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Abstract. The water quality of the Têt River, mainly referred to nutrients and organic matter compounds, is lower than the desirable. Their management must be largely improved. In this sense, the present work takes part in a global development and evaluation of reliable and robust tools, with the aim of allowing the control and supervision of its lowland area (at the south Mediterranean coast of France). A simplified simulation model, based on mass balances, has been developed to estimate nutrient (basically, nitrogen) and organic matter levels in the stream and to describe the river water quality. Kohonen self-organizing maps (KSOMs) were used to avoid the data missing. This kind of neural networks proved to be very useful to predict missing components and to complete the available database, describing the chemical state of the river and the WasteWater Treatment Plant (WWTP) outflows. The simulation model also proved to be a good tool for the evaluated system. The results provided by it reveal the high impact of the WWTPs located along the studied reach, due to their malfunction and the effects of the tourism activities.

Keywords. WWTP; river; Kohonen self-organizing maps; mass balance; diagnostic; supervision; nitrogen; DOC.

1. Introduction

For many years, the management of hydraulic resources, the efficiency of WasteWater Treatment Plants (WWTPs) and the protection of environment are major concerns. Water managers and scientists agree that a bad resources management, as well qualitative as quantitative, or a plant malfunction can have an extremely negative impact on both environmental (fauna and flora) and human health. One of the most important impacts is the bad water quality.

In the last decades water quality of European aquatic systems has especially decreased being one of the most serious problems to solve. Rivers have suffered a nutrient enrichment (nitrogen and phosphorus) due to large nutrient loads from human activities (i.e. effluents from WWTPs), which leads to a river functionality loss (Sterba et al., 1997; Comas et al., 2003; Llorens, 2004; Martí et al., 2004). As rivers can not assimilate all nutrients, these are transported downstream affecting, at the last term, the coast ecosystems. As a consequence, nitrogen has become the major contributor to coast marine ecosystems pollution (Howarth, 2004). Moreover, the situation in Mediterranean regions is in general more critical (Llorens et al., 2004); due to the scarcity of water (related with the deep seasonality of river flows) and high tourism impacts (i.e. high density of population placed in the lowland river basins or in the coast increases the demand for water resources and the quantity of generated wastewater).

The European Water Framework Directive (WFD) (Directive 2000/60/EC) appeared as an attempt to face the situation. Its aim is to achieve a good health of surface waters by 2015. According to it, the WFD establishes a set of steps to follow. The present paper is a contribution in the Têt River studies focused in one of these steps: estimation and identification of point pollution sources and evaluation of their impacts to the river. In this sense, the present work takes part in a global development and evaluation of reliable and robust tools (Grieu et al., 2005), with the aim of allowing the control and supervision of the Têt River's lowland area. This is affected by one tributary and two WWTPs. As they seem to be the main nitrogen and organic matter pollution sources in the reach, the main purpose is to estimate their loads within the river and to evaluate their impact to the river chemistry health.

As a lot of Mediterranean coastal rivers, the hydrological system of the Têt River presents periods of low water level, intercepted by violent and devastating short rising period, essentially due to rain (Ludwig et al., 2004; Guillén et al., 2005). This kind of contrasted systems needs to be better understood (Alvarez Cobelas et al., 2005).

A simplified mathematical model based on mass balances was developed to estimate nutrient levels in the stream and to describe the river water quality. However, the application of mathematical models for river water quality as support tools is often limited by the availability of reliable data (Deksissa et al., 2001).

The processing of data which contain missing values is a complicated and always awkward problem, especially when the data come from real-world contexts. Most of the statistical software

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simply suppresses incomplete observations. It has no practical consequence when the data are very numerous. But if the number of remaining data is too small, it can remove all significance to the results. To avoid suppressing data in that way, it is possible to replace a missing value with the mean value of the corresponding variable, but this approximation can be very bad when the variable has a large variance. So it is very worthwhile seeing that the Kohonen algorithm perfectly deals with data with missing values, without having to estimate them beforehand. So, Kohonen self-organizing maps were used to avoid the data missing, (Alhoniemi et al., 1997; Simula et al., 1999).

The paper presents the both developed methodologies (maps and model) and the provided results related to the nitrogen and organic matter compounds.

2. Study area

2.1. The Têt River

The Têt River catchment is located in the Pyrénéés-Orientales department, south of France. The river has a total length of 120 km and drains a catchment area of about 1380 km². It originates from the Carlit Mountain, in the eastern part of the French Pyrenees and discharges into the Mediterranean Sea. From its lengthened form (west-eastern orientation) two quite different parts can be distinguished:

- The upper part *(upstream)* comprises the origins of the Têt River until the Vinça's dam. Its average altitude is about 1026 m and its average slope, about 22.6°.
- The lower part *(downstream)* comprises the reach from the city of Vinça to Canet-en-Roussillon, which is close to the place where the river flows into the Mediterranean Sea. The average altitude of this part is about 280 m and the average slope, about 8.9°.

The study area covers the last 14 km of the downstream, where the major economic activity is tourism. The studied reach is affected by one tributary (La Basse) and two WWTPs, located at Perpignan and Canet-en-Roussillon (Thiery et al., 2005). Perpignan is the capital of the Pyrénées-Orientales department with a current population of about 100000 inhabitants. The town of Canet-en-Roussillon is a seaside resort and its population considerably increases during the summer period.

2.2. The Perpignan's WWTP

The Perpignan's WWTP was built to treat the urban wastewater of 160000 inhab.-eq. from six towns: Bompas, Canohès, Perpignan, Saint-Estève, Le Soler and Toulouges. This WWTP has a biological Biocarbone treatment for organic matter elimination and nitrification processes. It has not the technology for actively remove nitrogen or phosphorus.

2.3. The Canet-en-Roussillon's WWTP

The Canet-en-Roussillon's WWTP was built to treat the domestic wastewater of 75000 inhab.-eq. from two towns: Canet-en-Roussillon (10185 inhab.) and Saint Nazaire (2378 inhab.). It is a weak charge biological plant based on an activated sludge process. The plant consists of parallel treatment modules, where denitrification and biological dephosphatation are done in addition to the organic matter removing. Its module structure permits to adapt its operation to seasonal population variations.

3. Materials and methods

3.1. The Kohonen self-organizing map (KSOM)

The KSOM is a neural network based on unsupervised learning (Grieu et al., 2006; Hong et al., 2003).

3.1.1. Network structure

The Kohonen self-organizing map consists of a regular, usually two-dimensional, grid of neurons (output neurons). Each neuron *i* is represented by a weight, or model vector, $m_i = [m_{i1},\ldots,m_{in}]^T$ where n is equal to the dimension of the input vectors. The set of weight vectors (code-vectors) is called a code-book (Alhoniemi et al., 1997).

The neurons of the map are connected to adjacent neurons by a neighbourhood relation, which dictates the topology of the map. Usually rectangular or hexagonal topology is used. Immediate neighbours belong to the neighbourhood N_i of the neuron *i* (Figure 1). The topological relations and the number of neurons are fixed before the training phase allowing the configuration of the map. The number of neurons may vary from a few dozens up to several thousands. It determines the granularity of the mapping, which affects the accuracy and generalisation capability of the KSOM.

3.1.2. Kohonen training algorithm

The Kohonen training algorithm is a simple procedure which consists of randomly selecting a training pattern, determining the winning node, updating the weights of all nodes (code-book) within the winning neighborhood, and modifying the training parameters (Hong et al., 2003).

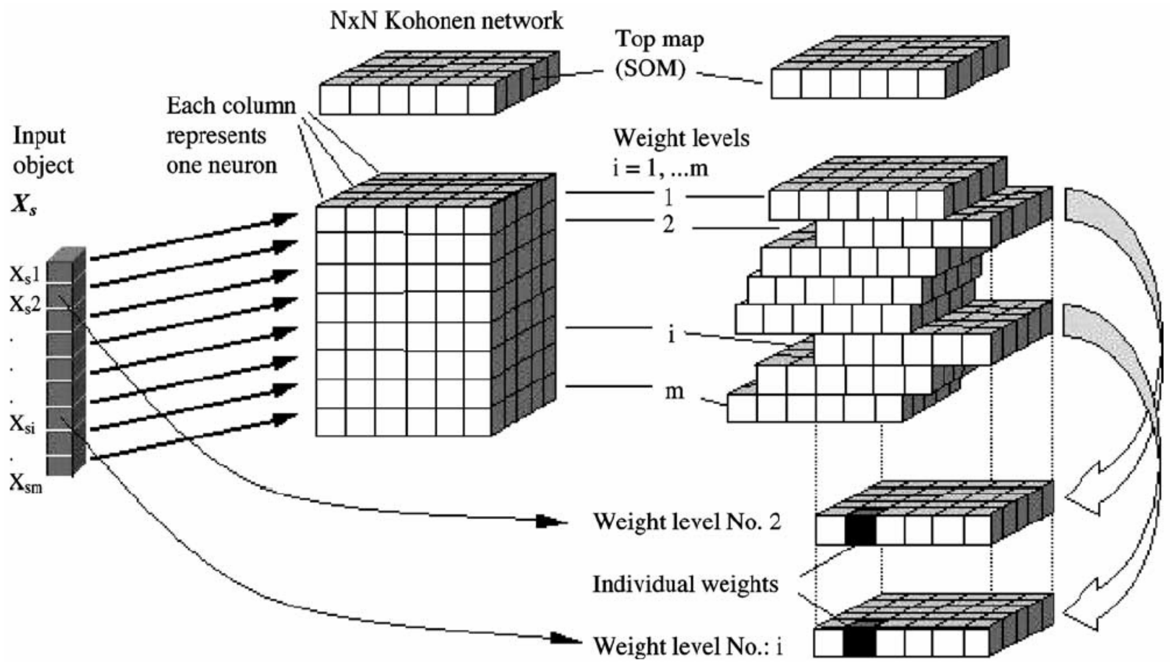


Figure 1. Kohonen network structure (Marini et al., 2005).

In determining the winning unit, a certain distance metric is used, and the node which registers the minimum distance relative to the current training pattern is referred to as the winning unit (the best matching unit). Changes in the weights will subsequently involve only nodes in the region surrounding this winning unit. The most common metrics used are the Euclidean distance, the Manhattan distance, and the cosine of the angle of the current input vector and each nodes weight vectors. The neighborhood size is decreasing in value as the number of training cycles increases. This winning neighborhood is the set of nodes surrounding the winning unit which will undergo weight update. Outside nodes in the map will not change their weights. Meanwhile the winning unit would depend on the presented training pattern, the winning neighborhood moves around the map throughout the training phase.

The neighborhood size is typically denoted by a "radius", which is the number of "hops" from one node to another. In a rectangular map, the radius between a given node and all its 8 direct neighbor nodes is 1. Its distance to the 16 next nearest nodes has a radius of 1, and so on. There are no hard and fast rules as to the initial value of the neighborhood size. But setting it initially to be equal to the size of longest map dimension (height or width of map in terms of number of nodes) is adequate.

3.1.3. Adaptation of the Kohonen algorithm to estimate missing values in a data set

The observations are real-valued p-dimensional vectors to be clustered into n classes. When the input is an incomplete vector x, the set M_x of the missing components numbers is first defined. M_x is a sub-set of $\{1, 2, \dots, p\}$. If $C = (C_1, C_2, \dots, C_n)$ is the set of code-vectors (named code-book) at this stage, the winning code-vector $C_{i_0(x,C)}$ related to x is computed as by setting:

$$i_0(x,C) = \arg\min_i \|x - C_i\| \tag{1}$$

where the distance $\|x - C_i\|^2 = \sum_{k \notin M_x} (x_k - C_{i,k})^2$ is computed with the components present in vector x. One can use incomplete data in two ways (Cottrell et al., 2003):

(i) If they are used during the construction of the code-vectors, at each stage, their update (the winning one and its neighbours) only concerns the components present in the observation. $C^t = (C_1^t, C_2^t, \dots, C_n^t)$ is the code-vector at time t and if a randomly chosen observation x^{t+1} is drawn, the code-vectors are updated by setting:

$$C_{i,k}^{t+1} = C_{i,k}^t + \varepsilon(t)(x_k^{t+1} - C_{i,k}^t) \tag{2}$$

for $k \notin M_x$ and j neighbour of $i_0(x^{t+1}, C^t)$. Otherwise:

$$C_{i,k}^{t+1} = C_{i,k}^t \tag{3}$$

The sequence $\varepsilon(t)$ is [0,1]-valued with $\varepsilon(0) \approx 0.5$ and converges to 0 as $1/t$. After convergence, the classes are defined by the nearest neighbour method.

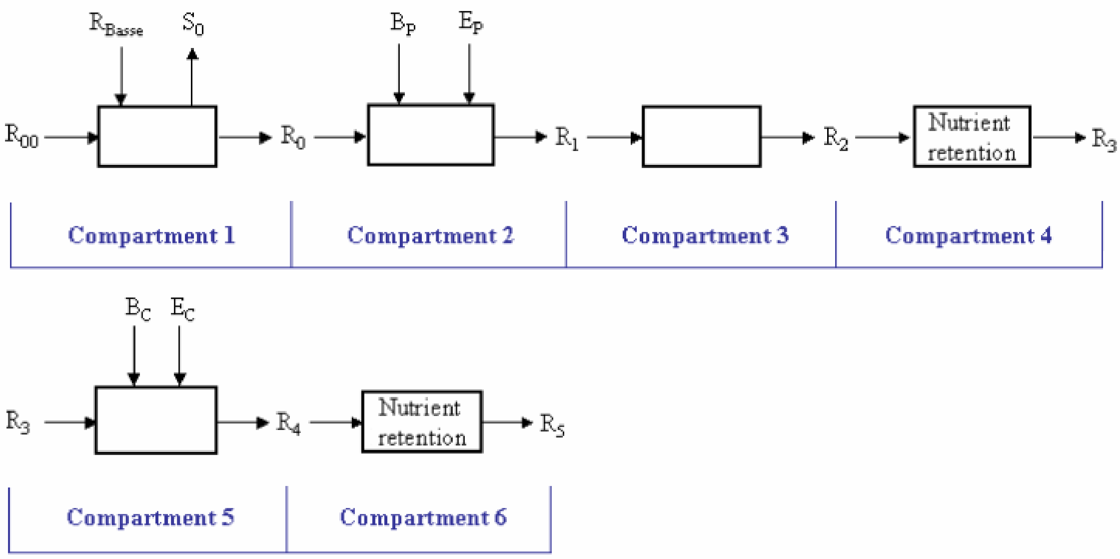


Figure 2. Model structure, where, R is a sampling point into the Têt River or La Basse tributary, S refers to the Têt water taking, B is the WWTPs' bypass, E is the WWTPs' effluent, P refers to the Perpignan's WWTP and C refers to the Canet-en-Roussillon's WWTP.

(ii) If the data are numerous enough to avoid using the incomplete vectors to build the map, one can content oneself with classifying them after the map is built, as supplementary data by allocating them to the class with the code-vector which is the nearest for the distance restricted to non-missing components.

Whatever the method used to deal with missing values, one of the most interesting properties of the algorithm is that it allows an a posteriori estimation of the missing values. If M_x is the set of missing component numbers for the observation x, and if x is classified in class i, for each index k in M_x, one estimates x_k by:

$$\hat{x}_k = C_{i,k} \tag{4}$$

Because in the end of the learning, the Kohonen algorithm uses no more neighbours, the code-vectors are asymptotically near the mean values of their classes. Therefore this method consists in estimating the missing values of a variable by the mean value of its class.

3.2. The simulation mass balance model developed

A simplified mathematical model based on mass balances was developed to estimate nutrient levels in the Têt stream and to describe its water quality.

3.2.1. Mass balances

A mass balance is an accounting of material entering and leaving a system. The main particularity of the mass balances is that they assume the conservation of mass principle (i.e. matter can not disappear or be created). Taking into account this principle, the mass that enters a system must either leave the system or accumulate within the system, i.e. E + G = S + A, where E denotes what enters to the system, G denotes the production term, S denotes what leaves the system and A denotes accumulation within the system. G and A may be negative or positive.

Mass balances have been used to design chemical reactors, to analyse alternative processes in production of chemicals, in pollution dispersion modelling, etc. Although they are often developed for total mass crossing the boundaries of a system, they can also focus on one element (i.e. carbon) or one chemical compound (i.e. ammonium).

In the present study, the system is the lowland of Têt River. The model is focused on different chemical compounds (nutrients and organic matter), considered indicators of water pollution.

3.2.2. The model structure

As cited in the previous paragraph 2.1, the developed model tries to represent the last 14 km of the Têt River, before flowing into the Mediterranean Sea.

In order to represent as maximum as possible the system, this is divided in six subreaches (Figure 2). Each subreach corresponds by one compartment, where the inputs, outputs and retention processes for nutrients are described in a mass balance environment. Because of the characteristics of one compartment are different of the characteristics of the other ones, each compartment has its particularity. So, the compartments 3, 4 and 6 describe what happens into the stream, where nutrient retention processes play an important role (except in the compartment 3) and where polluted inputs are not considered. Compartments 2 and 5 describe those subreaches where Perpignan's and Canet-en-Roussillon's WWTPs dump into the river, respectively. Two inputs to the river derived from both WWTPs are considered: the bypass (on raining days and/or when waste water flow is so high that WWTP can not treat all) and the effluent (the resulting water of depuration processes). Finally, compartment 1 describes the subreach where La Basse tributary flows into the Têt River and where some water is taken for agriculture activities and drinking consumption. In this compartment nutrient retention processes are not considered like the compartments 2 and 5, because of in these the large of the subreach is not enough for the retention processes. Moreover, the large of the subreaches is another differential aspect (i.e. while the large of compartment 2 and 5 is considered negligible, the large of compartment 4 is 2.5 km).

In all of them it is considered that there is no accumulation, taking the term A as zero. In reference of the production term G, this is zero where nutrient retention processes are not considered. The consideration of the nutrient retention existence in each compartment is the result of the treatment of some Têt experimental data (Ludwig et al., 2004), in order to represent as maximum as possible the processes within the river. Where the stream experiments nutrient retention processes, G is composed by self-depuration equations developed for nutrients compounds within the STREAMES European project (Llorens, 2004). The equations that sum up the model are the following ones:

$$\sum_{1}^{m} Q_s = \sum_{1}^{n} Q_e \qquad (5)$$

$$C_{s,i} = \frac{\left(\sum_{1}^{n} \left(Q_e \cdot C_{e,i}\right)\right)}{\sum_{1}^{m} Q_s} \qquad (6)$$

$$C_{s,j} = \frac{\left(\sum_{1}^{n} \left(Q_e \cdot C_{e,j}\right)\right) - G_{k,j}}{\sum_{1}^{m} Q_s} \qquad (7)$$

where, for each subreach, n is the number of inputs, m is the number of outputs, Q_e is the input flow, Q_s is the output flow, C_s refers to the input concentration, C_e refers to the output concentration, i refers to the compound of dissolved organic carbon (DOC), nitrites or nitrates, j refers to the compound of phosphates or ammonium, k is the reference number of the compartment and G refers to the nutrient retention (which is $\neq 0$ when $k = 4$ and j = phosphates or ammonium and is $\neq 0$ when $k = 6$ and j = phosphates.

3.3. Linking KSOMs with the mass balance model

In order to face the limited reliable data and the data missing (filling out the existing lacks in the database), KSOMs were used. The provided data completed the available database, which was after used by the mass balance model as input data. These data were related to the river and either the bypass and effluent of both Perpignan's and Canet-en-Roussillon's WWTPs.

4. Results and discussion

This section presents the results, obtained using KSOMs and mass balance model, allowing the estimation of the impact of organic matter and nitrogen on the chemical state of the Têt River.

4.1. KSOMs results

Ten KSOMs have been trained using available and complete data characterizing the Perpignan's WWTP, the Canet-en-Roussillon's WWTP and the sampling point R_{00} within the Têt River for two periods of year 2001 (winter and summer).

Table 1 summarizes the optimal size of its output layer for each network and the optimal number of epochs carried out during its training phase, in order to obtain the weakest average quantization error.

Table 1. KSOMs grids sizes and training epochs.

Location	*Season*	*Optimal grid size*	*Average quantization error*	*Optimal number of epochs*
Perpignan's WWTP (bypass/effluent)	*Summer*	*11x5*	*2.419*	*500*
	Winter	*10x5*	*2.673*	*450*
Canet-en-Roussillon's WWTP (bypass/effluent)	*Summer*	*9x5*	*1.987*	*450*
	Winter	*8x5*	*2.038*	*450*
Têt River (R_{00})	*Summer*	*10x6*	*1.602*	*300*
	Winter	*9x6*	*1.793*	*300*

Quantization error of an input vector is defined as the difference between the input vector and the closest codebook vector. For a set of input vectors, one can reflect on the similarity of the input data set and the KSOM by investigating the distribution of the quantization errors. The range of quantization error tells the smallest and the largest amount of error. Thus, the evaluation of the trained maps quality has been done by calculating the average quantization error over the input samples.

Table 2 presents the results of the missing (and needed) components estimation for incomplete days of February (winter) and June (summer) 2001, using the ten trained KSOM neural networks. The units of the presented results were modified according to their subsequent use in the running of the mass balance based model. Predicted components are displayed in grey and available components in the database are displayed in white. The analysis of the provided data by the KSOMs reflects a strongly fitting between the nutrient data for the Têt and the Perpignan's WWTP (both effluent and bypass) and its historical pattern, accordingly to the season. However, the situation is different for the results of the effluent of Canet-en-Roussillon's WWTP. Ammonium and nitrates data fit moderately with the winter pattern. The same occurs for total phosphorus in summer. Although, the error rate is so small that data is considered good to use in the mathematical model.

4.2. Estimation of the nitrogen and organic matter levels: related river water quality

Some relevant results, basically related to the stream flow and to the dissolved organic carbon (DOC), ammonium (NH4), nitrites (NO2) and nitrates (NO3) concentrations instream, were obtained from the running of the developed simulation mass balance model.

Table 2. Results for the missing components estimation (in grey: predicted components, in white: available components).

Perpignan's WWTP effluent (Ep)								
Day	*02.06.01*	*02.13.01*	*02.20.01*	*02.27.01*	*06.06.01*	*06.12.01*	*06.19.01*	*06.26.01*
Flow (m^3/d)	*36837*	*38824*	*37291*	*36730*	*36530*	*39505*	*41044*	*35437*
NH4 (mg/l)	*39.2*	*18.8*	*35.4*	*27*	*44.5*	*28.5*	*28*	*32.3*
NO2 (mg/l)	*0.85*	*0.5*	*1.13*	*0.2*	*1.2*	*0.63*	*0.5*	*1.3*
NO3 (mg/l)	*2*	*4*	*3.2*	*2.2*	*1.1*	*2.8*	*2.8*	*3.5*
PT (mg/l)	*1.4*	*0.6*	*1.8*	*0.4*	*2.1*	*1.5*	*1.5*	*1.8*
DBO (mgO_2/l)	*28*	*27*	*25*	*21*	*19*	*22*	*20*	*20*

Perpignan's WWTP bypass (Bp)								
Day	*02.06.01*	*02.13.01*	*02.20.01*	*02.27.01*	*06.06.01*	*06.12.01*	*06.19.01*	*06.26.01*
Flow (m^3/d)	*0*	*440*	*0*	*0*	*0*	*0*	*0*	*0*
NH4 (mg/l)	*0*	*56*	*0*	*0*	*0*	*0*	*0*	*0*
NO2 (mg/l)	*0*	*0.02*	*0*	*0*	*0*	*0*	*0*	*0*
NO3 (mg/l)	*0*	*0.8*	*0*	*0*	*0*	*0*	*0*	*0*
PT (mg/l)	*0*	*9.4*	*0*	*0*	*0*	*0*	*0*	*0*
DBO (mgO_2/l)	*0*	*246*	*0*	*0*	*0*	*0*	*0*	*0*

Canet-en-Roussillon's WWTP effluent (Ec)								
Day	*02.06.01*	*02.13.01*	*02.20.01*	*02.27.01*	*06.06.01*	*06.12.01*	*06.19.01*	*06.26.01*
Flow (m^3/d)	*1701*	*1510*	*1604*	*1651*	*1530*	*1624*	*1525*	*1725*
NH4 (mg/l)	*1*	*4.4*	*1.33*	*1.33*	*1.16*	*1.33*	*1.16*	*3*
NO2 (mg/l)	*1*	*0.6*	*0.33*	*0.33*	*2.12*	*0.33*	*2.12*	*1*
NO3 (mg/l)	*5*	*5.2*	*0.64*	*0.64*	*1.42*	*0.64*	*1.42*	*4*
PT (mg/l)	*4*	*2.7*	*1.7*	*1.7*	*1.9*	*1.7*	*1.9*	*5*
DBO (mgO_2/l)	*10*	*5*	*5*	*3*	*6*	*4*	*5*	*4*

Canet-en-Roussillon's WWTP bypass (Bc)								
Day	*02.06.01*	*02.13.01*	*02.20.01*	*02.27.01*	*06.06.01*	*06.12.01*	*06.19.01*	*06.26.01*
Flow (m^3/d)	*1668*	*1902*	*1736*	*1512*	*2746*	*2191*	*2245*	*2868*
NH4 (mg/l)	*50*	*50.5*	*48.2*	*50.2*	*45*	*49*	*40*	*43*
NO2 (mg/l)	*0.03*	*0.03*	*0.02*	*0.03*	*0.05*	*0.01*	*0.05*	*0.01*
NO3 (mg/l)	*0.14*	*0.14*	*0.2*	*0.1*	*0.02*	*0.02*	*0.02*	*0.22*
PT (mg/l)	*9.7*	*9.7*	*8.6*	*9.7*	*7.5*	*7.5*	*9*	*9*
DBO (mgO_2/l)	*160*	*218*	*162*	*197*	*263*	*263*	*294*	*284*

Têt River (R_{00})								
Day	*02.06.01*	*02.13.01*	*02.20.01*	*02.27.01*	*06.06.01*	*06.12.01*	*06.19.01*	*06.26.01*
Flow (m^3/d)	*756000*	*645408*	*743040*	*438048*	*135648*	*95040*	*20736*	*19008*
NH4 (mg/l)	*0.06*	*0.06*	*0.05*	*0.06*	*0.03*	*0.03*	*0.03*	*0.09*
NO2 (mg/l)	*0.07*	*0.03*	*0.07*	*0.03*	*0.09*	*0.07*	*0.09*	*0.14*
NO3 (mg/l)	*4*	*3.5*	*3.37*	*4.32*	*5.1*	*5.82*	*6.38*	*5.91*
PO4 (mg/l)	*0.18*	*0.18*	*0.18*	*0.18*	*0.24*	*0.16*	*0.23*	*0.17*
DOC (mgC/l)	*2.04*	*2.1*	*2.19*	*1.95*	*1.7*	*1.98*	*2.17*	*2.58*

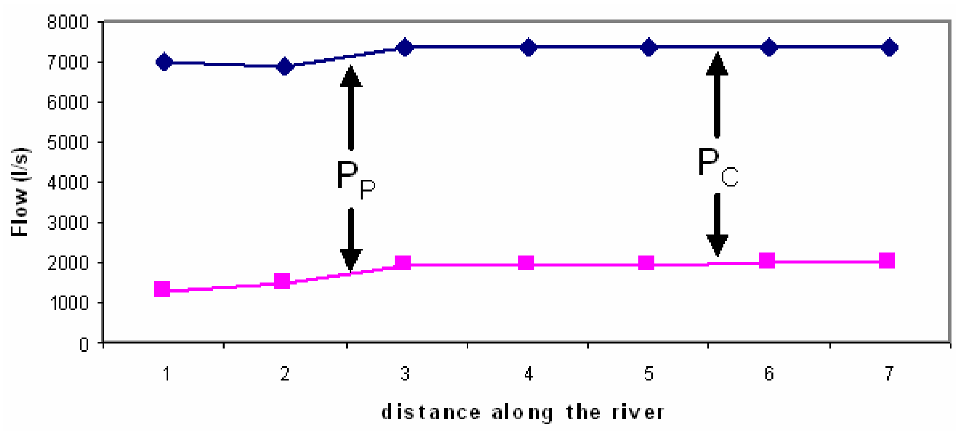


Figure 3. Flow values along the study site for both seasons.

These data allowed the estimation of the nitrogen, the organic matter and the flow levels within the study reach (the lowland of the Têt River) for February (winter) and June (summer) of 2001. Both months were considered the best to observe the WWTPs impacts to the river water quality due to their different meteorological features. High river flow dependence of meteorology (the average flow in the ending of winter is 7217±159 l/s and in the beginning of summer, 1788±236 l/s) corroborates it. This situation is typical of the Mediterranean area. Average flow levels along the river site are represented in the Figure 3, where the distance numbers refer to the compartment outputs of the model (except point 1, which refers to R_{00}). The darker line represents the winter and the lighter line, the summer. The entrance of the Perpignan's WWTP (Pp) outflows can be clearly observed and even, the opposite effects of the tributary La Basse and the taking water activity. However, the input of the Canet-en–Roussillon's WWTP (Pc) is difficult to see due to its outflows are very low in comparison with the stream flow.

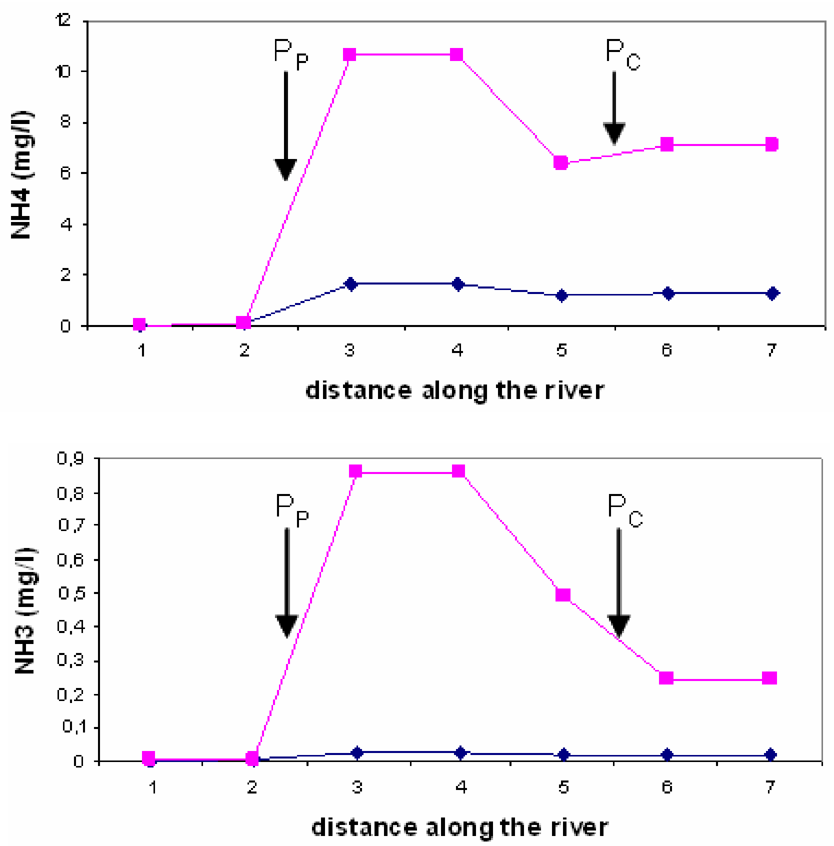
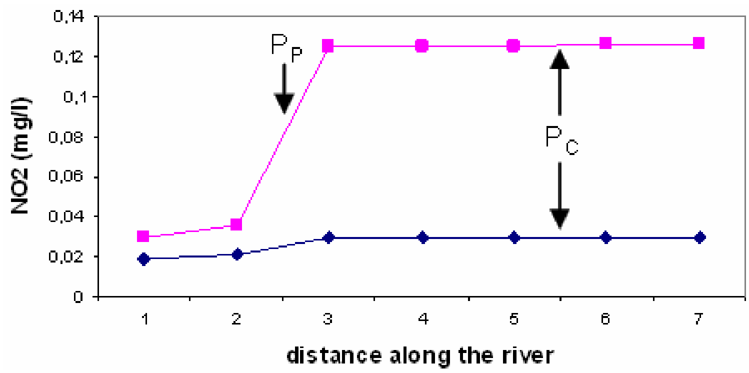


Figure 4. Nitrogen compounds concentrations along the study site.



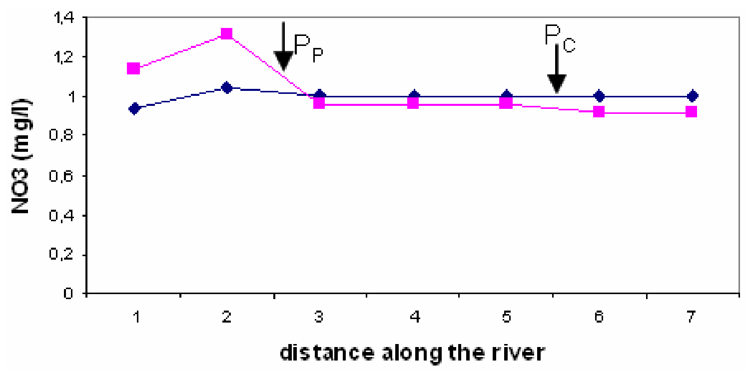


Figure 4. (Continued).

The average nitrogen levels of the river water along the study stream are represented in the Figure 4. The Pp seems to have a greater negative impact to ammonium, ammonia and nitrites concentrations than the Pc, because of it treats a higher amount of water. However, the situation for nitrates is different, as the Basse impact is higher than the both WWTPs. Even, it is possible to see in the figure that the outflows of Pp and Pc contribute to the river nitrate dilution. All of these cases can be especially observed during summer conditions, when water discharge is lower and a higher part of the flow down of WWTPs is the effluent and bypass of both WWTPs. The effect of their outflows is magnified by low stream flow.

To sum up, in concentration terms, the Pp contributes to the increasing ammonium and nitrites loads within the river, meanwhile its impact on nitrates is very small or even positive. These conclusions lead to think that the nitrification processes in the Pp are partial and they should be improved to reduce its impact to the river. By other hand, the major impact of the Pc is on ammonium terms. But, in water quality terms the conclusions change due to they are referred to qualitative values and not to quantitative. Meanwhile the river water quality (SEQ-EAU V2, 2003) has a Very Good category for nitrates in both seasons and a Very Good (in winter) / Good (in summer) category for nitrites along the study site, the situation is very different for ammonium and ammonia. In both cases the quality before the Pp outflows is Very Good. After them, it becomes Very Bad for ammonia in both seasons and for ammonium in summer. In winter the water quality for ammonium after the Pp is Moderate. So, these values corroborate the greater impact of Pp on river water quality in reference with ammonium and ammonia compounds.

Finally, the average DOC levels of the river water along the study site are represented in the Figure 5. Comparing the season values, it is evident the impact of both WWTPs to the Têt River during the summer season. However, the average flows and DOC concentrations of the effluent and bypass of the Pp are maintained along the time. This lets to think that the high impact of Pp on summer is basically due to the low stream flow, which intensifies the effects of Pp outflows. Related to the Pc, the effluent is maintained along the seasons (flow and DOC). For the bypass it is a bit different because meanwhile the flow only experiments a very small increment (10 l/s), the DOC concentrations increase an average of 5.19 mg C/l. The increment of the DOC loads seems to be the result of the tourism activities in the town of Canet-en-Roussillon. In water quality terms, only the Pc contributes the change from Very Good to Moderate category value in summer. In winter, neither of WWTPs contributes to a change of the quality category, which is Very Good in all 14 km of the study site. So, in both quantitative and qualitative terms of organic matter, the Pc has higher negative effects to the river chemical health, specially in summer.

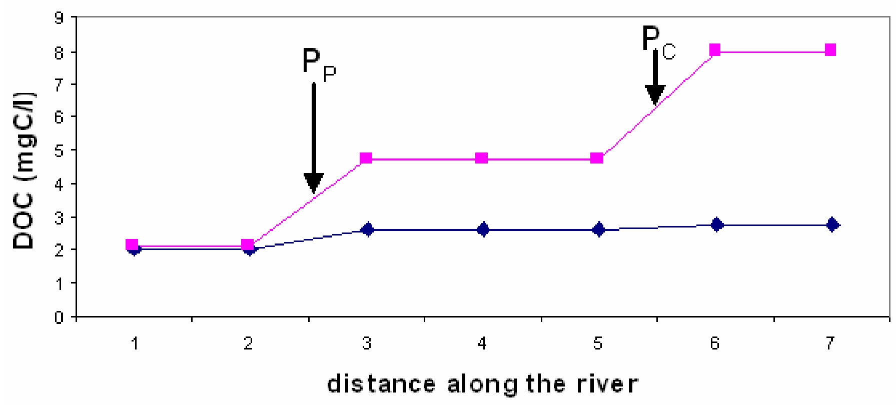


Figure 5. DOC concentrations along the study site.

Table 3. Results from the EDSS running for each compartment.

Problem	*Season*	*Comp. 1*	*Comp. 2*	*Comp. 3*	*Comp. 4*	*Comp. 5*	*Comp. 6*
Eutrophication	*Winter*	*No*	*No*	*No*	*No*	*No*	*No*
	Summer	*Low*	*No*	*No*	*No*	*No*	*No*
Excess of nitrogen	*Winter*	*No*	*Moderate ammonium*	*Moderate ammonium*	*No*	*No*	*No*
	Summer	*No*	*Ammonia* (Severe ammonium)*	*Ammonia* (Severe ammonium)*	*Ammonia* (Moderate ammonium)*	*Ammonia* (Severe ammonium)*	*Ammonia* (Severe ammonium)*
Organic matter pollution	*Winter*	*No*	*No*	*No*	*No*	*No*	*No*
	Summer	*No*	*No*	*No*	*No*	*Severe*	*Severe*

**Ammonia higher than 0.02 mg/l.*

4.3. Estimation of the river problems according to the nutrient and organic matter levels

The obtained results from the simulation model were used to run the STREAMES EDSS (Llorens et al., 2004) with the aim of corroborate the above commented assumptions and determine the instream problems of Têt River. The STREAMES EDSS is a useful tool, especially developed for the Mediterranean area, able to integrate point and non-point pollution to help water managers on decision-making processes related to the river water domain. It provides 3 types of outputs: diagnosis, actions and prognosis. The interest of the present study is focused on the diagnosis output, which supplies a list of the main problems affecting the studied stream reach.

The system was run for all compartments of the model. According to the results (Table 3), the river does not have problems of eutrophication. Only it is diagnosed a low eutrophication in summer in the first subreach, due to the phosphorus loads of the tributary La Basse. The river recovers speedily after this point.

Related to the nitrogen problems, the impact of the Pp (in the Comp. 2) on ammonium excess is evident. Luckily, the river recovers in winter thanks to its selfdepuration capacity. But, the situation is different in the summer period, where the system diagnoses an important amount of ammonia (very dangerous for fish population) due to the physico-chemical characteristics of the river water (pH, temperature and ammonium concentration). In this case the contribution of Pc maintains and even deteriorates the situation. The selfdepuration capacity of the river is not able to solve the problem, only to reduce its degree.

Finally, the river does not experiment organic matter pollution in winter. However, the contribution of Pc in organic matter seems to be very important as the EDSS diagnoses severe organic matter pollution in summer after its outflows. In this case the river has not the capacity of recovering before its flowing into the Mediterranean Sea.

5. Conclusion

As a lot of Mediterranean rivers, the water quality of the Têt River must be largely improved and better monitored. In this sense, a tool has been developed and is presented in this paper, based on both Kohonen self-organizing maps and simulation mass balance modelling, to estimate nutrient and organic matter levels in the stream and to describe the river water quality. The study area, where the major economic activity is tourism, covers the last 14 km of the river (from Perpignan to Canet-en-Roussillon) and is affected by one tributary and two WWTPs.

Kohonen self-organizing maps were first used to face the limited reliable data and to fill out the existing lacks in the available database related to the chemical state of the river and the WWTPs operation. This kind of neural network proved to be very useful for estimating missing values in a database, using available values by means of a training phase, independently of the nature of the studied system (i.e. river, WWTP outflows …). The results obtained using KSOMs, in order to avoid the data missing, can be considered as satisfactory in spite of the system complexity and strong non linearity.

By other hand, a simplified simulation model based on mass balances has been developed and proved to be an efficient diagnostic tool. It allowed efficiently estimating the nitrogen, the organic matter and the flow levels within the lowland of the Têt River. Completed data from months February (winter season) and June (summer season) of 2001 has been used to highlight the WWTPs impacts to the river water quality according to different meteorological features.

Finally, the obtained results from the simulation model were used to run the STREAMES EDSS with the aim to corroborate the assumptions and determine the instream problems of the Têt River.

After these interesting preliminary results, future works will focus on modelling all the Têt River catchment area and improving the simulation model taking into account new parameters impacting the ecological and chemical states of the Têt River. The developed model will also be integrated in a global tool allowing the control and supervision of the Têt River catchment area, with the aim of improving its water quality.

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