TSS, BOD5 AND COD ACCUMULATION AND TRANSPORT OVER URBAN CATCHMENT SURFACES: A MODELLING APPROACH

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Introduction

There is an increasing awareness of pollution problems in urban sewer management. This is the reason why, in France, a national experimental program on urban runoff pollution has been started (3). In the study reported in this paper, the data which have been collected for more than one year from the four experimental catchments (Maurepas and Les Ulis near Paris, Aix-Zup and Aix-Nord in Aix-en-Provence) have been used. We propose here to develop a modeling approach for the production-accumulation mechanisms and for the surface transport of TSS, BOD_5 and COD. For TSS, we will summarize the main results and refer the reader

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tion modeling objectives can be theoretically defined. Nevertheless. the nature and accuracy of the available data will set

Empirical modeling of the rainfall-runoff process has been shown to possess certain limits (5). Moreover, it appears that the determination of statistical relationsips would be unduly influenced by high magnitude events for which the probability of occurrence is quite low.

For these reasons a conceptual procedure is proposed which is compatible with the representativeness of the sampling program and with the trends arising from the data analysis (5,6).

TSS Accumulation and Transport Modelling Approach

This section summarizes the main results for the modeling approach developed earlier (2,5).

A linear TSS accumulation model, based on the following hypotheses, was selected :

It is then possible to write (5):

$$Pr = \frac{\sum_{i=1}^{n} Ei}{\sum_{i=1}^{n} DTSi} \qquad \text{(Eq. 2)}$$

Pr, as computed by Equation 2, was checked such that the constraint Ei $\leq$ Mdi was appropriate for each event.

The computed daily production rate for the catchments under consideration are:

- 1.7 kg ha^{-1} d^{-1} in Aix-Zup
- 2.6 kg ha^{-1} d^{-1} in Maurepas
- 3.1 kg ha^{-1} d^{-1} in Les Ulis

(we could not model masses in Aix-Nord because of unresolved problems in volume estimates).

Examination of the chronology of sampled rainfall events can determine successive residual masses over the catchment sur-

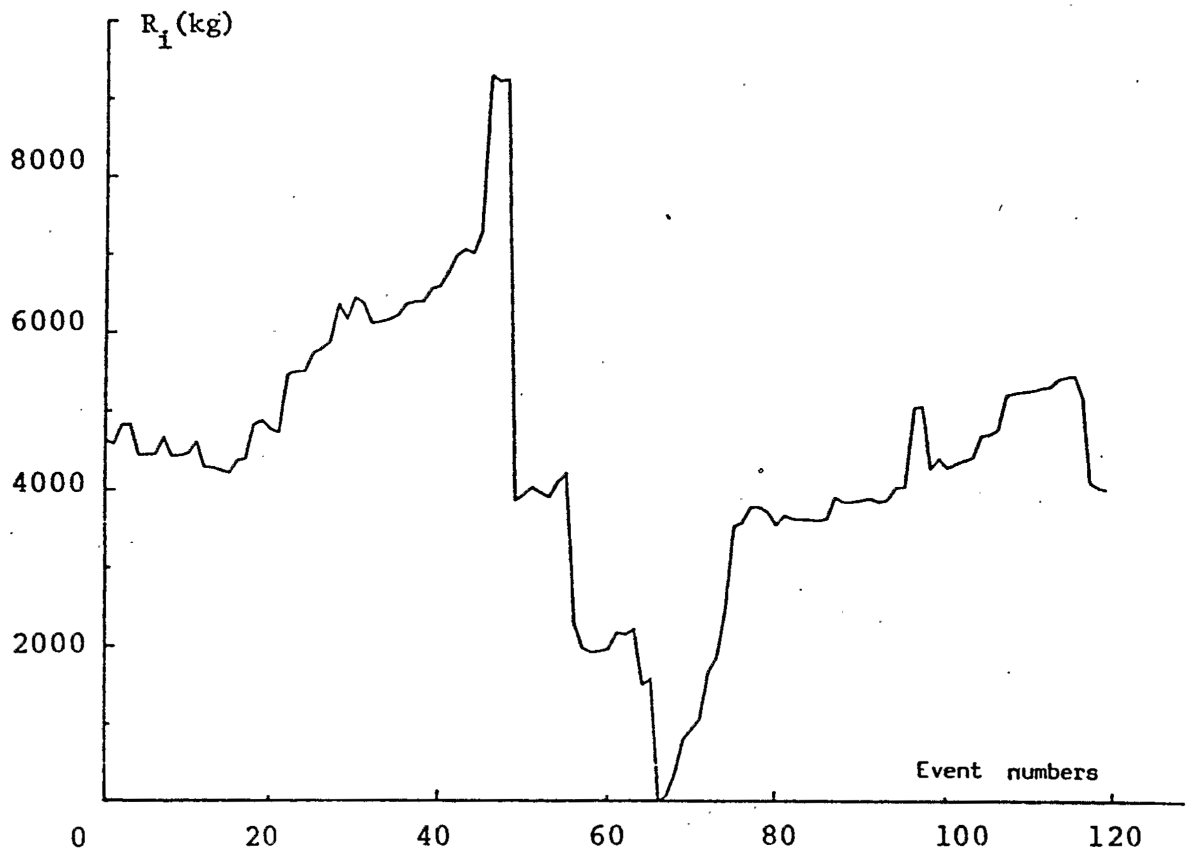

Figure 1 - Residual mass over catchment surface (Ri) after each rainfall event.

Catchment: Maurepas
(Linear accumulation model)

- Available mass, Md (kg)
- Maximum intensity within a five-minute time interval, Imax 5 ($mm\ h^{-1}$)
- Runoff Volume, VR (m^3)

The chosen model is:

$$E = K.Md^{\alpha}\ Imax5^{\beta}\ VR^{\gamma} \qquad \text{(Eq. 3)}$$

in which:

E = transported mass during any event (kg)
Md, Imax5, VR = defined above
K, α , β, γ, = parameters peculiar to each catchment.

Model parameters were identified using Rosenbrock's method (4), based on the minimization of the sum of the square of the deviations between observed and computed values, subject to the two following constraints:

Table 1 - K, α, β, γ values for each catchment

Table 2 - Results for the three experimental catchments: Total Suspended Solids - TSS

$$E = K\ Md^{\alpha}\ Imax5^{\beta}\ VR^{\gamma}$$

	AIX-ZUP	LES ULIS	MAUREPAS
Average carried mass (kg)	225.56	417.70	187.25
Average quadratic deviation as a % of the average carried mass	14.1%	10.7%	10.6%
Criterion function	50.981	92.757	20.408
Observed and computed total mass deviation (%)	- 5.8%	+ 5.3%	- 13.0%
Deviation-calibration (%)	- 6.1%	1.4%	12.0%
Deviation-verification (%)	- 5.6%	9.8%	- 33.6%

Rainfall intensity within a five minute time interval is the lowest time boundary used to determine rainfall aggressivity during the French national program. The use of other rain gauges with very low integration times should supply data on rainfall aggressivity which is even more representative. Additional climatic variables such as wind speed, humidity, etc... would further improve the results.

BOD5 and COD Accumulation and Transport Modeling Approach

As a first step, a statistical analysis of the observed mean concentrations and masses was performed (6). The results are similar to those we could get for TSS. Concerning the observed BOD_5 and COD masses, which are the parameters we are interested a lesser degree the dry weather period between two rainfall events (DTS). The transport model will be partially built up from these first results.

Accumulation Modelling Approach

Four pollutant accumulation models were tested including an asymptotic model, a power function, a parabolic model with an upper limited stock, and a linear model.

The asymptotic model:

$$M(t) = M(to)\, e^{-K(t-to)} + \frac{Pr}{K}\left(1 - e^{-K(t-to)}\right) \qquad \text{(Eq. 4)}$$

in which:

- $M(t)$ = accumulated mass in time t (kg).
- K = part of the accumulated particles removed during a time interval.
- Pr = pollutant production rate during a time interval (kg/time interval unit).

However, this model was found to produce daily rates much too high, for BOD_5 and COD, except if the asymptote is reached after a two month period ($K = 0.025$). Such a model is not appropriate for a phenomenon for which the time scale is on the order of a "few days". The power function model can be written:

in which :

- $M(t)$ = accumulated mass in time t (kg).
- a = function of the pollutant production rate during a time interval, Pr.

and $n < 1$.

To compute a, we can assume that for tc = x days, we have:

$$\left.\frac{d\ M(t)}{dt} = 0.05\ Pr\right|_{t = tc} \qquad \text{(Eq.6)}$$

It is then possible to compute a and Pr for different values of n. Plausible values of daily production rates of pollutants (BOD_5 and COD) were reached for low n (n = 0.2) and high tc (tc = 60 days) (see Table 3).

Table 3 - BOD_5 and COD Daily Production Rates

($Kg\ ha^{-1}\ d^{-1}$)
n = 0.2 tc = 60 days

	AIX-ZUP	LES ULIS	MAUREPAS
BOD_5	.3	.2	.5
COD	8.6	1.5	3.7

However, as for the previous scheme, these results are not representative of the studied phenomenon. To get such values of Pr, if Equation 6 is confirmed with tc = 10 days, n should be about 10^{-3} or 10^{-4}, which has no meaning.

For the parabolic model with an upper limited stock:

$$M(t) = -\alpha \frac{t^2}{2} + Pr\ t \qquad \text{(Eq. 7)}$$

where:

$M(t)$ = accumulated mass in time t (kg)
$\alpha = f\ (Pr)$

It has also been assumed that for tc = x days, Equation 6 is verified. The upper limit of the stock is reached when:

$$\left.\frac{dM(t)}{dt} = 0\right|_{t = t\ lim} \qquad \text{(Eq. 8)}$$

As in the two previous modeling approaches, we have computed Pr for several hypotheses. Results do not agree with the "time-scale" of the phenomenon in so far as they seem to be plausible for t values about 60 days for BOD_5 and for COD, as given by Equation 6.

As a result, the linear accumulation model was chosen. Conceptually, it may not be the most satisfactory model, given that such a model does not consider the degradation phenomenon that should occur with BOD_5 and COD. However, the measuring procedures may not be accurate enough to allow a modeling approach that integrates pollutant degradation.

Given the hypotheses developed for TSS:

- A constant production rate within a time interval.
- An initial stock close to the final one on the surface catchment when considered over a long time observation.
- The transported mass during an event i less or equal to the available mass ($Ei \leq Mdi$).

It is then possible to write Equation 2 for BOD_5 and COD:

$$Pr = \frac{\sum_{i=1}^{n} Ei}{\sum_{i=1}^{n} DTSi}$$

Ei = transported mass during a rainfall event i

DTSi = the dry weather period which separates rainfall events i and i-1.

The computed daily production rates are in Table 4.

Table 4 - BOD_5 and COD Daily Production Rates, Linear Accumulation Model

	Pr ($kg\ ha^{-1}\ d^{-1}$)		
	AIX-ZUP	LES ULIS	MAUREPAS
BOD_5	0.22	0.26	0.16
COD	1.20	1.25	1.10

Results agree with previous hypotheses except for Les Ulis, where the final stock is very different from the initial one, considering BOD_5 as well as COD. This could be due to a measuring procedure failure but this cannot be confirmed. This is the reason why two transport modeling approaches have been tested. The first one considers the available mass as a variable of the model, the second does not (since none of the accumulation models tested is fully satisfying).

Transport Modelling Approach

As mentioned before, two approaches were tested:

- The first one, given by Equation 3, is similar to the TSS model and considers the three same control variables:
  - Available mass, Md (kg)
  - Maximum intensity within a five minute time interval, Imax5 mm/h)
  - Runoff volume, VR (m^3)

- The second one considers a two-level pollution stock on the catchment surface: a first level which is usually requested, and a second one, called "deep level", which is sometimes requested but which cannot be a bounding factor. In this case, two control variables are suffi-

[illegible]

Table 6 – BOD_5: Results for the Three Experimental [redacted]

[redacted]

Average carried mass (kg)	37.9	41.8	13.1

[redacted]

strictly speaking, this model should not have been used with Les Ulis data because one of the assumptions of the accumulation model was not met. The results are not as good as they were with TSS, especially those on the Maurepas catchment. There are large differences between calibration and verification results. Therefore, if the reproduction of the total observed transported mass is quite accurate (excluding Maurepas), we cannot say that the proposed modelling approach is a fully satisfying one.

$$* \; E = K' Imax5^{\beta'} \; VR^{\gamma'}$$

K', β' and γ' values are given in Table 8. Results expressed as deviations and criterion functions are in Tables 9 and 10 for BOD_5 and COD, respectively.

Table 8 - K', β', and γ' Values for each Catchment

$$E = K' \; Imax5^{\beta'} \; VR^{\gamma'}$$

	AIX-ZUP		LES ULIS		MAUREPAS	
	BOD5	COD	BOD5	COD	BOD5	COD
K'	0.994	1.252	1.214	1.875	0.158	0.745
β'	1.085	0.793	0.216	0.398	0.462	0.739
γ'	0.148	0.464	0.459	0.579	0.534	0.487

Deviations between observed and computed masses are similar to those of the previous model. The reproduction of the total observed transported mass is not as good as it was with TSS, since differences between calibration and verification results are not at all negligible. However, results are of the same order as those obtained previously. The investigation shows that for the events with high transported masses, the differ-

Table 9 - BOD_5: Results for the Three Experimental Catchments

$$E = K' \, Imax5^{\beta'} \, VR^{\gamma'}$$

	AIX-ZUP	LES ULIS	MAUREPAS
Average carried mass (kg)	37.9	41.8	13.1
Average quadratic deviation as a % of the average carried mass	12.6%	7.8%	11.5%
Criterion function	1.121	0.520	0.103
Observed and computed total mass deviation (%)	-1.3%	-3.1%	25.1%
Deviation-calibration (%)	-0.25%	2.4%	13.0%
Deviation-verification (%)	-5.4%	-8.7%	35.0%

Table 10 - COD: Results for the Three Experimental Catchments

$$E = K' \, Imax5^{\beta'} \, VR^{\gamma'}$$

	AIX-ZUP	LES ULIS	MAUREPAS
Average carried mass (kg)	213.8	205.2	85.5
Average quadratic deviation as a % of the average carried mass	9.1%	7.4%	10.9%
Criterion function	18.502	11.150	3.948
Observed and computed total mass deviation (%)	-8.2%	10.0%	36.0%
Deviation-calibration (%)	-12.4%	-1.7%	-0.4%
Deviation-verification (%)	6.4%	27.0%	87.5%

ence between observed and computed masses is usually between $\pm$ 10% and $\pm$ 30%, which is interesting in so far as it embraces most of the particle masses discharged to the receiving waters.

For the same level of accuracy, it seems more appropriate to use the second model, because it is not necessary to compute available masses of pollutant. For TSS, we think that the inclusion of climatic variables such as wind speed, humidity, etc... would further improve the results.

Likewise, more rain gauges, having very low integration times, could have shown much higher intensities with shorter time intervals (30 seconds or 1 minute) that would be even more representative of rainfall aggressivity. In urban areas, rainfall aggressivity must be considered as the most important index to explain the transport of pollutants, since once they have been entrained from the ground surface they are almost certain to be flushed by the runoff.

Several other formulations were not adopted (6), including:

$$E = K' \, Md \, (1 - e^{-\beta'} \, Imax5) \quad VR^{\gamma'}$$

$$E = K' \, (1 - e^{-\beta'} \, Imax5) \, VR^{\gamma'}$$

$$E = K \, Md^{\alpha'} \left(1 - \frac{1}{Imax5^{\beta'} \quad VR^{\gamma'}}\right)$$

$$E = K' \, Imax5^{\beta} + \delta \, DR + \gamma \, VR + \alpha$$

in which:

DR = runoff duration (days).

They were not adopted for several reasons:

- A mean quadratic deviation which varies too much from one catchment to another.

- The criterion function shows high values.
- Differences between calibration and verification are high.

Conclusions

Using data from a national experimental measurement program, the modeling objective was to reproduce the total TSS, BOD_5 and COD loads for selected urban catchments. A two-step approach involving accumulation and transport was first performed

For the Maurepas catchment, BOD_5 and COD computed balances are always overestimated, irrespective of the approach used. No [illegible]

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