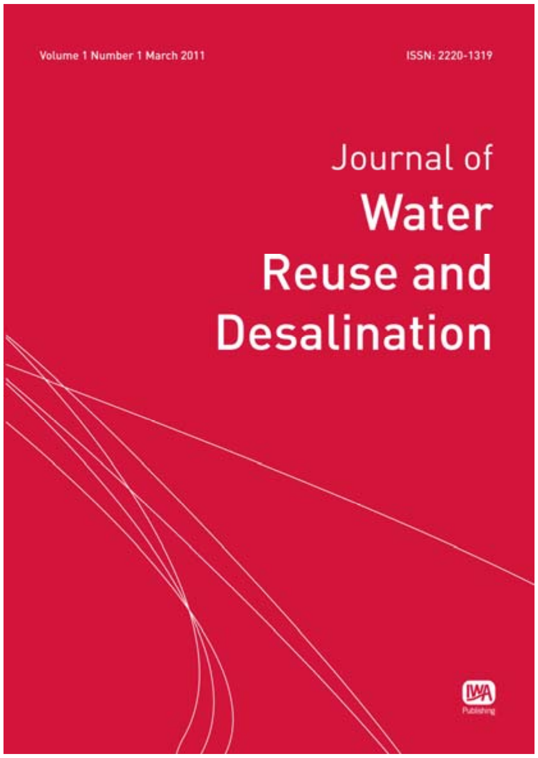
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# The River Segura: reclaimed water, recovered river

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## ABSTRACT

The Region of Murcia is located in southeast Spain, an area known for structural water stress. The most important water source that runs through the Region is the Segura River, which is the main irrigation water resource. Late last century there was a significant environmental problem in the Segura River caused by an increase of inadequately treated wastewater discharges, in a period of low flow rates and intensive use of water resources. The situation reached such a critical point, that the Regional Government presented a General Plan for Wastewater Reclamation, to be developed in 10 years. This paper details the content and guidelines in the Plan, as well as aspects related to policy development and objective achievement: water availability has increased and the Segura River conditions have improved. In short, it can be concluded that wastewater reclamation marks a good starting point for bettering water management in arid areas. Furthermore, the case of the Region of Murcia reveals that comprehensive action lines and optimized engineering and knowledge of wastewater management is highly beneficial.

**Key words** | agriculture water reuse, environmental water reuse, river recovery, wastewater management system, wastewater treatment plants, water reclamation planning

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## INTRODUCTION

### Background

The Region of Murcia, located in the extreme western Mediterranean area (southeast Spain), has a dry climate (average rainfall 300 mm) and a population of 1.5 million people. Weather conditions and hundreds of years of expertise in irrigation techniques have made this Region a prime fruit and vegetable producer. The strategic location of Murcia in the EU has contributed to making fruit and vegetable exports one of the main economic pillars of this Region (Ródenas 2004).

The Segura River, the main irrigation resource in the Region, runs through all of Murcia. Water flow in the river is fully managed by head reservoirs. The highly monitored Segura basin, with an average runoff (natural scheme) of 803 $Hm^3$ year-1 (MMA 2000), allows for an average water availability factor of 500 $m^3$ person year-1 (Ródenas 2010). In spite of significant efforts aimed at saving water and optimizing its use, there is still a structural water shortage and insufficient guarantees of water supply in the Region of Murcia. River water resources are depleted in the middle and low stretches, meaning no water reaches the river mouth.

In the 1980s, irrigation increased significantly and so did business activity of the canning industry, both coinciding with a long, severe drought (especially in the 1992–1995 period). There was a double negative impact: on the one hand, river flow decreased, and on the other, industrial and urban wastewater discharges increased, with not enough treatment systems in operation. As a result, the self-purification capacity of the river collapsed, leading to a condition of permanent pollution that was lethal for river life in the middle and low stretches. The river banks degraded significantly and there were foul smells in the towns near the river banks, especially in the city of Murcia (400,000 people), causing profound public rejection and social alarm (Ródenas 2004).

The evolution of these situations is presented in Figure 1, which includes monthly water quality and flow data gathered at the Contraparada control station between the years 1975 and 2011. The Contraparada control station, located about 10 km upstream from the city of Murcia, is considered

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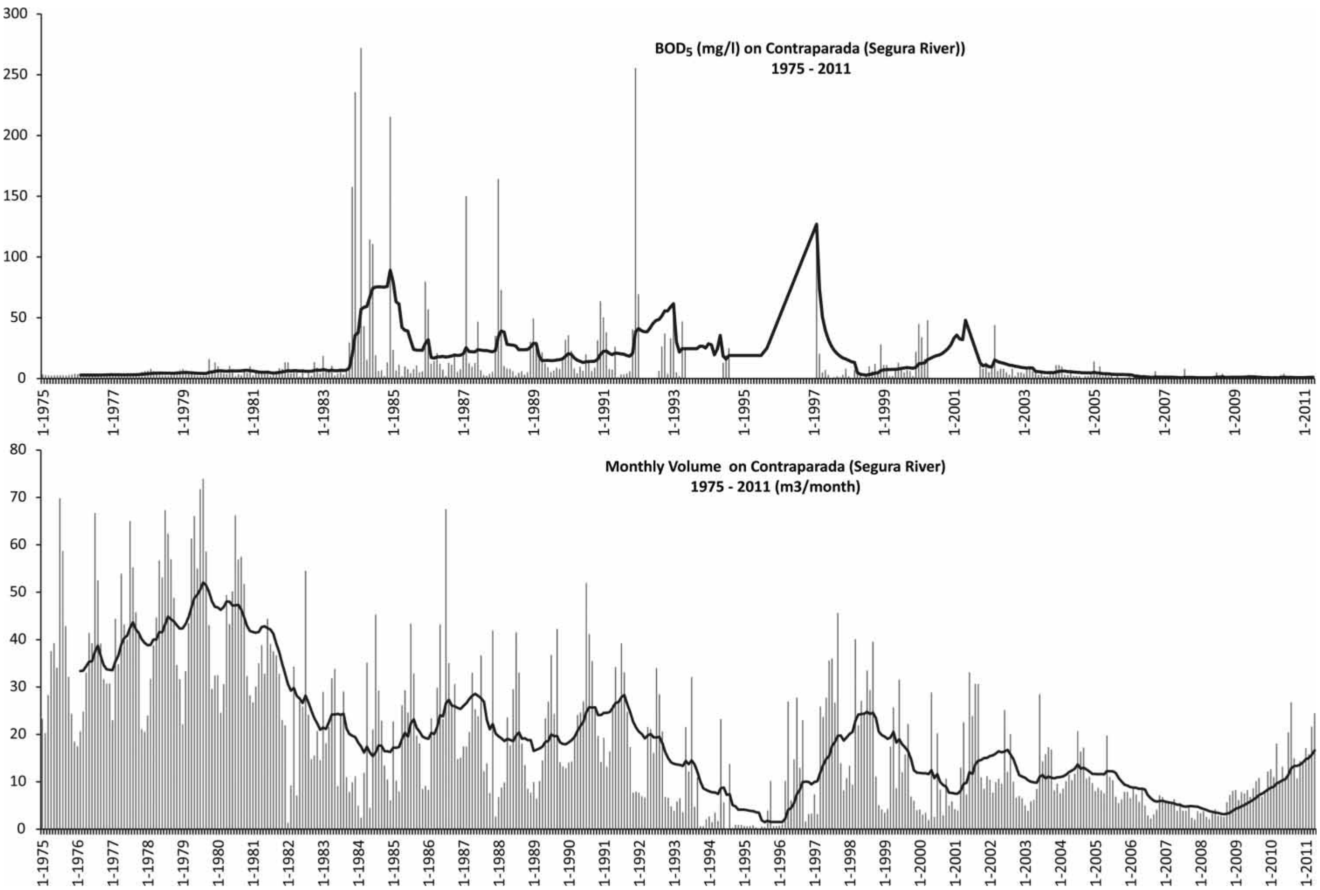


**Figure 1** | Water quality and flow of the Segura River in Contraparada. Moving average 12 periods. *Sources:* Nicolás (1987); García Balibrea (2000); CHS (2011).

representative of the middle stretch. Biochemical oxygen demand ($BOD_5$) peaks of 250 mg $L^{-1}$ equivalent to raw wastewater with no dilution, were observed. In other words, the river had turned into a sewer.

### Objectives

The severe water pollution affecting the middle stretch of the Segura River moved the Region of Murcia Parliament to adopt a policy (Law 3/2000), which included the development of a 'General Plan for Wastewater Reclamation' between 2001 and 2010 (hereafter referred to as the 'Plan') (Master Plan 2001–2010), in addition to other measures.

The Plan included two main objectives: the environmental recovery of the Segura River and an increase of water availability by means of wastewater treatment and reuse. Another general objective, in line with Directive 91/271/EEC (1991), was aimed at ensuring wastewater treatment.

## STRATEGY AND IMPLEMENTATION

### Development and design of the treatment plant

This 10-year Plan, originally created in 2001, included an environmental assessment and public consultation process before it was signed by the Region of Murcia Government.

One of the aims of the Plan was to coordinate the actions lines established by different public administration bodies (National, Regional and Municipal). The basic legal framework of the Plan was determined by Community Directives: 91/271/EEC and 2000/60 (Water Framework Directive) as well as a number of applicable water norms in Spain: Water Laws and Coastal Laws. Plan implementation was also coordinated with other plans: Royal Decree-Law 11/95 of National Sewerage and Water Treatment Plan (Ministerio de Obras Públicas, Transportes y Medio Ambiente 1995), elaborated within the context of the implementation of the European Directive 91/271/CEE, Royal Decree-Law 10/2001 of Hydrologic National Plan (Law 10/2001 2001), Water Plan for the Segura River Basin (1998) and Spain's National Plan for Sewage Sludge (2001).

Four basic policies were established to achieve Plan objectives: (1) build the necessary collection systems and wastewater treatment infrastructures; (2) implement a management system to ensure proper infrastructure maintenance and operation; (3) monitor wastewater discharge to the sewerage system; (4) facilitate industrial waste treatment at the source.

**Figure 2** | Alhama: tertiary treatment plant.

## Design criteria for wastewater treatment plants

The Plan established that treatment plants should supply reusable water suitable for two main purposes: discharge in the river for 'indirect reuse' downstream (the most common scenario), or 'direct reuse' as irrigation water in the case of water shortage. In the case of 'indirect reuse', it is necessary to minimize water environment impact because dilution is simply not possible. As for 'direct reuse', it is necessary to ensure that water quality is suitable for irrigation purposes (Ródenas 2002).

The criteria selected for the process engineering in water treatment were based on information published in international guidelines and studies (Mujeriego 1990; Tchobanoglous *et al.* 2004; Asano *et al.* 2007). Thus, in order to design new treatment plants, Plan guidelines determine that in addition to conventional 'Secondary Treatment', it is also necessary to implement advanced treatment processes in all treatment plants: 'More Stringent Treatments' to eliminate nutrients and specific 'Tertiary Treatments' to favour reuse (Figure 2). These higher treatment standards and their application to all treatment plants, is a differentiating feature of the Region of Murcia Plan.

## Secondary treatments

The good condition of urban wastewater in the Region of Murcia usually facilitates its biological treatment. Hence, the general approach for Secondary Treatment is based on the process of biological purification of activated sludge. One of its advantages is the creation of high-performance, compact installations specialized in organic pollution removal. In this Secondary Treatment phase, the reference effluent limits are 25 mg $L^{-1}$ $BOD_5$ and 35 mg $L^{-1}$ SS (suspended solids) (Directive 91/271/EEC). Depending on specific circumstances, the conventional activated sludge system (including pre-decanting or 'Primary') could be used, as well as other process possibilities such as extended aeration (reactor + clarifier system) and double stage (double system – reactor + clarifier system in series) (Tchobanoglous *et al.* 2004). Extended aeration is the most commonly applied option because of its robustness, easy operation and long life.

## More stringent treatments

Biological treatment processes include More Stringent Treatments to ensure nutrient removal. This treatment is much more intense and even mandatory in case of discharges in sensitive areas so as to prevent eutrophication (Directive 91/271/EEC).

In order to remove nitrogen compounds in wastewater, a nitrification-denitrification process is followed. In addition to improving biological sludge and effluent treatment, this process favours energy recovery. Generally speaking, the reference value for Nt content in the effluent is 15 mg $L^{-1}$, or 10 mg $L^{-1}$ in the case of larger agglomerations (>100,000 h $e^{-1}$). Treatment plants in the Plan must also be capable of removing phosphorus compounds, the other main nutrient in wastewater; some installations partially reduce their content by biological means and in all cases it is necessary to use chemicals to ensure total phosphorus content reduction. The reference value for total phosphorus in the effluent is 2 or 1 mg $L^{-1}$, depending on conurbation size (Master Plan 2001–2010).

## Tertiary treatments

The Plan establishes gradual implementation of Tertiary Treatments aimed at minimizing suspended matter and disinfecting thoroughly so as to improve water reuse health guarantees. The design criteria included in Title 22 of the California Water Code (1978), which has been scientifically recognized, universally accepted and widely borne out by experience, were used as a reference. The reference effluent values in Tertiary Treatments are turbidity <2 NTU and total coliforms <2.2 cfu 100 $mL^{-1}$. The Royal Decree-Law 1620/2007 of Purified Water Reuse (2007) established the legal regime of treated wastewater reuse after the Plan was launched. Treatment usually includes additional processes such as floculation, coagulation and complementary clarification (generally lamellar), followed by filtration. There is a large variety of filtering devices installed. An open sand bed filter is the most commonly used, although other types have also been built such as closed sand bed filter, ring filters, mesh filter or cloth filter. There are also dynamic filters for continuous backwash filtration. The most used disinfection process is ultraviolet radiation, although an additional chlorination labyrinth is always used and even a maturation pond for natural disinfection in some cases (Master Plan 2001–2010).

Due to the specificities of certain locations, some treatments include the use of membrane biological reactors (MBR). The MBR process requires much less space than a conventional treatment plant and provides water of exceptional quality. Important installations in the Region of Murcia use the MBR technology, including the application of ultrafiltration membranes. The San Pedro del Pinatar treatment plant (built in 2007) should certainly be referred to in that regard, for its large capacity (20,000 $m^3$ $day^{-1}$) in the European Union (Figure 3).

**Figure 3** | Detail of San Pedro treatment plant.

## Collecting systems

The Plan of the Region of Murcia overarches other municipal urban plans. This is of relevance when establishing the general scheme for installation of treatment plants and collecting systems because it goes beyond municipal frameworks and is implemented based on technical criteria for environmental, economic and energy efficiency.

The Plan includes total wastewater collecting, building massive intake areas and collecting systems so as to connect as many agglomerations as possible, even those of a smaller size. Plan guidelines also recommend that water collection be prioritized at collecting systems, reducing the number of treatment plants and making these as large as possible. Although the cost of collecting systems is initially higher, they are more beneficial in the long term: better treatment performance and lower treatment, management and control costs. Collecting systems also contribute to minimizing the inevitable environmental and social impacts resulting from the construction of a treatment plant. All these aspects have been properly assessed.

## Design of the wastewater management system

One of the basic policies included in the Plan was aimed at determining how to manage the infrastructures built. Law 3/2000 established a 'Wastewater Reclamation Levy' as an economic tool funding their maintenance, operation and control. In addition, the regional agency ESAMUR was created in 2002 to specifically work on these areas.

The Wastewater Reclamation Levy is a targeted regional tax that levies wastewater discharge to the public sewerage system. The tax, proportional to the level of contamination, is based on the 'you contaminate, you pay' principle. This tax was first levied in 2003.

## Control of industrial discharges and treatment at source

Industrial discharges can damage infrastructures, inhibit biological treatment processes and introduce undesirable elements hampering future reuse. Thus, one of the main policies in the Plan focuses on facilitating purification at the source and monitoring industrial discharges to the sewerage system.

The larger volumes of industrial discharges in the Region of Murcia come from the food industry and canning sectors, with significant amounts of biodegradable organic matter. All industrial discharges require municipal authorization; ESAMUR assists and collaborates with city councils on this matter. The actual Wastewater Reclamation Levy is an economic deterrent that somewhat drives firms to reduce pollution at the source.

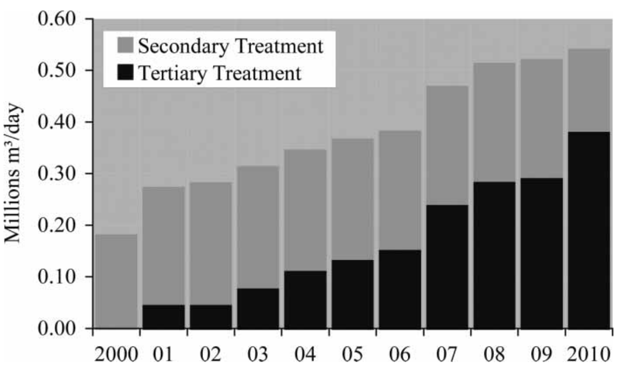


**Figure 4** | Treatment plant implementation.

## Infrastructure installation

A total of 47 large wastewater treatment plants (500–100,000 $m^3$ $day^{-1}$) have been built within the framework of the Plan, with a maximum daily treatment capacity of 540,000 $m^3$ (70% Tertiary) (Figure 4).

Most of these infrastructures were built by the Consejería de Agricultura y Agua – Dirección General del Agua (Region of Murcia), with 70–80% funded by the European Union (ERDF and Cohesion Fund). These subsidies were vital for the implementation and economic feasibility of the Plan.

Other treatment plants built within the scope of this Plan were funded by the central Spanish Government and some city councils. ESAMUR has played a key role in the rehabilitation of 50 additional treatment plants in small agglomerations.

The collecting systems built serve 99.4% of the urban population, and 97.7% of them are connected to treatment plants. The total investment in infrastructures made or committed by the different administration bodies amounts to about € 635 million.

# RESULTS AND DISCUSSION

## Management results for the treatment and reuse system

After implementation of Plan policies, current indicators and their evolution are presented (Table 1) (ESAMUR 2010). Figure 5 includes ESAMUR data related to the

**Table 1** | Operation results 2003–2010 (ESAMUR)

| Operation | Ud. | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|
| Treated wastewater | $Hm^3$ | 96.1 | 106.1 | 105.7 | 100.7 | 102.5 | 99.6 | 102.1 | 110.9 |
| Evacuated sludge | Tm × 1,000 | 75.1 | 96.1 | 99.0 | 103.8 | 117.9 | 128,3 | 134.9 | 128.8 |
| Received $BOD_5$ | Tm × 1,000 | 49.5 | 54.4 | 56.0 | 52.7 | 50.9 | 48.3 | 43.7 | 40.1 |
| Removed $BOD_5$ | Tm × 1,000 | 41.6 | 47.8 | 50.0 | 48.6 | 48.1 | 47,1 | 42.8 | 39.3 |
| Removal $BOD_5$ | % | 84% | 87.8% | 89.0% | 92.0% | 94.4% | 97.6% | 97.9% | 97.9% |
| Consumed energy | GWh | 48.7 | 53.6 | 56.9 | 56.5 | 59.7 | 65.6 | 66.1 | 63.4 |
| Electric ratio | kWh $m^3$ | 0.51 | 0.51 | 0.54 | 0.56 | 0.58 | 0.66 | 0.65 | 0.57 |

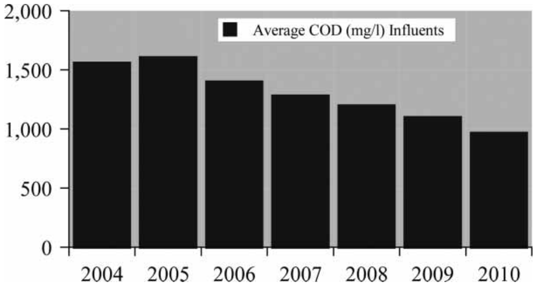


**Figure 5** | Influent quality.

industrial contamination load found in water treatment plant influents, which shows a declining trend partly as a result of industrial treatment at the source. This trend is largely due to better discharge control and to the deterrent effect of the tax.


**Figure 6** | Reclaimed water.

In 2010, the 97 treatment plants in the system treated 111 $Hm^3$ of wastewater. The overall contamination load elimination performance reached 97.9% for $BOD_5$; this remarkable performance was achieved by applying the most rigorous treatments in the Plan (ESAMUR 2010).

It is estimated that in 2010, around 100 $Hm^3$ has been reused 'directly' or 'indirectly' in the Segura River or its tributaries, for a value of 90% of all the water treated. The remainder of treated waters, found mostly in coastal installations, have not been used in farming due to their high salinity content.

Approximately 50% of all wastewater treated has undergone additional tertiary treatment, as specified in Title 22 of the California Water Code. This percentage will increase in 2011 once operational tests of tertiary systems recently built have been completed. Thanks to the implementation of the Plan, the treated water supplied contributed to a 13% increase in natural river basin resources. Thus, the objective has been achieved (Figure 6).

## Recovery of the Segura River

Figure 7 includes graphs produced by the Public Water Authority for the Segura River (CHS), showing the history of organic contamination in the Segura River (left) and at three specific control points (right) in the high, medium and low stretches (Abarán, Contraparada and Orihuela – downstream from the city of Murcia) (CHS 2011). Plan implementation has contributed to neutralize the negative effects of wastewaters, resulting in better water quality.

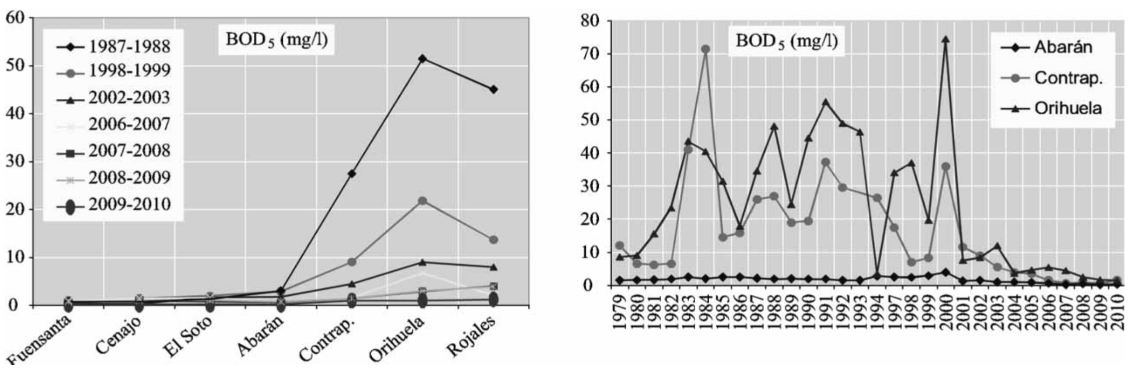


**Figure 7** | Water quality in the Segura River.

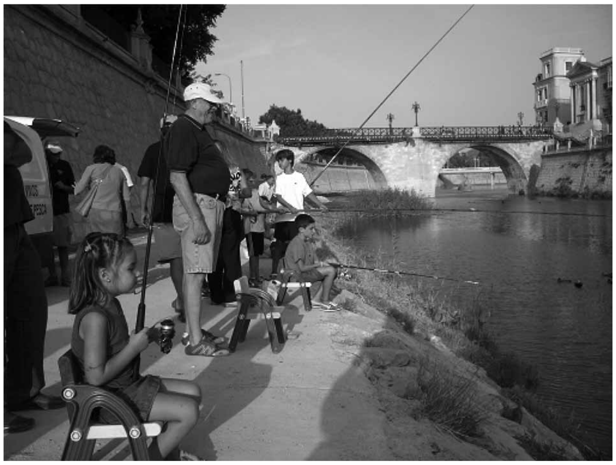

**Figure 8** | Fishing in the Segura River, Murcia.

**Figure 9** | Recovered birdlife fauna.

The city of Murcia has clearly realized the recovery of the Segura River, including its flora and fauna. Citizens come near the Segura and fishing, canoeing and water sports enthusiasts are now found enjoying the river (Figures 8 and 9). This Plan objective has also been achieved (Figure 6).

## CONCLUSIONS

The work carried out in the Region of Murcia concludes that wastewater reclamation is a good, basic principle of water management in dry areas that contributes to increasing water availability and reducing contamination.

This work also shows the advantages of comprehensive pre-planning as a rational, effective method that helps to solve complex problems associated with water management. An example of this is the Region of Murcia General Plan for Wastewater Reclamation (2001–2010); the objectives in the Plan have been satisfactorily achieved in a reasonable period of time.

The contribution of hundreds of professionals and companies engaged during the Plan creation and implementation has strengthened wastewater management knowledge and engineering in the Region of Murcia.

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