Coupled water flow and quality modelling of an intermittent French river: The Vène

Nanée Chahinian, Marie-George Tournoud, Jean-Louis Perrin, Bernadette Picot
HydroSciences Montpellier, Université Montpellier 2, Case courrier MSE, Place Eugène Bataillon, 34095 Montpellier Cedex 5, France. chahinian@msem.univ-montp2.fr

1. Introduction

Coastal intermittent rivers have a specific hydrological behaviour resulting in long draught periods interrupted by floods of high intensity and short duration, which also influence water quality dynamics. Indeed during low flow periods pollutants accumulate in the river bed and are flushed away by the first floods (Dorioz et al., 1996 ; Walling et al., 2003). These rivers often constitute the only available water resource in semi-arid countries and hence are vulnerable to diffuse and point source pollution. To assess these impacts quantitatively, a number of studies have used coupled hydrological and water quality models (Plus et al., 2006, Tournoud et al., 2006, Bouraoui et al., 2005).
SWAT is one of the most widely used models in the hydrologic community (see Gassman et al., 2007 for a full review). Although its use for nutrient modelling is less documented in the literature than for flow modelling (Tolson and Shoemaker 2007) more material is becoming available (Tolson and Shoemaker 2007, Srinivasan et al., 2005 , Muleta and Nicklow, 2004; Santi et al., 2001).

One of the important assets of SWAT is that the minimum data to run it is predominantely available from US governmental agencies (Bekele and Wicklow, 2007; Nietsch et al., 2005). It can also account for point inputs and thus springs and STW loads can be included into the modelling scheme without the need for a detailed understanding of their inner workings. However the use of SWAT on foreign catchments is not a straightforward task because the requested data is not always available, or at least not at the desired time or space scales. A common problem in the case of French catchments for instance, is that point pollution data is not always available. Indeed, for STWs that receive less than 120 kg of organic waste per day, nitrogen and phosphorous monitoring are not mandatory (Journal Officiel, 1995). In addition, the monitoring frequency imposed for the remaining parameters does not necessarily match the modeller's requirements or the catchment's hydrological dynamics. This is a crucial problem when working on small intermittent rivers because flow conditions vary rapidly and alter the river's chemical and bacteriological composition. Hence, one may question whether SWAT is a suitable tool for such rivers.

The main purpose of this study is to explore the adaptability of the SWAT model to intermittent rivers having direct inputs in the river from small STWs or karstic springs, in a setting where most of the sediments and nutrients do not originate on the hillslopes and where point inputs are tainted by various uncertainty levels. We will highlight the use of SWAT through an application for coupled flow and sediment simulations.

2. Materials and methods

2.1 The study zone

The Vène River drains a 67 km² topographic catchment with elevations ranging between 2 and 323m amsl. The catchment has a mixed landuse pattern consisting of natural karstic zones (63% of total area), agricultural zones (34%) of which 21% are vineyards and residential areas which are in fact 3 villages (3%) (Fig. 1).
The river has a 12 km course with a regular slope of 0,4% and a Strahler stream order of 3. The cross-sections are about 5 m wide covered by a dense riparian vegetation, with abrupt banks (35%), straight-walled banks (15%) or a combination of both. In addition to the runoff produced on the hillslopes, the river is fed by two karstic springs: Cournonsec in the upper part of the catchment and Issanka in the lower part. The later is used to supply drinking water to the city of Sète, with a daily pumping rate of 9000 $m^3.day^{-1}$. A compensation water flow of 0.11 $m^3.s^{-1}$ is reserved for the Vène river during its low flow period.
Uptil june 2005, the river received the inputs of two wineries and three sewage treatment works (STWs), two lagoons and an activated sludge. One of the STWs (Cournonsec-activated sludge) is currently shut down, however, the remaining two still pour into the river. The wineries operate only during summer and fall. The effluents of the STWs have a strong seasonal variability due to the extensive treatment process.

The vène river flows into the Thau lagoon, a site of economical importance because of its shellfish farming activities. The impact of the river on the nutrient load of the lagoon has been established for the past two decades (Picot *et al.*, 1990).

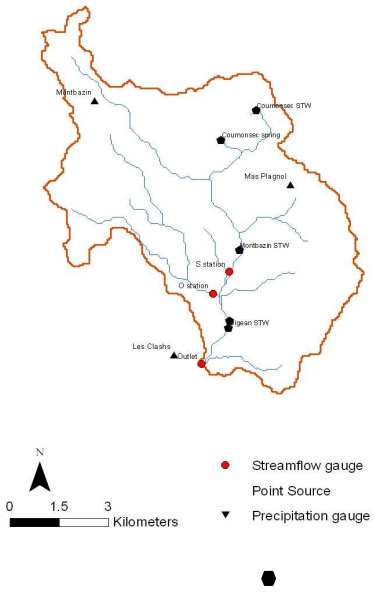

Fig. 1 The Vène catchment

The experimental setting

The Vène is an experimental catchment on which water and nutrient fluxes have been monitored at various spatial scales since 1994. Currently, rainfall is monitored by means of three tipping-bucket rain gauges (0,2 mm capacity). The longest available record is that of the Montbazin station (Aug. 1994) and the shortest that of the Les Clash station (March 2003). River stages have been installed at four locations and water heights are recorded at a 5-min interval. These are combined with hourly conductivity measurements (Fig. 1). Discharge data for the Cournonsec karstic springs is available through the measurements at stations K. Its influence is also monitored indirectly by using the conductivity measurements, a parameter frequently used for studies on the hydrodynamics of kartsic systems.

Every fortnight, water samples are collected manually and water quality probes are used for the in-situ measurement of temperature, pH, conductivity, Eh, and dissolved oxygen content. The water samples are used to determine both the chemical signature of water (major elements and trace elements, nitrogen, phosphorous) and its bacteriological quality (EColi and Streptococcus).

In addition to the regular measurements, several one day field campaigns have been undertaken to assess the spatial variability of given parameters. The detailed methodology and results are presented in Tournoud et al., 2006. Biogeochemical parameters have also been measured in soils and sediments during specific campaigns.

Main hydrological processes

Four hydrological years stretching from 09/2002 to 09/2006 are used in this study. This period was selected because it is the richest in terms of both hydrological and hydrochemical data. The main hydrological characteristics of the study period are summarized in table 1.

Although the yearly mean evapotransipration is relatively stable (CV= 3%), rainfall and outflow values vary considerably (CV=30% and 79% respectively). This configuration is of course not surprising for Mediterranean countries. In this instance, the outflow fluctuations are further dampened by the input from the karstic springs and the STW discharges. Hence the rainfall-runoff relationship is not a strictly linear one.

It is interesting to the note that the intra-annual variability is also very high as illustrated by the monthly hydrographs presented in figure 2. As in most Mediterranean catchments, the Vène is subject to two rainy seasons; one in the autumn and another in spring with short duration and high intensity rainfall spells in the summer. Hence long drought periods occur where the river bed is completely dry. A combined study of flow and electrical conductivity records at the catchment outlet established the low flow limit at $Q<0.06$ $m^3.s^{-1}$ (Grillot, 2006). Thus, the number of low flow days over the study period fluctuates between a minimum of 57 days to a maximum of 237 days per year. During these periods, the inflows from the STW are the major contribution to the river. The latter influence both the water flow and quality of the Vène.

Table 1. Main hydrological characteristics of the study period

	1999-2000	*2000-2001*	*2001-2002*	*2002-2003*	*2003-2004*	*2004-2005*	*2005-2006*
Annual precipitation (mm)	712	666	648	950	1028	385	615
Annual outflow (mm)	265	293	64	630	799	52	367
Annual Penmann Potential Evaporation (mm)	1281	1331	1312	1353	1320	1386	1365
Number of low flow days ($Q<0.06$ $m^3.day^{-1}$)	169	184	237	64	57	262	153

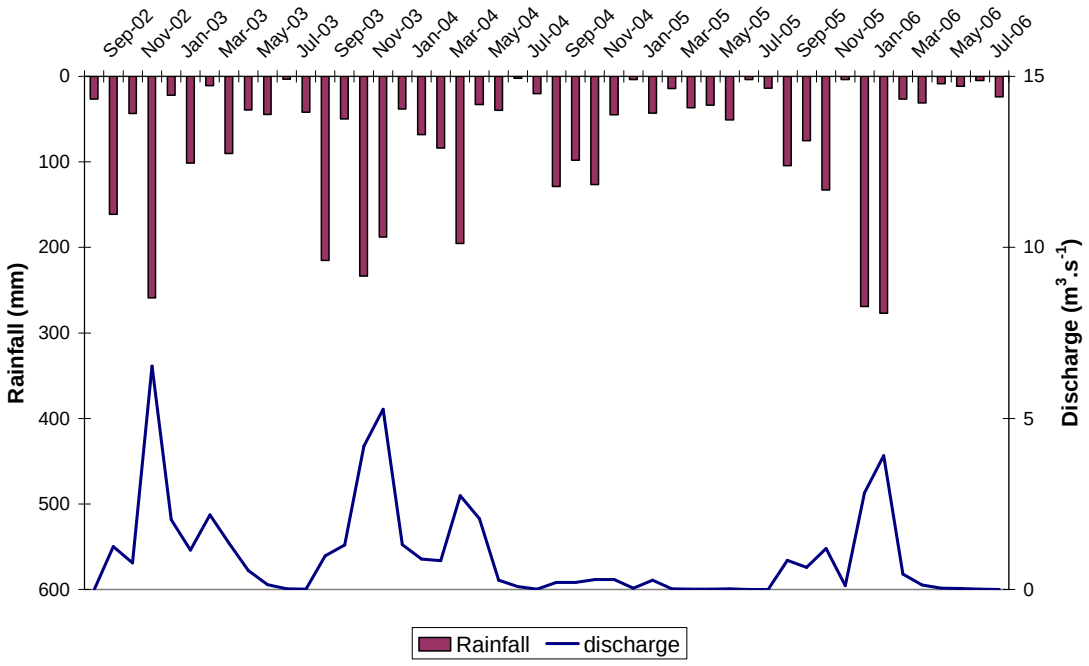

Fig. 2 Monthly rainfall and discharge value

Sediment and nutriment dynamics

Analysis of monitoring data shows that in terms of bulk volume sediment transport is of minor importance on the Vène. However, sediments, and most importantly suspended solids, are a crucial part of the nutriment transport processes. Indeed experimental data shows that during low flow conditions nutrients and pollutants accumulate in the sediments which later act as pollutant sinks (Tournoud et al., 2005). Hence the main contributions to the river's water quality vary according to the flow conditions (Tournoud et al., 2005; Jouret, 2004). Nitrogen sources for the same flow conditions are more numerous. The STWs are the main contributors to the nitrogen fluxes at the outlet during low flow conditions however a major part of these fluxes is lost through denitrification (David, 2005). During high flow conditions, the karstic springs contribute also greatly to the nitrogen fluxes, both in terms of flow volume and through NOx concentrations.

Nutrient dynamics during floods is complex. During summer flash floods, the remobilization of the phosphorous accumulated previously in the sediments is clearly supported by experimental data. These findings cannot be totally extended to nitrogen as rain input may also contribute to the fluxes. During winter floods, the inflows from the karstic springs increase the nitrogen fluxes and decrease the phosphorous fluxes by dilution. On a yearly basis the nutriment input from the agricultural areas is low as vineyard owners do not use vast quantities of fertilizers and weeding is mostly done by tillage. The contribution from the agricultural areas is predominant in terms of nitrogen mainly during flow recession periods.

2.2 The model

SWAT 2005 (Soil and Water Assessment Tool; Arnold et al., 1998; Neitsch et al., 2005) was used to simulate nitrogen and phosphorous dynamics on a monthly basis.

SWAT is a semi-distributed model originally developed to predict the impact of land management practices on water, sediment and chemical yields in complex catchments. It has been widely described and constantly updated since its first publication. The documentation and software can be freely downloaded through the internet http://www.brc.tamus.edu/swat/.

SWAT runs in continuous mode and uses a two-step spatial discretisation scheme to account for the catchment's spatial variability. The catchment is divided in sub-catchments based on the site's topography and the sub-catchments are further divided into Hydrologic Response Units (HRU) i.e. homogenous areas with regards to landuse, soil and management practices. The responses of each HRU are determined individually and then aggregated at the sub-catchment level (land phase) and routed to the corresponding reach first and to the catchment outlet later using the channel network (water or routing phase).

Each HRU is divided vertically into 4 components: the root zone, the unsaturated zone, the shallow unconfined aquifer and a deep confined aquifer which is connected to the system only through pumping. The hydrologic model accounts for precipitation, evapotranspiration, surface runoff, infiltration, lateral flow and percolation. The water balance equation insures mass conservation throughout the system.

The model has additional modules to simulate plant growth, erosion, nutrient and pesticide movement and transformation and various management practices.

In this work the latest version of the model (ArcSwat2005 version 1.3) is used. This version is interfaced with ESRI's ArcGIS software and thus data processing can be done through a GUI. The model's hydrological and sediment transport modules are used at a daily time step. The hydrological model is based on the SCS model for rainfall/runoff partitioning coupled to the variable travel time transport function. The erosion and sediment transport modules are based on the Modifiled Universal Soil Loss Equation (MUSLE).

Model parameterisation and calibration

As no information is available on the Issanka spring, we decided to calibrate the model on the area delimited by station S i.e. 56% of the total catchment area and validate it on the outlet (Fig. 1). Using ArcSwat's automatic segmentation procedure the calibration area was divided into 9 sub-catchments and 45 HRUs whereas the total catchment was divided into 23 sub-catchments and 64 HRUs.

SWAT includes soil, landuse and weather databases that may be used to parametrise the model when used on US catchments. Two of the landuse classes encountered on the Vène, "Garrigue" and "Vineyards" were not included in the SWAT database and had to be added manually. The values provided in Plus et al., 2006 were used as a reference for the growth parameters of both covers. The management model of the garrigue was set similar to that of the rangeland brush. For the vineyards, the growth date was set to the 15th of March and the harvest to the 15th of September, in accordance with the farming practices of the study zone. Although tillage practices can be used for weeding purposes, no information is available on the tillage dates or the number of tillage operations per year. Hence this detail was not accounted for in the management model.

The soil topology was based on the French National Agricultural Research Institute's (INRA-Montpellier) soil database (Jamagne et al., 1996, Bornand et al., 1998) and soil profile descriptions undertaken by the university of Essen and HydroSciences Montpellier

Experimental data from the Mèze weather station located 16 km to the South of the study zone was used to build the weather database requested by SWAT, with the exception of the Penmann Potential Evaporation data which was obtained from Météo-France's weather station located in Frejorgues i.e. some 30 km to the north east of the study zone.

Point source inputs

Over the study period, three SWTs discharged into the Vene; two stabilisation ponds (Gigean and Montbazin) and an activated sludge-extended aeration with specific denitrification (Cournonsec). The later was shut down in June 2005 and its collectors were diverted to the Montpellier STW.

Out of the three STWS, the Gigean plant has the longest published data record. While the Montbazin and Cournonsec stations being of smaller capacity (< 2000 PE) are not within the quality control requirements imposed by the EU Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. In the case of the Montbazin plant, even basic daily flow data is not available. Thus we reverted to the PE concept (Dégremont, 2005) to estimate the monthly flows.

Lack of daily flow data was also a problem for the Issanka spring, a major contributor to the flows at the outlet. Given the importance of the spring, we decided to "rebuild" daily flow records using joint conductivity and flow measurements based on the framework suggested by Grillot (2006). The later had identified two distinctive conductivity signals corresponding to karstic springs and STWs and had thus determined each point source family's contribution to the flows at the outlet. We assumed that the two karstic springs had the same contribution and using equation 1, calculated daily flow values for the Issanka spring

$$\begin{aligned} &If\ Q_{spring1} < 0 \Rightarrow Q_{spring2} = Q_{compensation} = 0.11\ m^3.s^{-1} \\ &If\ Q_{spring1} > 0 \Rightarrow Q_{spring2} = Q_{outlet} * contribution_{spring1} \end{aligned} \quad (1)$$

This relation is only valid for flow as in-stream processes greatly alter sediment and nutrient fluxes along the river. Hence no attempts were made to rebuild the water quality records of Issanka. As a direct consequence no input value was set for the sediment concentrations of the spring.

For all input sources, the daily sediment and nutrient loadings are calculated using a modified version of Salles et al.'s (2008) relation

$$Load = V \frac{\sum_{i=1}^{n} q_i C_i}{\sum_{i=1}^{n} q_i} \quad (2)$$

Where:

V : Volume corresponding to mean daily discharge based on 5min interval data
C(i) : Concentration
Q(i) : Instantaneous discharge at time of sampling
n : Number of samples

If only a single concentration measurement is available then n=1 and the relation reduces to

$$Load = VC \tag{3}$$

One may question the representativity of the load values calculated through eq(3) as only a single concentration value is used. It is true that for the karstic spring and the activated sludge this can be an important source of uncertainty. However, the outputs of the lagoons are usually spilled after a residence time of 1-3 months, hence they may be considered already as averaged samples.

Objective functions and calibration procedure

The model calibration procedure is two-fold. First, a manual calibration is undertaken by "trial and error" and then SWAT's in-built "PARASOL" automatic calibration procedure (Van Griensven and Mexner, 2004) is used to "fine tune" the results. The model is first calibrated for flow, then for sediment loads. Five objective functions are used to assess the model's performance based on "classical" goodness of fit measures such as the Nash and Sutcliffe (1970) efficiency, the bias and the root mean square error. High flows and floods will influence the criteria calculated on discharge values, whereas those calculated on the ln(Q) will be more influenced by low flows. The criteria calculated on √Q will represent all the discharge values, giving equal weight to both high and low flows.

The parameters to be calibrated are selected based on the recent literature available on SWAT (Bekele and Nicklow, 2007; Van Griensven et al., 2006; Muleta and Wicklow, 2005) on previous modelling applications carried out on the Thau Lagoon using SWAT (Plus et al., 2006 and 2003) and on a sensitivity analysis we undertook using SWAT's in-built tool.

$$NSE = 1 - \left(\frac{\sum_{t=1}^{N} (X_{sim,t} - X_{obs,t})^2}{\sum_{t=1}^{N} \left(X_{obs,t} - \bar{X}_{obs,t} \right)} \right) \tag{4}$$

$$NSE(\sqrt{X}) = 1 - \left(\frac{\sum_{t=1}^{N} (\sqrt{X_{sim,t}} - \sqrt{X_{obs,t}})^2}{\sum_{t=1}^{N} \left(\sqrt{X_{obs,t}} - \sqrt{\bar{X}_{obs,t}} \right)} \right) \tag{5}$$

$$RMSE = \sqrt{\frac{1}{N} \left(\sum_{t=1}^{N} \left(X_{sim,t} - X_{obs,t} \right)^2 \right)} \tag{6}$$

$$RMSE\ln(Q) = \sqrt{\frac{1}{N} \left(\sum_{t=1}^{N} \ln\left(X_{sim,t} + \frac{\bar{X}_{obs,t}}{10} \right) - \ln\left(X_{obs,t} \frac{\bar{X}_{obs,t}}{10} \right) \right)^2} \tag{7}$$

$$Bias = \left[\frac{\sum_{t=1}^{N} \left(X_{sim,t} - X_{obs,t} \right)}{\sum_{t=1}^{N} X_{obs,t}} \right] * 100 \tag{8}$$

Swat's automatic calibration is undertaken using the sum of squared residuals.

$$SSQ = \sum_{t=1}^{N} \left[X_{mes,t} - X_{sim,t} \right]^2 \tag{9}$$

Where
N : Number of time steps used;
t : Time step index;
X : Simulated variable, sim and obs refer to simulated and observed variables

Data from the first year of the study was used to warm up the model. However, a one year period is not sufficient to stabilize flow and nutriment fluxes. Hence, the warmup period was extended to 10 years using the same 2002-2003 dataset. Thus, the 2002-2004 was used for calibration and 2004-2006 for validation.

3. Results

3.1 Flow

Table 2 summarises the calibration results both in terms of parameter values using manual and automated calibration (a) and objective function values (b). In order to check the validity of the calibrated results, we performed a split-sample test using SWAT's automatic calibration procedure. Hence the model was also calibrated on the 2004-2006. The calibrated parameters are identical, with variations < 1%.

The calibration method (i.e. manual vs. automatic) does not affect the value of some of the parameters (CN2, GW_delay, GW_revap, Soil_revap, Soil_AWC, Sol_K); however others such as Gwqmin, Revapmin and Surlag undergo important variations. Surlag refers to the catchment's lag time and the value obtained by automatic calibration is not realistic as data suggests that it should not exceed 1 day. As for revapmin its negative value sets it outside of the parameter's possible range. This is an indication of the automatic procedure's failure in determining this parameter accurately probably because of the karstic nature of the aquifer which clearly does not correspond to the single porosity aquifer concept on which the groundwater fluxes are based in SWAT. Hence the parameter regulating the exchanges between the surface and the groundwater is also altered by the automatic calibration (Revapmin). Finally, in the absence of piezometric data in the study zone and taking into account the peculiar behaviour of karstic aquifers, the representativity of the parameters governing groundwater flow cannot be established. The CN values are in accordance with those reported in the literature for the urban areas and the garrigue, but not for vine. Indeed the value recommended for Californian vines varies between 79 and 84 (USDA, 1990), while Plus (2003) used the default values given for "row crops, straight row" i.e. a range of [72-91]. However the SCS curve number remains an empirical parameter that regulates the runoff/infiltration ratio and its value is not necessarily an indication of accurate process representation. Furthermore, given the inter-dependency of parameters, one can always compensate for this parameter by adding a high value of channel infiltration (CH_K).

Table 2a. Calibrated parameter values for flow simulation

Parameter name	Manual calibration 2002-2004	Automatic calibration 2002-2004	Automatic calibration 2004-2006
Alpha_Bf	0.37	0.37	0.37
Ch_K2	0.47	0.47	0.47
Ch_N	0.07	0.55	0.55
CN2 Vine	39	37.05	37.05
CN2 urban areas	97	92.15	92.15
Gw_Delay	9.00	9.91	9.91
Gw_Revap	0.02	0.02	0.02
Gwqmn	100.00	55.95	55.9
Revapmin	1.00	-72.06	-72.1
Sol_Awc	0.21	0.23	0.24
Sol_K	10.00	11.12	11.25
Surlag	1.00	9.19	9.19

Table 2b. Objective function values for flow simulation

Objective function (%)	Calibration method		Validation	
	Manual	Automatic	Manual	Automatic
NSE	90	87	81	83
NSE(√Q)	92	91	84	85
RMSE	46	51	46	44
RMSE(lnQ)	19	19	19	18
BIAS	-5	-2	-19	-11
SSQ	139	168	152	139

The results of both the manual and automatic calibration are successful in terms of overall adequate representation of the measured flow values (fig 3) as highlighted by the high NSE (> 85%) values and the low SSQ (<170) and bias values (<5%). Average flow values are well replicated (NSE√Q>90%) and the overall shape of the hydrograph is respected despite local estimation errors on peakflows and low flows (RMSE(lnQ>14%), although no clear tendency or bias can be observed.

Good results are also obtained when using the calibrated parameters on the first period to simulate the flows of the second as highlighted in figure 4. Although the bias criterion increases to respectively 56% and 89%, the SSQ is not altered and the NSE, despite its decrease, remains within acceptable bounds. It should also be noted that the RMSE is improved, although the errors on low flows have increased (RMSE(lnQ)>29%).

These results are an indication that despite the doubtable values obtained for the CN on vineyards, SWAT is able to reproduce the daily flow values accurately. Similar conclusions were reached by Plus et al., (2003 and 2005) who modelled the entire Vène catchment using rough monthly estimates for the Issanka Spring.

In order to validate the model fully, we used the parameters calibrated at the sub-catchment scale to simulate discharge values at the outlet without further tuning. The results presented in figure 5 indicate a good simulation of the rising limb of the hydrograph despite an underestimation of the peakflow, and a relatively poorer fit of the recession limb. The resulting Nash and Sutcliffe efficiency is of 42%. Given the uncertainties related to the inputs of the Issanka Spring, this result is rather encouraging. It can probably be improved by a better estimation of the spring's discharge into the river and by further calibration using the outlet's flow records.

3.2 Suspended solids

Data regarding the sediment transport consists of punctual suspended solid samples. For the 731 days of the calibration period (09/2002-09/2004), only 48 measurement points are available. This data set can be used to fit 3 parameters at the upmost as the number of observations should be at least 20 times the number of parameters to be estimated (Soorooshian and Gupta, 1995).

The results of the sensitivity analysis indicated that out of the 6 parameters specific to the sediment transport module, the three most sensitive are those related to the maximum amount of sediment that could re-enter the channel (Sp_Con), the channel cover (Ch_Cov) and the channel erodability (Ch_Erod).

We attempted several manual calibration trials and then used SWAT's automatic procedure in an effort to improve the results (tab. 3a). However, in all instances and despite more than 10000 simulations, we were not able to get a good fit between measured and simulated TSS concentrations. This is not surprising as the calibration data sample is far from being optimal given its frequency distribution. Indeed, 70% of the sediment concentrations are below 20 $mg.l^{-1}$ with only two measurements exceeding 500 $mg.l^{-1}$ (Fig 6). The high concentration values correspond to samples obtained during floods, either through routine monitoring or specific flood monitoring campaigns. In the case of the later a greater number of data points is used to calculate the mean daily concentration and hence these values have higher accuracy. Thus calibrating sediment data clearly involves a dilemma. Should one privilege the most frequently observed values (i.e. low concentrations ≤ 20 $mg.l^{-1}$) or the values which, albeit rarer, contribute more to both sediment and nutriment transport? Another solution would have been to split the calibration dataset in two and attempt to obtain a separate set of parameters for the low and high values.

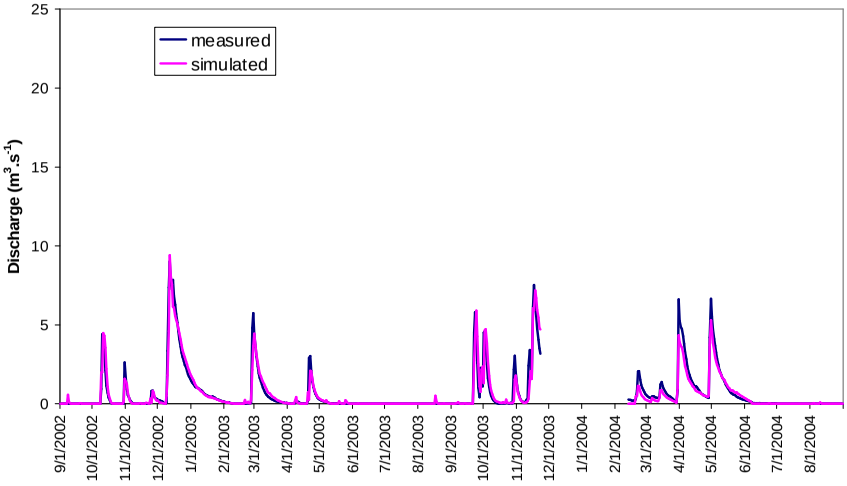

Fig. 3 Simulated and measured hydrographs for the calibration period

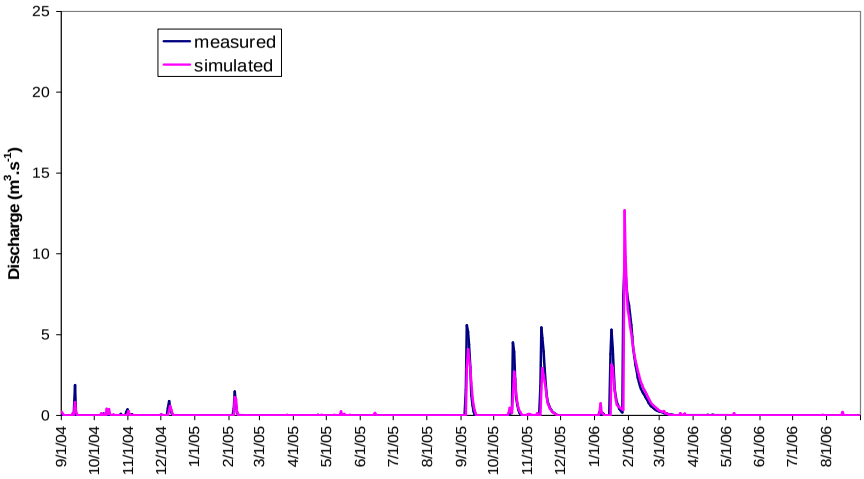

Fig. 4 Simulated and measured hydrographs for the validation period

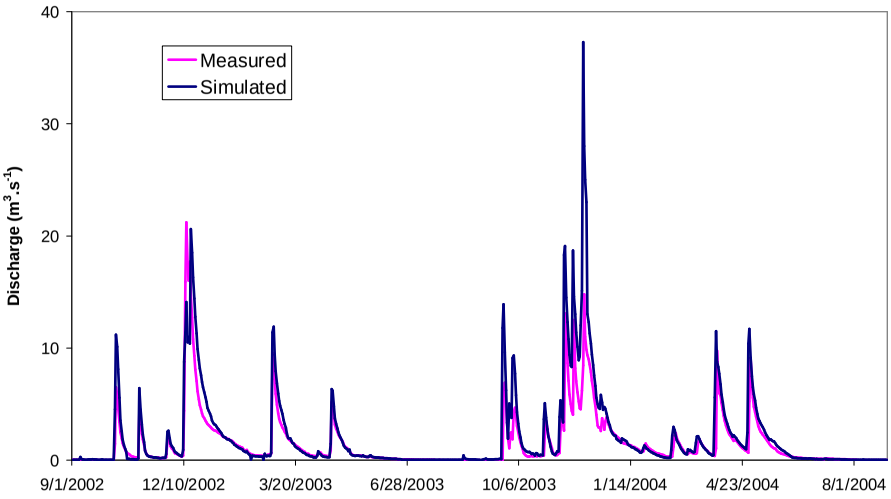

Fig 5 Measured and simulated hydrographs at catchment scale

However, this option would result in an even smaller data set for each type. Thus, the idea was not carried on.

Table 3.a Calibrated parameter values for sediment simulation

Parameter	Manual calibration	Automatic calibration
Ch_Cov	0.1	0.9991
Ch_Erod	0.1	0.9996
Spcon	0.0001	0.0005

Table 3b. Objective function values for sediment simulation

Objective function (%)	Calibration method		Validation	
	Manual	Automatic	Manual	Automatic
NSE	-5	9	-11	-300
NSE(√Q)	-29	-23	-17.49	-241
RMSE	16516	15400	149123	285955
RMSE(lnQ)	243	18	56	11.5
BIAS	-21	-52	-90	-51
SSQ	1.31E+06	1.14E+06	1.16E+06	4.25E+06

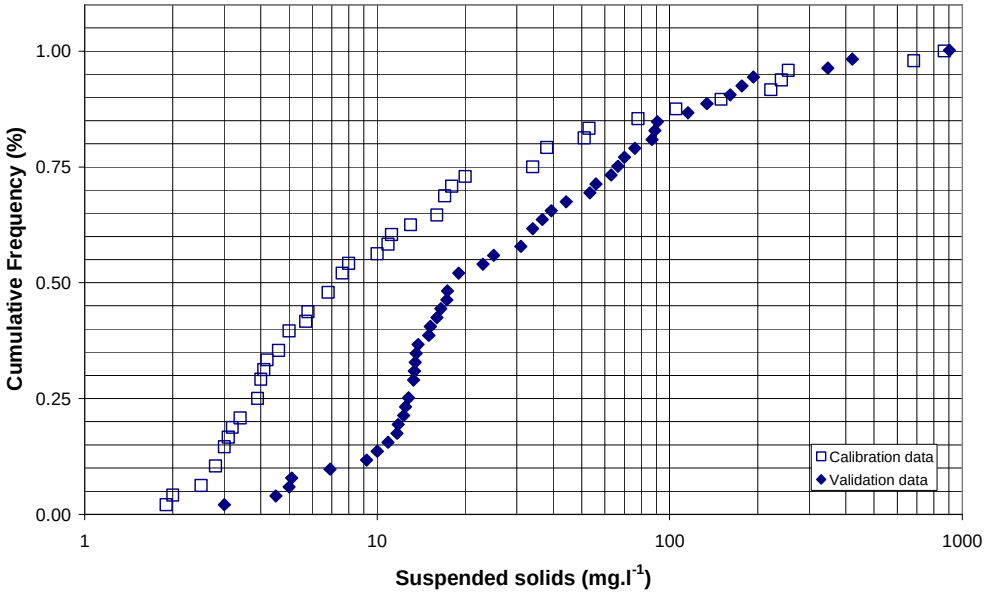

Fig.6 Frequency distribution of the Suspended solids data used in the study.

As the automatic calibration results indicate (tab. 3a), it is quite impossible to determine a unique set of parameters that can be fitted to the entire data set, although during our tests we were able get average concentrations of simulated TSS that were within the same order of magnitude as the measured one. However, the "good parameter" set obtained through automatic calibration has a very wide uncertainty range of nearly 100%. The "best parameter" set corresponds to the maximum range thus

indicating the failure of the calibration procedure: the optimum is more likely to correspond to a local minimum rather than a global solution.

Data scarcity can partly explain this phenomenon. However, numerical problems are not solely to blame. Indeed, SWAT's sediment module assumes that the amount of sediment in the river is directly linked to either channel degradation or soil degradation on the HRUs but these two mechanisms are not of great importance on the Vène as they reprensent only 25% of the sediment input to the river (Grillot, 2006). Hence, the majority of the sediment content is a direct input from the point sources, namely the karstic spring. Indeed, over the entire study period (09/2002-09/2006) the average concentration in suspended solids at the outlet is of 234 $mg.l^{-1}$ against 383 $mg.l^{-1}$ for the spring. This corresponds to an average yield of 9 kg against 273 kg for the karstic spring i.e. nearly a ratio of 1/30.

The limited success of the calibration resulted in high values of the calibration criteria (tab. 3.b). The errors on suspended solids are not correlated with the errors on flow (Coeff=-0.05), even when a high correlation is imposed between the peakflows and the sediment inflow by setting a high value for SWAT's PRF parameter. In this instance, the correlation coefficient increases in absolute value to 0.26 but still indicates no correlation between the two sets of values.

These results were further confirmed during the validation phase. The validation data set consists of 52 measurement points as opposed to 48 for the calibration period with a cumulative frequency distribution which is still concave downward but its shape indicates that it is relatively less positively skewed (Fig 6). This didn't make a difference on the results though and poor simulations were obtained as highlighted by the error criteria (tab. 3b).

Other authors also reported difficulties in using SWAT for sediment transport. The soil erosion module used in the model i.e. MUSLE, has attracted criticism in the literature (see a review in Boardman, 2006). While using SWAT Santhi et al., (2006) noted a failure in simulating sediment loads when using grab data and explained it by the reduced number of data points that were available. Tolson and Shoemaker (2007) also noted an underestimation of TSS peak values although the monthly TSS trends were fairly well replicated. The calibration data used in their study consisted, like ours, of bi-weekly monitoring and event based sampling. In this instance the authors explained TSS underestimation by an underestimation of daily flows especially during high flow events. This, according to Benaman and Shoemaker (2005) who have intensively investigated the matter is even truer for short duration events i.e. 3-5 days partly because SWAT is not a storm-event based model.

SWAT's limitations in reproducing flood dynamics and MUSLE's inadequacy to reproduce anything but average erosion rates over long periods may be valid explanations for these shortcomings. However, in our case, another factor may also influence the results. Indeed, on an intermittent catchment such as the Vène, a constant sediment input from the STWs combined with a decrease of the river's flow regime leads to less dilution and hence a slight increase in TSS concentration values. However, SWAT's erosion and sediment transport module fail to simulate any sediment input in the absence of flow. Hence it seems that SWAT cannot account for sediment inputs originating mainly from the point sources.
This hypothesis is confirmed by looking at the results obtained at the outlet (Fig.7). In the absence of sediment input data for the Issanka spring, we resorted to calibration in order to compensate for the lack of data. Thus, we had to increase the maximum amount of sediment that could re-enter the channel (Sp_Con), and the channel erodability (Ch_Erod) to make up for the missing data. The simulated concentration curves did reproduce the overall sediment dynamics despite a clear underestimation of both flood and low flow values. These problems cannot be overcome solely by getting better estimations of the sediment concentrations from the various sources of the catchment. SWAT's sediment routing module will also have to be modified in order to better account for sediment dynamics during recession flows.

4. Discussion and conclusion

In this work we attempted to use the Soil and Water assessment tool to simulated flow and sediment fluxes on a small intermittent catchment. The model was calibrated using daily data over a 3 year period and validated using a record of similar length at both sub-catchment and catchment scales.

The results indicated that SWAT can adequately reproduce the flow values and hydrograph shapes and account for the point sources' direct input into the channel network. This is a clear advantage for catchments with karstic springs as the latter's influence on runoff can be accounted for without resorting to complex hydrodynamic models, provided of course the springs are monitored. SWAT can

also account for crop management practices and thus represent the influence of the vegetation on the water and nutrient fluxes.

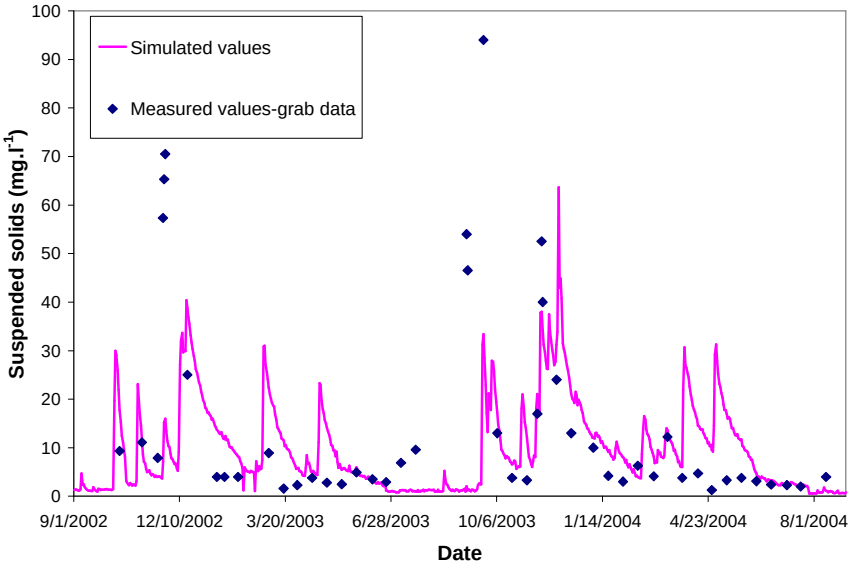

Fig.7 Suspended solid concentrations obtained through recalibration at the outlet

Regarding sediment flow, the results obtained with SWAT are less encouraging. This is not a new finding as various other authors before us had pointed out certain limitations in the use of the model's sediment transport module. However, in this study, we were able to explore the shortcomings in a context of intermittent flow where land erosion was less predominant than input from point sources. The main downfall of SWAT in this setting is not related to its flow component but rather to its sediment transport module. This in turn impacts the nutrient transport module which relies heavily on the previous for the particulate forms of phosphorous and nitrogen.

Therefore, even in an "ideal" data configuration, the current version of SWAT will not be able to reproduce the nutrient dynamics of small coastal intermittent rivers as it cannot simulate increasing concentrations for decreasing flows. Yet the model is often used indiscriminately on catchments inside and outside of the US, because of its availability and its ease of use. In the Mediterranean region, it has even been coupled to an ecological model and used to assess primary production in the Thau lagoon (Plus et al., 2006). Given all the sources of uncertainty and model limitations, one cannot but recommend caution when analysing the results of such studies.

Understanding and identifying sources of uncertainty is a crucial issue in any modelling study and is receiving increasing consideration by the scientific community. These aspects are even more important for coupled models because the sources of uncertainty are multiplied. In addition, most coupled models are based on multi-disciplinary approaches and the modeller can rarely have equal knowledge and expertise in all these fields. Hence important issues can be partly ignored. This is itself may lead to a wrong perception of the system's driving mechanisms and predictions of low accuracy. Models are nowadays increasingly used to help stake holders in various decision making processes and the caution recommendations provided with the results are often discarded in time of crisis, when a solution has to be suggested quickly. Therefore, testing the adaptability of a model thoroughly becomes even more important.

Acknowledgements

The authors are grateful to the Société de Distribution d'Eaux Intercommunale (Eric Blin, Bruno Bujon and Gisele Monnerau) for providing the data on the Cournonsec and Gigean STWs. This study was partly funded by the tempQsim European project (EVK1-CT-2002-00112).

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