Dynamic simulation of water quality in rivers. WASP5 application to the river Nalón (Spain).

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Abstract

This study was aimed at developing dynamic water quality models applied to the upper stretch of the river Nalón. They will be used in planning the sanitation of the Nalón basin. These models will be used to study the daily fluctuations in water quality and the impact combined sewer overflow (CSO) has on the aquatic system. In the past a steady state model based on the QUAL2E model was developed for the river Nalón. The theoretical model used, WASP5 (Water Analysis Simulation Package, ver. 5x; AMBROSE *et al.*, 1991), is backed up by the US EPA.

The model was approached using the validated model based on the QUAL2E program. The steady state model was validated and calibrated by specific field studies. All field study data and kinetic constants and parameters have been used for the dynamic model. The main daily wastewater discharges (flows and concentrations) are variables in the new simulations. The daily variation of dissolved oxygen has been studied and the following parameters have been simulated: BOD, ammonia, organic nitrogen, nitrates and total nitrogen. The final calibration-validation of the dynamic model was very good. The lagrangian sampling technique is appropriate for dynamic model calibration. The WASP5 program permits river water quality simulation with some limitations. The partial simulation of the CSO impact on the river is possible using the created model.

1.- INTRODUCTION

Water quality models have already been developed for the rivers Nalón, Caudal and Nora in Northern Spain with the aim of obtaining a tool by which it was possible to plan the sewer networks and treatment plants and to determine the ecological flows (TEJERO, 1993; SAINZ, 1990, 1991a, 1991b). The United States Environmental Protection Agency (US EPA) QUAL2E (BROWN and BARNWELL, 1985) model was used, in its NCASI version. The permits water quality be modelled in a steady state. The phosphorus and nitrogen cycles, algae, coliform and BOD cycles were simulated using the developed models and the dissolved oxygen balance was determined. A laborious collection of information and data was necessary in order to conceptualise and adapt the rivers to the steady state model. Specific work of hydraulic characterisation and of wastewater discharge and river water characterisation were carried out. Two periods of low water during different years were used to construct the steady state models. One was used for the calibration and the other for the validation. The steps performed were as follows: a) construction of a premodel; b) construction of an initial model using calibration; c) validation of the initial model in order to obtain a final model.

In order to understand more about the pollution phenomena which affect water quality, new objectives were set based around modelling the CSO impact. Unit sewer overflows during storms generate intense transitory pollution in rivers. Dynamic models of river water quality must be constructed to study this type of event because stationary models are not adequate.

In this article a dynamic model of water quality in the river Nalón is outlined. Once the model is constructed, a simulation is made of the impact of the CSO generated by the sewer network in the town of Sama-Langreo (Asturias) (40,000 inhabitants). The main features of this river are its high gradient and short length. The lowest flow rate takes place in summer. The catchment area is a historic coal mining region and consequently contains important industrial zones and centres of population. The estimated summer flow rate in the last modelled reach is 1.85 m^3/s and the mean annual flow rate is 17 m^3/s.

2.- GENERAL METHODOLOGY

During a CSO pollution event the aquatic system is subjected to both immediate and accumulative effects. The immediate effects of a determined contaminant may be studied as isolated events and their overall impacts analysed using techniques based on the occurrence of extreme events (HARREMOES, 1986). MANCINI (1989) considered that it was also necessary to take into account the transport and resuspension of sediments and all their associated phenomena which produce accumulative effects.

Once all the characteristics necessary for the model had been determined, a revision was carried out on the available programs. The US EPA's WASP (Water Analysis Simulation Package) was finally adopted (AMBROSE, *et al*, 1991). The WASP, version 5, is a dynamic model of water quality which is compartmentalised into blocks. It is linked with the DYNHYD, a nodal based unidimensional hydrodynamic model. The kinetics of the water quality parameters are organised into subroutine modules which can be written or modified by the user. Two interchangeable kinetic blocks exist: the EUTRO and the TOXI. The EUTRO includes the most up-to-date kinetics of eutrophication (linked to BOD and dissolved oxygen). The model allows the simulation of suspended solids and their associated pollution. The basic quality kinetics (N, P and OD) are almost mimetic with those of the QUAL2E. The WASP5 may be used in different degrees of complexity. The WASP5 Level 3 of complexity was used for the dynamic simulation of the immediate effect of a CSO on the river Nalón water quality. The parameters simulated were BOD, organic nitrogen, ammonia, nitrates, total nitrogen and dissolved oxygen.

The information obtained with the steady state model based on QUAL2E was used in the construction of the dynamic model. The construction process was structured in 2 phases: initial model elaboration or steady state WASP model, and final model construction or dynamic WASP model. The situations of calibration and validation used with the QUAL2E were studied in both models.

The initial model is a steady state model based on the WASP5 to which the conceptual structure, parameters, constants and discharge data of the QUALIIe based steady state model have been applied. Some changes were necessary and some still had to be used to adapt the above data to the peculiarities of WASP5, both in hydrodynamic aspects and water quality.

The final model consists of a dynamic model of the river based on WASP5. The flow and concentration of the discharges were made to change along with the water temperature throughout the day and the contaminant concentration at the head of the modelled stretch of the river Nalón.

3.- STATIONARY MODEL WASP5 CONSTRUCTION

The WASP5 model is based on the superposition of two computational structures: one which calculates hydrodynamics and another which calculates water quality. To adapt the hydrodynamic grid to the upper reach of the Nalón it was decided to opt for modelling the same length of river that was taken for the QUAL2E. The same segment length, 800 meters, used for calculation in the stationary model was adopted. This distance later conditions the computational stability in the numerical resolution of the equations. The complete hydrodynamic model of the river Nalón contains 51 junctions and 50 channels. An extra junction was added to the structure in order to include boundary contours simulating the existence of a reservoir. The same Manning rugosity values as those used in the stationary model were adopted. The DYNHYD resolves the equations of continuity and momentum.

The structure of the water quality model consists of a set of blocks or control volumes representing the physical configuration of the water mass. Only water column type blocks are simulated, benthic blocks were not simulated. A control volume of water was given to each hydrodynamic junction. Only the advective flow and the dispersive mix in the water column were used. In order to define the dispersive transport the same dispersion coefficients as those obtained in field work for the Nalón stationary model were used.

Level 3 of EUTRO-WASP takes into account the oxidation of the carbonaceous organic material and the nitrogen cycle. In the nitrogen cycle, the nitrite stage is not taken into account, representing an important difference with respect to the simulation of the nitrogen cycle in QUAL2E. An important problem in the simulation of river water quality was provoked by not simulating the disappearance of the carbonaceous organic material and nitrogen with sedimentation of solid particles. As they do not disappear from the water mass they continue producing a demand and affect the OD profile. The option for automatic optimisation of the time step was used in the simulation of water quality. The fact that the river has an average hydraulic retention time of 1.5 days must be taken into account.

As it was possible to modify the source code we chose to modify the superficial reaeration option included in EUTRO. The coefficient of superficial reaeration is a function of the average velocity of water, depth, wind and temperature. The original EUTRO4 calculated, using the Covar method (COVAR, 1976), the reaeration induced by the flow type. In the QUAL2E, after trying different options, the formula of Lamgbien and Durum (LAMGBIEN and DURUM, 1967) was adopted and introduced into the dynamic model.

TABLE N° 1.-Values of the environmental constants adopted for the initial dynamic model of water quality for the upper stretch of the river Nalón.

NALÓN RIVER / CONSTANTS FOR EUTRO-WASP MODEL / INITIAL MODEL				
Name (WASP)	**N°**	**Description**	**Value**	**Units**
		AMMONIA		
K12C	11	Nitrification rate at 20° C, per day.	**1**	$days^{-1}$
K12T	12	Temperature coefficient for K12C.	**1.08**	---
KNIT	12	Half-saturation constant for nitrification - oxygen limitation.	**0.8**	$mg\ O_2/L$
		BOD		
KDC	71	BOD deoxygenation rate at 20 °C, per day	**0.6**	$days^{-1}$
KBOD	74	Half-saturation constant for nitrification - oxygen limitation.	**0.000**	$mg\ O_2/L$
KDT	75	Temperature coefficient for carbonaceous deoxygenation in water column.	**1.05**	---
		ORGANIC NITROGEN		
K71C	91	Mineralization rate of dissolved organic nitrogen, per day.	**0.2**	$days^{-1}$
K71T	92	Temperature coefficient for K71C.	**1.05**	

Below may be found the initial results of water quality for the river Nalón with this first stationary model based on the WASP5 (Figure 1). The results are compared with the river water quality values obtained during the stages of calibration and validation. It must be remembered that the work performed on water quality in order to construct the stationary model using QUAL2E were carried out using the criteria of following the drop. Three samples were taken throughout the day at each selected point. Each sample was taken at eight hour intervals. The moment of the sample was calculated by taking into account the water circulation times of the river which were obtained during the hydraulic characterisation.

TABLE Nº 2.- Reference values for hydraulic characterisation.

	PARAMETER	MIN.VALUE	MAX.VALUE
CALIBRATION STAGE	Flow (m^3/s)	3.86	6.22
	Velocity (m/s)	0.32	0.65
	Depth (m)	0.31	0.71
	Manning number	0.050	0.175
VALIDATION STAGE	Flow (m^3/s)	2.13	4.01
	Velocity (m/s)	0.56	0.26
	Depth (m)	0.24	0.57
	Manning number	0.025	0.170

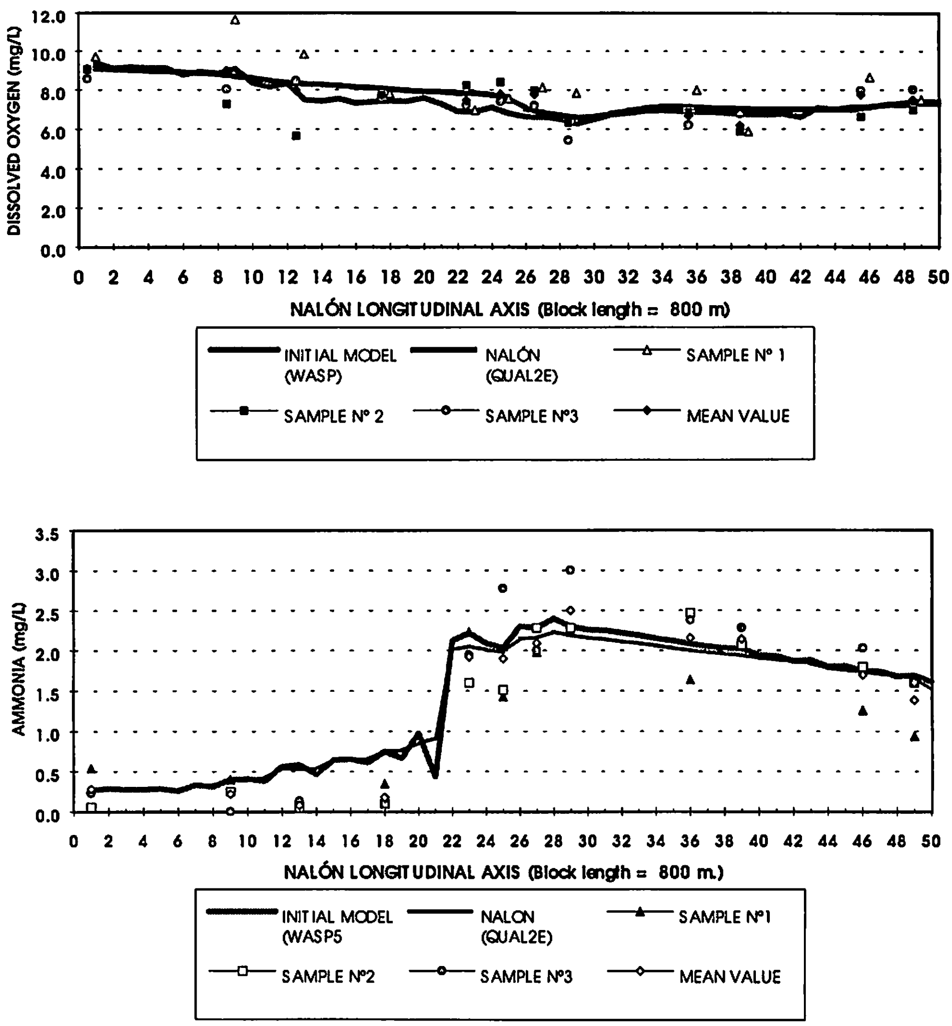

Figure 1.- Initial results of water quality for river Nalón. Model based on the WASP5.

4.- DYNAMIC MODEL WASP5. CALIBRATION AND VALIDATION.

The daily variable discharge points were at first considered to be determinate factors in the variation of the river water quality. Both the industrial wastewater and the urban wastewater discharges vary in the river basin. Industrial discharges were considered constant and more important urban discharges were made to change throughout the day. The flow and load curves for urban wastewater discharges were defined using regional data. Discharges from settlements of less than 1,000 inhabitants were adopted as constants. The number of variable discharges was six. The largest simulated discharges were generated by a town of 25,628 inhabitants, with a peak coefficient of 2.1, and the smallest of 4,617 inhabitants, with a peak coefficient of 2.40 (SUÁREZ, 1994).

The temperature of the water is also a determinant factor in the daily variation in water quality. During the work carried out on calibrating and validating the model of the Nalón based on QUAL2E, both the air and water temperatures were taken. At the same time water quality data were obtained from the modelled upper reach of the river. Three samples were taken of the head water, one every eight hours. In order to model the variation in water quality at the head, a lineal variation in time is assumed between the field values.

The numerical values of the simulation are presented in graph form. In the X-Y diagram the simulations appear as multiple lines. Each line corresponds to an instant of the day. Each day has been distributed into 0.025 days (36 minutes). Although it is very difficult to differentiate what instant corresponds to which curve, it is interesting to see the variation range of the different water quality parameters throughout the day. The simulation results are compared with those obtained during the water quality calibration and validation field work (Figure 2). As three variables are available (river longitudinal axis, water quality parameter and time of day) the results can be represented three-dimensionally (Figure 3)

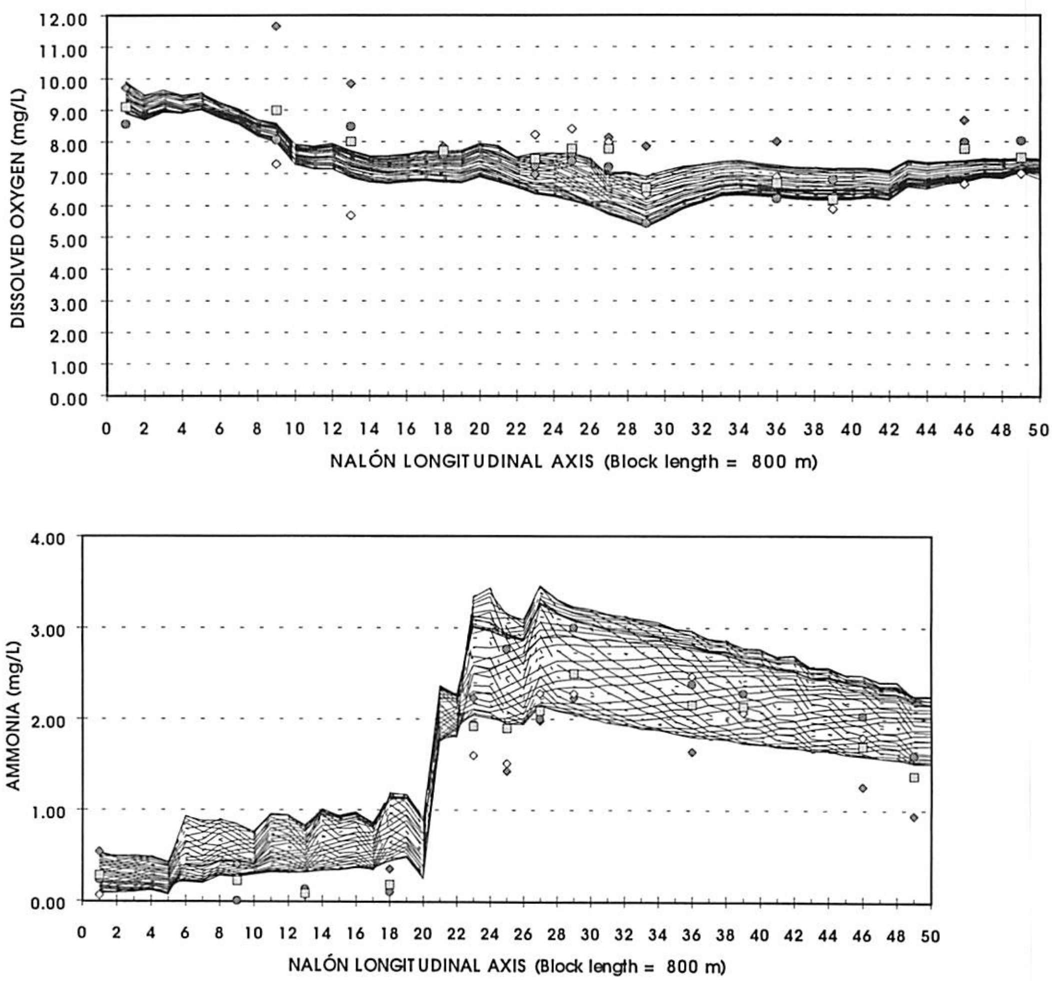

Figure 2.- Numerical values of the dynamic simulation. Final model WASP5

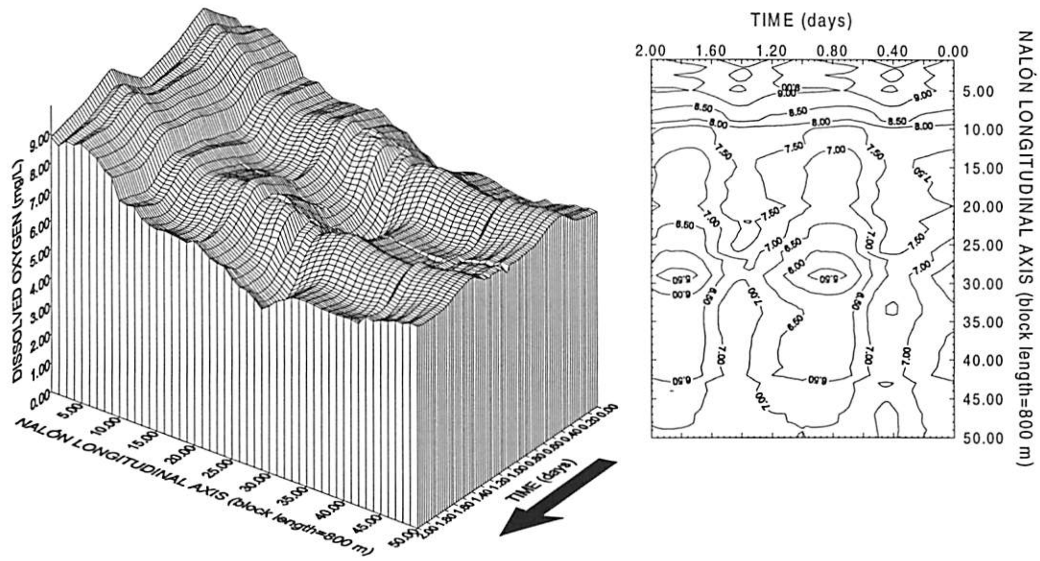

Figure 3.- Dissolved oxygen results. Final model WASP5.

5.- CSO APPLICATION

Once a dynamic water quality model is constructed for the river Nalón, it will be possible to study transitory pollution phenomena. One of the most complex phenomena to study is the effect CSO has on river water. During periods of low water the river aquatic system is more sensitive to pollution. A sufficiently heavy rain storm after a period of prolonged drought may provoke CSOs and generate situations of contamination in the river, "estiaje húmedo". The acute effect of CSO on the river Nalón is studied in this work taking into account that the sanitation plan in sewer networks, overflow control and treatment systems and wastewater treatment plants are constructed and working.

Since the flow profile adopted by the river in the validation stage is similar to the situation of low water they have been considered as the same, with a modification caused by the elimination of a large part of the discharges, their flows being reincorporated downstream at the location of a wastewater treatment plant.

The SWMM (Storm Water Management Model) (HUBER, 1988) was used to obtain a CSO representative of the basin and of the implimented sewer system. Different CSO were studied, variations being made to the fundamental variables on which they depend. CSO is produced through an overflow structure equiped with a 1400 m3 (7 m3/Ha net) storage tank. The flow directed to the WWTP is four time the average flow during dry spells, is 464 L/s. Although the probability of a rainfall of 13.68 mm/h is high in the river Nalón basin, other situations have to be simultaneously produced in order to provoke the most unfavourable effects on the system: maximum number of dry days before the storm and minimum flow of water in the river. The return period of this very bad event will be greater than eleven months. Zero dissolved oxygen is considered for the CSO presented (Figure 4).

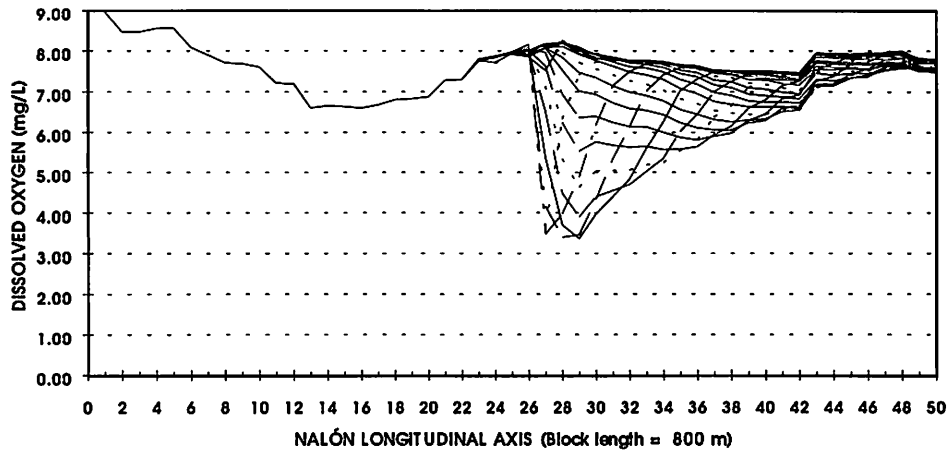

Figure 4.- Results of dissolved oxygen depletion in the river Nalón. CSO impact.

When studying the effects of CSO on aquatic systems different quality criteria should be used from those used in studying the impacts of continuous discharges of urban and industrial wastewater. Concentration and contaminant limit curves should be used which take into account the magnitude, duration and frequency of the event, along with the definition of the organism that need to be protected (HOUSE, 1989; LIJKLEMA, 1993; WHITELAW, 1989). An example of the OD evolution in the stretch of river affected by CSO is presented in Figure 4. The evolution of OD level, time of infulfillement (e.g. OD≥6 mg/L) and the stretch of river affected can be seen in the topography (Figure 5).

TABLE Nº 3.- Main parameters of used CSO.

CSO´s CHARACTERISTICS	
Catchment surface = 400 Ha.	Wastewater flow (dry weather) = 116 L/seg
Runoff coefficient = 0.5	BOD5 concentration = 260 mg/L
Average slope = 0.005	Ammonia concentration = 25 mg/L
Inhabitants = 40000	Rain intensity = 19.034 L/s.Ha.
Wastewater flowrate = 250 L/ha.day	Rain duration = 1 hour
Nº of dry days since last rain = 7	Rain returned period = 0.90 years

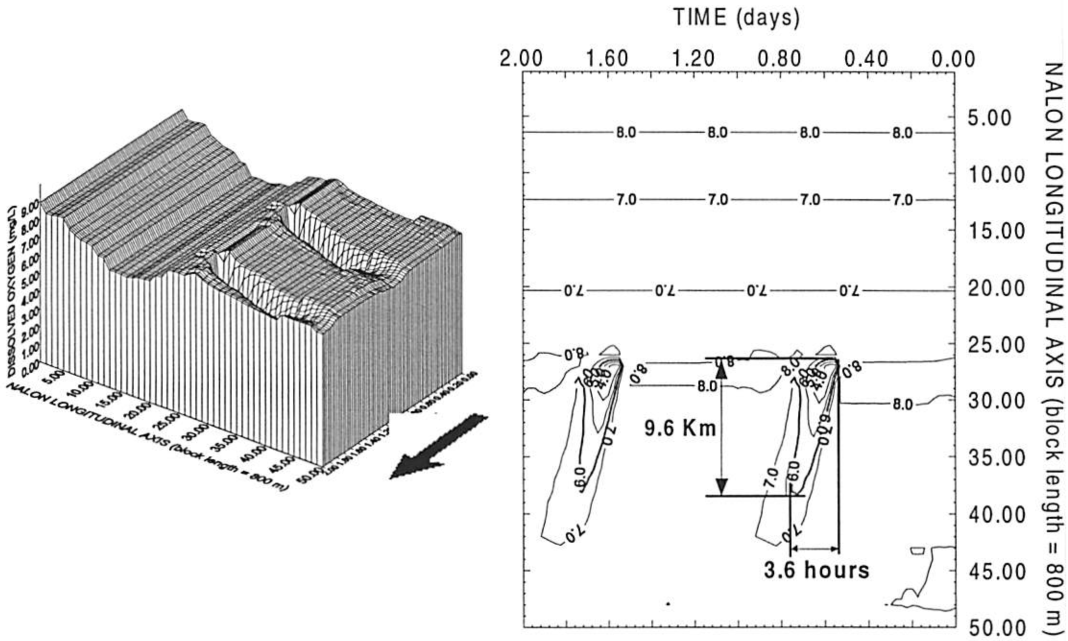

Figure 5.- Evolution of OD, time of infulfillement and the stretch of Nalón affected

6.- CONCLUSIONS

- WASP5 may be used (with modifications) to construct a representative dynamic model for rivers with similar characteristics to the Nalón. Although from a water quality point of view, the dynamic model is simpler than the stationary one, it simulates the principal phenomena occurring in the river adequately.
- The method followed for calibration and validation based on the stationary model has turned out to be robust for the construction of the dynamic model.
- The dynamic model simulates the instantaneous effect of *estiaje húmedo* (wet low water) pollution. During low water conditions the river studied supports the impact of CSO considered in terms of dissolved oxygen, taking into account the existence in the sewer network of adequate overflow control and treatment systems (OCTS). The interest in the production and introduction of water quality regulations and standards for extreme pollution events is reaffirmed. It is important to control the quantity of dissolved oxygen which the CSO incorporates into the river.
- The hydraulic characterisation of this type of river is very difficult and, at the same time, its influence on the evolution of water quality is very important. Limitations have been found in the dynamic model (WASP5) which reduce its possibilities for the simulation of river aquatic systems. The obligation of setting equal rates for all the river is one of these limitations. In the river studied, the consumption of dissolved oxygen by nitrification is of the same importance as that which is consumed during the oxidation of carbonaceous material.

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