Improving drinking water treatment without tariff impact: the Spanish case study

José Antonio Palomero-González and Francesc Hernández-Sancho

ABSTRACT

Water is essential for our lives and activities. Everyone can drink good quality water, the question is whether they have access to it in the first place. Water quality and its treatment depend on the water source. This treatment has costs that users have to pay in the water tariff. It is very important to establish a water tariff that permits the best water treatment and has a low impact on the users. Cost functions are a useful tool to predict costs before an implementation or improvement. This article, using three easy steps (analysis, obtaining costs and modification of the water tariff) proposes improving water purification treatment using cost functions in order to find the best solution for providing the best quality water with the least cost impact on the water tariff. This methodology aims to help supply managers justify their decisions in order to optimise the available economic resources.

Key words | cost functions, water purification treatment, water quality, water tariff

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INTRODUCTION

Water is very important in our society. However, not everybody can access quality drinking water. Drinking water quality is of such importance that the European Union, in Directive 98/83/EC (Europe 1998), legislates in order to protect human health from the adverse effects of any type of pollution of water intended for human consumption, guaranteeing its health and cleanliness.

There are many contributions about drinking water quality in the literature: about source and pollutant distribution in water distribution networks (Clark *et al.* 1993; Marín *et al.* 2015), and pollutant dispersion control systems (Godé *et al.* 1997). The Water Safety Plans aim to ensure the safety and quality of drinking water, by focusing on ensuring water quality through monitoring systems and periodic evaluation of service (Matía *et al.* 2008; Bartram *et al.* 2009; Dominguez-Chicas & Scrimshaw 2010).

If the water supply sources are of good quality, it is possible to have water free of health risks, requiring minimal water purification treatment and the costs that entails. The Water Framework Directive, in Article 9, takes into account the cost recovery principle in water-related services, including environmental costs (European Directive 2000/60/EC; Europe 2000).

In order to pay for the cost of the water service it is necessary to establish a water tariff, which is defined as an amount fixed by the administration as payment by users for obtaining a water supply suitable for human consumption. The water tariff aims to achieve a price that encourages responsible, equitable consumption, and promotes water saving. The main objectives of the tariff are: cost recovery, reducing consumption and equity-justice. The water tariff should be designed so that all households, including those with lower incomes, have access to basic water consumption and at the same time ensure the financial sustainability of the service provider. Water tariff design is complex, as the various goals often conflict (Maldonado-Devís & Hernández-Sancho 2013).

Studies of water tariffs have an important presence in the literature, for example: about water pricing practices

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(Gistau 2010; OECD 2010; Ozeki 2013; Blanco-Orozco 2015); about water tariff social impact (Arbués & Barberán 2012; Gonçalves *et al.* 2014); and water tariff efficiency, cost recovery and sustainability (Cole *et al.* 2012; Hoque & Wichelns 2013; Zetland & Gasson 2013; Grafton *et al.* 2015).

Water tariffs usually have two parts: a fixed portion (the price paid for water service) and a variable portion (the price per cubic metre for consumption). The variable portion can be volumetric or in increasing or decreasing blocks. A volumetric variable portion is paid by the consumer as an amount per cubic metre consumed. In a block variable portion, consumption is divided into ranges, where each has its own water price. The consumer's payment depends on the range their consumption falls into.

The most common tariffs in Spain are tariffs with two parts: a fixed part and a variable part (in blocks). There are two variants of the variable tariff by blocks: the increasing block tariff (IBT) and the increasing rate tariff (IRT). With an IBT variable block tariff consumers pay the first cubic metre according to the price of the first block, and those who go over are charged the price of the second block. In contrast, consumers pay the same price as the last cubic metre consumed for every cubic metre consumed, with the IRT variable block tariff. If the last cubic metre consumed is an upper block, all consumption is paid at that price. Choosing an IBT or IRT variable block tariff depends on the intended purpose. In principle, it seems best to choose an IRT variable block for cost recovery. However, the best option to save water is the IBT variable block. There is no regulation or organisation to establish criteria to define the water tariff, leading to a wide variety of tariff systems (Martínez-Espiñeira *et al.* 2012).

The low price of water suggests that not all costs are recovered. According to figures from the Spanish Department for Environment, companies only recover 75–90% of the costs. The main cause is the implicit subsidy system for water consumption. Many of the investment costs are paid by European funds instead of the consumer. This produces a distortion which means the consumer does not pay the true cost. We must therefore increase the water price to comply with the cost recovery principle. The president of the Spanish Association of Water Supply and Sanitation (AEAS) suggests that to achieve this objective the price of 2010 should be doubled in 2015 (Gistau 2010).

The aim of this paper is to develop a methodology to help water managers decide how to improve water purification treatment with the least tariff impact. The methodology consists of three steps: choosing technologies that improve the current water purification treatment, using cost functions to obtain the investment costs and the operation and maintenance costs, and finally changing the water tariff to recover costs with the least social impact.

METHODS

The first step in developing this methodology is to define the drinking water improvements, to analyze the water purification treatment, and then, choose the best option to improve the current water treatment. The literature defines drinking water quality as water which satisfies quality parameters and has no negative effects on consumer health. This methodology defines water quality improvement as when a technology ensures a reduction of physical, chemical and biological parameters that generate risks, including non-mandatory parameters, to minimise health risks. Next, it is necessary to do a focused analysis of water quality and risk reduction to choose the best technology to improve water treatment.

The second step is to predict the costs of enhancements before implementation, using the cost functions that identify the interrelations between the representative variables and the cost. One of their main uses is cost prediction. Cost functions are usually used in the design phase to compare different alternatives or measures, so as to choose the greatest net benefit possible, before planning the measures and their implementation, and showing the relationship of cost to the rest of the variables (Shepherd 1970; Shephard 1981). The equations usually used to obtain cost functions are:

Linear ($Y = a - bx$),
Exponential ($C = AV^b e^{(\Sigma \alpha_i x_i)}$),
Logarithmic ($\ln C = \ln A + b \ln V + \Sigma \alpha_i x_i$).

Cost functions are used widely in the literature from many water fields, such as in simulations for water quality management (Li *et al.* 2012) or to develop water supplies and sanitation technologies (Ketema *et al.* 2015). Cost functions are very useful for modelling wastewater treatment cost, as shown in some papers (Papadopoulos *et al.* 2007; Hernandez-Sancho *et al.* 2011; Tsagaraki *et al.* 2014). However, there are not many references about cost functions as applied to water purification treatment in the current literature. There is an example for the use of water technologies to improve water quality by the Environmental Protection Agency Water Office (EPA 2005).

This methodology uses the cost function provided by the United States (US) Environmental Protection Agency Water Office to obtain operation and maintenance costs and capital costs easily, quickly and reliably. The US Environmental Protection Agency Water Office cost functions are logarithmic equations designed to obtain costs based on design flow. These equations are obtained using three models: Very Small Systems Best Available Technology Cost Document (VSS model), Water Model, and Water and Wastewater Cost. These functions were obtained by statistical and mathematical data with historical data (EPA 2005).

The capital costs were divided into three main components: process costs, which include, for example, manufactured equipment, concrete, steel, instrumentation and controls, piping and valves; costs for engineering and construction; and finally indirect costs, including housing, land, operator training, piloting and education for management. Estimates of total capital costs are based on processing costs, which are then multiplied by a factor of specific costs to estimate the direct costs of capital. A cost factor of 2.5 is used for systems less than 1.0 million gallons per day (mgd) and a cost factor of 2.0 is applied to systems of more than 1.0 million gallons per day (EPA 2005). A million gallons per day is equivalent to 3,785.4 cubic metres.

Operation and maintenance costs are the annual costs required for the operation of the technology. They are the sum of each of the components, with no weighting factor, and include labour, chemicals, energy and spare parts (EPA 2005)

It is necessary to know the design flow to use the US Environmental Protection Agency Water Office cost functions, because this flow allows the costs to be obtained directly. We use the cost functions to obtain the capital costs and operation and maintenance costs associated with this technology. All the costs obtained are in gallons/US dollars. To make the results comparison easier, we changed the US dollars to euros, taking June 16, 2014, as reference. The change was $1.00 equating to €0.74.

The third step is the modification of the water tariff. Usually, the water managers modify some parts of the current water tariff because it is easier and faster, and it is already accepted by society and the administration. The modification usually changes either the fixed or the variable part of the water tariff and the cost recovery period. Combining these three variables to recover the water purification improvements allows for recovery of all the costs with the least tariff impact, meaning the least increase in water bills. First, the total investment cost is calculated. Then, the selected parameters will be modified to recover the total investment cost. The main objective is to equalise income with expenses. This increase will be made with the minimum impact on the current water tariff.

RESULTS AND DISCUSSION

The statistical information will be considered first. All data are real and have been obtained from a water company that supplies one of the main cities on the Mediterranean coast of Spain. In order to understand the water supply system, 2014 is used as a representative year. Drinking water use is shown in Figure 1. Table 1 shows the water supply service data in 2014.

There are two water purification plants that supply the city: Water Purification Plant A (which has three treatment

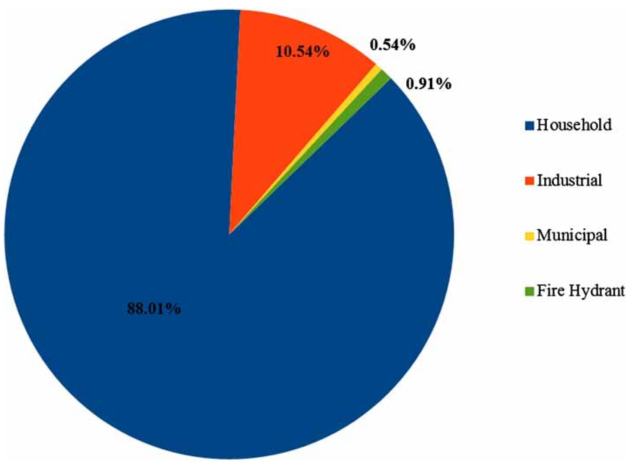

Figure 1 | Drinking water uses. *Source:* Water Company.

Table 1 | Water supply service data in 2014

Water supply service data in 2014	
Number of users	433,098
Checked volume (m^3/year)	42,760,963
Annual consumption (m^3/user year)	98.73

Source: Annual Report Water Company 2014.

lines: A1, A2 and A3) and Water Purification Plant B (one treatment line: B1). Both plants treat surface water, both plants have a standard treatment (pre-treatment, decantation, filtration and chlorination), both have intermediate chlorination (small dosages of chlorine to maintain the disinfection level during the water treatment), present activated carbon filters and use the same reagents and the same design flow (3 m^3/s), and each serves half the city. In Figures 2 and 3 flow diagrams of the water treatments can be seen. The differences are that Water Purification Plant A has UV disinfection in all the treatment lines, and Treatment Line A2 treats more or less 90% of the water, using the other lines (Treatment Lines 1 and 3) when the water demand requires.

The water tariff in 2014 is a fixed and variable IRT-type model. Table 2 shows the water tariff composition, and Figure 4 shows the percentage of taxes and cost of water on a water bill (Diario Oficial de la Comunitat Valenciana 2014).

The methodology explained in the methods section will now be applied. The first step is to analyse the water plant treatment. To study the water treatment it is necessary to focus our attention on water quality at the end of the treatment, as seen in Tables 3 and 4. The water source is surface water. The water treatment has a high efficiency but there are parameters that do not change, such as electrical conductivity, which represents the salt content. This parameter is very important in the Mediterranean area because water has a lot of salts dissolved, which generates water with less quality (worse taste, higher chlorine dosage). As a result, we choose two quality improvements for water purification plants, ultraviolet disinfection for 3 m^3/s flow and nanofiltration for 3 m^3/s and 2 m^3/s.

Ultraviolet disinfection is exclusive to Water Purification B and the nanofiltration step for a 3 m^3/s flow is for both plants. Ultraviolet disinfection was chosen because it allows water disinfection to be improved, eliminating pathogens with chlorine resistance. Ultraviolet radiation also leaves us free to reduce the chlorination dose. Reducing the total dose of chlorine indirectly improves the taste and odour of water, which are the most important water quality parameters for users. With this technology we are going to minimise the health risk in Water Purification Plant B. Implementation of ultraviolet disinfection in Water Purification Plant B (with same flow diagram as Water Purification Plant A) is shown in Figure 2.

The second technology used is the nanofiltration system. We chose this technology over other possible membrane separation techniques because it separates organic compounds, such as pesticides and heavy metals, minimising human health risks, and especially the salt content in the water will be reduced. It will also improve the organoleptic qualities (taste and smell) of water. Nanofiltration works at lower operating pressures than reverse osmosis, and the lower operating pressure means lower energy costs.

The best option to install the nanofiltration stage would be in a new line parallel to the filtration after decantation as shown in Figure 5. At the end of the treatment it is necessary to mix the water treated in the two lines. This will improve the final water quality by varying the percentage of flow treated in this new line. With this flow diagram it is possible to have the same water quality and health risk reduction and, at the same time, reduce the salt content.

In the second step we obtain the investment costs and the operation and maintenance costs for these technologies, using the US Environmental Protection Agency Water Office cost functions. The process to obtain the costs is explained in the Methods section. The cost summary of the improvements is seen in Table 5.

In the last step, we combine the previous improvements in four proposals to obtain the best water quality with the least health risks and the least social impact.

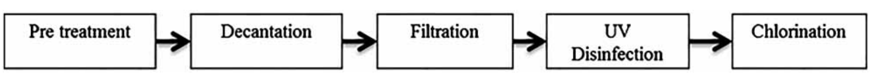

Figure 2 | Flow diagram of the water treatments in Water Purification Plant A. *Source:* Own elaboration.

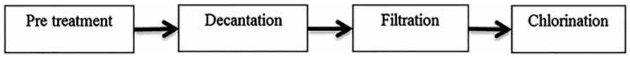

Figure 3 | Flow diagram of the water treatments in Water Purification Plant B. *Source:* Own elaboration.

Table 2 | Water tariff composition in 2014

Water tariff composition in 2014

Council investment rate (€/month)	0.90
Investment plant tariff (€/m^3)	0.05
Service fee (€/month)	5.43
Share of consumption (€/m^3)	0.17
Water transport, regulation, control, investments and water management (€/m^3)	0.33
River basin authority tax and other taxes (€/month)	20.00

Source: Diario Oficial de la Comunitat Valenciana (2014).

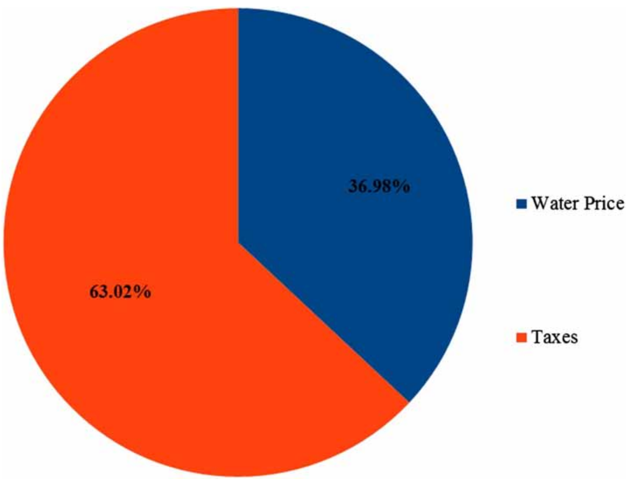

Figure 4 | Percentage of taxes and cost of water on a water bill. *Source:* Own elaboration.

These proposals are a combination of all the alternatives that we have to improve the water purification treatment. The first proposal includes the installation of UV disinfection and a nanofiltration step for 3 m^3/s flow at Water Purification Plant B, and a nanofiltration step for 2 m^3/s flow at Water Purification Plant A; the second proposal is the same as the first, without UV disinfection; the third proposal includes installation of a nanofiltration step for 3 m^3/s flow at both water purification plants; and the fourth proposal is like the third, with UV disinfection for Water Purification Plant B.

Table 3 | Water analysis in Water Purification Plant A

Water analysis in Water Purification Plant A

	Input	Output
Turbidity (UNT)	2.59	0.39
pH	8.06	7.65
Nitrites (mg/L)	0.03	0.03
Ammonia (mg/L)	0.20	0.20
E. coli (UFC/100 mL)	524.17	0.00
Clostridium (UFC/100 mL)	27.18	0.00
Enterococcus (UFC/100 mL)	51.92	0.00
Aluminium (mg/L)	–	0.03944
Cl_2 (mg/L)	–	1.01

Source: Own elaboration.

Table 4 | Water analysis in Water Purification Plant B

Water analysis in Water Purification Plant B

	Input	Output
Turbidity (UNT)	1.00	0.41
pH	8.60	7.87
Nitrites (mg/L)	0.03	0.03
Ammonia (mg/L)	0.20	0.20
E. coli (UFC/100 mL)	116.87	0.00
Clostridium (UFC/100 mL)	40.00	0.00
Enterococcus (UFC/100 mL)	95.00	0.00
Aluminium (mg/L)	–	0.03874
Cl_2 (mg/L)	–	1.03

Source: Own elaboration.

To finance the proposals, we modify the current tariff as explained in the Methods section. The chosen tariff parts were council investment rate, investment plant tariff and service fee and share of consumption. This calculation is independent of tariff increases such as increasing operating costs and inflation. The first column of Table 6 shows the current tariff, and the second shows the same tariff modified to finance the proposal.

The next step is to verify whether the tariff impact is small. A standard subscriber will be simulated, assuming average consumption in a month (8.23 m^3/user month).

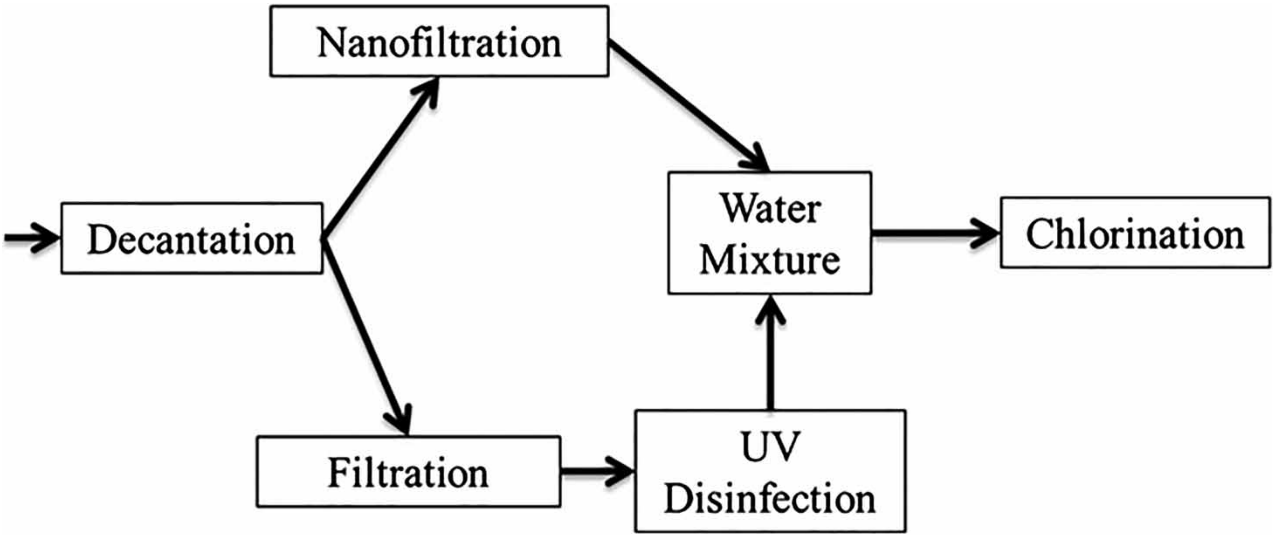

Figure 5 | Flow diagram of the water treatments with the nanofiltration step. *Source:* Own elaboration.

Table 7 shows the current water bill, and the water bill if we choose the proposals explained above.

This small increase in the water tariff would improve water quality greatly, with minimal impact on the user. Water prices in Spain are also low, as mentioned in the introduction, so a small price increase would not have a large social effect. The increases are all around 4 euros/ month for users. The difference between installing ultraviolet disinfection or not is 0.03 €/month user (Proposals 1 and 4).

Using the US Environmental Protection Agency Water Office cost function it is possible to predict the investment costs and operation and maintenance costs, and then to simulate the impact on the water tariff. The main objective of this methodology is to help water managers to choose the best way to improve water purification treatment in

Table 5 | Improvement costs summary

Ultraviolet step for 3 m^3/s	
Operation and maintenance costs	93,183 €/year
Capital costs	1,919,602 €
Nanofiltration step for 3 m^3/s	
Operation and maintenance costs	10,465,672 €/year
Capital costs	38,058,113 €
Nanofiltration step for 2 m^3/s	
Operation and maintenance costs	7,509,102 €/year
Capital costs	30,691,891 €

Source: Authors.

Table 6 | Increasing the price of water for the recovery of costs

	Current price	Cost recovery price
Tariff modified for Proposal 1		
Council investment rate (€/month)	0.90	0.98
Investment plant tariff (€/m^3)	0.05	0.22
Service fee (€/month)	5.43	5.44
Share of consumption (€/m^3)	0.17	0.34
Tariff modified for Proposal 2		
Council investment rate (€/month)	0.90	0.97
Investment plant tariff (€/m^3)	0.05	0.22
Service fee (€/month)	5.43	5.44
Share of consumption (€/m^3)	0.17	0.34
Tariff modified for Proposal 3		
Council investment rate (€/month)	0.90	1.01
Investment plant tariff (€/m^3)	0.05	0.24
Service fee (€/month)	5.43	5.45
Share of consumption (€/m^3)	0.17	0.36
Tariff modified for Proposal 4		
Council investment rate (€/month)	0.90	1.04
Investment plant tariff (€/m^3)	0.05	0.24
Service fee (€/month)	5.43	5.45
Share of consumption (€/m^3)	0.17	0.36

Source: Own elaboration.

Table 7 | Comparison of water bills

Monthly water bill for a standard subscriber

Tariffs	Price
Current tariff	30.89 €
Tariff with Proposal 1	33.78 €
Tariff with Proposal 2	33.75 €
Tariff with Proposal 3	34.19 €
Tariff with Proposal 4	34.22 €

Source: Own elaboration.

order to improve water quality, with the least tariff impact before implementation.

CONCLUSIONS

It is important for people to be able to drink water without health risks. Treating water to remove physical, chemical and biological pollutants has costs: investment costs, and operation and maintenance costs. These costs are recovered through water tariffs. The current problem is how to combine the lowest water tariff with the best water quality (including less health risk). The contribution of this paper is to combine improving water quality and cost functions in order to find the best way to provide quality drinking water with the least impact on the water tariff.

We presented a methodology to help water managers to choose a means to improve water purification treatment with the lowest tariff impact in three steps. We applied this methodology in a real case study to improve water treatment in two water purification plants in a Mediterranean city. In this real case, we chose UV disinfection and a nanofiltration step to improve water quality and to minimise the risk to human health. We combined these technologies in four proposals to improve water quality. The next step is to find out how much these technologies cost. We used EPA cost functions to predict the investment, and the operation and maintenance costs. The third step is to modify some parts of the current water tariff to finance these proposals. By manipulating the fixed part, variable part and the cost recovery period we reduced the tariff impact. The results show that an increase of around 4€ month/user could improve water quality, at the least tariff impact.

These results demonstrate how small modifications of the tariff can achieve great improvements in water quality. In conclusion, this methodology favours the sustainability of resource management from a technical, economic and environmental perspective.

REFERENCES

Arbués, F. & Barberán, R. 2012 Tariffs for urban water services in Spain: household size and equity. *International Journal of Water Resources Development* **28** (1), 123–140. DOI: 10.1080/07900627.2012.642235.

Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A. & Stevens, M. 2009 *Manual para el desarrollo de planes de seguridad del agua*. World Health Organization, Geneva, Switzerland.

Blanco-Orozco, M. 2015 *Regulación en Europa. Prácticas tarifarias*. XXXIII Jornadas Técnicas de AEAS, Burgos, Spain.

Clark, R. M., Grayman, W. M., Males, R. M. & Hess, A. F. 1993 Modeling contaminant propagation in drinking-water distribution systems. *Journal of Environmental Engineering* **119** (2), 349–364. DOI: 10.1061/(ASCE)0733-9372(1993)119:2(349).

Cole, G., O'Halloran, K. & Stewart, R. A. 2012 Time of use tariffs: implications for water efficiency. *Water Science & Technology: Water Supply* **12** (1), 90–100. DOI: 10.2166/ws.2011.123.

Diario Oficial de la Comunitat Valenciana 2014 *Diario Oficial de la Comunitat Valenciana*. January 11, 2014, Num. 7189.

Dominguez-Chicas, A. & Scrimshaw, M. D. 2010 Hazard and risk assessment for indirect potable reuse schemes : an approach for use in developing water safety plans. *Water Research* **44** (20), 6115–6123. DOI: 10.1016/j.watres.2010.07.007.

EPA (Environmental Protection Agency) 2005 *Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule*. US Environmental Protection Agency, Water Office, Washington, DC, USA.

Europe 1998 Directive 98/83/EC on the quality of water intended for human consumption. *Official Journal of the European Communities* (5.12.98), 32–53.

Europe 2000 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy is established. *Official Journal of the European Communities* (22.12.2000), 1–73.

Gistau, R. 2010 Contraprestación económica de los servicios de abastecimiento de agua y saneamiento: la factura del agua. *Revista de Obras Públicas: órgano profesional de los ingenieros de caminos, canales y puertos* **3510**, 7–22.

Godé, L. X., Serena, C., Matía, R. L. & Ariño, R. 1997 Redes automáticas de control de la calidad de las aguas superficiales. *Tecnología del agua* **168**, 23–32.

Gonçalves, I., Alves, D. & Robalo, G. 2014 Social tariffs for water and waste services in mainland Portugal: an impact analysis. *Water Science & Technology: Water Supply* **14** (4), 513–521. DOI: 10.2166/ws.2014.002.

Grafton, R. Q., Chu, L. & Kompas, T. 2015 Optimal water tariffs and supply augmentation for cost-of-service regulated water utilities. *Utilities Policy* **34**, 54–62. DOI: 10.1016/j.jup.2015.02.003.

Hernandez-Sancho, F., Molinos-Senante, M. & Sala-Garrido, R. 2011 Cost modelling for wastewater treatment processes. *Desalination* **268** (1–3), 1–5. DOI: 10.1016/j.desal.2010.09.042.

Hoque, S. F. & Wichelns, D. 2013 State-of-the-art review: designing urban water tariffs to recover costs and promote wise use. *International Journal of Water Resources Development* **29** (3), 472–491. DOI: 10.1080/07900627.2013.828255.

Ketema, A. A., Lechner, M., Tilahun, S. A. & Langergraber, G. 2015 Development of cost functions for water supply and sanitation technologies: case study of Bahir Dar and Arba Minch, Ethiopia. *Journal of Water, Sanitation, and Hygiene for Development* **5** (3), 502–511. DOI: 10.2166/washdev.2015.067.

Li, H., Li, Y., Huang, G. & Xie, Y. 2012 A simulation-based optimization approach for water quality management of Xiangxihe river under uncertainty. *Environmental Engineering Science.* **29** (4), 270–283. DOI: 10.1089/ees.2010.0439.

Maldonado-Devís, M. & Hernández-Sancho, F. 2013 Urban water pricing and tariff structure in Spain. In: *Third International Conference on Water Economics, Statistics and Finance*, Marbella, Spain.

Marín, R., Montesinos, I. & Gallego, M. 2015 *Generación de subproductos de desinfección en el proceso de potabilización de aguas.* XXXIII Jornadas Técnicas de AEAS, Burgos, Spain.

Martínez-Espiñeira, R., García-Valiñas, M. A. & González-Gómez, F. 2012 Is the pricing of urban water services justifiably perceived as unequal among Spanish cities? *International Journal of Water Resources Development* **28** (1), 107–121. DOI: 10.1080/07900627.2012.642231.

Matía, Ll., Paraira, M. P., Céspedes, R. & Ganzer, M. 2008 Valoración y gestión de los riesgos sanitarios en el agua de consumo. *Tecnología del agua* **301**, 24–34.

OECD (Organisation for Economic Co-operation and Development) 2010 *Pricing Water Resources and Water and Sanitation Services*. OECD, Paris, France.

Ozeki, G. 2013 Business management and tariff structure for safe drinking water. In: *Third International Conference on Water Economics, Statistics and Finance*, Marbella, Spain.

Papadopoulos, B., Tsagarakis, K. P. & Yannopoulos, A. 2007 Cost and land functions for wastewater treatment projects: typical simple linear regression versus fuzzy linear regression. *Journal of Environmental Engineering* **133** (6), 581–586. DOI: 10.1061/(ASCE)0733-9372(2007)133:6(581).

Shephard, R. W. 1981 *Cost and Production Functions* (repr. of the 1st edn). Springer-Verlag, Berlin, Germany.

Shepherd, R. W. 1970 *Theory of Cost and Production Functions.* Princeton University Press, Princeton, NJ, USA.

Tsagaraki, M. I., Komorowski, M. P., Boda, B., Popa, T., Gega, D., Nikolaou, I. E. & Tsagarakis, K. P. 2014 An exploratory approach for evaluating the energy and personnel share of operation and maintenance costs for water utilities in selected emerging economies of Europe. *Journal of Water Supply: Research and Technology – Aqua* **63** (5), 368–378. DOI: 10.2166/aqua.2013.228.

Zetland, D. & Gasson, C. 2013 A global survey of urban water tariffs: are they sustainable, efficient and fair? *International Journal of Water Resources Development* **29** (3), 327–342. DOI: 10.1080/07900627.2012.721672.

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