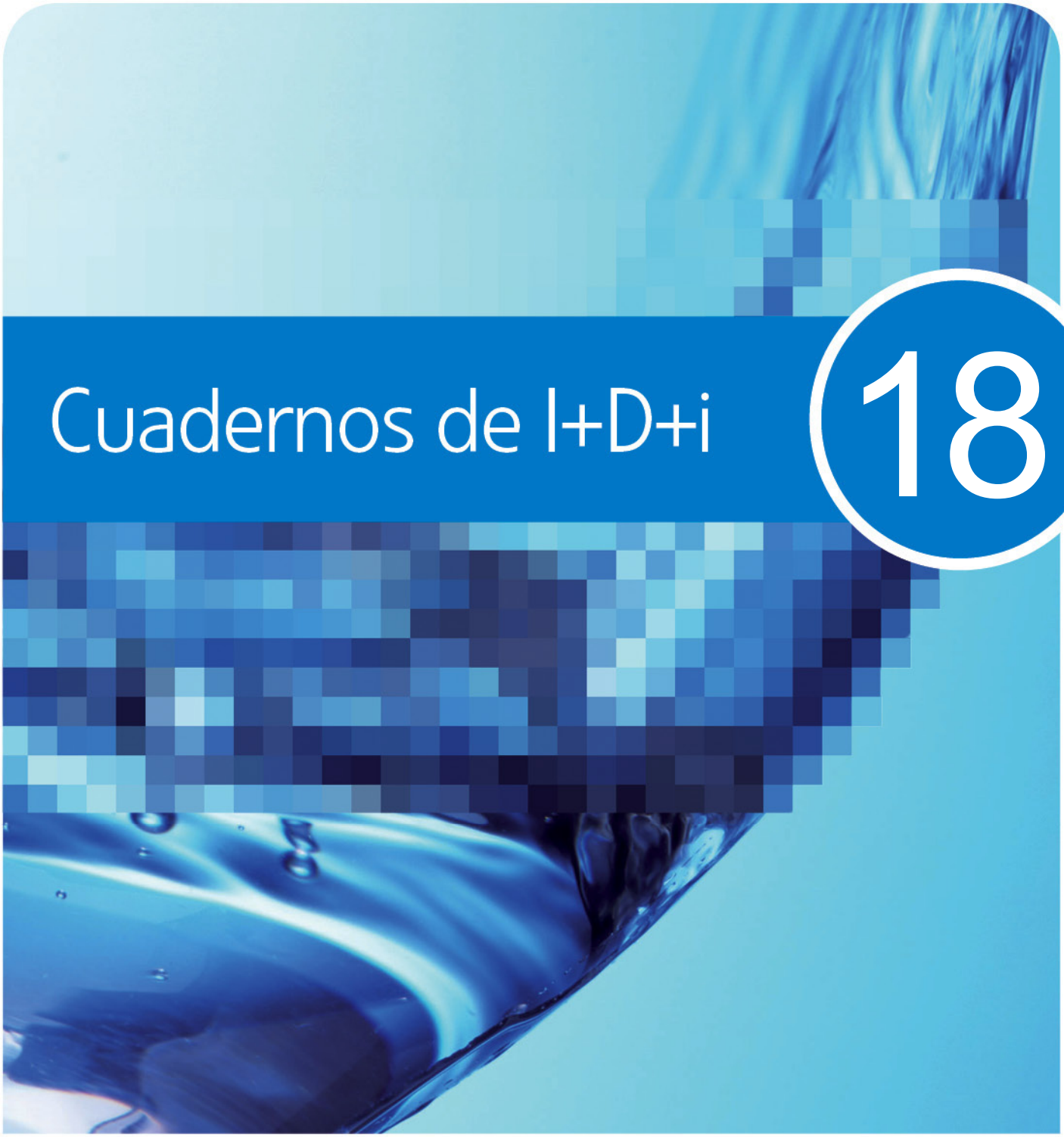


Cuadernos de I+D+i

18

Canal de Isabel II gestión

Booklets. Research+Development & Innovation

Inflow of nutrients from the basin to Pinilla reservoir. Effect on the eutrophication process.

Authors
Fluvial Dynamics and Hydrological Engineering (Flumen),
Ecology Department, Barcelona University
Rafael Marcé Romero
Gonzalo González González
Jaime Ordóñez Salinas
María de los Ángeles Gallegos Cañadas
Joan Armengol Bachero

Canal de Isabel II Gestión, S.A.
J. Iñaki Urrutia Gutiérrez

Project Direction
Juan Carlos Ibáñez Carranza

Acknowledgments
We would like to thank the following people for their cooperation and special contributions:
Alma Mª Jiménez Rodríguez, Adela Llamazares Prados and María del Carmen Gordo Muñoz
from the Water Quality Sub-directorate (Canal de Isabel II);
Jaime Flores Cabeza and Francisco Cubillo
from Canal de Isabel II R+D+i Sub-directorate (Canal de Isabel II);
and the Department of the Environment and Land Ordinance
of the Comunidad de Madrid for providing the mapping and sampling permits.

Print Version ISSN: 2254-8955
Electronic Media Version ISSN: 2340-1818
Digital online Version ISSN: 2340-1818

Legal Deposit: M-27079-2013

Presentation

Canal de Isabel II Gestión's Research, Development & Innovation Booklets form part of the company's Knowledge Management Strategy and of the development involved in its Investigation, Development and Innovation Plan.

These Booklets represent an element for diffusion of projects and initiatives that are developed and sponsored by the Company for innovation in those areas related with water service in the urban environment.

A series of different problems that have been undertaken in each project are put forward in the Booklets, along with the results that have been obtained. The intention behind their diffusion by means of these publications is to share the experiences and knowledge that has been acquired with the entire water services sector, with the scientific community and with all those working on investigation and innovation tasks. What is pretended with the publication of these Booklets is to contribute to improvement and efficiency in water management and, consequently, in the quality of the service that is provided for the citizens.

The R&D&I Booklets published to date are as shown below by their titles in the following table.

Collection Number	*Research, Development and Innovation Booklets published*
1	Transferences of Water Rights between Urban and Agrarian Demands. The case of the Community of Madrid
2	Identification of Hydrometeorological Runs and Tendencies within the scope of the Canal de Isabel II system
3	Contribution of Canal de Isabel II to the International Demand Management Project (IDMF)
4	Micro-components and Explanatory Factors on Domestic Water Consumption in the Comunidad de Madrid
5	Virtual Water and Hydrological footprint in the Comunidad de Madrid
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid
7	Potentials of efficiency in using dishwashers in the Comunidad de Madrid
8	Accuracy in the measurement of individual water consumption in the Madrid Region
9	Research project to define and assess the applicability of a Bioassay Test to determine the toxicity of water using Zebra Fish embryos
10	Water Use Efficiency in Gardening in the Region of Comunidad de Madrid
11	Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid
12	Cyanotoxin Dynamics Study in two of the Canal de Isabel II's supply reservoirs in the autonomous region of the Comunidad de Madrid
13	Development of a validation, estimation and prediction of hourly consumption by sector, for the distribution network of Canal de Isabel II
14	Monitoring of the consolidation urban development in the Comunidad de Madrid using remote sensing techniques
15	Sectorization of the hydraulic distribution and transport network in the Comunidad de Madrid
16	Integration of weather forecasting in the management modules supply system of Canal de Isabel II, via daily contributions models
17	Improvement in forecast capacity of monthly and seasonal runoff in the scope of Canal de Isabel II

Project Outline

Project Title	Inflow of nutrients from the basin to Pinilla reservoir. Impact on the eutrophication process: evaluation, modelling and palliative measures
Research Line	Basin scale impacts on the quality of the water in reservoirs
Canal de Isabel II Gestión areas involved	Water Quality Sub-directorate; Research, Development and Innovation Sub-directorate
External Participation	FLUMEN, Fluvial Dynamics and Hydrological Engineering, Ecology Dept., Barcelona University
Aim and justification of the project	Canal de Isabel II has a series of facilities that include the five reservoirs located in the Lozoya basin. Generally speaking, the water supply provided by these reservoirs is of good quality after the water stored has passed through the reservoirs in the basin. However, there are important problems with the water quality in Pinilla reservoir, which is undergoing an obvious process of eutrophication. In particular, the generation of anoxic layers; the release of metals from the sediment, foul odours and the impoverishment of the fish fauna. For this reason, this study aims to characterize the inflow of nutrients and organic matter into the reservoir from the basin of Pinilla reservoir in order to propose measures to mitigate this problem.
State of the art contribution	The study of the inflow of organic matter and nutrients to Pinilla reservoir was made using next-generation tools in order to characterize the sources of the nutrients and organic matter entering the water bodies, including fuzzy logic based methods developed by the authors, and statistical models with spatial references, thus representing one of the first applications of the SPARROW model in the Peninsula Ibérica. A spectroscopic model was developed on the class of organic matter with the most advanced methodology for characterizing ecological impacts in reservoirs, and the information obtained was used to generate scenarios for mitigating the eutrophication process in a completely new way. In addition, the latest advances in neural networks were used in order to understand the factors governing the dynamics of the concentration of chlorophyll in the reservoir.
Project development summary and milestones	A total of 25 field studies were made during which 16 sampling points were visited, distributed at strategic points along the basin, to collect samples which were submitted to approximately 9,200 determinations regarding diverse components and physical properties. Based on this information, balances of the components were established by sub-basins and the origin of the materials was modeled statistically with the SPARROW model for the purpose of locating the main sources of the materials affecting the reservoir eutrophication process. This was combined with diverse models for predicting the chlorophyll concentration and the generation of anoxic layers in the reservoir, thus enabling the main factors governing these variables to be established. Lastly, different scenarios of reservoir nutrient and organic matter load management were tested for the purpose of mitigating the eutrophication process and the hypothesis of climate change having negative effects on the water quality in the short and mid -term was discarded.
Obtained results summary	The areas downstream of Valdesquí, Rascafría, the Umbría stream, and the stretches immediately before the reservoir and the Pinilla water treatment plant effluent were defined as the most important points for the inflow of materials with a negative effect on the quality of the water in the reservoir. The results show that control of the ammonium concentration in the water treatment plant effluent and the water cycle in the towns of the basin would be the most effective measures for controlling the reservoir eutrophication process. The establishing of a monitoring point on the Lozoya river was also recommended, at the entrance to the reservoir, for a more effective control over the evolution of the reservoir.
Research Lines open for continuing the work	Spatially-distributed statistical models are extremely efficient tools for studying the origin of materials which could affect the quality of the water in reservoirs; for this reason, this study may serve as a model for the application of these methodologies in other locations. The study of organic matter by fluorescence gives rise to the possibility of controlling organic matter that is especially harmful for the level of oxidation of water bodies through the development of specific fluorescence sensors in the field, which is expected to be a very profitable field in the future. Lastly, the study offers the possibility of applying innovative technologies to reduce ammonium in water treatment plant effluents and the detailed study of the urban water life cycle in the basin, for the correct treatment of wastewater. The FLUMEN research group estimates that scale activities on the basin and the water treatment plant in Pinilla could be a particularly appropriate topic for the European Commission LIFE Programme.

Executive Summary

Canal de Isabel II Gestión supplies water to almost 6 million inhabitants in the Comunidad de Madrid. To provide the necessary water volume to do this, it uses water from seven rivers in the Guadarrama mountains: the Alberche, the Guadarrama-Aulencia, the Guadalix, the Manzanares, the Lozoya, the Jarama and the Sorbe, as well as the main aquifers of the region: the Tertiary detritic aquifer and the limestone aquifer systems of Torrelaguna. It has a series of facilities, including 14 reservoirs, with a total water storage capacity of 945.9 cubic hectometres. The five reservoirs located in the Lozoya basin (Pinilla, Riosequillo, Puentes Viejas, El Villar and El Atazar) form one of the main axes with respect to the storage of the controlled resources.

Pursuant to the agreement of the Comunidad de Madrid Government Council of 1st of July of 2012, Canal de Isabel II Gestión, S.A. was set up in order to provide the services of supply, treatment and reuse of water, including customer service and sales activities, maintaining the designation Canal de Isabel II for the public corporation responsible for the entire water cycle of the Region of Madrid. (Throughout this document, both names will be used to refer to the company).

In general, the water supplied by these reservoirs is of good quality, since most of the water is caught in El Atazar dam, after most of the water stored there has passed through the four other reservoirs of the basin. Pinilla reservoir is undergoing an evident process of eutrophication. The term eutrophication means the massive growth of algae on the surface layers in a reservoir due to an excessive supply of nutrient salts from the basin. In addition to posing an aesthetic and operational problem, as it increases the organic matter in the water, this has other negative consequences. In particular, it leads to the generation of anoxic layers on the bed, the release of metals from the sediment, foul odours and the impoverishment of the fish fauna. The quality problems detected through limnological monitoring of the reservoirs in the Lozoya basin reveal the need to include the reservoir system hydrographic basin in a study on the quality of the water supplied by those reservoirs. The steps involved in the study were as follows:

1. Canal de Isabel II entrusted the FLUMEN research group (Barcelona University) with a study about the inflow of nutrients from the basin to Pinilla reservoir (Figure 1), its effect on the eutrophication process and a definition of palliative measures.
2. The combination of field data and basin scale modelling highlighted the towns of Rascafría, Lozoya and urban settlements, the water treatment plant of Pinilla, the section prior to the reservoir, Valdesquí ski resort and the Umbría stream, as the main sources of nutrients and organic matter. The presence of extremely labile organic matter was detected at most of these points.
3. In the models, the uses of urban land are related to important loads of materials, particularly ammonium, COD and nitrogen, and total phosphorus (Figure 2).
4. The inputs from the Lozoya river represent the majority of inflows to the reservoir for most materials, although the water treatment plant is the main source of ammonium and iron (Figure 3).
5. The reservoir acts as an exporter of phosphorus and manganese, and this confirms the redissolution process from the sediment (Table 1).
6. Pinilla reservoir can be classified as moderately eutrophic, based on its chlorophyll concentrations (Figures 4 and 5), with a real risk of this situation being suddenly aggravated if the phosphorus loads undergo a noticeable increase. The algae populations appear to be controlled on a seasonal scale by the inflow of materials from the river and in particular, total nitrogen inflows.
7. Although the development of anoxic layers in the reservoir is moderate, metal and nutrient redissolution phenomena have been detected from average hypolimnetic oxygen concentrations of 2.5 mg L^{-1} (Figure 6).

8. The hypolimnetic oxygen consumption mass balance plays a very important role in the sedimentary demand, particularly at low flow rates. The COD from the basin dominates the oxygen balance when there are high flow rates. The effect of the water treatment plant is less than 10 per cent of the total consumption in all cases (Table 2).

FIGURE 1. CALCULATION OF BALANCES, LOZOYA SYSTEM SUMMARY

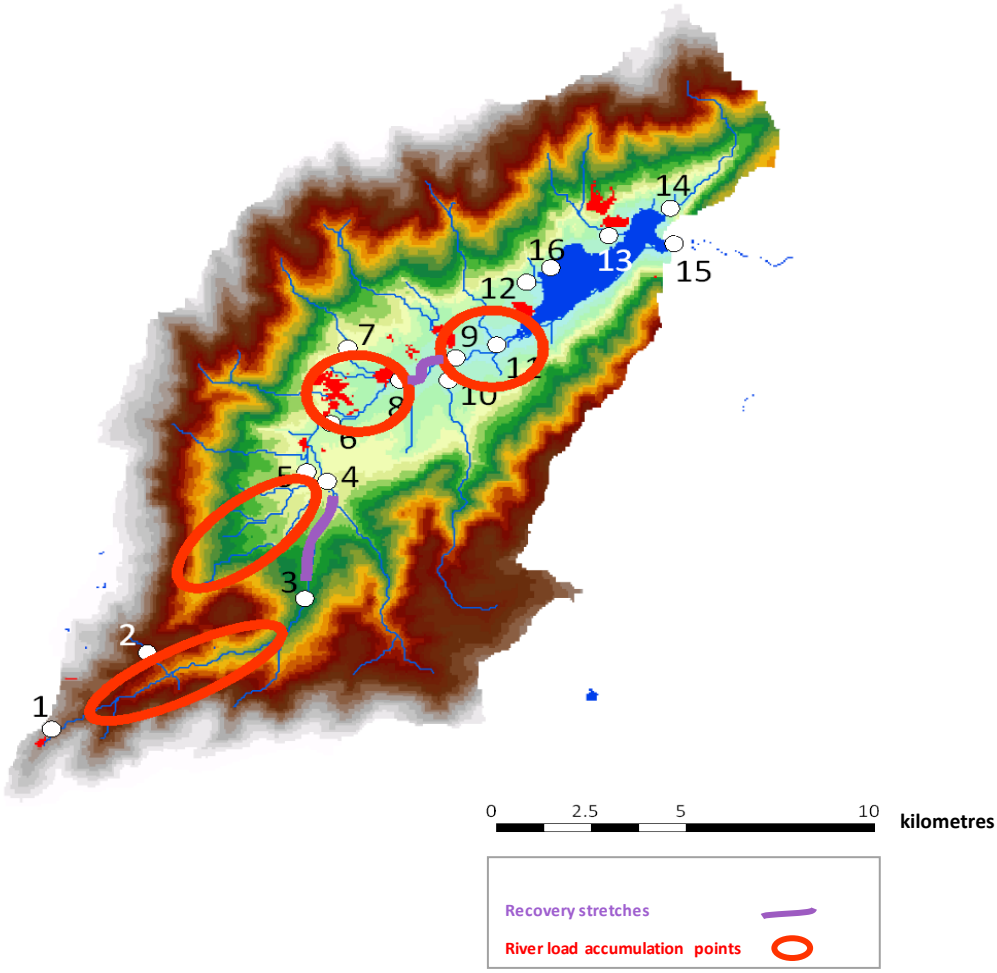


FIGURE 2. MATERIAL LOADS AND PERIODS. AMMONIUM INCREMENTAL LOAD (kg/year)

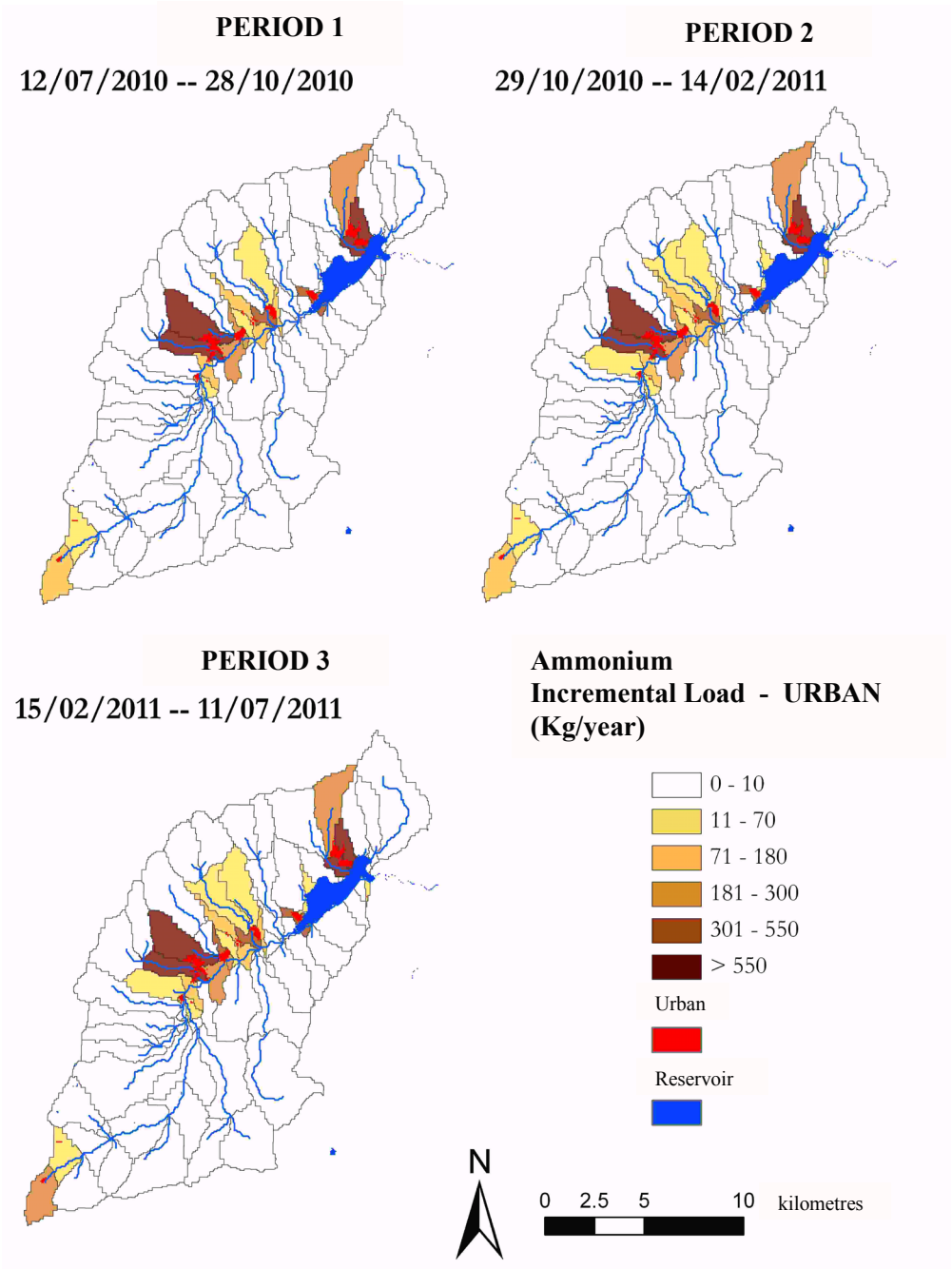


FIGURE 3. SPARROW MODELLING, SOURCE OF LOADS DEPOSITED IN PINILLA RESERVOIR

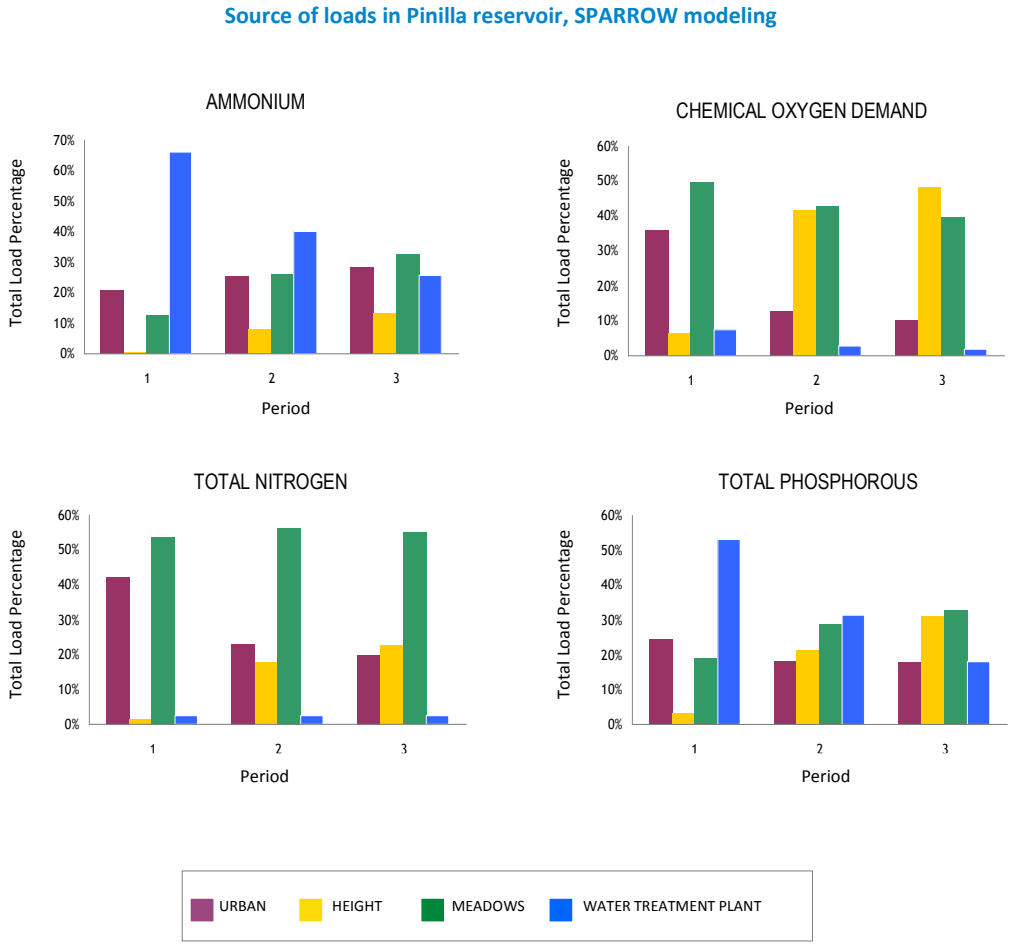


TABLE 1. REDISSOLUTION PROCESSES FROM THE SEDIMENT IN PINILLA RESERVOIR

Element	*Drain*	*Exporter*
PT		X
NT	X	
NTP		X
CTP	X	
NPOC		X
NH_4	X	
COD	X	
NO_3	X	
PO_4		X
Fe	X	
Mn		X
Cl		X
Si	X	

FIGURE 4. EMPIRICAL LOAD-RESPONSE MODELS FOR PREDICTING THE CHLOROPHYLL CONCENTRATION

Annual scale

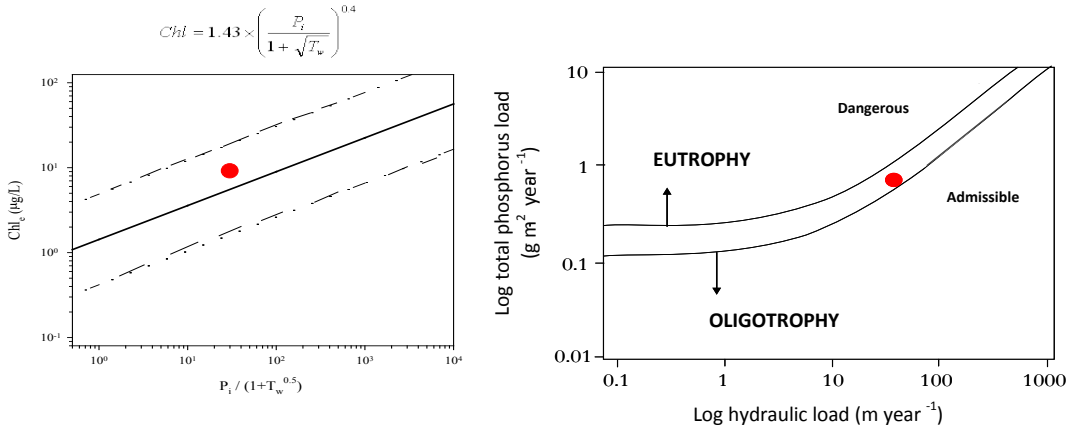


FIGURE 5. NEURAL NETWORK MODELS FOR PREDICTING THE CHLOROPHYLL CONCENTRATION

Fortnightly scale

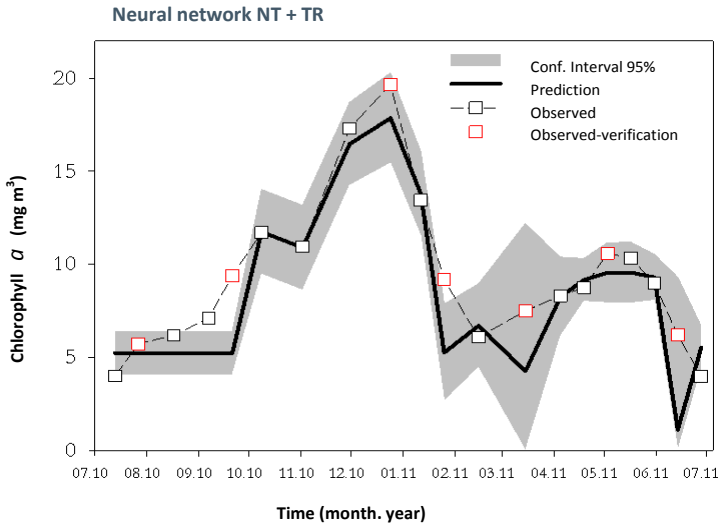


FIGURE 6. ROLE OF ORGANIC MATTER IN GENERATING ANOXIS LAYERS

Role of organic matter in generating anoxic layers

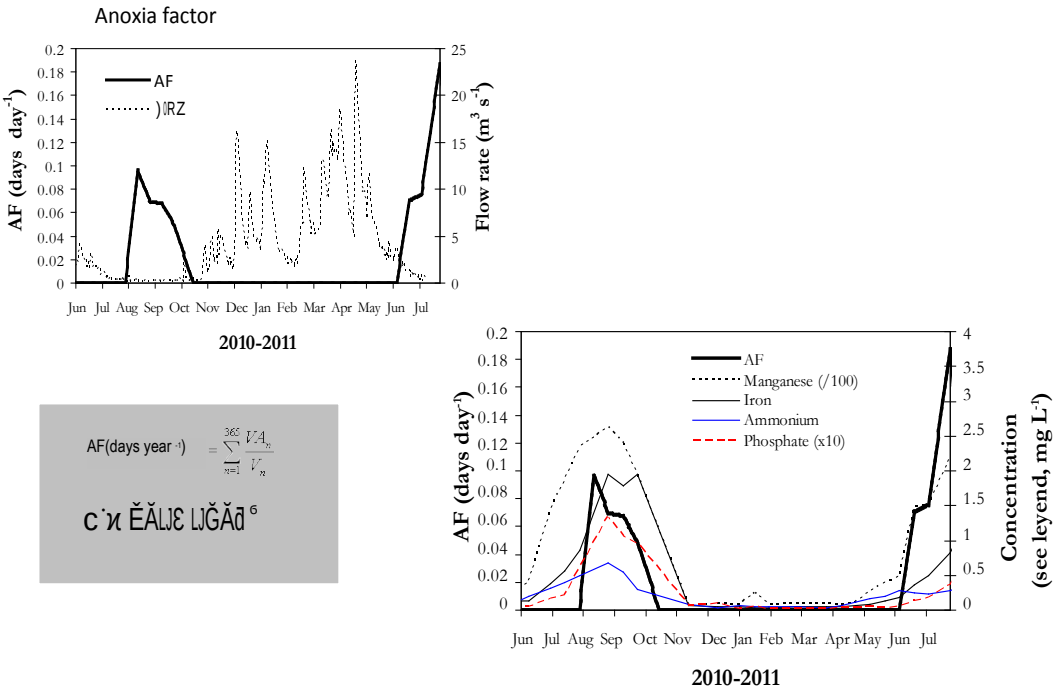


TABLE 2. PARAMETERS MEASURED BY THE NATURAL WATER DEPARTMENT

Period	*Apparent consumption of O_2*	*Total effective COD*	*% of apparent consumption by tributaries*	*% of apparent consumption by treatment plant*	*% of apparent consumption by sediment*	*Sediment demand ($g\ O_2\ m^{-2}\ day^{-1}$)*
Dry	47.5	12.8	20	7	73	0.69
Wet	189.7	103.2	52	2	46	0.59

9. Total phosphorus control only has an evident effect in the chlorophyll concentration and the risk of eutrophication in the reservoir if basin scale measures are applied (PT1). Actions limited to the Pinilla water treatment plant would have insignificant results (PT2 and PT3), (Figure 7).

10. The ammonium load control from the plant could have a noticeable effect on the seasonal evolution of chlorophyll in the reservoir (NT4). If the actions also include urban uses in the basin, the improvements would be even more evident in high flow rate situations during the winter (NT2), (Table 3, Figure 8).

FIGURE 7. PHOSPHORUS AND CHLOROPHYLL LOAD AND THE RISK OF EUTROPHICATION

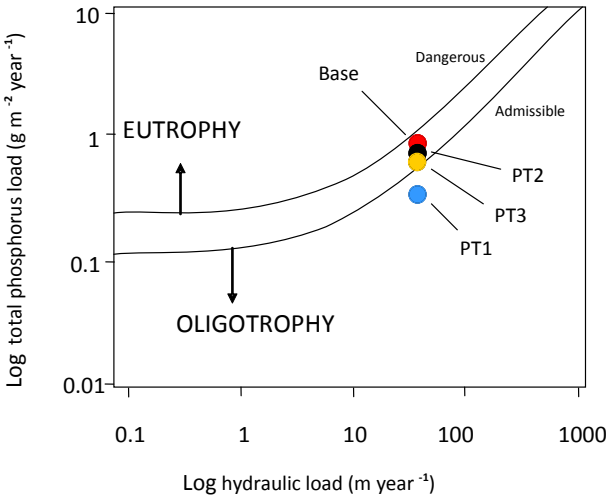
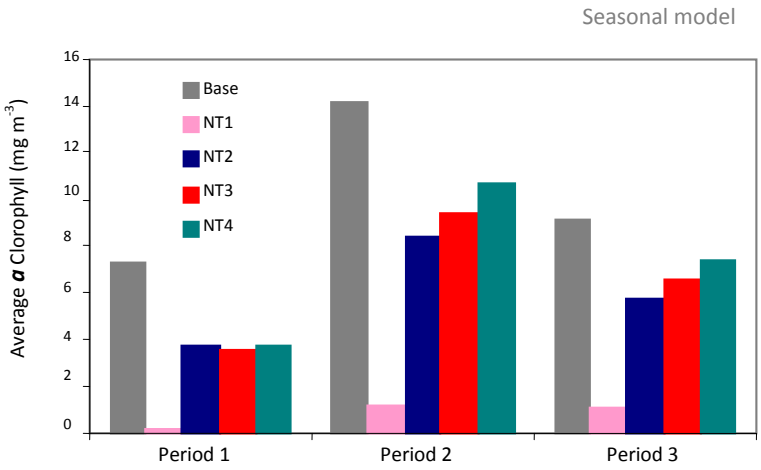


TABLE 3. CONTROL OF AMMONIUM LOADS

Scenario		*Definition*	*Load reduction % compared to total*		
			Urban use	*Meadow use*	*Water Treatment Plant*
Scenario	NT1	Ideal	100	50	100
Scenario	NT2	Course of action determined	250	0	70
Scenario	NT3	Realistic	0	0	100
Scenario	NT4	Realistic (focused on NH_4^+)	0	0	100 of NH_4^+

FIGURE 8. SEASONAL MODEL



11. During dry spring-winter periods, ammonium load control from the treatment plant could prevent the generation of anoxic layers and limit the internal load (see definition of scenarios in Table 4 and Figure 9).

TABLE 4. DEFINITION OF SCENARIOS FOR OXYGEN BALANCE

Scenario	*Definition*	*Load reduction % compared to total*		
		Urban Use	*Meadow Use*	*Water Treatment Plant*
Scenario NH1	Ideal	100	50	100
Scenario NH2	Course of action determied	50	0	70
Scenario NH3	Realistic	0	0	100

Scenario	*Definition*	*Load reduction % compared to total*	
		Tributaries	*Water Treatment Plant*
Scenario COD1	Ideal	100	100
Scenario COD2	Course of action determined	50	70
Scenario COD3	Realistic course of action determined	20	0
Scenario COD4	Realistic	0	100

Scenario	*Definition*	*Load reduction % compared to total*		
		COD Tributaries	*NH_4^+ Water Treatment Plant*	*NH_4^+ Urban Use*
Scenario COM1	Extreme action	30	70	50
Scenario COM2	Course of action determined	10	70	50
Scenario COM3	Realistic course of action	10	90	0

12. During wet spring-summer periods, the labile COD load must be controlled from the basin, to prevent the generation of anoxic layers. This is more effective if combined with the restriction of ammonium loads from urban uses and the water treatment plant.

FIGURE 9. OXYGEN BALANCE - PERIOD 1

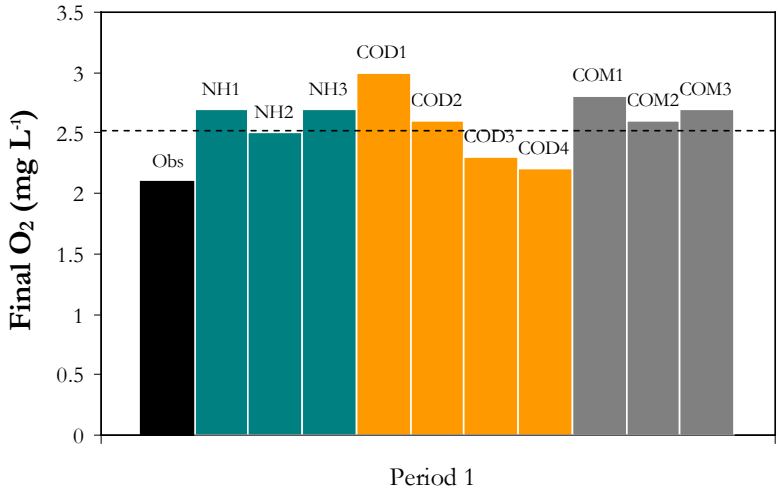
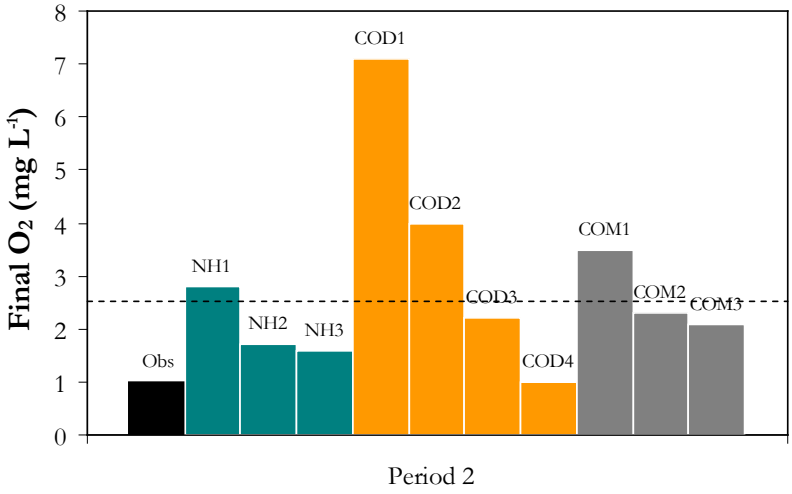


FIGURE 10. OXYGEN BALANCE - PERIOD 2



Recommendations

13. It is advisable establishing a sampling point at the main entrance to Pinilla (Lozoya river), as part of the monitoring carried out by Canal de Isabel II.

14. It is recommended to take the necessary steps to strictly limit ammonium loads from the Pinilla water treatment plant effluent.

15. To apply mitigation measures in the basin, it would be very important to know the details of the water cycle in the towns of Lozoya and above all, Rascafría and the towns close to Pinilla, in order to ascertain whether there are any untreated landfills or serious limitations in the drainage network or in the water treatment plant connection.

http://www.canalgestion.es/es/galeria_ficheros/comunicacion/publicaciones/CUADERNO_18_IxDxi.pdf

Santa Engracia, 125. 28003 Madrid
www.gestioncanal.es