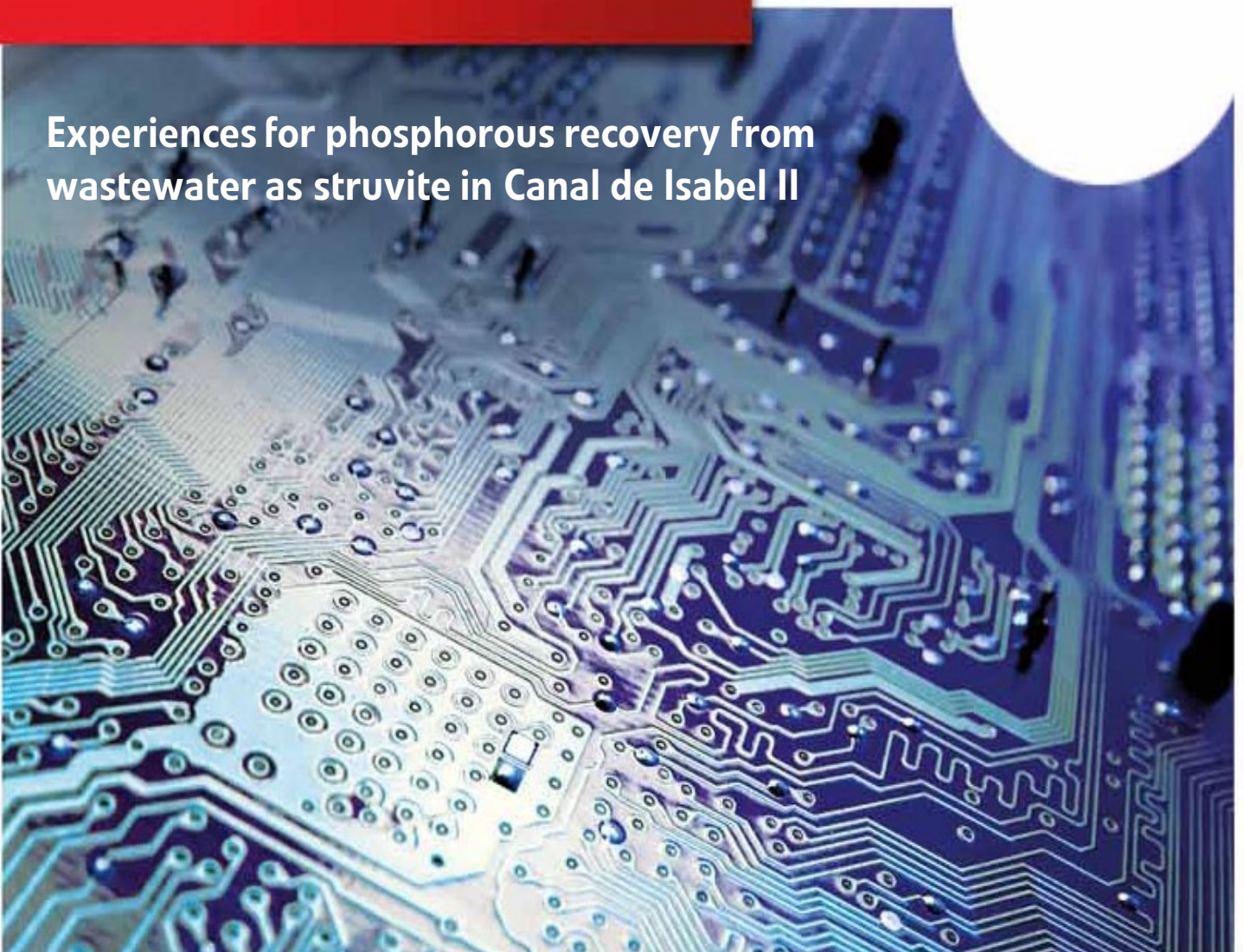


# BOOKLETS

Research + Development & Innovation

# 15

Experiences for phosphorous recovery from  
wastewater as struvite in Canal de Isabel II



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<sup>1</sup> CSIC: Spanish National Research Council



## Experiences for phosphorous recovery from wastewater as struvite in Canal de Isabel II

Booklets  
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Canal de Isabel II

# 15



# Introduction

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

These Booklets represent an element for diffusion of projects and initiatives that are developed and sponsored by Canal de Isabel II 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 aimed with the publication of these Booklets is to contribute to improvement and efficiency in water management and, consequently, in the quality of service that is provided to the citizens.

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

**Table. Titles published in the collection**

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 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 urban consolidation evolution in the Autonomous Region of Comunidad de Madrid using remote sensing techniques

# Project Outline

Project title	Pilot plant in WWTP to assess the phosphorous recovery procedure from wastewater as struvite
Research line	Environmental integration and sustainability
Canal de Isabel II areas involved	<ul style="list-style-type: none"> <li>• Subdirección de Operación de Depuración</li> <li>• Subdirección de Ingeniería y Construcción</li> <li>• Subdirección de I+D+i</li> </ul>
External participation	<ul style="list-style-type: none"> <li>• CSIC (Spanish National Research Council )</li> <li>• CYCLUS ID</li> </ul>
Aim and justification of the project	<p>The incidence of the discharge of nutrients in the eutrophication problems and the foreseeable lack of phosphorous, as a finite element in nature, have both led researchers, in the last 10-12 years to carry out dozens of studies designed not only to develop efficient technologies to recover phosphorous from waste-water as struvite, but also to study the variables effecting the process and the application of struvite as a fertilizer.</p> <p>Canal de Isabel II decided to carry out an R&amp;D&amp;i project with the aim of building a Pilot Plant on a semi-industrial scale to assess the struvite precipitation procedure in a controlled way.</p>
State-of-the-art contribution	The project is a breakthrough in knowledge about technologies to recover phosphorous from wastewater as struvite.
Project development summary and milestones	<p>The project, carried out in collaboration by the Subdirección de Operación de Depuración, Subdirección de Ingeniería y Construcción and the Subdirección de I+D+i of Canal de Isabel II during 2008 to 2010, was undertaken after an agreement with CSIC, regulating a patent license and exploitation rights, a drafting and construction contract for building the Pilot Plant, its maintenance and subsequent dismantling, and a technical assistance during the construction of the plant and management of the experimental plan.</p> <p>The procedure, in a simple way, consists in mixing, in a fluidized bed reactor, the effluent from the dewatering overflows from centrifugation of anaerobic digested sludge (CO<sup>2</sup>), suitably decanted and pH adjusted, with a reagent (a solution of magnesium derived from the reaction of a by-product from magnesium mining with CO<sub>2</sub> from the exhausts of motor-generators), obtaining a product, struvite, a high-performance slow-release fertilizer.</p>
Obtained results summary	<ul style="list-style-type: none"> <li>• The most important parameters that affect the performance of the struvite production reaction have been researched and optimized.</li> <li>• The effect of P concentration in CO effluent on the efficiency of the process has been quantified.</li> <li>• Under certain conditions, the technical and economic viability of a process that allows removing P, N and CO<sub>2</sub> has been demonstrated, obtaining struvite as an end-product.</li> </ul>
Research Lines open for continuing the work	<ul style="list-style-type: none"> <li>• The relation between the P increased biological elimination and the recovery of P as struvite instead of chemical precipitation.</li> <li>• Market research on struvite as a fertilizer.</li> </ul>

<sup>2</sup> CO: Centrifugation Overflows: Dewatering overflows by centrifugation of the anaerobic digestion sludge of the WWTP, used as an influent in the precipitation of struvite.

# Executive Summary

The great industrial and demographic development occurred in recent years has led to an increase in water pollution. The discharge of nutrients into water bodies has contributed to an increase of eutrophication problems, with serious effects on aquatic life and the sources of water supply for industrial and domestic uses.

Many legal initiatives have been undertaken to solve these problems. The European Union directive 91/271 regulates urban waste-water treatment and one of the most important matters in this directive is the elimination of phosphorous and nitrogen when the dumping occurs in "sensitive areas".

It must be eliminated phosphorous before wastewater discharges. The waste-water treatment industry currently uses different techniques to eliminate this element. Some methods are used on a large-scale and others only on an experimental scale and therefore, on a small-scale, but whatever the scale is, the phosphorous is extracted in a solid fraction.

Dewatering overflows from centrifugation of anaerobic digested sludges in large wastewater treatment plants contain a high concentration of phosphorous. Therefore it is very interesting trying to recover this phosphorous, by crystallization, from the drainage of the dehydration.

**Struvite** is a crystalline compound that appears spontaneously, as incrustations, in some areas of the waste water treatment plants (WWTP). Struvite is made up of phosphorous, nitrogen and magnesium, with a low concentration of water and heavy metals. It can be used as a slow-release fertilizer and for industrial uses (cleaning products, chemicals, etc.).

Different techniques have been used in the WWTP either to prevent or eliminate these incrustations such as dosing iron salts or adding chemical inhibitors. However, the success of these actions is not only determined by the elimination of struvite, but also by the cost associated. Considering struvite as a good fertilizer and an easy way to eliminate nitrogen and phosphorous, the idea to crystallize it in a specific reactor to prevent its spontaneous formation has been widely researched.

Many studies have been carried out to develop a cheap and efficient technology to obtain struvite from waste water from different sources and subjected to different pre-treatments. In most of the studies on a pilot scale, and in large scale struvite production plants, the crystallization procedure is based on using fluidized bed reactors to obtain greater effectiveness of the process.

In Gifhorn, a city in Lower Saxony in Germany, there is a large scale plant that has been operating since 2005, producing struvite from centrifuged anaerobic overflows of the municipal WWTP of this city that serves a population of 59,000 inhabitants.

From 2004 to 2008, the Centre for Environmental Sciences (hereinafter CCMA) of the Spanish National Research Council (hereinafter CSIC) started to study the application of a technology to obtain struvite, from the waste-water of WWTP located in the Community of Madrid. The production of struvite requires the presence of three elements: phosphorous, nitrogen and magnesium. The first two ones, phosphorous and nitrogen are plentiful in waste water, but the third one, magnesium, usually appears in small amounts and an extra amount of it has to be added to crystallize the struvite.

The process carried out by the CCMA has two new aspects, protected by a patent, in obtaining the additional magnesium regarding other production methods:

- Use of a by-product from the manufacturing of magnesite as a source of magnesium.
- Use of the combustion gases of the motor generators existing in the WWTP as a source of carbon dioxide, for the release of the magnesium in the mentioned by-product.

With the improvements developed in the CCMA, the phosphorous, nitrogen and magnesium come from low-cost or free sources, compared with other manufacturing methods, and therefore the final productions costs will be lower. These studies allow concluding that the manufacturing process was viable on a laboratory scale.

In 2010, Canal de Isabel II in collaboration with the CCMA, built a Pilot Plant on semi-industrial scale in the Arroyo del Soto WWTP (Móstoles, Madrid) to assess the struvite crystallization procedure using the technology developed by the CCMA (see figure 1). The project lasted twenty three months, including in this time the design and construction of the Pilot Plant.

**Figure 1. Pilot Plant**



Once the Pilot Plant running, the experimental tests were carried out, in order to define and optimize the parameters that control the precipitation process.

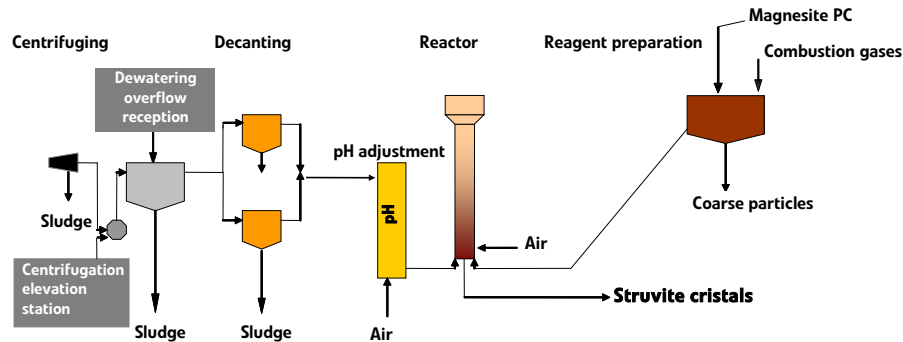
Several pre-treatments have to be applied to achieve a high performance in the crystallization of struvite, listed in figure 2. The overflow from sludge dewatering (hereinafter CO<sup>3</sup>) has to be decanted so that suspended solids concentration can be low enough. After sedimentation, the pH level of the CO overflow has to be increased to around 8.2. According to laboratory tests, this level is the most suitable for struvite crystallization.

On the other hand, the by-product obtained in the calcination process of magnesium oxide manufacturing, is dissolved in water and the exhaust gases of the electrical generators of the WWTP are injected into the solution. The carbon dioxide of these gases release the magnesium contained in this calcination by-product, and the result is a magnesium-rich solution.

<sup>3</sup> CO Centrifugation Overflows: Dewatering overflows by centrifugation of the anaerobic digestion sludge of the WWTP, used as an affluent in the precipitation of struvite.



Figure 2. Process diagram



Finally, the conditioned CO overflow and magnesium solution are injected into a fluidized bed reactor where the struvite crystallization reaction occurs. The product obtained is removed from the reactor and dried reducing its water content to 10%.

During the experimental plan several tests were carried out, in order to set the optimum operation parameters and working conditions, such as hydraulic retention times, gas dosing, stirring speeds, etc. After adjusting the plant to optimum operation parameters, it started to produce struvite to assess the achievable performance and quality of the end product.

## Conclusions

The end product obtained was a precipitate mostly constituted of a crystallized solid made up of struvite. According to the data collected, a product with a purity of over 90% can be obtained when there is a CO overflow from dewatering with a phosphorous concentration of over 40 milligrams per litre. The performance of the process, understood as the percentage of phosphorous eliminated from the CO overflow, depends on the concentration of phosphorous in the overflow. For the aforementioned 40 milligrams per litre a performance of only 50% was observed, while at concentrations over 80 milligrams per litre the performance exceeded 90%.

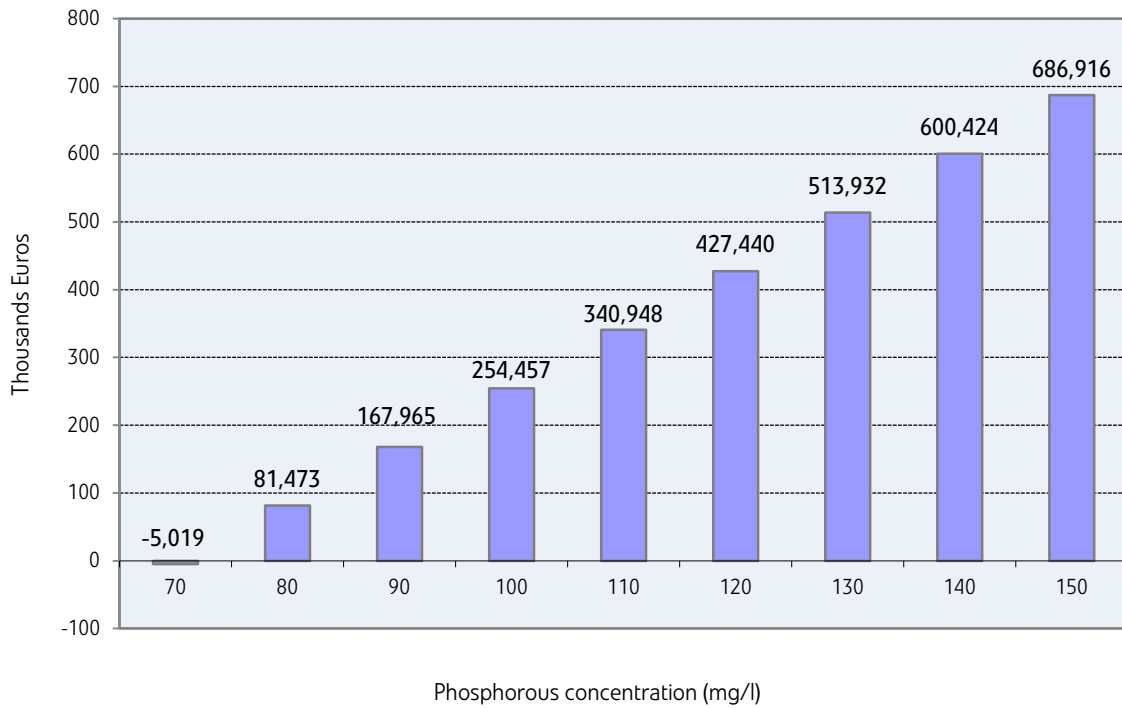
With the information obtained during the operating months of the Pilot Plant, it was possible to size a plant on an industrial scale and assess the cost of its construction.

It was estimated a construction cost of 500,000 euros for a CO overflow rate of 570 cubic metres per day and a phosphorous concentration of 80 milligrams per litre.

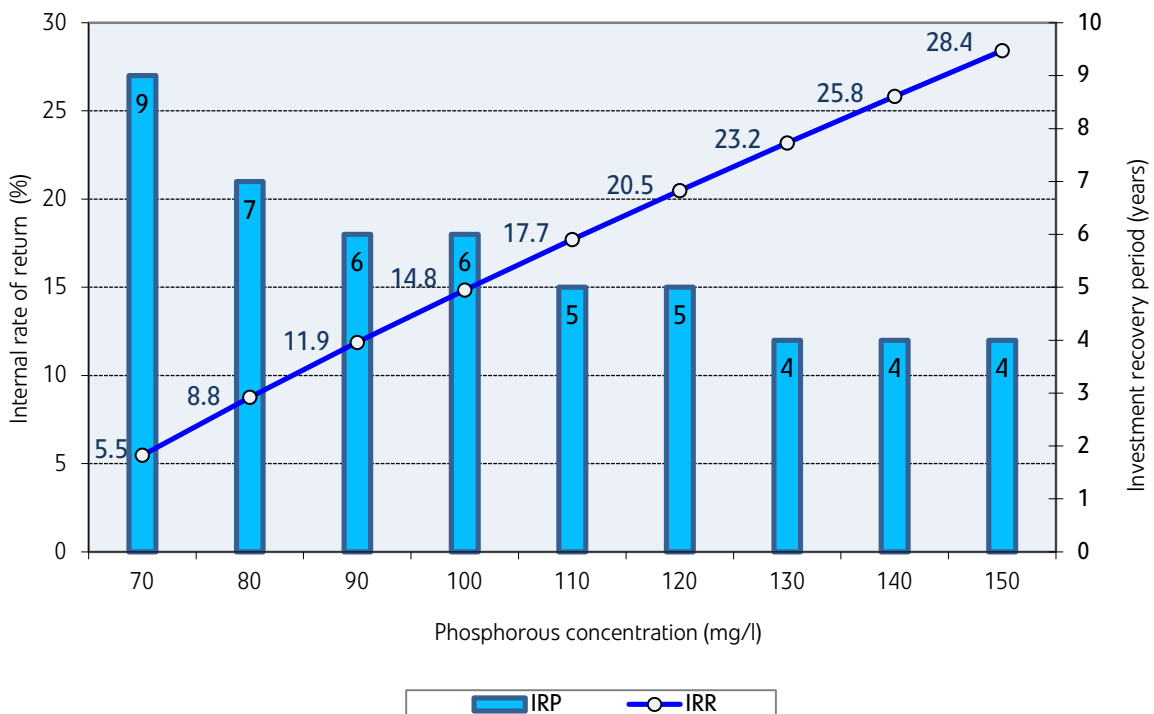
Taking into account this cost, the operating costs and the reductions in the chemical precipitation and sludge management costs, an economic analysis of an industrial scale plant was developed (figures 3 and 4).

When introducing this technology, another parameter that affects economic viability, is the minimum amount of phosphorous to be treated. The economic analysis allowed to set a value of 16.5 tons per year as that minimum amount of phosphorous.

**Figure 3. Net present value, Arroyo de la Vega WWTP**



**Figure 4. Internal rate of return and investment recovery period**



Finally, it was assessed the possibility of introducing the technology in the WWTP managed by Canal de Isabel II. This assessment was based on analyses of dewatering overflows by centrifugation of anaerobic digestion sludges that were available when the project was carried out. As the chemical analyses were not specifically carried out for this project, the conclusions reached can only be considered as a rough guide.

All the WWTP considered, except Arroyo de la Vega and Sur, have a phosphorous concentration under 80 milligrams per litre. Table 1 shows the phosphorous concentration values observed in Canal Isabel II WWTP.

**Table 1. P values in WWTP**

WWTP	Overflow flow rates Mean estimate	Operation dehydration	Centrifugation overflows CO			P total to be treated
	(m <sup>3</sup> /d)	(h/d)	P total (mg/l)			t/year <sup>(2)</sup>
			Mean <sup>(1)</sup>	Minimum	Maximum	
Arroyo de la Vega	280	20	<b>155</b>	91	200	<b>15.841</b>
Arroyo del Soto	540	20				
El Endrinal	190	12	34	32	37	2.389
Arroyo Culebro CMA	725	16	57	12	138	<b>15.084</b>
Arroyo Culebro CB	755	17	22	15	30	6.063
Torrejón de Ardóz	196	9				
La Reguera	192	8	15	5.8	23	1.051
Sur	1,710	24	<b>107</b>	53	168	<b>66.784</b>
Butarque	1,202	20	34	29	39	<b>14.921</b>
Sur Oriental	167	13	20	9	25	1.219
Viveros	1,578	23	45	12	89	<b>25.765</b>
China	1,815	24	20	12	32	13.250
Rejas	435	16	15	11	20	2.382
Valdebebas	174	13	16	8.6	28	1.016

<sup>(1)</sup> Total phosphorous values > 80 milligrams per litre

<sup>(2)</sup> Total phosphorous values close to the 16.5 tonne/year, threshold in bold

Consequently, considering both technical and economic aspects, the phosphorous could be eliminated by producing struvite in the WWTP: Arroyo de la Vega and Sur.

Bearing in mind other features of the two WWTP, the most attractive option would be Arroyo de la Vega.

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