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Development and application of a cost management model for wastewater treatment and reuse processes

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A B S T R A C T

The treatment of wastewater and its further reuse is an essential part of an efficient rationalization of water within the field of Environmental Management Initiatives. Opting for the regeneration of this resource will lead to an important increase in water supply. Few studies have specifically calculated the economic costs of wastewater treatment and reuse using cost accounting and management techniques. In this paper, a cost management model is designed and adapted to the wastewater treatment process. The model quantifies, in economic terms, the change of water state from treated to regenerated water, favoring more efficient decision making regarding this resource. A practical application of this model was carried out at the Wastewater Treatment Plant of Santa Cruz de Tenerife (Canary Islands – Spain). The costs of the resources consumed by the treatment plant were calculated, as well as the costs for the different activities identified in treatment and reuse processes. As a result of our calculation process, it can be noted that the reuse of wastewater is an interesting option in terms of costs compared to other existing sources of water: surface water, underground water or desalination.

1. Introduction

The specific features associated with water as an "eco-social" asset, with economic, social and environmental functions (Aguilera Klink, 2008) call for a social and economic model that recognizes regenerated water as a new water resource. To be able to do this, information systems must be designed that incorporate this new economic logic and favor efficient decision-making in its exploitation.

Current conventional systems of water supply have two main limitations. The first is due to a natural reduction in the production capacity of many hydrological sources caused by the imbalance between extraction and natural recharge (Collins et al., 2009). To this is added that climate change may substantially aggravate the water scarcity problem (Schewe et al., 2014). The second limitation is of an economic nature, given that there is a systematic reduction in the profitability of water supply services (reduction in quantity-quality of extracted water), which has the effect of increasing the costs of water supply (Pedro-Monzonís et al., 2015).

Bearing in mind the problems associated with conventional methods of water supply, the current hydrological situation of many areas, given their climatic and geographic circumstances, is such that they cannot supply themselves with rainwater, and they must resort to non-conventional sources to solve their water problems (Angelakis and Bontoux, 2001). Basically, there are two industrial alternatives to produce water that are gradually receiving greater attention and in which much hope is being deposited for the future: desalination and water reuse (Songoson Liu et al., 2012, Pereira et al., 2002).

Between these two options, wastewater treatment and its subsequent reuse provides us with a unique system of water rationalization (Molinos-Senante et al., 2013). Choosing to regenerate water leads to a substantial increase in water supply for certain activities and is a way of maintaining the vital ecological balance by subjecting used water to a cleaning treatment before being returned to the environment (Garcia and Pargament, 2015; Hochstrat et al. 2007).

The recognition that regenerated water is a new, alternative water resource, together with European Union requirements, which through the Water Framework Directive (Directive 2000/60/EC) stipulates the price of water should include all the costs of the

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service (including environmental costs) requires a response from the science of cost accounting.

In this context, this paper puts forward a cost and management system based on the activities (Armstrong, 2002), which also provides a series of technical and economic indicators to enable efficient decision making in the management of wastewater treatment and reuse. The paper is organized as follows: first, the main features of the cost and management model are described. Then, the application of the model to a real case, according to the information supplied by the Waste Water Treatment Plant (hereinafter WWTP) located in Santa Cruz de Tenerife (Canary Island-Spain) is explained. In the final sections, the main results are discussed, possible future research lines proposed and the most relevant conclusions drawn from the application of the method proposed.

The novel aspect of this study is the application of cost accounting and management techniques to this process that has been mainly analyzed from a technical perspective.

2. Material and methods: cost management model

Few studies have specifically calculated the economic costs of wastewater treatment and reuse using cost accounting and management techniques. Caballer and Guadalajara (1998) express, in an algebraic way, the cost of reused water as the sum of the cost of treatment plus the cost of transport, storage, and treatments required for its reuse. Sipala et al. (2003) obtain the unit cost of treated water from several different treatment processes and regeneration options; however, the main limitations of these models are that they only provide information on costs related to the size of the plant. Chen and Wang (2009) suggest a model for cost-benefit evaluation of wastewater treatment and reuse projects. Chu et al. (2004) consider that the costs of wastewater reuse consist of two components: capital costs and operating and management costs. Buyukkamaci and Koken (2010) distinguish between investment costs (construction costs, mechanical instrumentation costs, cost footprint) and operation and maintenance costs by obtaining a unit cost based on the type of treatment used in the plants under study. Hernández-Sancho et al. (2011) develop traditional models but include new variables such as the contaminants removed or the age of the facility. Lastly, Zessner et al. (2010) and Berbeka et al. (2012) calculate the costs of specific wastewater treatment processes; the former analyzes countries along the River Danube and in the latter, the costs of wastewater treatment in Poland. On the other hand, Yuan et al. (2010) examine the cost-effectiveness of two wastewater treatment models in China to provide options for policymakers. Hernández et al. (2006) use a method to assess the feasibility of a water reuse project taking into account not just the internal impact, but also the external impact.

The need to generate information to make appropriate decisions in business processes has brought about a rethinking of the traditional cost models. Mishra and Vaysman (2001) state that the majority of traditional cost models use arbitrary methods to associate costs with products, giving rise to erroneous information. From the mid-nineteen eighties onwards, new proposals to calculate costs that attempt to correct the significant limitations of traditional models have been suggested. Among these alternatives is the Activity Based Cost model (hereinafter ABC system), which is one of the most widely used.

The Activity Based Cost model arose as a management philosophy (Mallo Rodríguez and Merlo Bataller, 1995) to deal with the increasingly complex mass of indirect costs associated with a product making it particularly difficult to relate costs to products. This model has been applied to a multitude of areas (Ripoll and Tamarit, 2003) and has significant advantages among which the following should be noted:

- It eliminates distortions caused by the diversity of products.
- It improves the accuracy of the calculation of costs
- It enables the assessment of the impact of different designs on costs and provides greater flexibility for management.
- It contributes to continuous improvement by providing management with information on the activities carried out by a firm.
- It offers greater visibility of costs, helping analysis of resource consumption.

Moreno Campos and Rico Iglesias (2002) agree that it is convenient to use a cost management system based on activities, such as the Activity Based Cost system. The management philosophy behind this system is that the consumption of products and/or services requires resources. These resources are determined by the volume of activities and not the production. This way of proceeding allows us to identify those activities that do not add value and that, consequently, should be eliminated and also provides a series of technical and economic indicators that help maximize efficiency. Related to this, Alfarra et al. (2011) argue that it is important to base measurements of wastewater reuse on complete wastewater regeneration including on-site and low-cost means of reuse, in order to properly capture its potential. In this sense Zeng et al. (2008), Muga and Mihelcic (2008) or Sahely and Kennedy (2007) propose indicators for measuring technical and economic efficiency, but these are generic and non-specific for the different phases of the wastewater treatment and the reuse process. Meneses et al. (2015) concluded that Life Cycle Assessment (LCA) indicators provide useful additional information when evaluating control strategies in WWTPs.

Berbeka et al. (2012) recognize that their work needs to be extended with more in-depth analysis of major cost drivers of the WWTPs in order to gain an insight into the sensitivity of cost functions.

In order to apply ABC to wastewater treatment and reuse processes, the calculation procedure has been structured in the following phases (López Cruces and López Godoy, 2001):

1st Phase: Identifying the final products of the treatment processes and their units of measurement.
2nd Phase: Establishing product transformations and the activities carried out in order to make these transformations.
3rd Phase: Identifying the factors or resources involved in these transformations. Moreover, they need to be classified as either direct or indirect with respect to the cost objective that the management has established, and as fixed or variable, depending on their dependence on the volume of activity.
4th Phase: Developing a logical system of association between resources and activities and between activities and products which allows, in addition to the setting up of an internal management system, the calculation of the cost of the different transformations.

2.1. Phase 1: identification of final products and description of their units of measurement

Following guidelines for the rational use of water, we consider the following outputs:

Regenerated water (finished product). This is purified water following tertiary treatment making it suitable for agricultural use. Following Estevan and Naredo (2004), urban and industrial

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