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Modeling of non-point source pollution in a Mediterranean drainage basin

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SWAT ver. 2000 was used to predict hydrographs, and sediment, nitrate and total phosphorus loadings from a 1349 km^2 mountainous/agricultural watershed in Northern Greece. The model was calibrated and verified using continuous meteorological data from eight stations within the drainage area, and runoff, sediment and nutrient concentrations measured at nine stations located within the main tributaries of the watershed, for the time period from May 1st, 1998 to January 31st, 2000. Model validation methodology and resulting input parameters appropriate for Mediterranean drainage basins are presented. Predicted by the model hydrographs, sedimentographs and pollutographs are plotted against observed values and show good agreement. Model performance is evaluated using the root mean square error computation and scattergrams of predicted versus observed data. The validated model is also used to test the effectiveness of three alternative cropping scenarios in reducing nutrient loadings from the agricultural part of the watershed. The study showed that this model, if properly validated, can be used effectively in testing management scenarios in Mediterranean drainage basins.

Keywords: SWAT model, calibration, verification, hydrograph, sediments, nutrients, management scenarios, Mediterranean drainage basin

1. Introduction

Over recent decades, eutrophication of coastal and seawaters has been developing into a prominent concern. With the abatement of point-source pollution, the intensification of agricultural activities and the development of large urban centers, today eutrophication is mostly associated with non-point source pollution [1]. Thus, quantification of runoff, sediment yield and nutrient loadings from agricultural watersheds is required, in order to evaluate the effects of agricultural activities and management practices on surface water bodies.

Hydrological models have become an indispensable tool in assessing impacts of various pollution control policies and measures on nutrient fluxes in water bodies [2–4]. The basic requirement of any watershed model is the capacity to accurately estimate surface runoff, since this is the main factor in determining the transport of sediments and other non-point source pollutants, such as pesticides, nitrogen and phosphorus [5–9]. Once calibrated and verified, these models can be used in predicting the impacts of alternative scenarios on nutrient fluxes and water quality, and thus have the potential to be used as tools for supporting watershed management policy.

One such hydrological model, recently developed by the Agricultural Research Station (ARS) of the US Department of Agriculture (USDA), is the Soil and Water Assessment Tool (SWAT) [10–12]. SWAT links a simulation model with a built-in soil, land use and weather database for conditions in the United States, therefore, to be applied in other places of the world, it has to be adjusted for different weather, soil and local conditions. For example, Francos et al. [13] report such an application of SWAT in Finland.

This work reports the application of the hydrological model SWAT in a mountainous/agricultural drainage basin in Northern Greece, aiming at evaluating the applicability of this model under Mediterranean weather and soil conditions. The model was first calibrated and verified using meteorological, flow and water quality data collected during a nearly two-year period at various stations throughout the watershed, and then was used to test management scenarios to reduce pollutant loadings to the aquatic system. This study intents to provide a platform for future use of the model in Mediterranean drainage basins.

2. Methodology

2.1. SWAT model description

SWAT is a river basin or watershed scale model developed by the USDA Agricultural Research Service to predict water, sediment and nutrient yields in large complex rural watersheds with varying soils, land use and management conditions over short and long time periods [10]. SWAT incorporates features of several previous ARS models and is a direct outgrowth of the Simulator for Water Resources in Rural Basins (SWRRB) model [14]. Specific other models that contributed significantly to the development of SWAT were the Chemicals, Runoff and

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Erosion from Agricultural Management Systems model (CREAMS) [15], the Groundwater Loading Effects of Agricultural Management Systems model (GLEAMS) [16], and EPIC [17]. The hydrologic cycle, as simulated by SWAT, is based on the water budget equation [11,18]. To apply the model, the watershed is subdivided into sub-basins. Runoff is predicted separately for each sub-basin and is then routed through the channels to obtain total runoff hydrographs at various points of the watershed. Surface runoff is predicted for daily rainfall by using a modified version of the SCS curve number method [19]. Erosion and sediment yield are estimated for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) [20]. Nutrient (nitrogen and phosphorus) load and concentration predictions are based on a modification of the code in EPIC model [17,21]. Nutrient transport includes nitrogen and phosphorus in soluble and sediment-attached forms. Sediment-attached concentrations are associated with generated sediment loads. Soluble inorganic nutrients are determined on the basis of rainfall concentrations, soil solution concentrations and plant uptake. Sediment-attached nutrients are subjected to the same degradation processes as sediments, and soluble inorganic nutrients are treated as conservative constituents.

2.2. Study area

The study area is the Vistonis lagoon watershed in the region of Thrace, in Northern Greece (figure 1). Vistonis lagoon has a surface area of about 45 km^2 and its deeper part is about 3.8 m. It is an important wetland, which is protected by the Ramsar treaty and is considered as a first priority site under 'Natura 2000' network [22]. The drainage area contributing to the lagoon is approximately 1349 km^2. Geomorphologically, it consists of two major parts: the upper mountainous area, taking up 83% of the total surface, and the lower plain area taking the remaining 17% of the surface. Uppermost elevation is 1245 m a.s.l.

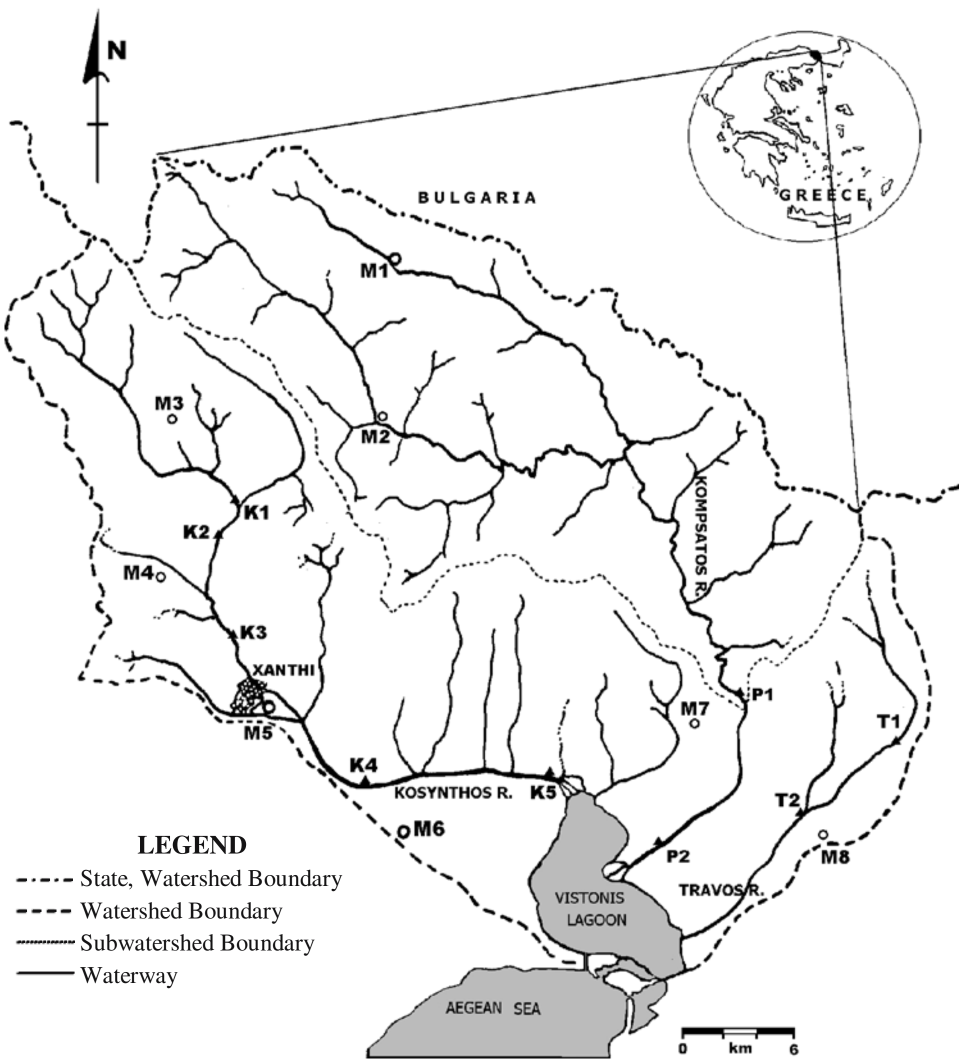

Figure 1. Study area, meteorological station location, flow and water quality sampling station location.

and outlet elevation of the watershed is at sea level. The watershed contains a complex system of torrents, which drain into the lagoon. The three main torrents are Kosynthos (80% mountainous), Kompsatos (nearly 100% mountainous) and Travos (30% mountainous). Mountains are covered by conifers and mixed deciduous forests. Main crops in the lower elevations are wheat, corn, cotton and tobacco. The lagoon connects to the Aegean Sea through a short and narrow channel and is under tidal influence. Over the past 20 years, the lagoon has suffered severe impacts

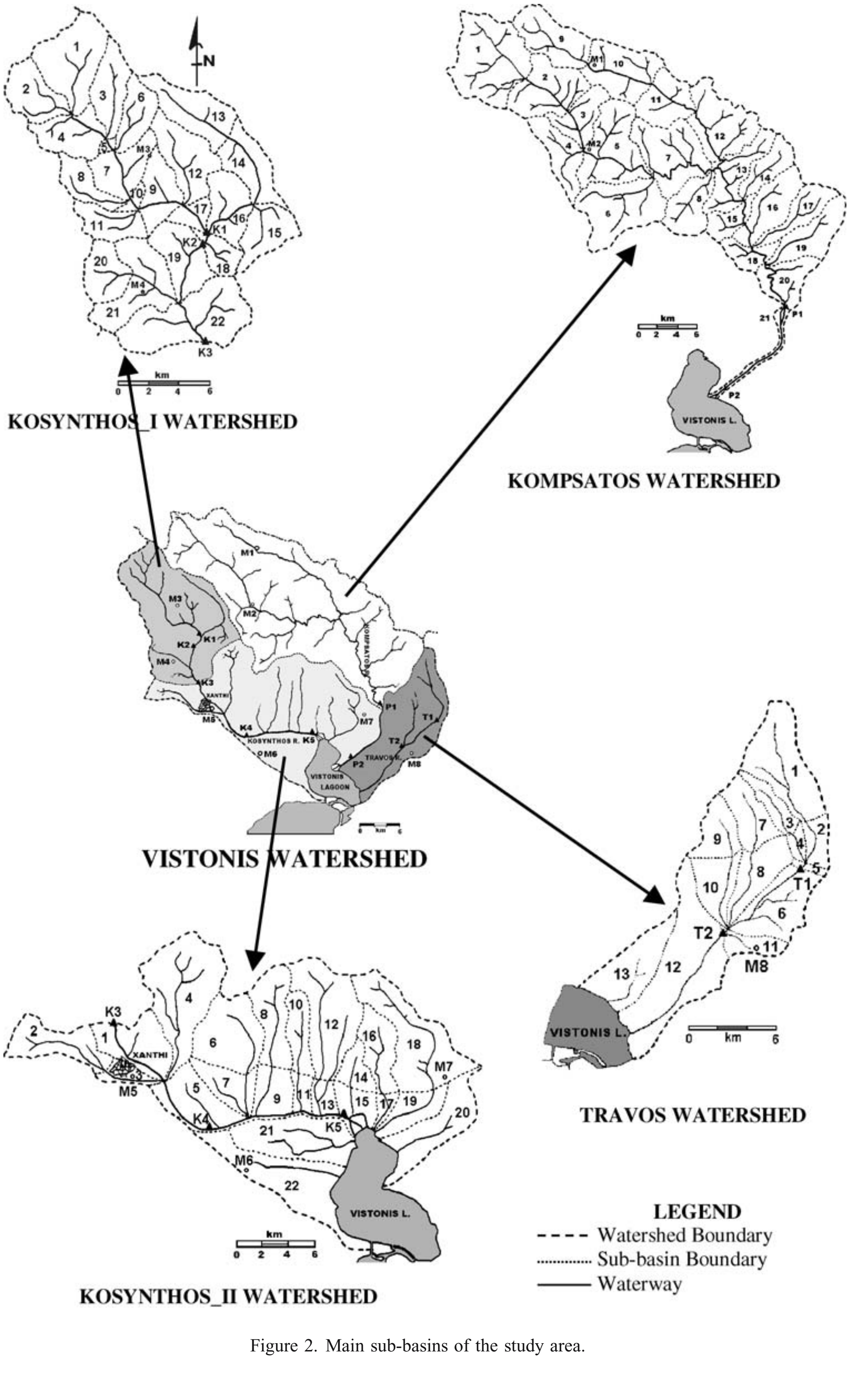

Figure 2. Main sub-basins of the study area.

due to point and non-point sources of pollutants. Over the last decade, however, several measures have been taken to reduce point source pollution, such as sewage treatment and diversion from the watercourses, proper solid waste management, and industrial waste elimination. Nevertheless, there are still pollutants entering the lagoon, mainly associated with agricultural land use practices.

2.3. Model input data

For model application, Vistonis watershed has been partitioned into four sub-basins: Kosynthos I and II sub-basins with surface areas of 236 and 383 km^2, respectively; Kompsatos sub-basin with a surface area of 570 km^2; and Travos sub-basin with a surface area of 160 km^2 (figure 2). Each sub-basin has been further divided into Hydrologic Response Units (HRUs) of varying sizes, as required by the model. Kosynthos sub-basins I and II have been divided into 22 HRUs each, Kompsatos into 21 HRUs and Travos into 13 HRUs.

Data required by the model include topography, soils, geology agricultural land management and daily weather data. Data on soil attributes, as well as land cover and use, were obtained from soil maps provided by the Greek Department of Agriculture. For each HRU, the soil percentage in clay, silt, sand, as well as percent of organic matter, were estimated for up to six soil layers from soil section data. Then, the dominant soil type was determined by using the USDA-SCS soil texture classification with the largest coverage in the HRU. A hydrologic category (A to D) was assigned to each HRU according to USDA-SCS [19]. A curve number was then assigned to each HRU based on the hydrologic soil group, land cover and land use [19]. The average slope and the average elevation of each HRU were estimated according to Williams and Berndt [23] from 1:50,000 and 1:100,000 maps.

Daily and mean monthly meteorological data used in this work cover the years from 1980 to 2000. Data collection from meteorological stations was tedious and time consuming, since data were not available in digital form. Moreover, daily precipitation and temperature data were available from eight meteorological stations (M1 to M8), evaporation data from stations M1 to M5 and M8, relative humidity from stations M5 and M8, wind speed from stations M5, M7 and M8 and cloud cover from stations M5 to M8 (figure 1). The available data from each meteorological station had to be converted into digital form, before statistical treatment. Thiessen polygons have been used to evaluate the influence of each station on each particular HRU.

Table 1
Parameter values used for calibration of the SWAT model.

Parameter	Typical range	Sub-basins			
		Travos	Kompsatos	Kosynthos_I	Kosynthos_II
Flow calibration					
Curve Number (CN)	15–95	71–74	70–72	72–73	71–73
Soil available water capacity (SOL_AWC)	0–1	0.11–0.18	0.13–0.14	0.09–0.13	0.11–0.15
Manning's n channel	0–1	0.10–0.15	0.03–0.10	0.08–0.10	0.03–0.10
Groundwater revap coefficient (GW_REVAP)	0.02–0.2	0.02	0.02	0.02	0.02
Baseflow alpha factor (ALPHA_BF)	0–1	0.025	0.027	0.028	0.027
Sediment calibration					
USLE equation soil erodibility (K) factor	0.0–0.7	0.23–0.26	0.20–0.26	0.21–0.26	0.12–0.26
USLE equation support practices (*P*) factor	0.1–1.0	0.15–0.30	0.30	0.30	0.15–0.30
Peak rate adjustment factor for sediment routing in the sub-basin (APM)	Default: 1	1	1	1	1
Peak rate adjustment factor for sediment routing in the channel (PRF)	Default: 1	0.06	0.04	0.03	0.03
Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing (SPCON)	0.0001–0.01	0.0001	0.0001	0.0001	0.0001
Exponent parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing (SPEXP)	1–1.5	1.40	1.43	1.47	1.45
Nutrient calibration (nitrogen, phosphorus)					
Nitrogen percolation coefficient (NPERCO)	0.0–1.0	0.2	0.4	0.25	0.38
Phosphorus percolation coefficient (PPERCO)	10	10	10	10	10
Concentration of nitrate in groundwater contribution to streamflow from sub-basin (GWNO3)		1.0–5.0	0.40	0.03–0.27	0.4–23.0
Concentration of soluble phosphorus in groundwater contribution to streamflow from sub-basin (GWMINP)		0.035–0.075	0.032	0.015–0.031	0.015–0.050

2.4. Flow, sediment and water quality data collection

The watershed was ungaged. Therefore, a data collection network was designed to collect flow, sediment and water quality data from five stations on the two Kosynthos sub-basins I and II (K1 to K5), two stations on the Kompsatos sub-basin (P1, P2) and two stations on the Travos sub-basin (T1, T2), (figure 1). The collection period lasted from May 1st, 1998 to January 31st, 2000. Data collection was done on a weekly basis, except in the summer (i.e., July and August), when discharge in the torrents stops. Discharge was estimated with the current meter method, using a Valeport, model 801, electromagnetic flowmeter. For suspended sediment (SS) sampling, a hand sampler (Hydrological Services LTP, model US DH-48) was used; SS were then determined gravimetrically following standard USGS procedures. Total phosphorus and nitrates were determined by spectrophotometry according to standard methods [24].

3. Model validation procedures and results

3.1. Calibration

The calibration of the model was conducted for the period from May 1st, 1998 to June 30th, 1999 using the field measurements collected at all stations. The calibration

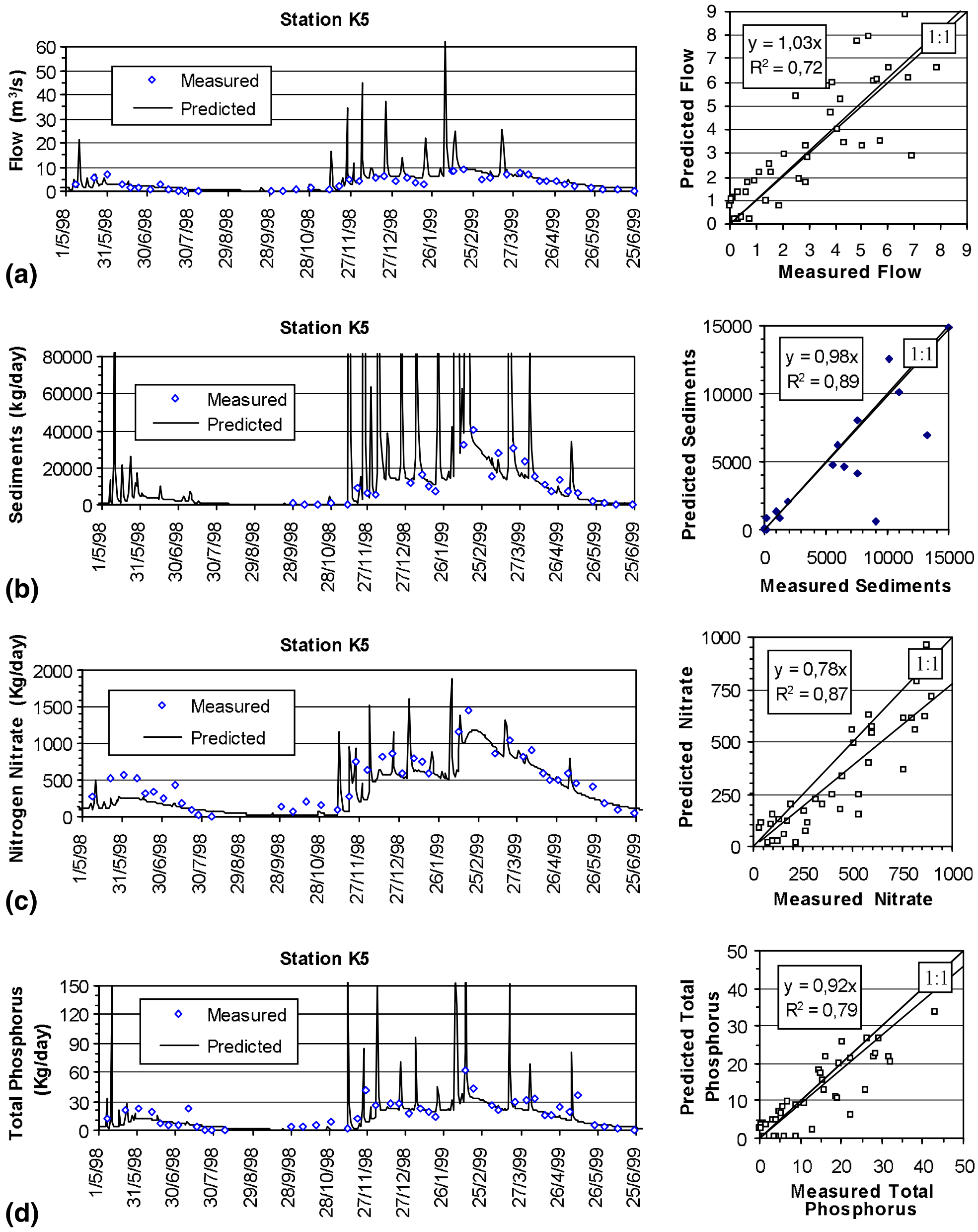

Figure 3. Model calibration: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station K5.

procedure was conducted first for water volume and flow rate, then for sediment quantity and then for nutrient quantities, according to the following steps:

1. Total water volume and discharge in the main torrents were calibrated in two steps: First, a curve number value was selected using standard SCS tables. Then, the value was varied within the range ±6 of this value until predicted and observed values approached [25]. Then the soil-available water capacity (SOL-AWC) was calibrated; this is estimated as the difference between the *in situ* water field capacity and the permanent wilting point, and represents the water volume that should be available to plants, if the soil, inclusive of rock fragments, was at field capacity. These steps were repeated until an acceptable fit to observed water volume at the outlet was obtained. Further agreement of observed and predicted values was achieved by adjustment of the groundwater parameters GW_REVAP, REVAPMN and GWQMN. Finally, better adjustment of the shape of the hydrograph was achieved by varying the base flow alpha factor (ALPHA_BF).
2. Sediment production was estimated by the MUSLE equation. The soil erodibility factor K was estimated from nomograms based on available soil data, according to Wischmeier and Smith [26] and Kirby and Morgan [27]. The erosion control practice factor P was estimated from percent slope and agricultural practices for erosion control, according to Wischmeier and Smith

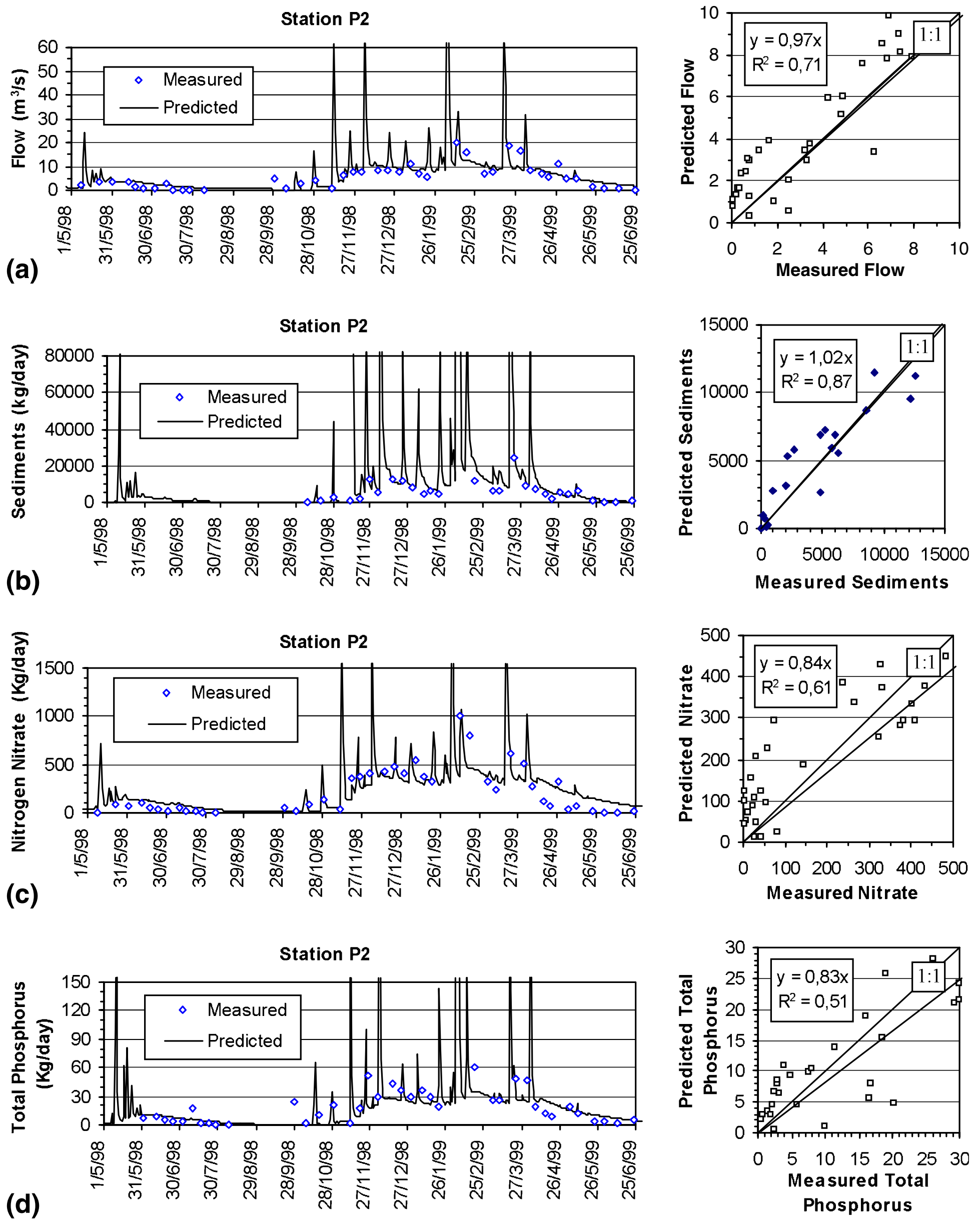

Figure 4. Model calibration: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station P2.

[26]. The peak rate adjustment factor for sediment routing in the sub-basin (APM) was kept to its default value. The peak rate adjustment factor for sediment routing in the channel (PRF) was varied for each channel first; then the linear parameter SPCON and the exponent parameter (SPEXP) of the channel sediment transport equation was varied until an acceptable fit of observed and predicted sediment loading was achieved.

3. According to SWAT configuration, a fraction of nutrients transported is sediment-attached. Therefore, nutrient transport calibration was done after flow and sediment calibration. With SWAT ver. 2000 [12], contribution of nitrate and phosphorus groundwater concentrations to stream concentrations is also possible, and is represented by two parameters: GWNO3 (groundwater contribution to nitrate concentration) and GWMINP (groundwater contribution to phosphorus concentration), respectively. In addition to parameters NPERCO and PPERCO, these two parameters had also to be adjusted accordingly to match observed and predicted values in all torrents.

4. The above procedure was stopped when for each of the four parameters (i.e., flow rate, and sediment, nitrate and total phosphorus quantities) there was a good match between observed and predicted values. This good

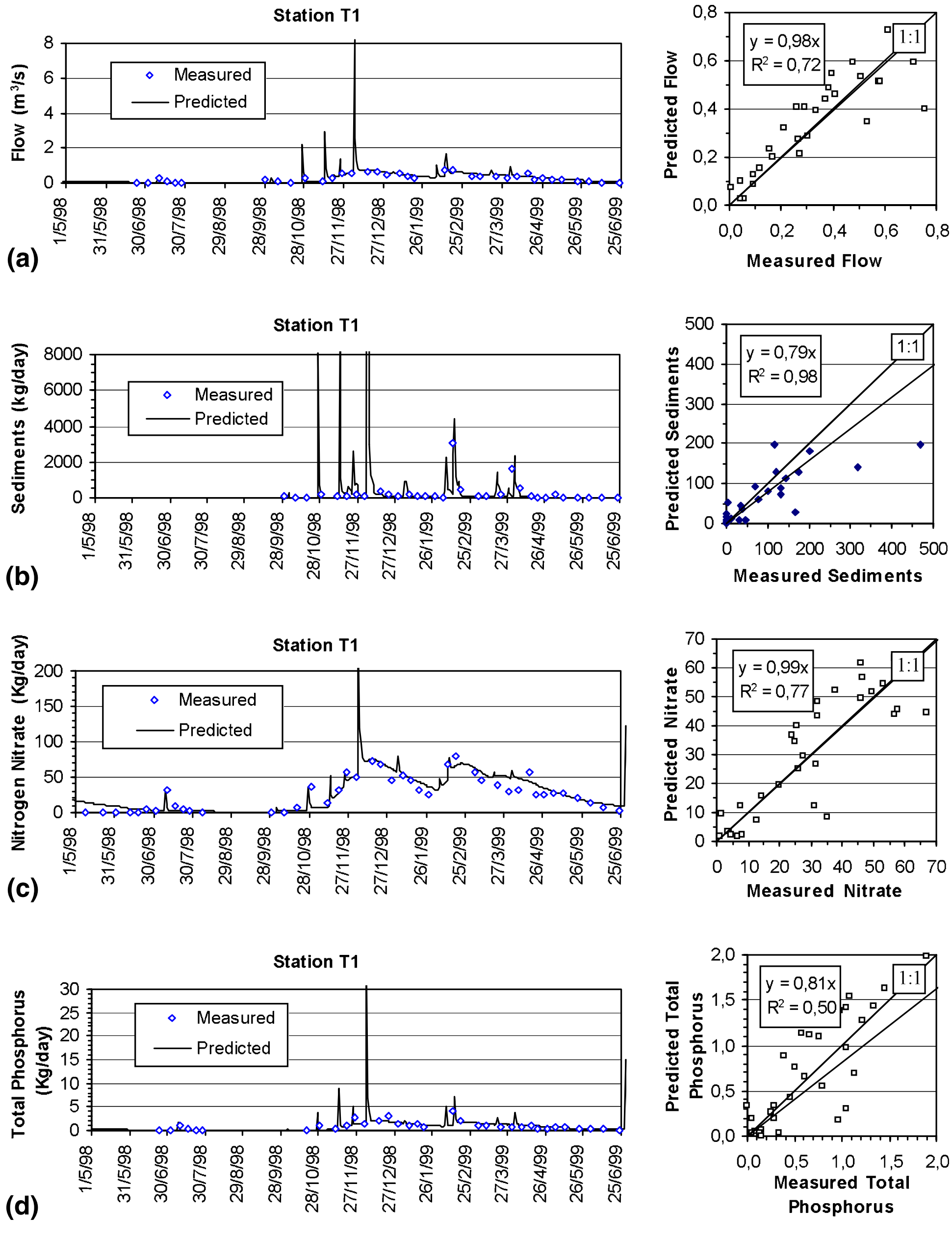

Figure 5. Model calibration: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station T1.

match was determined by computing for each model run the sum of square deviations between predicted and observed values, based on the following equation (1):

$$\mathrm{ERR}_X = \sum_{j=1}^{N} \left(X_{p_j} - X_{o_j}\right)^2 = \min \tag{1}$$

where X implies any one of the above mentioned four parameters, i.e., flow rate, and sediment, nitrate nitrogen and total phosphorus quantities; the subscript j implies the jth measured data point; and N is the number of measured points. The model was run several times for various values of the input parameters mentioned above until a minimum value was obtained for this sum.

Values of the various model input parameters, which resulted from the model calibration procedure, are summarized for each sub-basin in table 1. Typical comparisons of observed and predicted values are presented in figures 3–5 for one station at each sub-basin, i.e., stations K5 in Kosynthos, P2 in Kompsatos and T1 in Travos torrents, and for the four parameters, i.e., flow rate, and sediment, nitrate nitrogen and total phosphorus quantities. One can see that all predicted values at all stations, for the four parameters for the entire simulated period show good and very good agreement with measured values.

In order to determine the accuracy of the predictions of model calibration, two methods were used:

1. The mean square error (*MSE*) and the root mean square error (*RMSE*), also called normalized objective function (*NOF*) [28] for all data and the four parameters were computed based on the following equations:

$$MSE_X = \sqrt{\left[\frac{\sum_{j=1}^{N} \left(X_{p_j} - X_{o_j}\right)^2}{N}\right]} \tag{2}$$

$$RMSE_X = NOF_X = \frac{MSE_X}{X_m} \tag{3}$$

where parameters X, j, N and subscripts o and p were described above, and X_m is the mean of measured values. According to Kornecki et al. [28], the ideal value of *NOF* is 0.0. However, a model is accepted for *NOF* values less than 1.0 when site specific data are available for calibration. In that case, the model can be used to estimate and determine results associated with management practices.

Table 2
Best-fit criteria used for calibration and verification of SWAT model.

Station	Parameter	Calibration				Verification			
		Flow	Sediments	Nitrate nitrogen	Total phosphorus	Flow	Sediments	Nitrate nitrogen	Total phosphorus
K1	γ	0.88	0.97	1.02	0.78	1.15	1.16	1.05	0.95
	R^2	0.79	0.40	0.75	0.50	0.91	0.98	0.88	0.64
	NOF	0.36	1.00	0.42	0.50	0.38	0.43	0.34	0.40
K2	γ	0.97	1.04	0.96	0.79	1.07	0.79	1.07	0.80
	R^2	0.86	0.58	0.67	0.79	0.89	0.34	0.89	0.74
	NOF	0.27	0.91	0.46	0.37	0.30	0.73	0.31	0.37
K3	γ	0.99	0.78	0.92	0.80	1.04	0.92	1.11	0.77
	R^2	0.78	0.51	0.51	0.70	0.89	0.56	0.86	0.70
	NOF	0.35	0.68	0.57	0.40	0.23	0.62	0.38	0.43
K4	γ	1.10	0.99	0.97	0.90	0.92	0.98	0.82	0.83
	R^2	0.89	0.58	0.78	0.75	0.89	0.60	0.57	0.69
	NOF	0.31	0.81	0.35	0.47	0.33	0.65	0.50	0.41
K5	γ	1.03	0.98	0.78	0.92	0.87	1.12	0.74	0.75
	R^2	0.72	0.89	0.87	0.79	0.88	0.90	0.63	0.72
	NOF	0.43	0.32	0.35	0.44	0.37	0.67	0.45	0.45
P1	γ	1.00	0.99	0.91	0.82	0.95	0.77	0.88	0.73
	R^2	0.73	0.90	0.68	0.56	0.88	0.98	0.82	0.61
	NOF	0.47	0.50	0.52	0.55	0.34	0.55	0.40	0.54
P2	γ	0.97	1.02	0.84	0.83	0.92	0.68	0.77	0.74
	R^2	0.71	0.87	0.61	0.51	0.90	0.87	0.84	0.97
	NOF	0.48	0.63	0.54	0.54	0.31	0.50	0.43	0.36
T1	γ	0.98	0.79	0.99	0.81	0.88	0.75	1.08	0.69
	R^2	0.72	0.98	0.77	0.50	0.82	0.60	0.69	0.43
	NOF	0.31	0.66	0.33	0.57	0.30	0.65	0.49	0.53
T2	γ	1.03	N/a	0.95	0.76	0.81	N/a	0.80	0.67
	R^2	0.77	N/a	0.79	0.82	0.72	N/a	0.67	0.60
	NOF	0.38	N/a	0.44	0.42	0.43	N/a	0.49	0.60

N/a not available.

2. Another way to assess the calibration is through the use of scattergrams [7–9] where predicted quantities (i.e., flow rate, and sediment, nitrate nitrogen and total phosphorus quantities) are plotted against observed ones. In the scattergram, a regression straight line of the following form is fitted through the data:

$$X_p = \gamma X_o \tag{4}$$

and its slope γ is compared with the 1:1 slope (perfect match). The value of the slope γ is a measure of the over- ($\gamma > 1.0$) or under-prediction ($\gamma < 1.0$) of the model compared to the observed data. In addition, the square of the correlation coefficient R^2 of the regression line is computed. The lower the value of R^2 falls below 1.0, the worse the data correlation is, i.e., the greatest is the scatter of the data around the line. Therefore, best calibration requires that values for both slope γ and R^2 be as close to 1.0 as possible.

Calibration statistics results are presented in table 2 for all sites and the four parameters. One can see that the *NOF* values are less than 1.0 in all cases, thus the model can safely be used for estimating and determining results

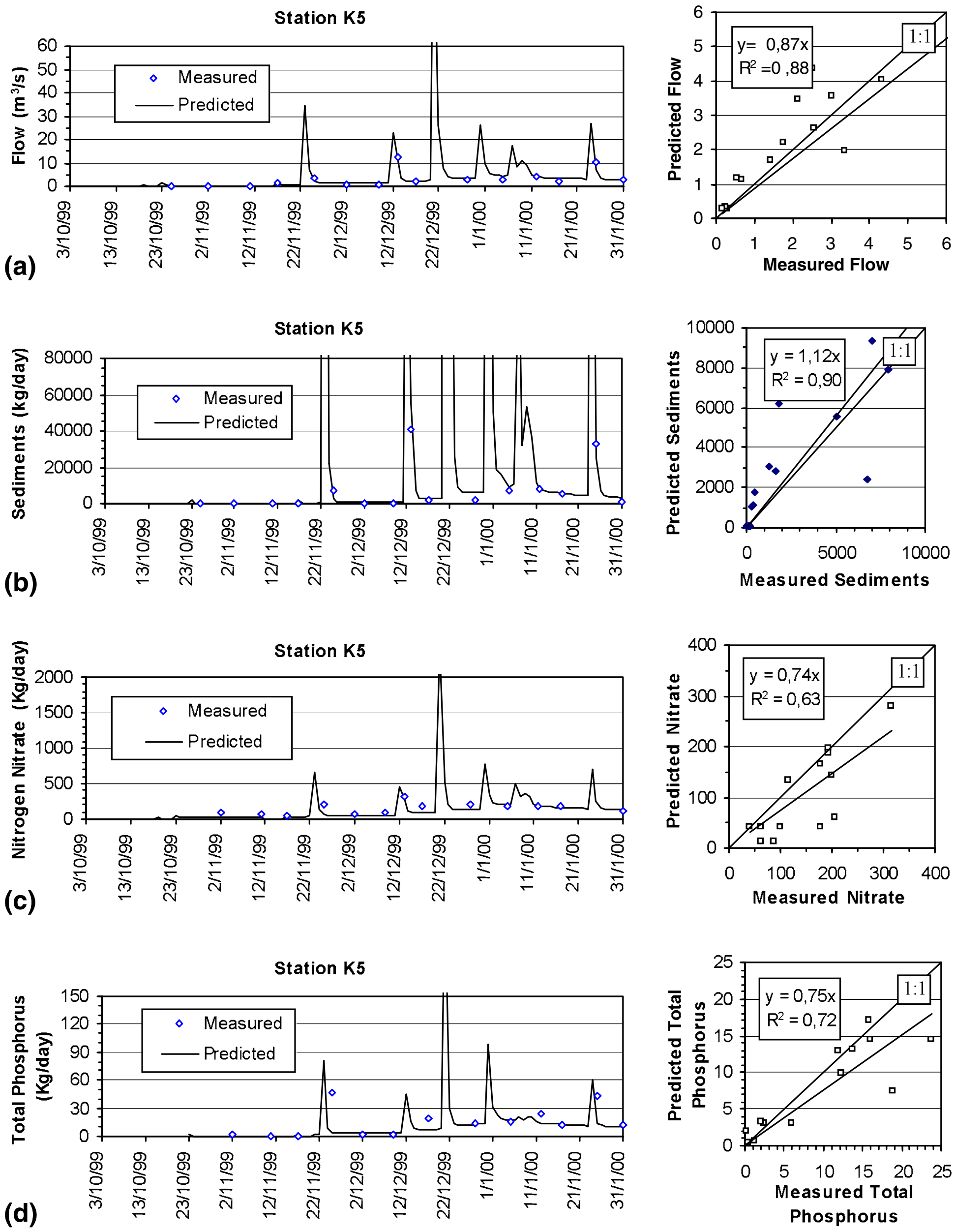

Figure 6. Model verification: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station K5.

associated with management practices [28]. Scattergrams for each parameter at three sampling sites, one in each sub-basin, are presented in figures 3–5. Values for the slope γ of equation (4) are close to 1.0 for all parameters, particularly for flow rate (γ between 0.88 to 1.10), sediment quantities (γ between 0.78 to 1.04) and nitrate quantities (γ between 0.78 to 1.02). Phosphorus is generally slightly underpredicted (γ between 0.78 and 0.92). Correlation coefficient values are closer to 1.0 for flow rate (R^2 between 0.71 to 0.89) and lower for the other parameters (R^2 between 0.40 to 0.98 for sediments, 0.51 to 0.87 for nitrates, and 0.50 to 0.82 for phosphorus), indicating some scatter around the straight line of equation (4).

3.2. Verification

Model verification was conducted using meteorological and field data collected from October 31st, 1999 until January 31st, 2000. The data set used in verification was different from that used in calibration (May 1st, 1998 to June 30th, 1999). Model input parameters used in verification were those found in calibration, as summarized in table 1. Typical visual comparison of observed and predicted values from verification runs for stations K5, P2 and T1 are shown in figures 6–8. As in calibration, these figures show that all predicted values at all stations, for the four parameters, for the entire simulated period show good and very good agreement with measured

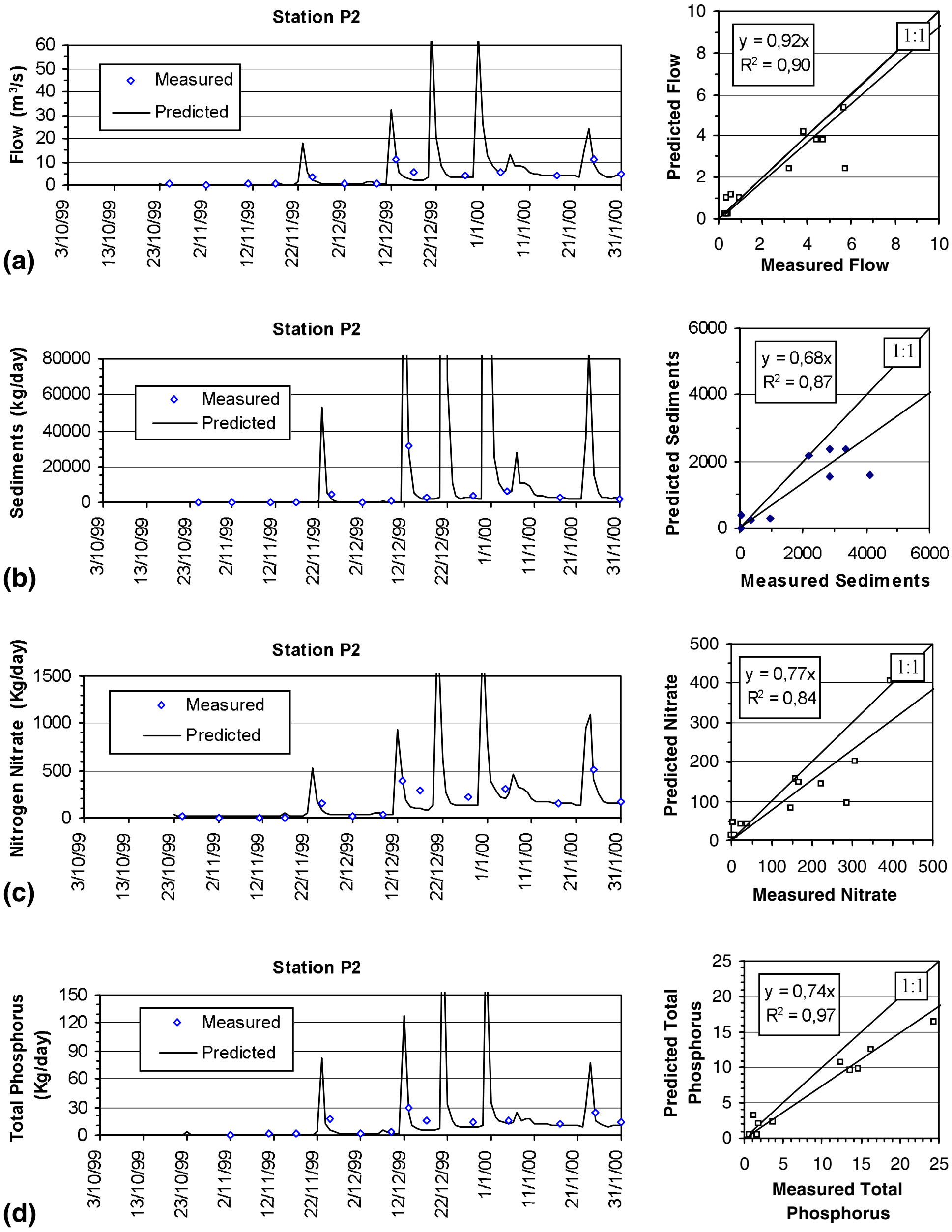

Figure 7. Model verification: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station P2.

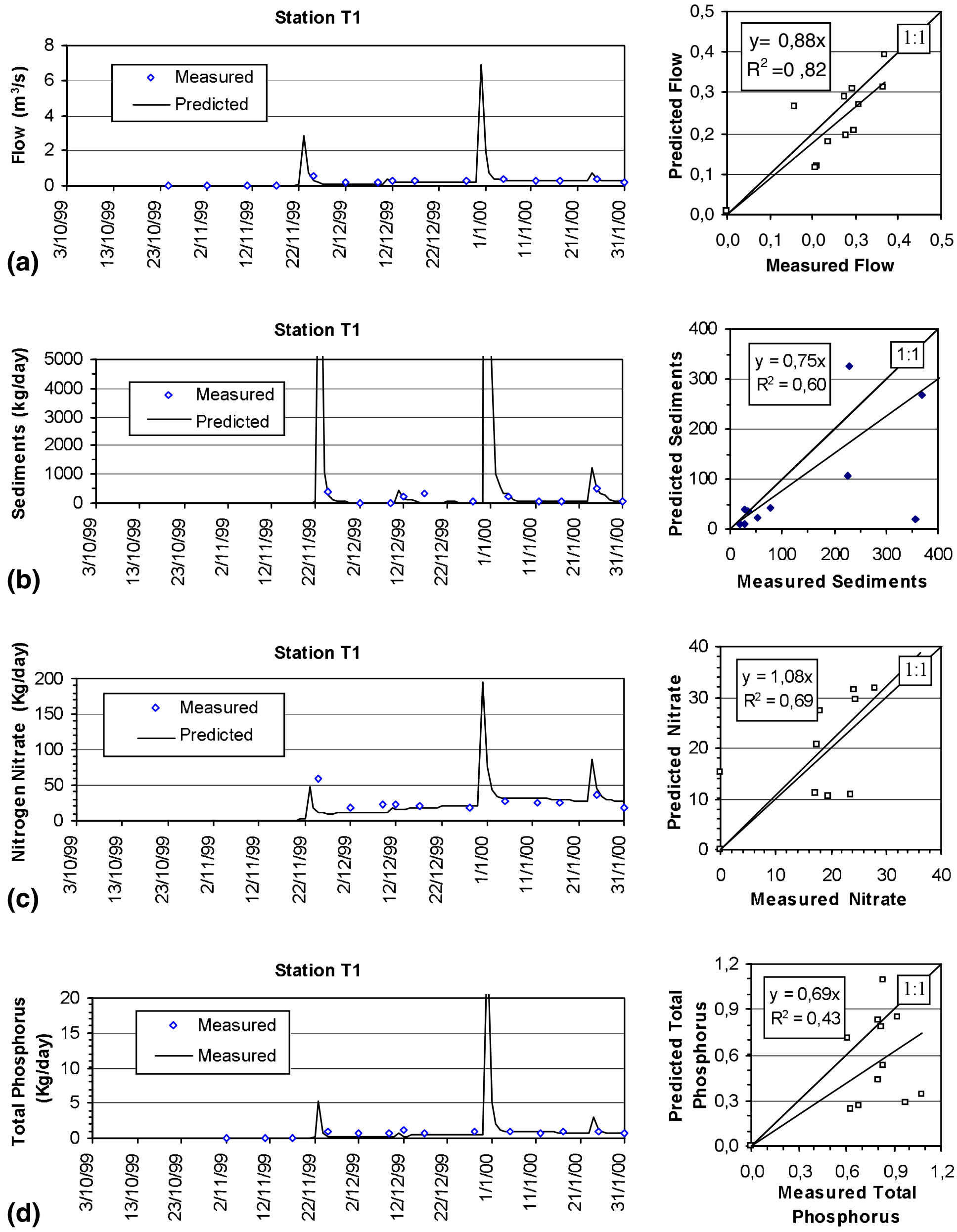

Figure 8. Model verification: measured and predicted flow, sediments, nitrate nitrogen, total phosphorus and corresponding scattergrams at station T1.

values. Accuracy of the predictions from verification runs was determined with the two methods also used in calibration, i.e., *NOF* computation equation (3) and use of scattergrams and equation (4).

NOF, γ and R^2 values are presented in table 2. One can see that the *NOF* values are less than 1.0 in all cases (and in most times less than 0.5), thus the model can safely be used for estimating and determining results associated with management practices [28]. Scattergrams for each parameter and site are presented in figures 6–8. Values for the slope γ of equation (4) are close to 1.0 for all parameters, particularly for flow rate (γ between 0.81 to 1.15), sediment quantities (γ between 0.68 to 1.16) and nitrate quantities (γ between 0.74 to 1.11). Phosphorus is again slightly underpredicted (γ between 0.67 and 0.95). Correlation coefficient values are closer to 1.0 for flow rate (R^2 between 0.72 to 0.91) and lower for the other parameters (R^2 between 0.34 to 0.98 for sediments, 0.57 to 0.89 for nitrates, and 0.43 to 0.97 for phosphorus), indicating some scatter around the straight line of equation (4).

In general, agreement between observed and predicted values is considered good for all parameters used, especially for flow and sediments, while nutrients are slightly underestimated in all torrents. Therefore, the model, with the calibrated input parameters shown in table 1, reproduces well the measured quantities during the verification time period, and thus, it can be safely used in testing management scenarios.

Table 3
Estimated flow, sediment and nutrient loadings to Vistonis lagoon from May 1998 to June 1999.

Drainage sub-basin	Flow		Sediments		Nitrate-N		Total *P*	
	$m^3 \times 10^6$	% of total input to the lagoon	tn	% of total input to the lagoon	tn	% of total input to the lagoon	tn	% of total input to the lagoon
Kosynthos	183.4	40.90	15,090	60.76	280.5	63.28	7.9	41.58
Kompsatos	238.6	53.21	9254	37.27	98.5	22.22	9.8	51.58
Travos	26.4	5.89	488	1.97	64.3	14.50	1.3	6.84
Total	448.4	100.00	24,832	100.00	443.3	100.00	19.0	100.00

4. Model application

4.1. Water, sediment and nutrient budgets

The budgets of water, sediments and nutrients in Vistonis lagoon, as estimated by SWAT model for the period of model calibration (May 1998 to June 1999) are shown in table 3. It can be seen that the medium in size torrent, Kompsatos, contributes about 53% of the total water volume to the lagoon, while the combined action of Kompsatos and Kosynthos comes to about 94% of the total water quantity. The remaining 6% of water flow is due to Travos torrent. Total phosphorus transport shows a similar distribution trend. Finally, Kosynthos alone transports more than 60% of total sediments and nitrates. Significant is also Travos' contribution of nitrates (about 14%), because of its relatively large agricultural area. With these observations one can easily identify the areas where measures to reduce nutrient loadings should be applied.

4.2. Management scenarios

Management scenarios were developed for the entire watershed. Travos watershed was selected here for demonstration of model application in the evaluation of the impact of alternative crop management scenarios on nutrient transport, because it has the larger agricultural area (70% of the catchment), with main crops wheat, corn and cotton. The seasonal fertilizer application and the estimated amounts of nutrients for these crops are shown in table 4. Corn needs the largest amount of both nutrients as compared to the other two crops; the fertilizer is applied from early or mid-April to late June, just before torrent flow stops. Fertilizer for cotton is applied at the same time periods as for corn; however, the required quantity is about half of that for corn. For wheat, fertilizer is applied twice a year (late March and mid-November); the late autumn application coincides with high rainfall and discharge that results in high nutrient leaching.

Three different scenarios of crop management have been applied; for each scenario, only one crop was considered covering the entire arable area: wheat, corn or cotton. In table 5, the nutrient transport from Travos catchment is summarized as a result of the three alternative crop scenarios. The 'only cotton' scenario predicts a considerable reduction of both nutrients. On the other hand, the 'only wheat' and 'only corn' scenarios predict an increase of the transport of both nutrients, but the 'only wheat' scenario is the worst, since an increase of 64% in N-Nitrate and of 38.5% in total *P* is predicted. The predicted seasonal fluctuations of both nutrients for each scenario are shown in figure 9.

5. Discussion

A sensitivity analysis of SWAT input parameters for the Upper Mississippi river basin, performed by Arnold et al. [25], showed that surface runoff is extremely sensitive to the curve number, which is related to both soil and vegetation cover. In our study area, soil variation is rather limited. The entire Vistonis watershed consists mainly of sandy loam. Kosynthos II sub-basin has a higher variety of soils, but sandy loam, sandy clay, silty clay loam, loamy sand and loam are found in most HRUs.

According to Eckhardt et al. [29], most surface runoff is generated on arable land compared to forest, because the soil cover is poor over long time periods, ET and interception are low, and the curve number used is relatively high. Our results (table 1) indicate the same trends: Travos sub-basin is 70% arable land in the low elevations. Only the higher elevation HRU had a CN value of 71; for the lower HRUs

Table 4
Period of annual fertilizer application and quantity of nutrients in Vistonis lagoon catchment.

Crop	Period of application	Total quantity (kg/ha)	
		Nitrogen	Phosphorus
Cotton	Spring	110	26
Corn	Spring	240	61
Wheat	Early spring and late autumn	200	26

Table 5
Estimated nutrient loads to Vistonis lagoon from different crop management scenarios in Travos watershed from May 1998 to June 1999.

Crop management scenario	Nitrate-N		Total *P*	
	Loading (tn)	Percent change	Loading (tn)	Percent change
Present state	64.3	0.0	1.3	0.0
Only wheat	105.3	+64.0	1.8	+38.5
Only corn	72.1	+12.1	1.7	+30.8
Only cotton	46.2	−28.0	1.0	−23.1

CN was 73 or 74. In the mountainous Kompsatos sub-basin CN values varied from 70 to 71, reflecting forest cover, since the mountainous region of this sub-basin is covered by deciduous, conifers or mixed forests.

Muttiah and Wurbs [30] assessed the changes in the mean and the variance of water balance components due to variability in soils and climate in large watersheds in Texas. They found that in relative dry climates (average annual precipitation of 663 mm), heterogeneity of soils in the watershed does not have as much impact on the mean of soil water storage as in wet climates. Vistonis watershed has a relatively dry climate type, since the average annual precipitation ranges from 475 mm at station M6 (figures 1 and 2) to 886 mm at station M2 (average about 680 mm), and relatively homogeneous soils which are mainly sandy clays and sandy loams. According to the SWAT manual, the corresponding SOL_AWC values for these two soil types are 0.13 and 0.14, respectively. Therefore, differences in the soil available water capacity due to either soil or climate are expected to be low and close to the values given by SWAT manual. Indeed, for Kosynthos I and II sub-basins, values ranged

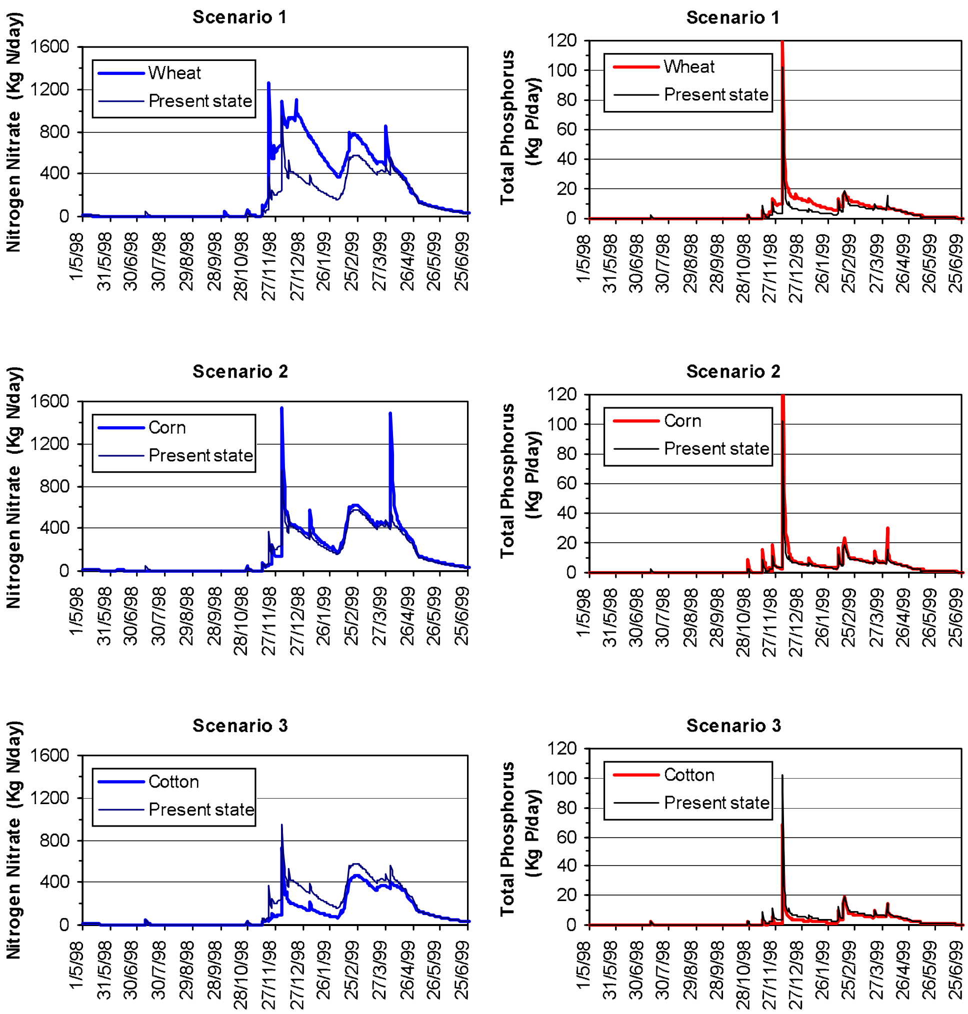

Figure 9. Comparison of three crop management alternatives with the present condition.

from 0.09 to 0.13 and 0.11 to 0.15, respectively (table 1). Generally, higher values of this parameter occurred in the lower sub-basin. For Kompsatos sub-basin this range was smaller (from 0.13 to 0.14). In Travos sub-basin, however, SOL_AWC values ranged from 0.11 to 0.18, with larger values in the lower agricultural HRUs. A possible explanation is that the soil in the lower areas is more saturated with water, as a result of the extensive crop irrigation and high groundwater table due to the proximity to Vistonis lagoon.

Fitzhugh and Mackay [31] reported the impact of input parameter spatial aggregation on streamflow prediction in the Pheasant branch watershed in Wisconsin. Their analysis involved sub-basin area delineation that ranged from 1593 to 26 ha and HRU area delineation that ranged from 165 to 3 ha. They found that streamflow and outlet sediment predictions were not seriously affected by changes in sub-basin size. More particularly, the average annual streamflow was underestimated, but it was within 20% of measured flows for sub-basins of up to 956 ha. Predictions were less accurate for monthly streamflows. Streamflow increased only 12% between the coarsest and the finest watershed delineations and it was evident in annual, monthly and daily model output. The delineation used in our study was comparatively coarse (sub-basin size ranged from 16,000 to 57,000 ha and HRU size ranged from 1073 to 1741 ha), but rainfall simulation was daily and comparisons of measured and predicted values were approximately on a weekly basis. As presented, most measured parameters at various points of the watershed were fairly well simulated (table 2). This implies that possible prediction errors originating from coarse delineation are at least partly compromised by a small time step to give predictions within acceptable limits [28,32].

According to FitzHugh and Mackay [31], there is an indication that monthly changes in output sediments are being driven by changes in streamflow. Also, they concluded that model accuracy is not greatly affected by changing the watershed delineation, because the opposite events of sediment production in the watersheds and sediment deposition in the channels fluctuate at the same rate, resulting in comparable outlet loadings. In our application, with a coarser delineation, but a daily time step, sediment prediction was within comparable limits of accuracy as water flow.

The parameter SPCON that provides a good fit between average annual measured and predicted outlet sediment was held unchanged in the lowest default value for all sub-basins and was equal to 0.0001; instead, tuning was obtained by adjusting the parameter SPEXP, which relates sediment loading exponentially to flow. It is worth to note that this parameter was close to the highest value limit suggested by the model. This indicates a high sediment transport in all sub-basins, expected due to their torrential character. The maximum value of this parameter in Kosynthos I and II sub-basins indicate high sediment generation, because of relatively higher slopes. The value of this parameter is lower in Travos, because most of its surface area is in relatively flat plain.

Nutrients were slightly underestimated in all sub-basins, but the model simulated fairly well the seasonal changes and trends. This was achieved because SWAT ver. 2000, takes into account the contribution of groundwater nitrate and phosphorus to streamflow through the GWNO3 and GWMINP parameters, respectively. The importance of groundwater as a nitrate source to streams has been suggested by Gerhart [33] and, more recently, by Reay et al. [34] and Arnold et al. [25]. The GNNO3 parameter had a higher value in Travos sub-basin, probably due to the high degree of soil water saturation, expressed by the relatively high value of the parameter SOL-AWC. It is worthy mentioning that previous than 2000 versions of SWAT do not contain parameters GWNO3 and GWMINP. Our early attempts to calibrate SWAT ver. 98.1 for nutrients, using the same dataset of measured nutrient concentrations, were not as successful.

6. Conclusions

The predictions of SWAT model tested in this study showed quite good agreement with the observed data. The procedures for calibration of SWAT presented herein and the derived values for various input parameters can be used as guidelines for modeling of stormwater runoff, and sediment and nutrient transport in Mediterranean drainage basins. Particularly, the values of the input parameters obtained from the calibration runs of the model can be used as a reference or starting point for calibration of this model in areas with similar characteristics. In addition, it seems that this model is a very useful tool in evaluating management alternatives in rural basins.

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