Modelling and scenario analysis in the management of the trophic status of Torrão reservoir, Portugal

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ABSTRACT
Torrão reservoir is located in the river Tâmega, one of the most important tributaries of the river Douro. The watershed is characterized by a variety of land uses and there are several urban areas in the watershed, with some major urban poles along the river, accounting for a total Waste Water Treatment Plants (WWTP) discharge of ~100,000 p.e. The geometric mean of surface chlorophyll-a field data from April to September (1996 to 2009) was above the threshold of 10 µg/l (10.6 µg/l), thus making the Torrão reservoir a eutrophic system according to the criteria defined by the National Water Institute based on the implementation of the WWTP directive. An integrated watershed-reservoir modelling approach was implemented in this study. The SWAT model was implemented to estimate the input loads (flows and concentrations) from the watershed, and the output was used afterwards as boundary conditions to the reservoir model, CE-QUAL-W2. Load reduction scenarios were performed to quantify the total maximum input load that allows the reservoir to be classified as mesotrophic, it was estimated that a load reduction of 10% of the reference situation load would allow that the geometric mean for surface chlorophyll-a in dam wall could reduce to 9.2 µg/l. In conclusion, actions should target primarily the effluent water quality in some WWTP, but also diffuse source reduction in order to achieve the total maximum input load and mesotrophic level.

KEY WORDS: *Watershed Modelling And Management, Eutrophication, Water-Quality Modelling, Land use*

INTRODUCTION

Management decisions related with the water quality in lakes and reservoirs require a combined land-water processes study approach. The complexity of these systems and their interrelated compartments can only be adequately tackled using numerical models (Lung & Bai, 2003; Marce *et al.*, 2010). This study provides such an example for the Torrão reservoir and watershed (Figure 1).

For water management purposes it is intended to quantify the reduction in the nutrient loads needed to change the actual eutrophic state of the reservoir to mesotrophic. Furthermore the weight of WWTP on the trophic level was assessed, to determine where to act in the basin to reduce the nutrient loads reaching the reservoir (WWTP, agricultural or both). These objectives were accomplished using a combined watershed-reservoir modelling approach.

REFERENCE SITUATION

Drivers

Torrão reservoir is located in the river Tâmega, one of the most important tributaries of the river Douro. Accordingly to Corine 2000 land cover map, the Torrão reservoir watershed is characterized by a variety of land uses, where pine forest is predominant (accounting for 43% of land occupation), followed by agricultural use with around 38% of the total area (33% by cold season annual crops and 5% by orchards), and range brush with about 14% of the area (Figure 2). Soil texture is mostly coarse and medium grain size (Figure 3).

There are several urban areas scattered in the watershed, with some major urban poles along the river Tâmega. The Torrão basin encompass the municipalities of Amarante, Boticas, Cabeceiras de Basto, Celorico de Basto, Mondim de Basto, Chaves, Marco de Canaveses, Montalegre, Penafiel, Ribeira da Pena, and Vila Pouca de Aguiar, most of which with several dozens of WWTP discharging into Rio Tâmega drainage network. In total these WWTP account for approximately 100,000 p.e.

State

Torrão reservoir was classified as eutrophic because the geometric mean of surface chlorophyll-a field data (from 1996 to 2009) from April to September was above the threshold of 10 µg/l (10.6 µg/l).

Surface field data for Torrão reservoir shows significant inter-annual variation, mostly due to the different yearly raining regime. This difference relies mostly in the range of values, since there is a clear seasonal pattern repeated in most of the years, consisting of a bigger phytoplankton bloom in spring, followed by a smaller one in summer. Chlorophyll concentration values usually peak between 20 and 30 µg/l chlorophyll-a during full bloom, but higher

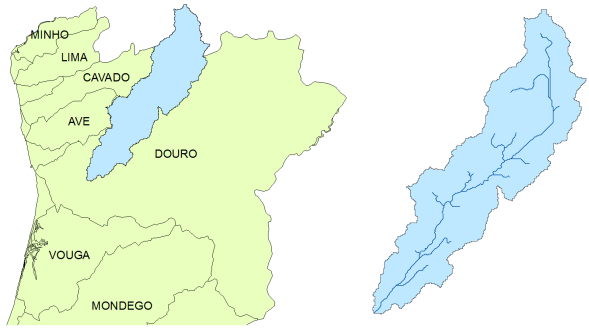

Figure 1. Location of Torrão drainage basin (left) in the north of Portugal, and a caption of the drainage network (right) in the watershed.

concentrations are not infrequent. Since most of the values for nitrate and phosphate are below the detection level of the laboratory analyses it is difficult to assess if they are depleted during bloom episodes.

For water management purposes it is intended to quantify the reduction in the nutrient loads needed to change the actual eutrophic state of the reservoir to mesotrophic. Furthermore the weight of WWTP on the trophic level was assessed, meaning to determine where to act the basin to reduce the nutrient loads reaching the reservoir (WWTP, agricultural or both). These objectives were fulfilled using modelling tools.

METHODS

CE-QUAL-W2 water quality model (Cole & Buchak, 1995; Cole & Wells, 2000) was applied to Torrão reservoir to i) reproduce the reference situation and ii) with the model validated to the reference situation, simulate load reduction scenarios to quantify the total maximum input load and possible management scenarios. Total maximum input load is the input load that allows the reservoir to be in mesotrophic level instead of eutrophic (reference situation).

In order to implement CE-QUAL-W2 model it is necessary the input loads (flows and concentrations) from the watershed, and since there was insufficient field data, SWAT model was applied to Torrão watershed to estimate them. WWTP discharges were introduced to the SWAT model assuming a water consumption of 100L/p.e./day and concentration from national legislation in "Decreto-Lei 236/98" about surface water protection publishing WWTP emission limits and "Decreto-Lei 152/97" and "Decreto-Lei 348/98" that transposed WWTP directive to national law.

The two models framework was then validated against field data in Torrão reservoir, that integrates internal reservoir processes and input loads.

RESULTS

Validation for the Reference Situation

Modelling results for Torrão reservoir in reference situation produced a geometric mean of surface chlorophyll-a concentration for the period 1995 to 2009 of 10.3 µg/l. The same parameter for field data was 10.6 µg/l (about 2.8% difference – see Table 1).

The time series comparison for Torrão reservoir (dam wall) between field data and model results for chlorophyll-a and nutrients are shown in Figure 4. Model results for chlorophyll-a and nutrients show that the model is able to reproduce the general trend of field values. Despite some over-estimated bloom peak concentrations of chlorophyll, model results capture seasonal fluctuations and the two different blooms that occur in some years. Figure 5 illustrates the evolution of temperature, nitrate and chlorophyll at the dam wall for the simulated period. Model results show significant season and inter-annual variation in nutrient concentration, but the fact that a significant number of values lies below the detection limit of the water quality analyses imposes series restrictions to the validation effort.

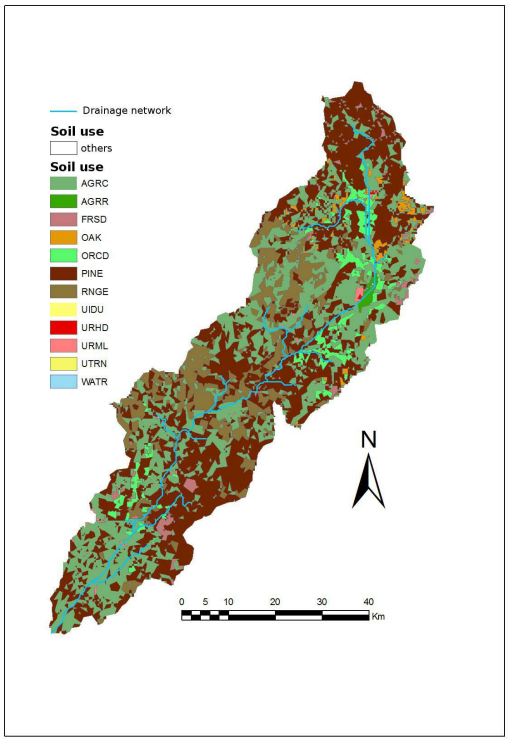

Figure 2. Land use in the Torrão watershed according to CORINE 2000 map.

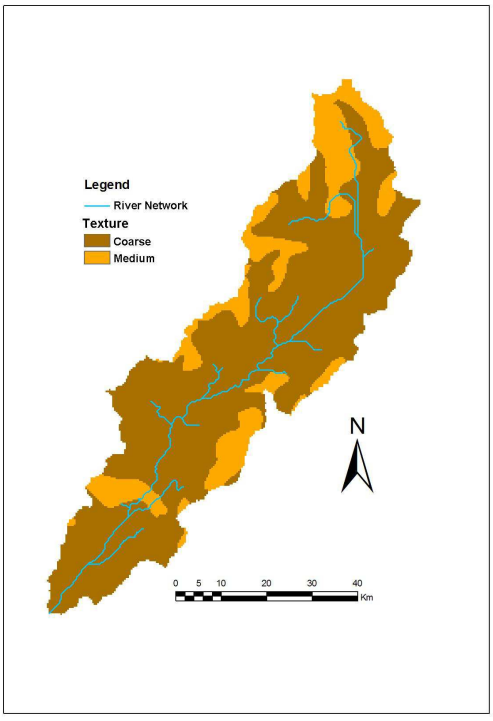

Figure 3. Soil texture in the Torrão watershed according to the European Soil Bureau

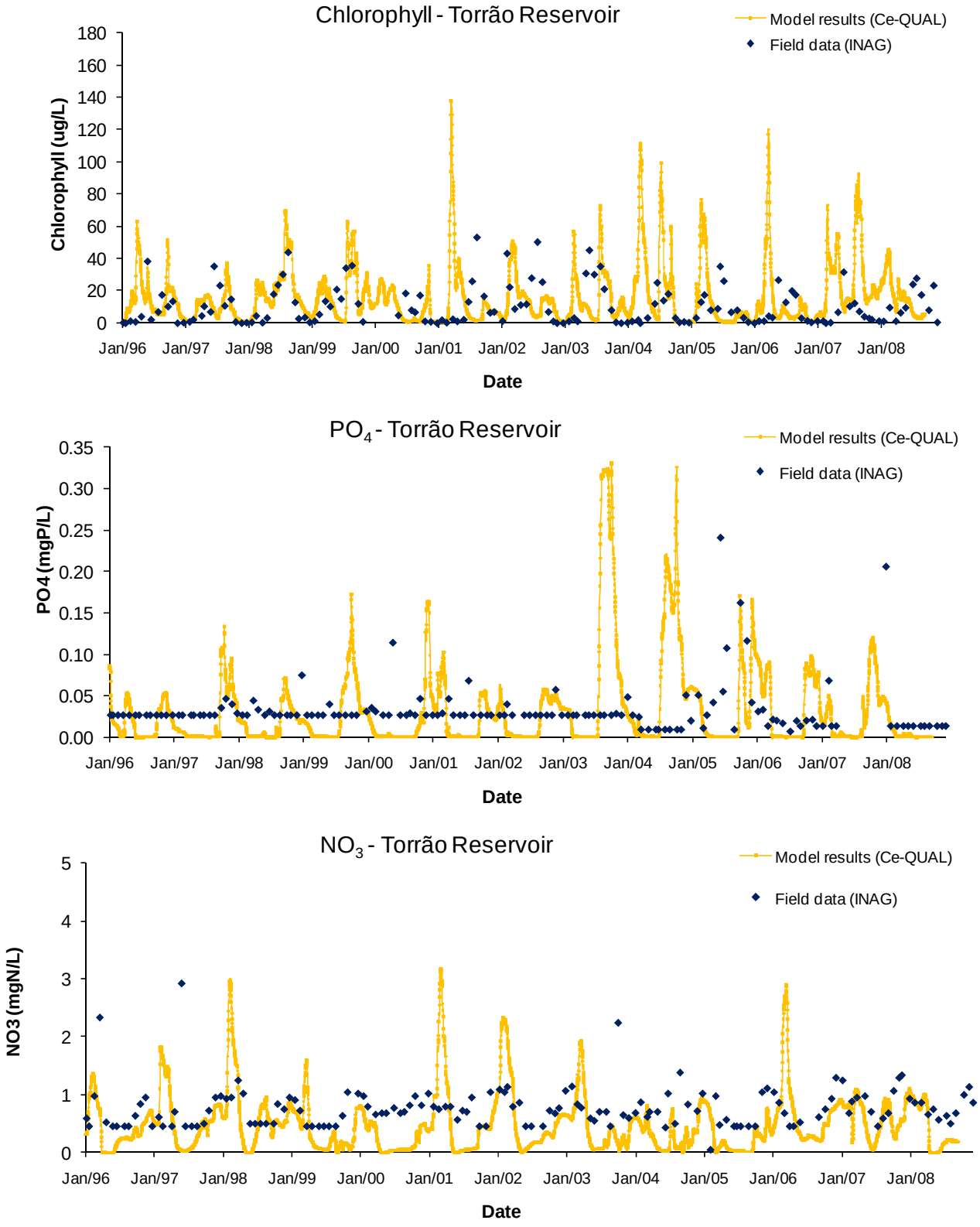

Figure 4. Comparison between chlorophyll and nutrients measures (blue dots, source: INAG) and model results (yellow line) for surface dam wall in Torrão reservoir.

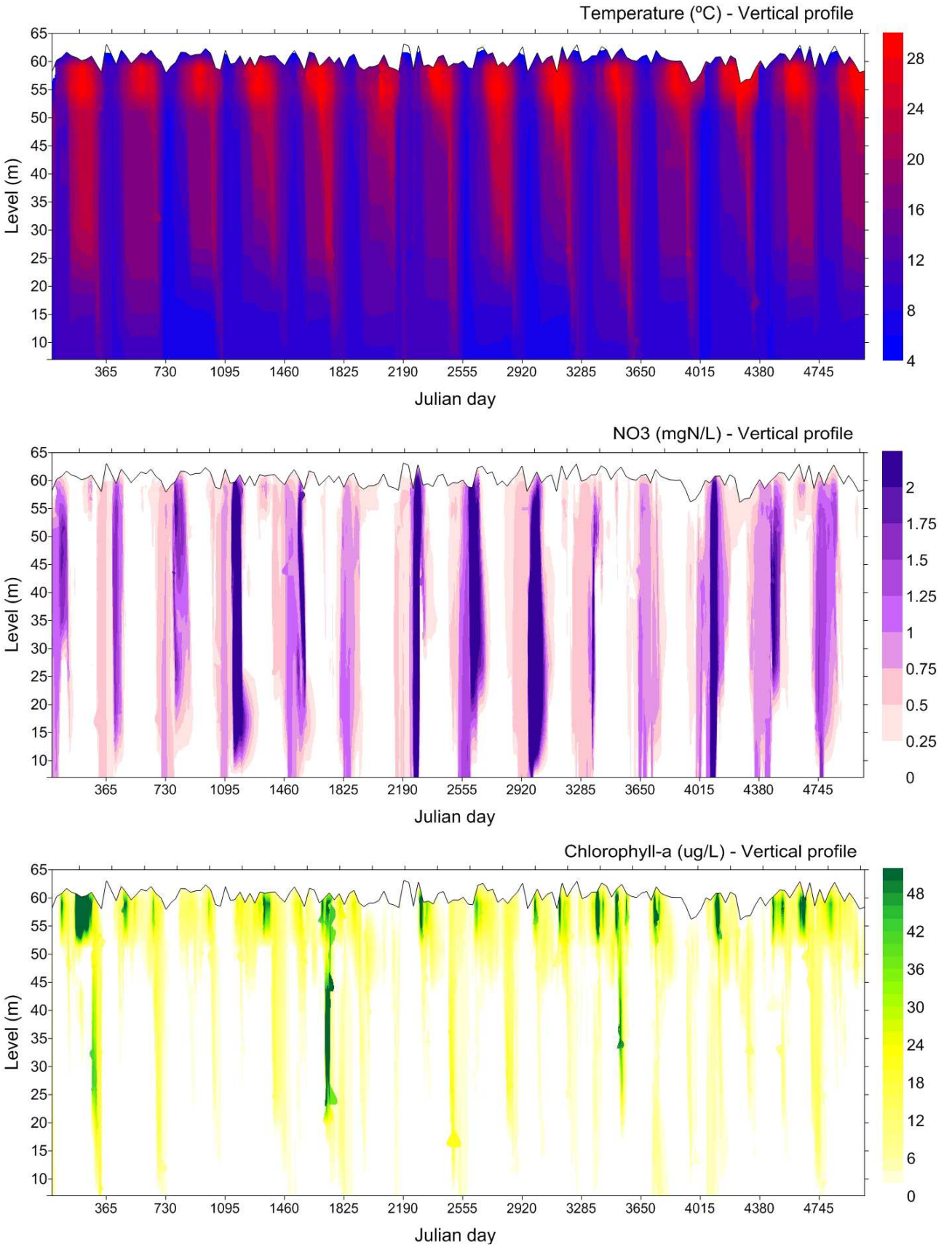

Figure 5. Vertical profiles of temperature, nitrate and chlorophyll at Torrão reservoir dam, as predicted by CE-QUAL-W2 for the simulation period (1996 e 2009).

Table 1. Trophic level for field data and model simulations for the period 1996 to 2009. (* geometric mean of surface chlorophyll-a concentration at dam wall from April to September in the period of 1996 to 2009.)

Scenario	Trophic level
Reference Situation – Field Data	10.6 (eutrophic)
Reference Situation - Modeling	10.3 (eutrophic)
Scenario With 10% reduction – total maximum load	9.2 (mesotrophic)
Scenario with only diffuse source	4.0 (mesotrophic)

Pressures

The validated model framework for reference situation estimated an input load to Torrão reservoir of around 2984 tonN/year being 61.5% inorganic (ammonia, nitrate, and nitrite) and 324 tonP/year with 77.8% inorganic (orthophosphate). Point sources from WWTP represent 1% for total nitrogen and 2% for phosphorus of the total load arriving to the reservoir, being the remaining diffuse loads from managed areas and forestry.

Maximum load to reservoirs

The modelling framework validation against data in reference situation allows the elaboration of load reduction scenarios and quantifies the gain in terms of trophic level reduction.

Load reduction scenarios were performed to quantify the total maximum input load that allows the reservoir to be classified as mesotrophic. Based on model results it was estimated that a load reduction of 10% from the reference situation was enough to change the classification of the system from eutrophic to mesotrophic. According to the model predictions, the load reduction of 10% would allow the geometric mean for surface chlorophyll-a at the dam wall to be reduce to 9.2 µg/l (Table 1).

IMPACTS AND MANAGEMENT RESPONSES

The reduction of input loads to Torrão reservoir (10% reduction for total maximum load) implies to act on sources in the watershed and it can be on point sources (in this case WWTP) and diffuse (apply agriculture best practices). Also it is important to remind that acting in point sources has more immediate effects than in diffuse since soil and aquifers will take longer to recover.

In terms of diffuse sources and because of the high agriculture area the responses may rely on the adoption of best agricultural practices.

To depict on where to act it is important to quantify the role of watershed sources of nutrients (point, diffuse) in the trophic level at the reservoir. Modelling results show that without considering the point sources (WWTP) in the watershed (only diffuse sources simulation) the geometric mean of surface chlorophyll-a from April to September drops to around 4 µg/l (Table 1), meaning that the contribution of point sources is significant and probably the major contribution to the trophic state of the reservoir.

Despite that relatively low percentage of nutrient loads that reach the reservoir are originated in point sources (around 2% in annual load), this contributions is nevertheless higher and crucial in summer months when river flow is low and the main source for primary production in the system. However, a complete removal of nutrient is not feasible for all WWTP in the watershed. As such, it is suggested that actions should target effluent water quality improvements in some WWTP, but also diffuse source reduction in order to achieve the total maximum input load and mesotrophic level.

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