

Sediment and nutrient flood loads in three small Mediterranean catchments

MARIE GEORGE TOURNOUD¹, CHRISTIAN SALLES¹,
BERNADETTE PICOT², SYLVAIN PAYRAUDEAU¹ &
CLAIRE RODIER¹

¹ *Laboratoire Hydrosociences Montpellier (UMR 5569 CNRS-IRD-UM2), Université Montpellier II, Maison des Sciences de l'Eau, F-34095 Montpellier Cedex 5, France*
tournoud@msem.univ-montp2.fr

² *Département Sciences de l'Environnement et Santé Publique, Université Montpellier I, Faculté de Pharmacie, F-34060 Montpellier Cedex 5, France*

Abstract Flash floods have been monitored in three small Mediterranean catchments. The temporal evolution of suspended solid, nitrogen and phosphorus concentrations has been measured. Continuous rainfall and discharge data are also available for each river. Total suspended solid, nitrogen and phosphorus loads have been calculated for twenty sampled floods. This study demonstrates that there is no significant correlation between discharge and concentration, for either suspended solids, or for total phosphorus and nitrogen. An attempt to link the measured loads to hydrological descriptors shows that the main explanatory factor is the rain depth for total nitrogen loads, the peak flow for the total phosphorus loads and the antecedent 30-day cumulative rainfall for the suspended solid loads.

Key words flash flood; Mediterranean rivers; nutrient loads; statistical analysis; suspended solid loads

INTRODUCTION

Small Mediterranean catchments are subject to short duration flood events which transport the main part of the annual loads of suspended solids, nutrients and other pollutants. Cherifi & Loudiki (1999) reported that in Moroccan basins more than 90% of the total matter was transported during floods. Letcher *et al.* (1999) observed that 86% of the annual total phosphorus load in the South Pine catchment (Australia), is transported in 2.8% of time. Meybeck *et al.* (1992) noticed that the annual load of small Mediterranean rivers transits in less than 20% of time.

Because they are heavily polluted these flash floods are potentially harmful for coastal waters where they may affect the sustainability of various activities such as fishing, shellfish farming and tourism. A correct evaluation of these flash floods is thus required to enhance water management, especially in Mediterranean regions where such events are common.

These high flow events, which must be taken into account for a better estimate of river inputs to the sea, have a low probability of being sampled under a regular sampling programme. Specific sampling protocols need therefore to be followed, that involve important task forces. Therefore, it is useful to determine relationships between flood loads and hydrological characteristics or basin geo-morphological characteristics, as observed elsewhere (e.g. Moss *et al.*, 1993; Milliman & Syvitski, 1992).

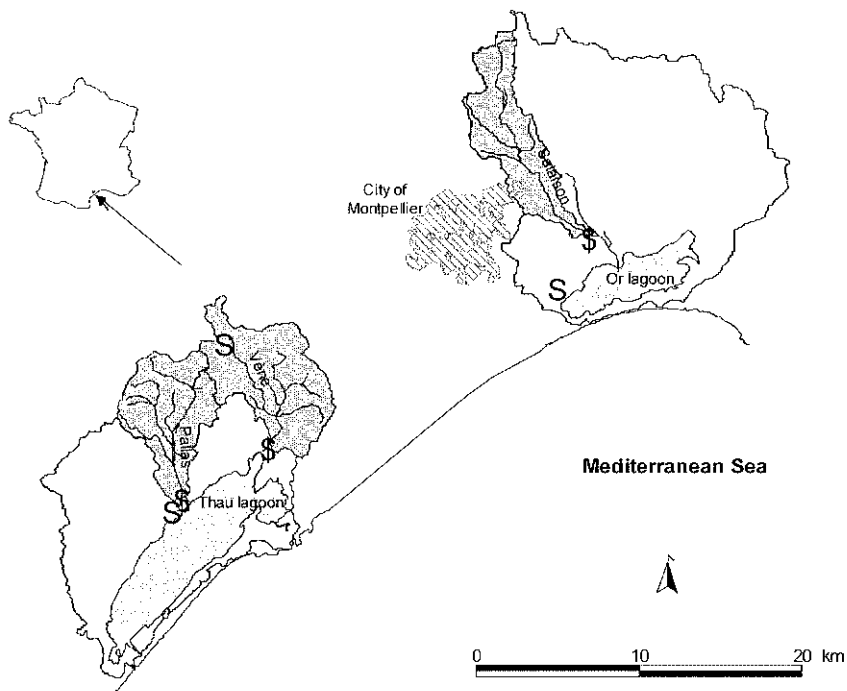


Fig. 1 Location of the study areas (from Payraudeau, 2002). **S** indicates the location of rain gauge stations; **\$** indicates the location of flow recording stations.

This study aimed to establish such empirical relationships for three small Mediterranean catchments. The available data consist of continuous rainfall and discharge monitoring, plus water sampling during some floods, at the outlet of the three basins. This study focused only on total nitrogen, total phosphorus and total suspended solids that are of major interest for coastal waters in terms of eutrophication processes. The study sought nutrient and suspended solid load relationships with easy to determine hydrological descriptors, during flood events. Characteristics of the flood event (mean discharge and peak flow), the rainfall event (rain depth and maximum intensity) and the hydrological conditions in the basin (baseflow, cumulative rainfall, dry period duration) were chosen as descriptors.

MATERIALS AND METHOD

Description of the basins

The studied rivers are located on the French Mediterranean coast (see Fig. 1). The Vène and the Pallas rivers are tributaries of the Thau lagoon renowned for its mussel and oyster farming. The Salaison River flows into the Or lagoon.

The Vène River drains a 67 km² basin, that consists mainly of Tertiary or Secondary limestone blocks highly karstified and overlain in the central part by Miocene clays (Ben Othman *et al.*, 1997; Petelet, 1994). Occasionally, during the wet

season, two karstic sources feed the Vène River. The Pallas River is a typical small Mediterranean ephemeral river. Its 52 km² basin is essentially composed of Eocene and Miocene marl-clay, partly filling karstic areas in the upper part. The Salaison River drains a 53 km² area. The geology of the basin consists of alluvial deposits in the southern part and marls and calcareous rocks in the northern part (Diop, 1980).

Because of a spatial annual rainfall gradient from east to west (Ascencio, 1984), the annual rainfall decreases from about 750 mm over the Salaison basin to less than 600 mm over the top of the Pallas basin. Most of the rain events occur between September and December and between March and May. Precipitation events occur mainly as short duration and intense storms—a feature of Mediterranean climate—generating flash floods on the small basins.

Flood monitoring and chemical analysis

Hydrological data The locations of the rain- and streamgauges are represented in Fig. 1. Rainfall data were collected by tipping bucket raingauges, with a 0.1 mm accuracy. Water level were continuously monitored, upstream of a weir. Water level was converted into flow with 10% accuracy, using rating curves established by carrying out *in situ* discharge measurements. Data are available on a five minute basis.

Sample collection and analysis Sampling was carried out at the streamgauges. Samples were collected on a two-hour basis during the rising flow. After the peak flow, the sampling interval was modified and varied from four hours when the flow decreased rapidly, to one day when the recession curves were slow.

The water samples were analysed for their total suspended solid (TSS), total phosphorus (TP) and total nitrogen (TN) contents. All the analyses were done following the Standard Methods requirements (1992). The TSS concentrations were determined on GFF filters; between 50 ml and 2 l of water was filtered, depending on the solid load. The TP concentrations were determined on unfiltered samples, after mineralization of phosphorus into phosphates. The TN concentration is represented by Kjeldahl nitrogen (NK) plus nitrates and nitrites (NO_x) concentrations. The NK concentrations were determined on unfiltered samples by titration with a standard mineral acid after digestion and distillation. The NO_x concentrations (nitrates plus nitrites) were determined on filtered samples, by spectrophotometry.

Flood loads and flood descriptors

Flood loads (L) were estimated using the averaging computation method proposed by Walling & Webb (1981). It combines \bar{Q}_i , the mean flow during the between sample interval and the instantaneous concentration, c_i , associated with individual samples:

$$L = \sum_{i=1}^n \bar{Q}_i c_i t_i \quad (1)$$

where t_i is the sampling time interval, (i.e. half the interval of time from the preceding to the following sample) and n is the number of samples.

The descriptors selected as explicative variables are divided into three categories. The peak flow (QM) and the baseflow (QB) before the event characterize the flood event. The rain event is described by the total rain depth (H), the mean intensity (I) and the maximum value of the intensity on a five minute time step ($IMAX$). The duration of the dry period and the rain depth recorded during the previous three ($P3D$) and 30 days ($P30D$) before the rain event are indicative of the hydrological conditions before the flood.

RESULTS AND DISCUSSION

The main flood characteristics, specific load estimate (i.e. loads obtained using equation (1) divided by the basin area) and timing are reported in Table 1 and in Fig. 2.

Flood data analysis

Twenty floods were sampled. Flood durations extend from 8 hours to 9 days, but are shorter for the Salaison and Pallas rivers than for the Vène River. Some events present a very low mean specific discharge, especially during spring.

Table 1 Characteristics of the twenty sampled floods.

Event name	Rain event characteristics		Flood characteristics			Loads		
	Depth (mm)	Duration (day)	Peak discharge ($l\ s^{-1}\ km^{-2}$)	Mean discharge ($l\ s^{-1}\ km^{-2}$)	Volume ($10^3\ m^3$)	TN ($kg\ km^{-2}$)	TP ($kg\ km^{-2}$)	TSS ($kg\ km^{-2}$)
Calibration set								
Pallas 10/94	119.0	1.7	155.8	85.42	1340	80	18	12270
Pallas 4/95	22.2	1.3	0.4	0.17	1.49	0.14	0.03	0.33
Pallas 3/96	67.2	2.3	130.4	54.22	1340	66	11	4867
Pallas 4/96	25.2	5.2	17.3	7.48	22.4	1.3	0.14	3
Vène 9/94	70.0	2.9	18.3	6.70	155	5.3	1.1	65
Vène 10/94	160.0	1.8	365.8	217.34	10070	241	55	16260
Vène 4/95	32.0	1.3	0.6	0.26	2.97	0.35	0.1	0.53
Vène 4/96	25.2	5.2	34.4	21.09	1100	22	2.3	55
Vène 5/99	115.2	1.6	161.4	92.98	807	29	4.4	1723
Vène 9/99	72.6	1.2	398.4	188.15	545	22	13	9436
Vène 10/99	105.2	2.5	125.2	83.09	3370	50	8.1	2047
Salaison 3/99	21.0	0.8	20.7	6.44	27	6.3	1.1	55
Salaison 4/99	39.2	0.5	33.9	14.52	33.2	4.2	1.1	67
Salaison 9/99	50.6	1.2	106.0	31.31	41.9	10	2.2	87
Salaison 10/99	48.6	0.7	78.3	36.44	234	12	1.7	629
Salaison 11/99	130.2	3.0	78.3	42.33	1070	67	5.5	1809
Salaison 4/00	34.4	1.0	36.3	5.81	66.6	13	1.7	85
Validation set								
Pallas 9/94	69.8	1.9	22.8	4.96	24.5	2.1	0.87	293
Vène 11/99	167.2	3.0	433.5	207.84	7220	129	26	14905
Salaison 5/99	85.2	2.0	79.9	25.16	230	14	2.5	542

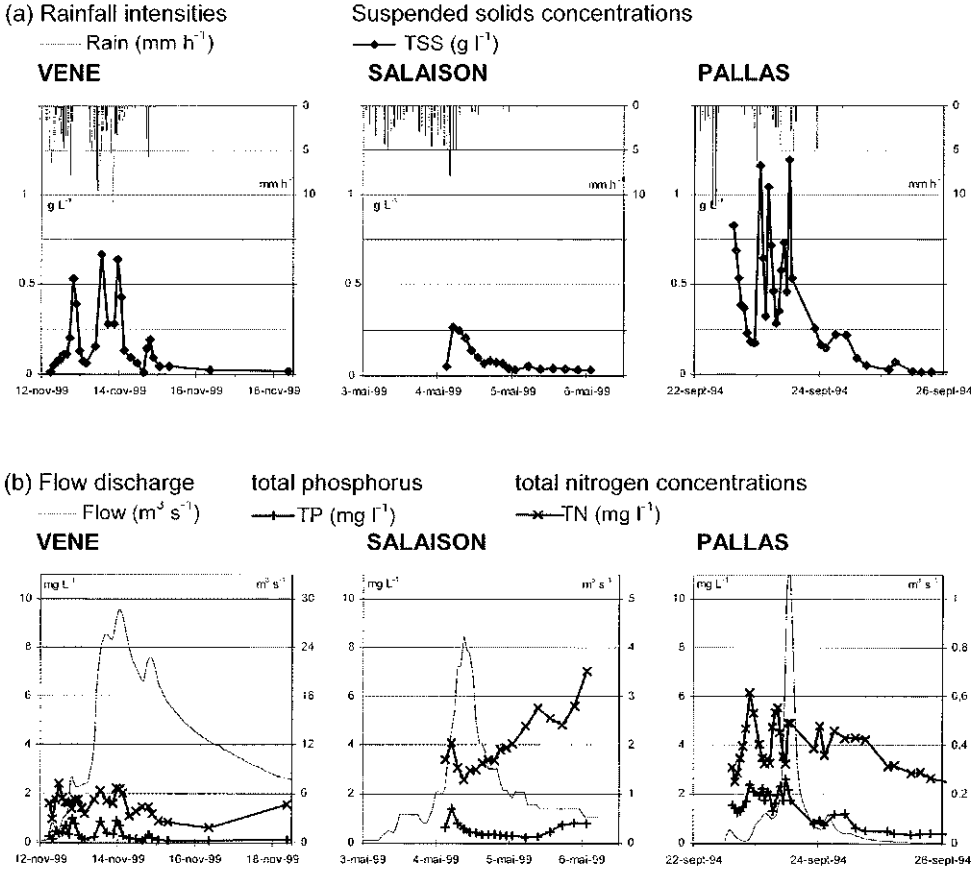


Fig. 2 TN, TP, TSS concentrations, discharge and rain intensity variations during three selected floods.

The runoff coefficients show great differences within and between basins. For the Pallas River, the coefficients range between 0.1 and 42.2%, three events out of five being less than 5%. Runoff coefficients from the Salaison River have a narrower range, from 1.5 to 8%, except for the later events (14.1%) that correspond to the highest rainfalls. The runoff coefficients of the Vène basin are quite exceptional, ranging from 0.1 to 87.9%, these especially high values result from out-basin feeding by the two karstic springs.

TP and TN concentrations are quite low in the Pallas and the Vène rivers (ranging from 0.03 to 2.6 mg-P l⁻¹ and from 0.6 to 9.1 mg-N l⁻¹) compared to the Salaison River (up to 7.7 mg-P l⁻¹ and 34.5 mg-N l⁻¹) where there is a greater urbanization impact. The Pallas River has the highest TSS loads. Higher and erratic concentrations are observed during the very beginning of the rising flow. At peak discharge and during the recession, the concentrations are comparatively lower. The TSS concentrations display the highest values during the first flash floods occurring after a long period of low flow. The TN concentrations tend to increase at the end of the flood.

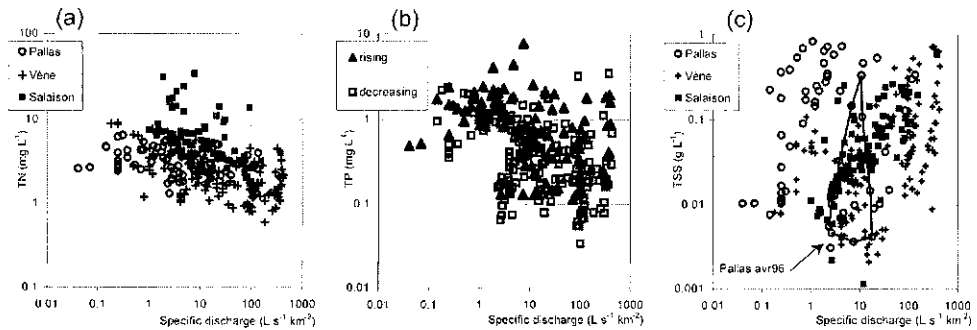


Fig. 3 TN (a), TP (b) and TSS (c) concentrations vs discharge.

Concentration vs discharge

When plotted against specific discharge, the TN, TP and TSS data display a large dispersion (Fig. 3(a,b,c)). Attempting to link concentrations to discharges with a classical power law:

$$[C] = a Q^b \quad (2)$$

does not give satisfactory results. The fitted laws only account for 22%, 18% and 8% respectively of the variance in TN, TP and TSS.

When one looks more closely at a given flood, the relation between concentration and discharge shows a loop (Fig. 3(c)). Given this well known hysteresis effect, concentrations versus discharges have been studied separately for the rising and falling period data (Fig. 3(b)). However, whatever the element, splitting the data set did not allow identification of a significant rating curve either for the rising or for the falling flood period.

If concentration versus discharge is studied separately on the three basins (see Fig. 3(a) and 3(c)) the results are just slightly improved. The best fit is obtained on TSS for the Salaison River where the model accounts for 55% of the variance. For the other elements or the other rivers no more than 35% of the variance is explained.

Therefore no significant concentration vs discharge relations can be inferred from our data set.

Regression analysis

Loads are inferred from the measurements of TSS, TP and TN concentrations and water discharges as explained above, and expressed in specific values (kg km^{-2}).

The data set was split in two subsets: the first subset, containing seventeen randomly chosen floods, was used to calibrate the regression models; the remaining floods were used for validation. The regression analysis was conducted, using a forward stepwise process (see the results in Table 2).

Considering one factor, the variance of TN loads, which are essentially dissolved elements, is mainly explained (at 59%) by the rainfall depth (H); for TP which is essentially associated with the particulate phase, the variable that explains the largest

Table 2 Regression analysis results.

Model	TN:		TP:		TSS:	
	R^2	Factors	R^2	Factors	R^2	Factors
1	0.59	H	0.56	QM	0.78	$P30D$
2	0.66	H Q_b	0.69	QM $IMAX$	0.79	$P30D$ QM
3	0.68	H QB QM	0.74	QM $IMAX$ $P30D$	0.85	QM $IMAX$ $P30D$

H : event rain depth; QM : peak flow; QB : baseflow; $IMAX$: maximum rainfall intensity on 5 minutes; $P30D$: cumulate rainfall recorded during the last 30 days.

part of the load variance (56%) is the peak flow (Qm); the TSS variance is explained (at 78%) by the cumulative rainfall depth recorded in the 30 days preceding the event ($P30D$), which characterizes the hydrological conditions in the basin.

Introducing a second explanatory factor slightly increases the coefficient of determination. When considering three factors, the effects of factors TP and TSS are identical, probably because both TP and TSS are mainly associated with particles. But introducing a third variable does not significantly increase the explained variance of the loads.

An attempt to link the residuals (i.e predicted vs observed loads) to the basin characteristics failed. Whatever is the number of selected explanatory variables the residuals fluctuate largely from flood to flood and dependencies with the basin characteristics cannot be demonstrated from our dataset.

The validation results are plotted on Fig. 4. For TN and TSS loads, the predictions obtained by the three factor models (TN3 and TS3) are quite good, even if the relative errors on the estimate reach more than 700% for the lower load values. For TP variable, the one factor model gives the best results.

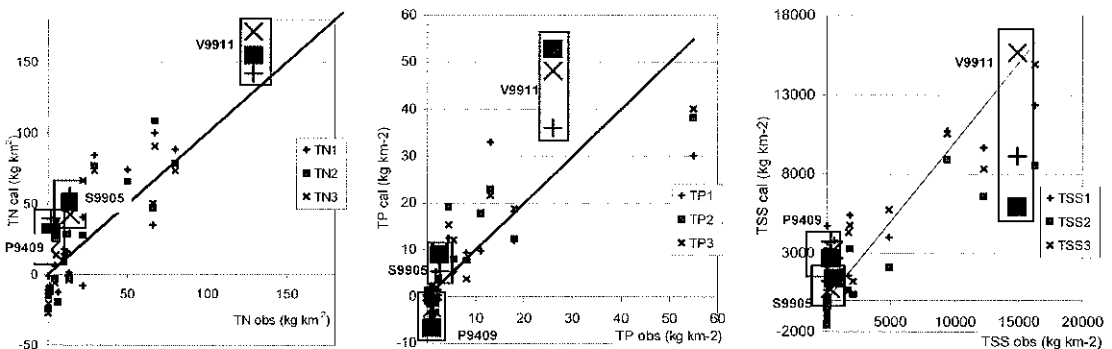


Fig. 4 Regression models: TN, TP and TSS calculated (cal) versus observed (obs) loads. Calibration and validation points.

CONCLUSION

In three Mediterranean catchments, flash floods have been monitored in order to characterize nutrient and suspended solid loads.

Initially, concentration versus discharge relationships were checked. The study shows that TN, TP and TSS concentrations are not directly related to discharge (nor to specific discharge), even when considering each basin separately or when splitting the data set between rise and fall periods. The discharge explains no more than 28% of the concentration variances.

The second step sought to establish empirical relationships between loads and hydrological descriptors that characterize the flood event, the rainfall event and the hydrological condition of the basin. One to three factor regression models have been tested. The one factor models that explain from 56% to 78% of the load variances, could be considered as already suitable. The main explanatory factor is the rainfall depth for total nitrogen loads, the peak flow for the total phosphorus loads and the last 30-day cumulative rainfall for the suspended solid loads. Increasing the number of factors does not significantly improve the results.

The next step would be to consider separately the particulate and dissolved forms of nitrogen and phosphorus that have distinct transport behaviour in the basin. But, at present the study suffers from the small number of sampled floods. Moreover more in depth investigations at the basin scale are needed to identify nutrient and suspended solid sources and transport processes.

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