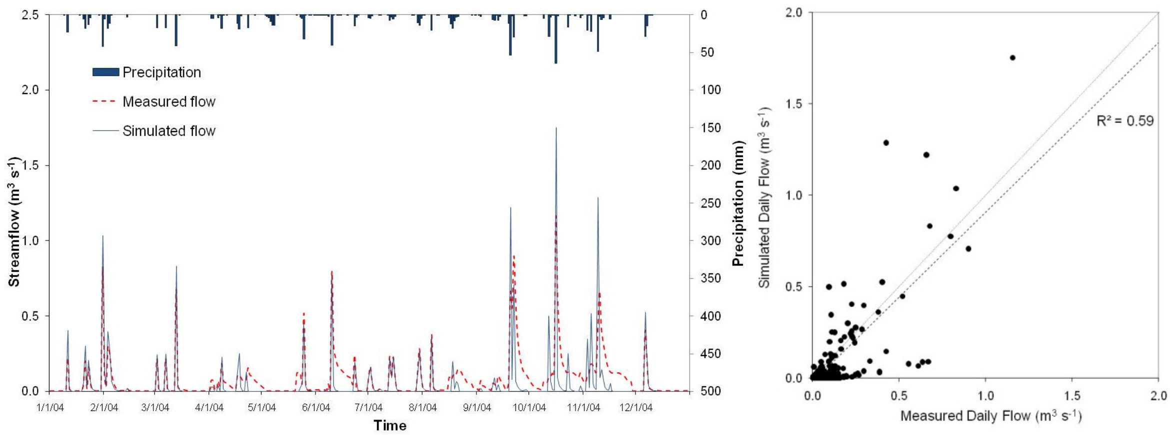

Figure 4 – Daily streamflow validation results.

1.4 - Conclusions

The SWAT model was used to simulate the hydrological water balance in the Arroio Lino watershed, located in Southern Brazil. An excellent agreement between monthly observed and simulated streamflow values was achieved during both calibration and validation periods at Arroio Lino watershed. At a daily time scale, the results indicated that the model simulations could not adequately capture the runoff peaks. Despite these limitations, the SWAT model produced good simulation results for monthly and annual time steps.

Having calibrated and validated the SWAT hydrology for the Arroio Lino Watershed, the next step will be to add the sediment and nutrient loading information. This tool will then assist in the simulation of multiple climate and land use scenarios. The results generated with the simulations, along with the existing ones can assist in environmental management and in the choice of economic alternatives that minimize environmental impacts caused by a particular land use.

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