The eutrophication in the river Vouga basin – impacts on the quality of water for public supply

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Abstract The aim of this paper is to make a characterization of water quality problems, in the river Vouga, regarding its use for public water supply. The river Vouga basin is located in a mountainous area, draining to the coastal lagoon of the Ria de Aveiro. Other medium size rivers also contribute to the load of pollution entering the estuarine system of the Ria de Aveiro. Two major impacts of the pollution in the river Vouga basin were identified. One is the eutrophication process of the lower reach of the river, including the Ria de Aveiro; the other is the occasional deterioration in the quality of the water abstracted from the medium reach of river Vouga. The causes of this deterioration are related to the enrichment of the river water with organic material. To improve the river water quality, both urban wastewater and agriculture related sources, must be controlled.

Key words water quality, suspended solids, nutrients, water treatment, filtration

INTRODUCTION

The impacts of nutrient and organic enrichment in the aquatic environment, which cause more concern, are frequently related to the change in dissolved oxygen concentration and the related ecosystem perturbation. Thus, the recent policy setting, both in the European Union and in the United States, gives priority to the goal of achieving a good ecological status of the aquatic environment and so maintaining a high potential for fishing and recreation in the surface water. However, the organic enrichment of water caused by the eutrophication process, has also important implications regarding a range of damages to the benefits that water provides to the ecosystem and to the human society. Of these, the damage on the quality of water for human consumption has been identified by Pretty *et al.* (2003), as the larger loss on the use value of water bodies subject to eutrophication.

The eutrophication process causes an increase in the concentration of particulate and dissolved organic material in the surface water, resulting in the degradation of water quality due to abnormal turbidity, color, taste and odor characteristics. The presence of organic compounds in the water treated with chlorine for disinfection, results in the formation of trihalomethane compounds which, when present in drinking water, are a cause of health concern. Additionally, the particulate material can be a vehicle for other pollutants, like pathogenic organisms or chemical toxicants, and so must be extensively removed by the treatment applied to the water. The high efficiency required in the removal of particulate material represents a major cost in the production of water for public supply. The problems of taste and odor in drinking water may be caused by volatile organic compounds produced by algae, by fungi and by actinomycetes (Nystrom *et al*., 1992).

The measures for minimizing the water quality degradation, linked to the control of eutrophication, must be applied both to point and diffuse sources of pollutants. Wastewater discharges can be controlled by organic and nutrient removal, prior to the discharge. The control of diffuse sources requires that Best Management Practices (BMP) will be used in agricultural, forestry and urban areas. BMPs can also be applied at the level of the water body, mainly by restoring wetland areas. However, these management options have high costs (Butt, A. J. and Brown, B. L., 2000). Besides the costs of control, the eutrophication of freshwater has also external costs related to the reduced ecological value (Pretty *et al.,* 2003).
Filtration is the most effective treatment process for removing particulate material from the water for public supply. Granular bed filtration can be done by gravity, in a sand bed open to the atmosphere, or under pressure in a tank. When the water contains fine particles, like clay or plankton, filtration alone can not meet the required quality for the treated water. In this case a chemical pretreatment process is generally used before the filtration. Back-washing of the filtration media must be done to guarantee the long-term functioning of the filter. In this operation, the mass of particles accumulated in the filter is washed out. The global efficiency of the filtration depends on this operation. When the filtration is done by gravity, the mass of solids accumulated at the surface of the media has a high biological activity which increases the efficiency of the process. However, it has also been observed that biofilms, growing in

slow sand filters used for water treatment can, under some conditions, release short-chain fatty-acids which cause severe odor problems (Karlsson *et. al.*, 1995). In the case of river Vouga, the water abstracted is filtered in the river bed, by a process similar to slow sand filtration.

CATCHMENT AREA OF RIVER VOUGA

River Vouga drains a catchment area of c. 2400 km2, of the total 3500 km2 draining to the Atlantic Ocean via the Ria de Aveiro coastal lagoon – estuarine system (see Fig.1).

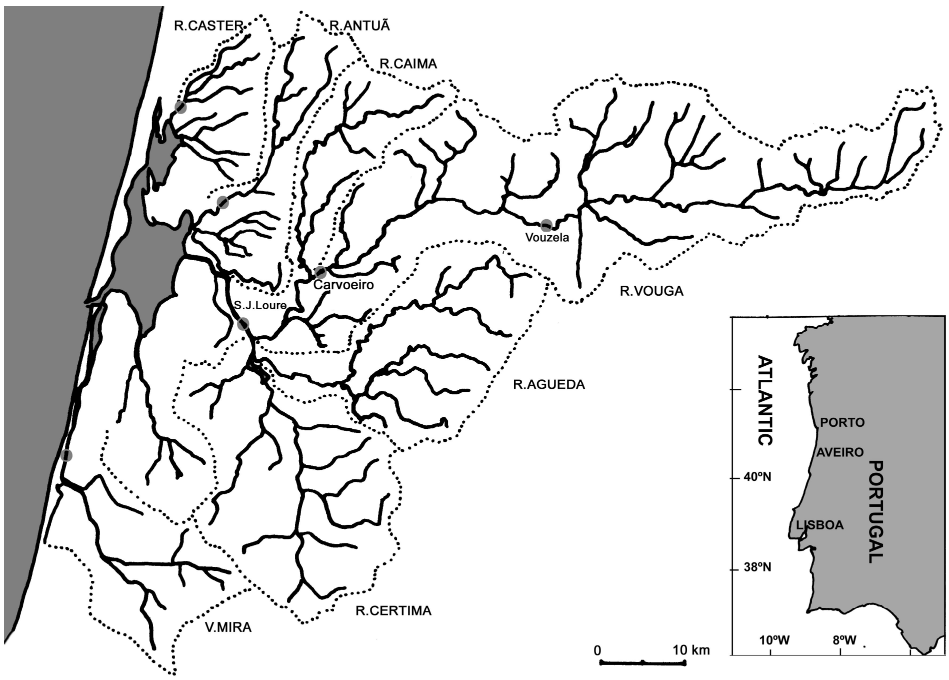

Fig. 1 The catchment area of the rivers flowing into the Ria de Aveiro. The limits of these areas are marked by doted lines. Sampling locations are marked by grey circles.

This river contributes with c. 2/3 of the total inflow to the lagoon. However, the river Vouga contribution originates not only from the principal river but also from a large tributary, river Agueda, joining in the lower reach of Vouga near the lagoon. Thus, the catchment area of river Vouga, upstream river Agueda, is only 1500 km^2. This area is located in the mountainous terrain underlain by rocks of low permeability. These characteristics, together with the regional weather pattern, cause a large seasonal difference between winter runoff events and summer base flow. During winter, frequent high flow events (> 100 m^3s^{-1}) occur, while by the end of summer the base flow can be less than 1 m^3s^{-1}.

The human occupation in the catchment area diverges between the lower reach located on the coastal plain, and the middle and upper reaches in the mountainous area (Silva *et al.*, 2002). The middle and upper reaches have a low density of c. 70 inhabitants.km^{-2}, the agriculture is restricted to 19% of the area and the major land use is forestry. However, there are some important urban /industrial zones (Sever do Vouga, Oliveira de Frades, Vouzela, S. Pedro do Sul) and also a large production of poultry. The total population in the area draining into the Ria de Aveiro is over 600 000, corresponding to a density over 170 inhabitant km^{-2}. The highest densities are in the northern zone, corresponding to the catchment areas of rivers Caster and Antuã. The areas around the lagoon and to the south have inhabitant densities close to the mean value, but in these areas agriculture and cattle production are more important, potentially contributing with organic and nutrient loads larger than those derived from the inhabitants. The causes of eutrophication in the river Vouga, upstream of river Agueda, are diverse and both urban areas and agriculture are important sources of nutrients. The increased concentrations of nitrogen and phosphorus compounds are caused by drainage from agriculture areas and also by urban wastewater. The relative importance of these sources of nutrients depends mainly on the agricultural and forestry practices and on the density of inhabitants and level of treatment provided to the wastewater. The rural areas use mainly septic tanks for treatment of sewage and have small installations for raising animals. The sludge produced by these activities is frequently applied to the soil for agriculture and also for forestry. With this type of land use, intense rainfall can cause erosion of the soil enriched with the sludge, and the runoff contains high concentrations of organic mater, nutrients and fecal bacteria. This situation will be aggravated after a dry period, with the first intense rain.

The first results of a monitoring program, presented by Silva *et al*. (2002), have shown that river Vouga, upstream of the tributaries Agueda and Caima, has the lower concentrations of nutrients and organic matter compared with the other rivers contributing to the Ria de Aveiro. Especially river Caster and river Antuã have relatively high concentrations of nutrients, thus contributing with an important load to the Ria de Aveiro.

The flow regime in the river Vouga is not significantly changed by dams; in the main river, only small dams were built for traditional corn-mills and recently for small electricity production operations. One large dam is to be built on a location near the mid course of the river. Water is abstracted in Carvoeiro, near the transition between the middle and lower zones of river Vouga, for a regional public water supply system. The river water is filtered via the sand bank forming the bed of the river. The filtered water is pumped from the wells to a treatment facility which increases its alkalinity, corrects the pH and disinfects the water with chlorine gas. The solids accumulating at the surface of the sand bed are removed naturally due to the water current in the river. The need to intensify this process, during low flow periods, resulted in the installation of pipes buried in the river bed, which can be used for backwashing. Another water abstraction, for industrial supply, is done in the tidal reach of the river. The water abstracted from both places, after being used is discharged into the Atlantic Ocean via a submarine outfall.

METHODS

This study is based on data from three different sources: A - Concentrations measured with a monthly frequency in 3 points of river Vouga, during the years 1991-2003, by the national environmental authority (available at www.inag.pt – Sistema Nacional de Informação de Recursos Hidricos). Some of the values were judged incoherent and rejected. B – Operational data concerning water quality before and after treatment in the Carvoeiro facility, obtained by the utility managing the water supply system (Águas do Vouga) during the years 1999-2004. Both river water and water pumped from the wells were sampled monthly and analyzed for suspended solids, BOD5, nitrate and fecal coliform bacteria. After treatment, residual chlorine was also determined. The total chlorine added to the water was calculated from operational data for 1999. C - Concentrations measured in the major rivers contributing to the Ria de Aveiro, using the field methods presented by Silva *et al.* (2002). The concentrations for S.J. Loure, obtained by these methods, were also used as a reference for the corresponding values obtained from source A. The locations of sampling points are shown in Fig. 1 and the period covered by the sampling is between April 2000 and May 2004.

RIVER WATER QUALITY PROBLEMS

The water quality problems in river Vouga, upstream of the water abstraction in Carvoeiro, can be attributed to microbial, organic and nutrient pollution. The concentrations of suspended solids, biochemical oxygen demand (BOD_5), fecal coliform bacteria and nitrate are key variables for analyzing these problems of water quality. The variation in the annual mean concentrations will reveal long term trends related to changes in climatic conditions and in pollution loads. The seasonal changes in those concentrations reveal the relative importance of different pollution mechanisms. Maximum concentrations occurring with wet weather are a signal of the importance of non-point sources. On contrary, when the major pollution loads are from wastewater discharges (point sources), a dilution effect will be observed with wet weather.

Time series, starting in 1991 and ending in 2003, obtained from Sistema Nacional de Informação de Recursos Hidricos, were used for identifying the long term trend in the concentrations measured in locations representative of upper reach (Vouzela), medium reach (Carvoeiro) and lower reach (S.João de Loure). Fig. 2 shows the graphics of annual mean values for suspended solids, BOD_5, nitrate and fecal coliform bacteria as well as the annual rainfall recorded in Burgães, a location representative of the upper and medium reaches of river Vouga. Some values in these series were rejected as non characteristic. It is noticeable a decrease in the concentrations of SST and BOD_5, and an increase of nitrate, after 1999. The present state of water quality along the river can be classified based on the mean concentrations obtained for the years 2000 to 2003. Table 1 contains the mean values, the standard deviations and number of values used. These results show that the upper reach of river Vouga is subject to a moderate pollution load, but the water quality improves along the medium reach. In the lower reach, represented by the point in S.João de Loure, the quality of river water degrades again in result of the loads transported by the Caima and Agueda tributaries. Thus, Carvoeiro offers the best condition for water abstraction regarding its quality.

The dates corresponding to maximum and minimum values were also identified in the time series measured in Carvoeiro. The months with maximum concentrations of nitrate are October and November, while the months when minimum values occurred more frequently are July and August.

Table 1. Mean concentrations in sampling stations in river Vouga, calculated over the period from January 2000 to December 2003 (based on results from Sistema Nacional de Informação de Recursos Hidricos). Standard deviation and number of values used are also given.

Sampling point	Vouzela	Carvoeiro	S.J.Loure
SST (mg/l)	7.0	5.8	13.6
St. Dev.	14.7	8.9	9.8
N	51	46	46
BOD_5 (mg/l)	1.5	1.2	1.5
St. Dev.	2.6	0.9	0.7
N	53	48	48
NO_3 (mg/l)	5.15	3.30	6.50
St. Dev.	1.90	1.14	5.31
N	47	53	48
P-total (mg/l)	0.12	0.06	0.08
St. Dev.	0.13	0.06	0.06
N	17	17	17
Fecal colif. (n/100ml)	8206	339	688
St. Dev.	8628	572	908
N	50	44	48

Thus, the wet weather processes dominate the transport of nitrate in the Vouga basin. However, as can be seen from the graphics in Fig. 2, the nitrate concentrations increase after a dry year and decrease after a wet year. For suspended solids concentrations, the month with more frequent maximum values is January, but in some years July had a maximum. Minimum values can occur in any month from February to October. The maximum values in winter are related to the increased transport of sediment with high river flow, while the maximum in summer is probably related to the growth of phytoplankton. As expected, a dry year corresponds to a decrease in the concentration of suspended solids. Similar considerations can be made with the mean values for each month. Fig. 3 contains the graphics of monthly mean concentrations calculated from the results obtained by Águas do Vouga for Carvoeiro, for the years 1999-2004. These include the mean fecal coliform bacteria (cells *per* 100 ml), also showing an increase in winter and a high value in August, possibly related to the recreational use of the river.

These results show that river Vouga has a low level of pollution. However, its contribution to the nutrient loading of the Ria de Aveiro is important as it represents c. 70% of the total river flow into this estuarine system. The other rivers, although much smaller, are also more heavily loaded with nutrients as shown in the graphics of Fig 4., comparing mean annual concentrations based on our results, for the four major rivers flowing into the Ria de Aveiro. Thus, to control the load of nutrients reaching the Ria de Aveiro, it is also necessary to improve the water quality in these smaller rivers.

DISCUSSION AND CONCLUSIONS

Considering the water quality requisites for public supply, the major problems found in the case of river Vouga, requiring control measures, are the concentration of suspended solids and the number of fecal coliform bacteria. In both cases point sources and non-point sources are the cause of the observed concentrations.

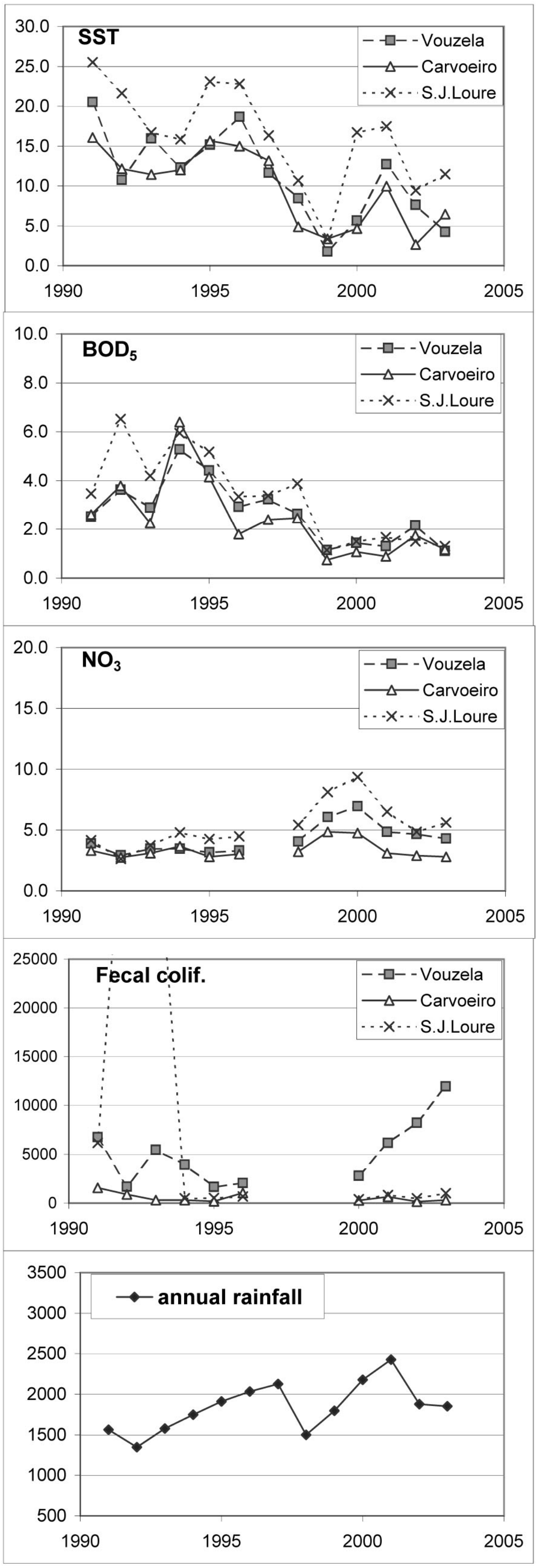

Fig. 2 Annual mean concentrations of suspended solids (SST), BOD$_5$, nitrate and fecal coliform bacteria, calculated with data from National Water Institute. The sampling stations in river Vouga are identified in the legends. Annual rainfall, representative of the catchment area is represented in the bottom graphic.

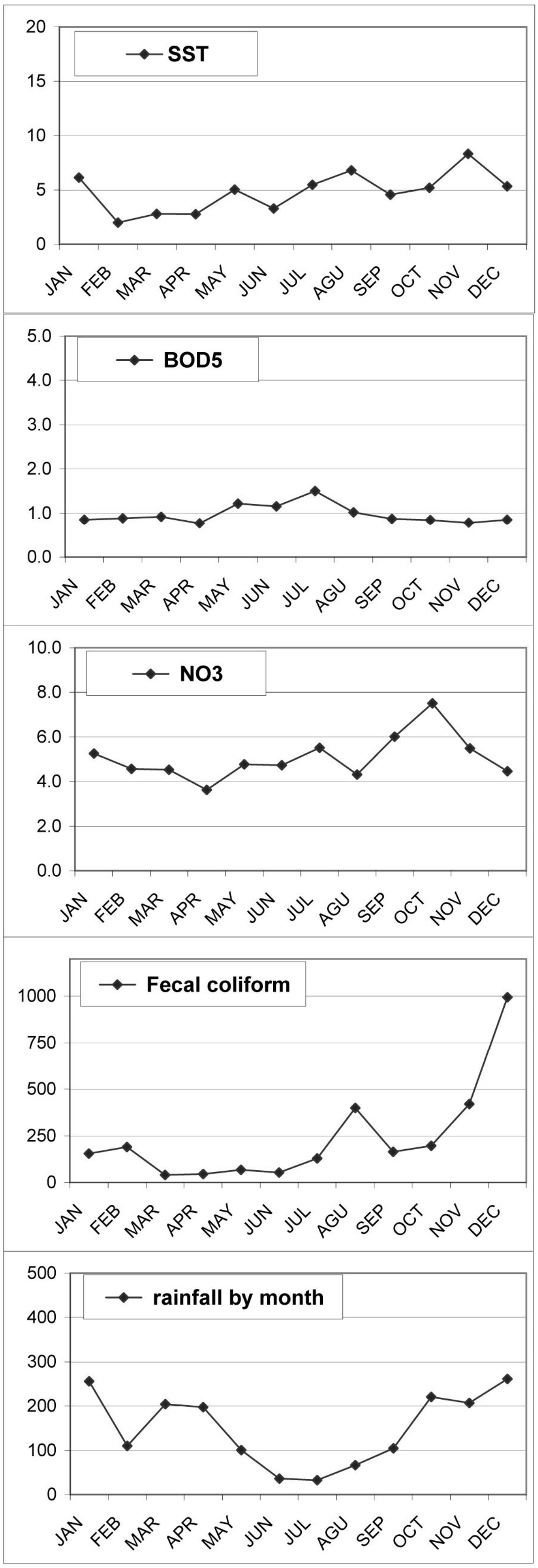

Fig. 3 Monthly mean concentrations of suspended solids (SST), BOD$_5$, nitrate and fecal coliform bacteria, calculated with data from Águas do Vouga. The sampling station in river Vouga is Carvoeiro. Monthly mean rainfall, representative of the catchment area is represented in the bottom graphic.

Regarding the suspended solids concentration, plankton growth also contributes to the problem. The main control measure used, as explained before, is slow rate filtration. This operation removes efficiently the suspended solids and the coliform bacteria from the water. The mean removal efficiency of fecal coliform bacteria, between the river water and the water pumped from the wells, calculated for the period 1999-2004, was found to be 93%. The efficiency of suspended solids removal, although not quantified, is of the same magnitude and the filtered water has a low turbidity.

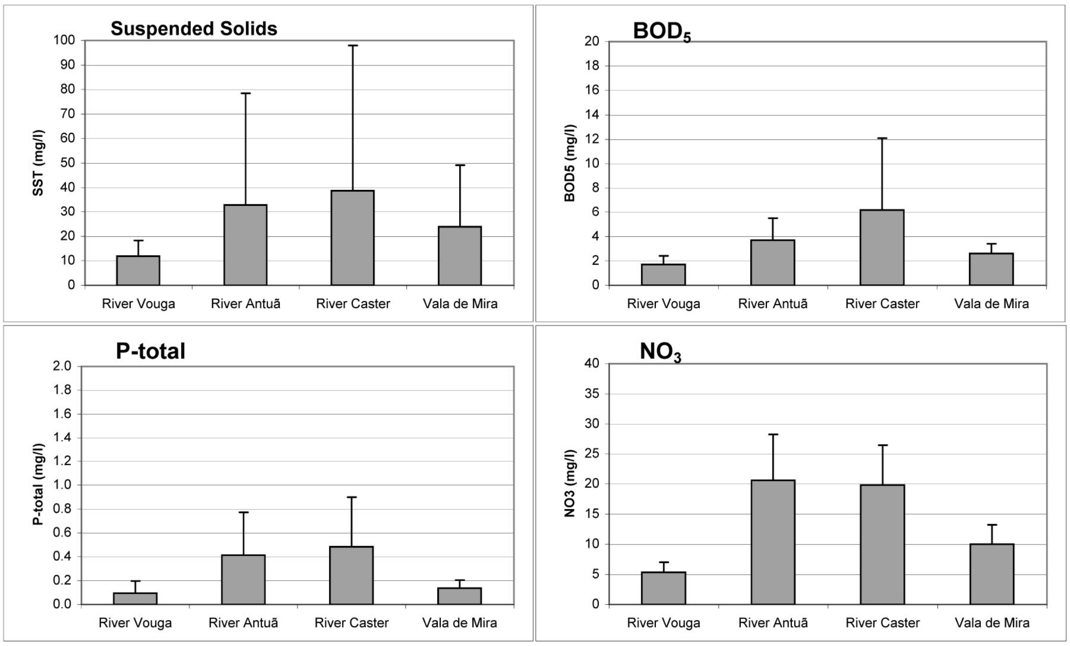

Fig. 4 Graphics of mean concentrations (April 2000 to May 2004) of suspended solids (SST), BOD_5, total phosphorus, and nitrate, obtained for rivers Vouga, Antuã, Caster and Vala de Mira. The bars show the standard deviations of these results (number of samples varied between 11 and 26), indicating the variability caused by hydrologic factors.

However two types of problems subsist:

– The filtered water still needs a large dose of chlorine for disinfection. The mean annual dose of chlorine added to the water, based on 1999 data, was 1.23 mg l^{-1} and the mean annual residual of chlorine measured in the water was 0.69 mg l^{-1}. The difference in these values corresponds mainly to the chlorine reacting with the organic material present in the water.

– The removed suspended solids, which accumulate in the river bed while the current speed is low, cause a reduction in the infiltration rate decreasing the pumping rate from the wells; occasional problems of odor in the water abstracted are probably related to microbial activity in the organic fraction of the solids accumulated. Recently, a backwash system was installed in the river bed, to help in controlling this problem.

Both types of problems are in part related to the nutrient enrichment of the aquatic environment, which leads to the increase in particulate and dissolved organic material. These effects will be aggravated by increasing the retention time of the water in the basin, as will happen due to the reservoir created by a large dam to be built soon near the mid course of the river Vouga. However, it is still possible to control more effectively the nutrient loads in urban wastewater and in the runoff from agricultural areas upstream of the dam.

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