DISPERSION MODELLING IN RIVERS FOR WATER SOURCES PROTECTION. A CASE STUDY.

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1. INTRODUCTION

River hydrodynamics and pollutants dispersion are determinant factors in river basin planning and management, when different water uses and aquatic ecosystems protection must be considered. The ever increasing computational capacities provides the development of powerful and user-friendly mathematical models for simulation and prediction receiving waters quality changes after wastewater discharges and land runoff.

The aims of this research work are to evaluate the performance of different mathematical models when applied to pollutant transport and dispersion modelling in a Mondego river reach (Figure 1). Runoff from Urgeiriça uranium mine discharged to a Mondego river tributary (Pantanha creek), located upstream of Seara abstraction point, has determined the interest of an environmental impact assessment.

2. STUDY AREA

The study area occupies the medium part of Mondego river basin, located in the central region of Portugal. The drainage area is 6670 km^2 and the annual mean rainfall is between 1000 and 1200 mm. The river reach considered in this work begins downstream Caldas da Felgueira bridge and ends at Tábua bridge, in a distance of approximately 24 km. The water is intensively used for hydropower generation, domestic and industrial water supply and agricultural irrigation.

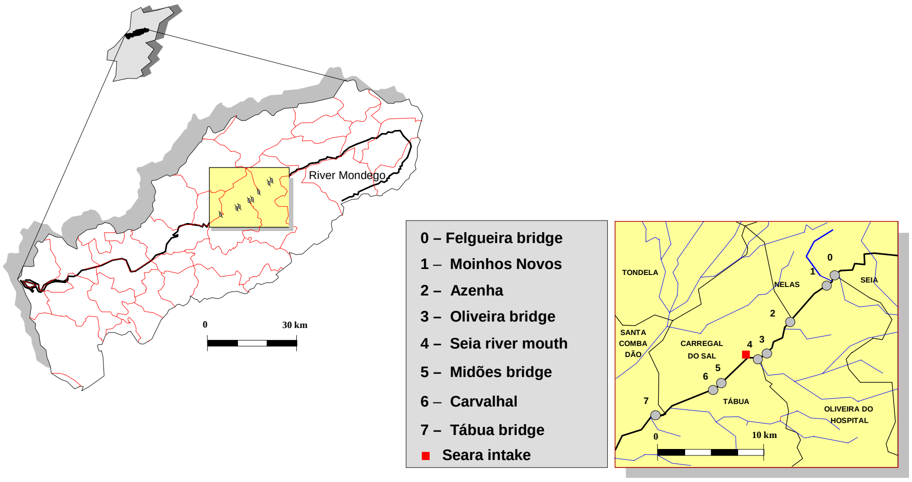

Figure 1 - General layout of Mondego river basin and sampling sites localisation

A monitoring program was carried out using tracer injection (rhodamine WT) to evaluate the *in situ* dispersion river water behaviour under three different flow regimes: flood (140 m^{3}s^{-1}), dry-weather (0,74 m^{3}s^{-1}) and frequent (40 m^{3}s^{-1}) conditions. Seven sampling sites were

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considered, being the site 0 (Caldas da Felgueira bridge) the upstream dye tracer injection point, where is located the unique gauge station in this reach and before Aguieira dam.

For operational convenience, dye tracer was discharged in two different river sections and the \water samples were collected at several sites downstream. With observed concentration data (under frequent flow regime), two models (DUFLOW and ADZTOOL) using different numerical techniques were calibrated in order to produce operational tools to define how long water abstractions need to be suspended after a spill, the probabilistic arrival/peak/recession times, and pollutant concentrations.

3. METHODOLOGY

Experimental data

The dye tracer used in this study was rhodamine WT (20% solution), recommended by its characteristics: not toxic, not reactive, good diffusivity, high detectability, low sorptive and acidity. For concentrations measurements a "Turner Designs" fluorometre was used. Blanks were taken in all sampling sites for river natural fluorescence determination. Table 1 presents the information about all the tracer injections on the three sampling programs made in this study.

Table 1 - Tracer injections record

Injection	Date	Hour	Point	River flow (m^3/s)	Rhodamine mass (g)
1	89-12-09	8:20	Site 0	140	100
2	89-12-09	15:40	Site 3	144	200
3	89-12-10	8:00	Site 0	100	200
4	89-12-10	8:30	Site 5	110	400
1	90-06-15	7:32	Site 0	0.74	400
2	90-06-15	8:30	Site 3	0.74	200
1	90-11-09	7:40	Site 0	40	400
2	89-11-10	8:00	Site 3	29	400

Figure 2 shows the rhodamine spread evolution for the first injection of November 90 monitoring program.

Figure 2 – Rhodamine spread after the injection at site 0

The dye tracer injected mass recovered at each sampling sites allows to assess the importance of physical and biochemical processes by quantification of precipitation, sorption, retention and assimilation losses.

Flow values considered for calculations were obtained from Nelas flow gauge station records. Mean water velocity in reaches was calculated with mean travel time and distances between sampling sites (Table 2).

Table 2 - Distance between injection points and sampling sites

SAMPLING SITES	Distance from injection points		
	Site 0	Site 3	Site 5
1	1.250	—	—
2	6.200	—	—
3	11.000	—	—
4	11.650	650	—
5	16.700	5.700	—
6	17.400	6.400	700
7	24.000	13.000	7.300

The flow regime of this river reach is strongly influenced by the Aguieira reservoir water level and by the fourteen weirs considered, as shown in Figure 3.

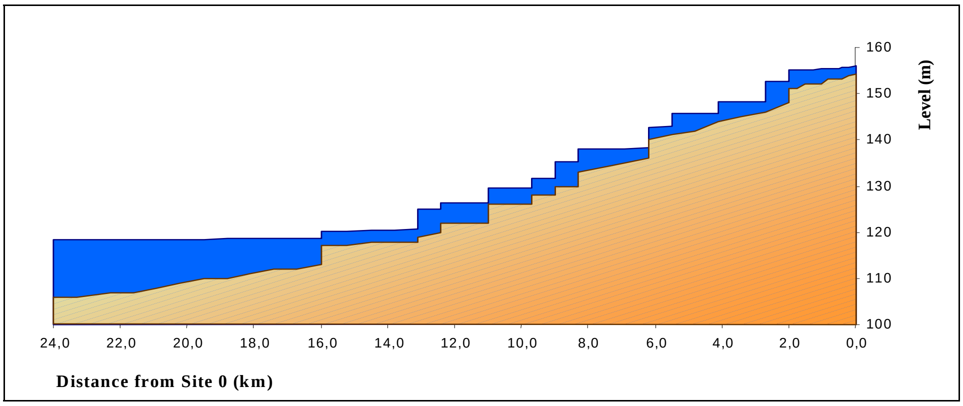

Figure 3 - River reach longitudinal profile

DUFLOW model

DUFLOW model was designed to cover a large range of applications in different water systems and to assess water quality problems. The hydrodynamic model is based on the one-dimensional partial differential equation that describes non stationary flow in open channels (ICIM, 1992). The equations are the mathematical translation of the laws of conservation of mass and of momentum. The water quality part of this package, based on the one-dimensional transport equation (Eqn.1), describes the concentration of a constituent as function of time and space.

$$\frac{\partial (AC)}{\partial t} = -\frac{\partial (QC)}{\partial x} + \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) + P \qquad (1)$$

The “production” term (P) includes all physical, chemical and biological processes to which a specific constituent is subject to. The process descriptions can be supplied by the user, that can create different types of kinetics.

Aggregated Dead Zones (ADZ) model

The ADZ modelling technique is a relatively recent approach to modelling dispersion processes that provides accurate predictions of the time travel and spread moving downstream in a natural stream (Lees and Camacho, 1998). For advection/dispersion parameters estimation, a simple method (ADZTOOL) uses derived relationships from observed concentration-time data measured at two downstream locations (Wallis et al.,1989), for simulate the effects of conservative solute transport in a river reach.

The first order discrete-time model implemented is only an approximation of the governing differential equations. Parameters estimation only derives from experimental data (with some errors), because there is no hydrodynamic module coupled with ADZTOOL. For each observed distribution, the time of first arrival (τ_i), centroid location (t_i), the mean travel time ($\bar{t}$), the time delay (τ) and ADZ residence time (T) are calculated for each reach between consecutive sampling stations.

4. RESULTS

Experimental results

Tracer concentration of samples collected on December 89 and November 90 monitoring programs are depicted in Figure 4 and 5, respectively.

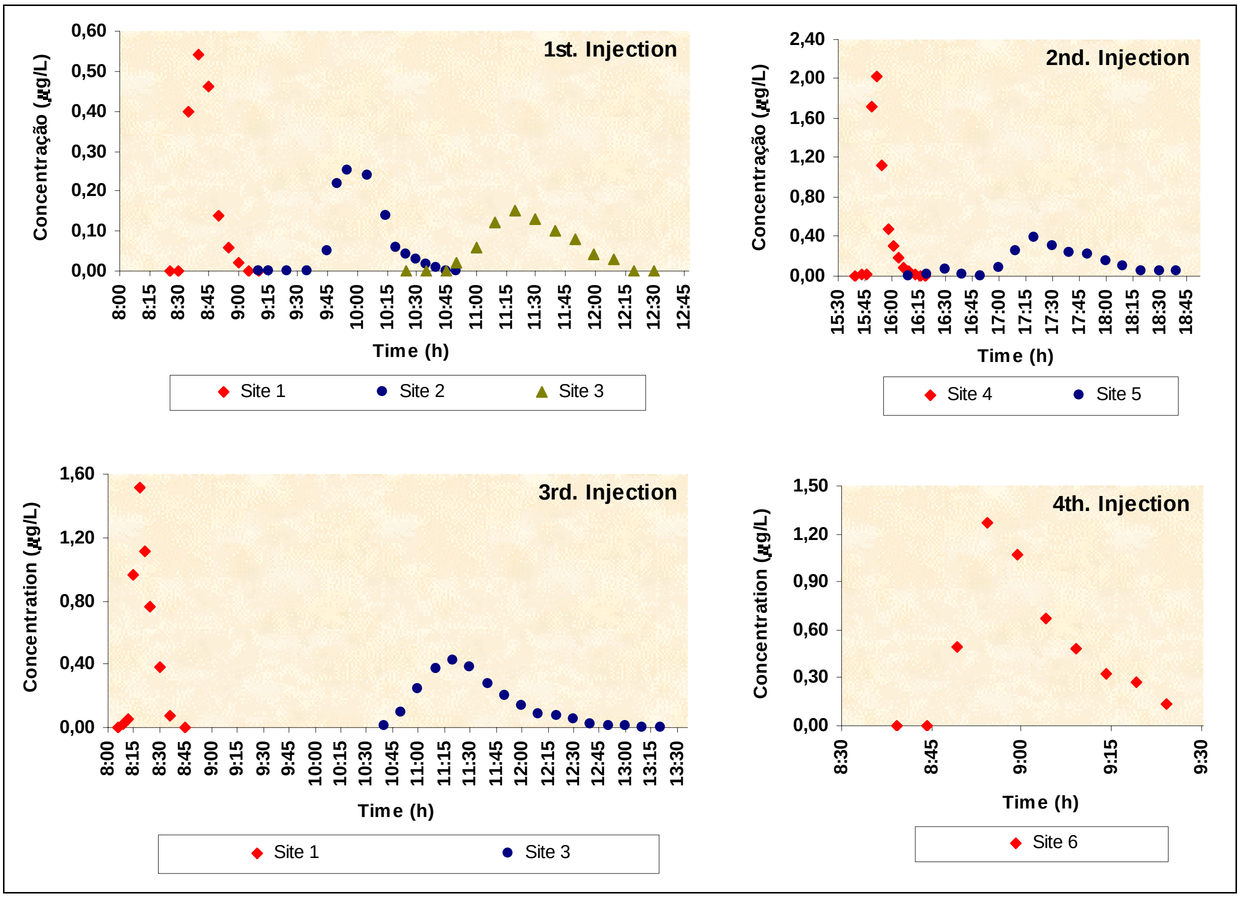

Figure 4 - Experimental results of December-89 monitoring program

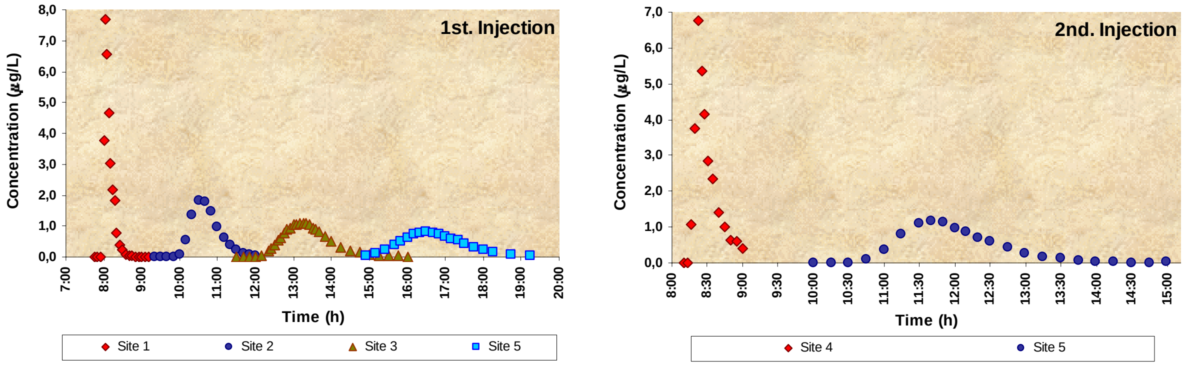

Figure 5 - Experimental results of November-90 monitoring program

Models calibration

The previous described models (DUFLOW and ADZ) were applied to the studied river reach in order to assess numerical techniques performance reproducing the observed river dispersion behaviour. Figure 6 shows the agreement between experimental concentration-time curves with model outputs and analytical solution results, at the four sampling sites considered in the first injection of November-90 monitoring program.

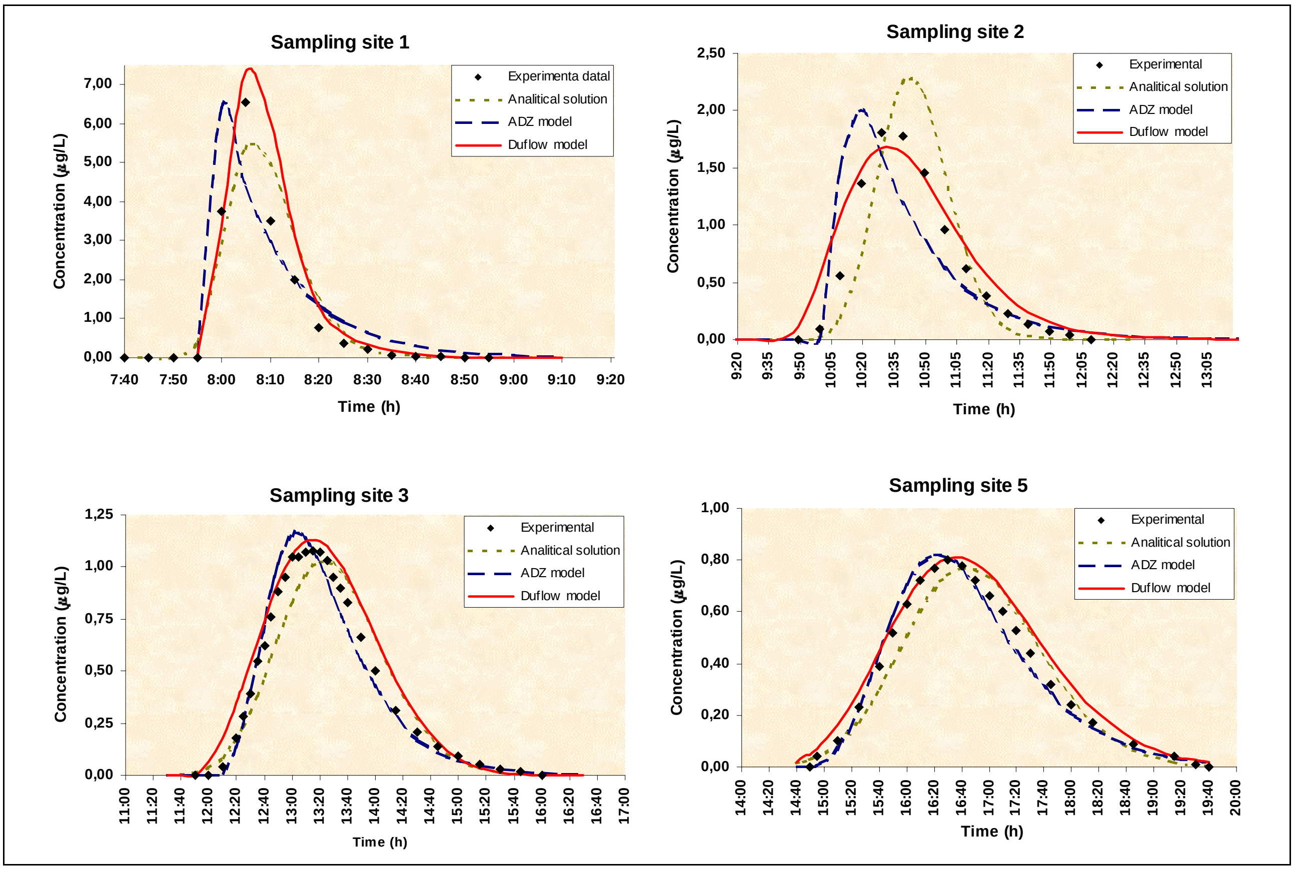

Figure 6 – Comparison of models results and experimental data

A good agreement of both numerical models with experimental data and a relatively better performance of DUFLOW model can be inferred from the depicted results. This conclusion can be supported with the correlation coefficients values calculated for the three worked models (Figure 7).

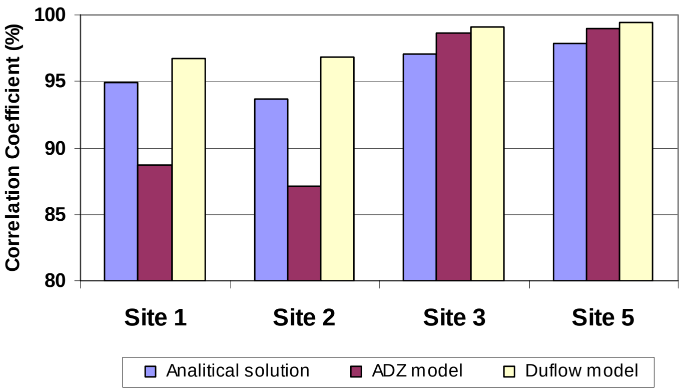

Figure 7 - Models results agreement with experimental data

Table 3 compares mean velocity, travel time and dispersion results obtained from DUFLOW and ADZ models with tracer experimental data. Experimental longitudinal dispersion coefficients were calculated from concentration-time curves at consecutive sampling sites, using the methodology described by Chapra (1997). It is apparent little differences between this longitudinal dispersion coefficients and the values adopted for DUFLOW model calibration.

Table 3 –Results discussion

MONITORING PROGRAM	REACH	MEAN VELOCITY (ms^{-1})			TRAVEL TIME (h)			DISPERSION COEFFICIENT (m^2s^{-1})			RECOVERED MASS
		EXPER.	ADZ	DUFLOW	EXPER.	ADZ	DUFLOW	EXPER.	ADZ	DUFLOW	(%)
3 rd. (Nov.-90)	E1 – E2	0.526	0.548	Var.	2:37	2:31	2:35	14	43	10	57
	E2 – E3	0.497	0.502	Var.	2:41	2:39	2:41	51	25	45	56
	E3 – E5	0.473	0.473	Var.	3:21	3:28	3:19	37	36	35	55
	E1 – E3	0.511	0.524	Var.	5:18	5:10	5:16	34	33	-	-
	E1 – E5	0.497	0.504	Var.	8:38	8:38	8:35	35	35	-	-
1 st. (Dec.-89)	E1 – E2	1.105	1.114	Var.	1:14	1:14	1:14	52	59	40	62
	E2 – E3	0.949	0.954	Var.	1:24	1:24	1:24	61	61	70	62
	E1 – E3	1.023	1.030	Var.	2:38	2:38	2:38	58	61	-	-

DUFLOW model validation

DUFLOW model has been validated using experimental data from December-89 monitoring program first injection, under flood flow conditions. A good agreement is also obtained (Figure 8).

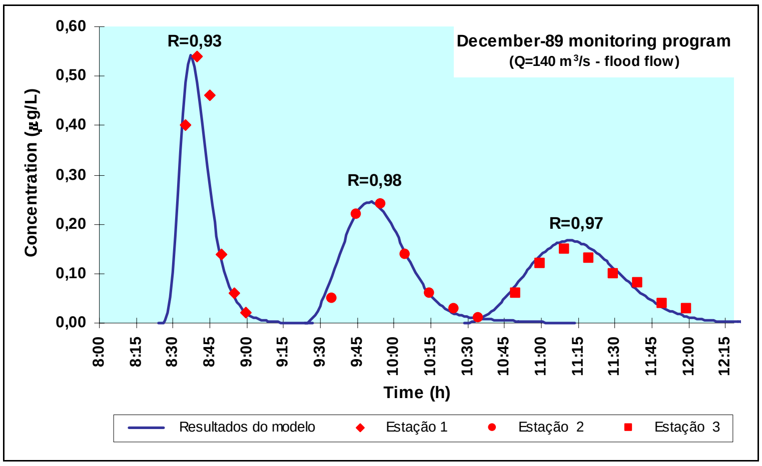

Figure 8 - Duflow model validation

In practice, river water dispersion characteristics can be evaluated from the peak concentration decrease with dye spread travel time variation at a downstream site (Hubbard et al., 1982). After initial tracer and river water mixing, the ratio – peak concentration (C_p) / total injected tracer mass (M_{inj}) – decreases with a power function of its travel times (Figure 12).

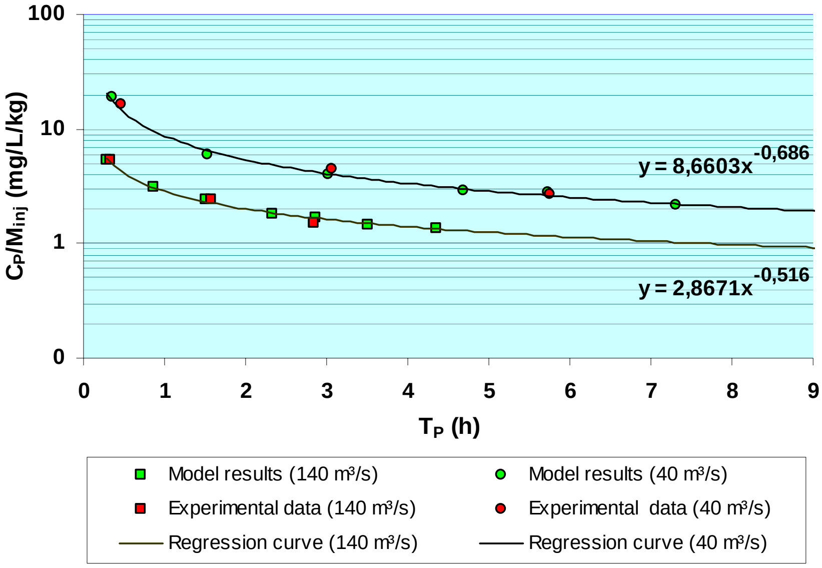

Figure 9 – Peak concentration variation with dye spread travel time

5. CONCLUSIONS

One-dimensional mathematical modelling revealed to be a powerful and accurate tool to solve pollutant transport problems in river systems with a dispersion behaviour similar to the studied river reach, even under different flow regimes.

Duflow model results showed the best agreement with experimental data, allowing a reasonable support for impact assessment of different discharges scenarios in the river water quality.

For similar studies, dye tracer mass calculation has to consider an initial average loss near 40 %. In this conditions, the conservative substance maximum concentrations at Seara abstraction point are 2,2 and 1,5 mg/L/kg of discharged pollutant, for flow discharge values of 40 and 140 m^3s^{-1}, respectively. Longitudinal dispersion coefficients average values are 35 and 60 m^2s^{-1}.

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